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Research Article

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Improvement of the energy efficiency of buildings by using Typha concrete in the load-bearing structure

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Abstract The use of Typha Australis in the non-load bearing walls of buildings has increased their energy performance. In this paper, we studied the impact of the use of this invasive plant in the load bearing structure.
For this purpose, we prepared concrete samples with Typha percentages varying from 10 to 60% in relation to the volume of sand. The thermal characterization of these samples shows a clear improvement of the thermal resistance of the Typha concretes compared to the control concretes with a mechanical resistance above the criteria required for a load-bearing concrete.
Thus, the use of these Typha concretes, with an optimization of their thermal and mechanical characteristics, allows to reduce the energy consumption of the buildings while contributing to the valorization of Typha Australis.

Keywords Typha Australis, load-bearing structure, thermal conductivity, Typha concrete, thermal resistance

Introduction

Energy consumption is nowadays one of the major challenges for the socio-economic development of all countries. Developing countries are particularly at risk, due to their low income and economic vulnerability.
In Senegal, electricity consumption has increased year after year. Indeed, it has seen a 12% increase between 2015 and 2018 [1-2]. Of this production, the building sector represents 25% to 30% of consumption [3]. Thus, given the significant share of energy and electricity consumption that households occupy, which corresponded to a carbon dioxide (CO_2) release equal to 5034 Gg in 2005 [4], there is reason to rethink the way we build our buildings.
In order to solve the paradox of energy inefficiency, which results in a waste of energy despite the high cost of electricity, the production of energy-saving materials has been implemented in buildings. The lack of financial means of the populations combined with a high energy consumption, make it also important to identify other more appropriate materials, more insulating and less energy consuming. It is not a question of turning away from the use of certain materials, in particular ordinary concrete which remains essential for many applications requiring high mechanical performances. But, it is rather a question of developing certain natural and renewable materials such as local plant resources in concrete, with the aim of finding a good conciliation of the mechanical properties of concrete with the thermal, acoustic or hygrometric properties of plants. It is in this perspective that the so-called biosourced materials or eco-materials like Typha Australis, which satisfy the sanitary concerns [5] and which present a promising perspective that can participate in the development of the local economy, are

studied in order to improve the properties of use of the materials used. Thus, the purpose of this study is to integrate Typha in the load-bearing structure of buildings while having a compromise between mechanical and thermal resistance.

Material and Methods

Preparation of the Specimens

Two series of control concrete were made. They differ in their cement class which increases from 32.5 MPa for the S1 series to 42.5 MPa for the S2 series. The gravel/sand ratio (G/S) is also increased for the S2 series by 9.3% compared to the value of S1 to reach a ratio of 2. The following Table 1 gives the mass of the different constituents of the two series:

Table 1 : Mass composition of the constituents of the control concrete for 1 m^3

Designation	S1	S2
Cement 32.5 MPa (kg/m³)	350	
Cement 42.5 MPa (kg/m³)	-	350
Sand (kg/m³)	680	680
Basalt 3/8 (kg/m³)	329	360
Basalt 8/16 (kg/m³)	917	1000
Water (kg/m³)	197	193

The determination of the Typha concretes was made from the control concretes of the S1 and S2 series by substituting a volume quantity of sand by Typha up to 10 to 60% for intervals of 10%. Thus, the composition of the Typha concretes is given in Table 2 below:

Table 2 : Composition of Typha concrete

Designation (kg/m³)		Concrete dosed with 10% Typha	Concrete dosed with 20% Typha	Concrete dosed with 30% Typha	Concrete dosed with 40% Typha	Concrete dosed with 50% Typha	Concrete dosed with 60% Typha
S1	**Cement 32.5 MPa**	350	350	350	350	350	350
	Sand	612	544	476	408	340	272
	Basalt 3/8	329	329	329	329	329	329
	Basalt 8/16	917	917	917	917	917	917
	Water	197	197	197	197	197	197
	Typha	1.54	3.08	4.63	6.17	7.71	9.25
S2	**Cement 42.5 MPa**	350	350	350	350	350	350
	Sand	612	544	476	408	340	272
	Basalt 3/8	360	360	360	360	360	360
	Basalt 8/16	1000	1000	1000	1000	1000	1000
	Water	197	197	197	197	197	197
	Typha	1.54	3.08	4.63	6.17	7.71	9.25

The Typha used in the study is cut after drying, then ground in a mill before being incorporated into the concrete. Its particle size curve is plotted in this Figure 1.

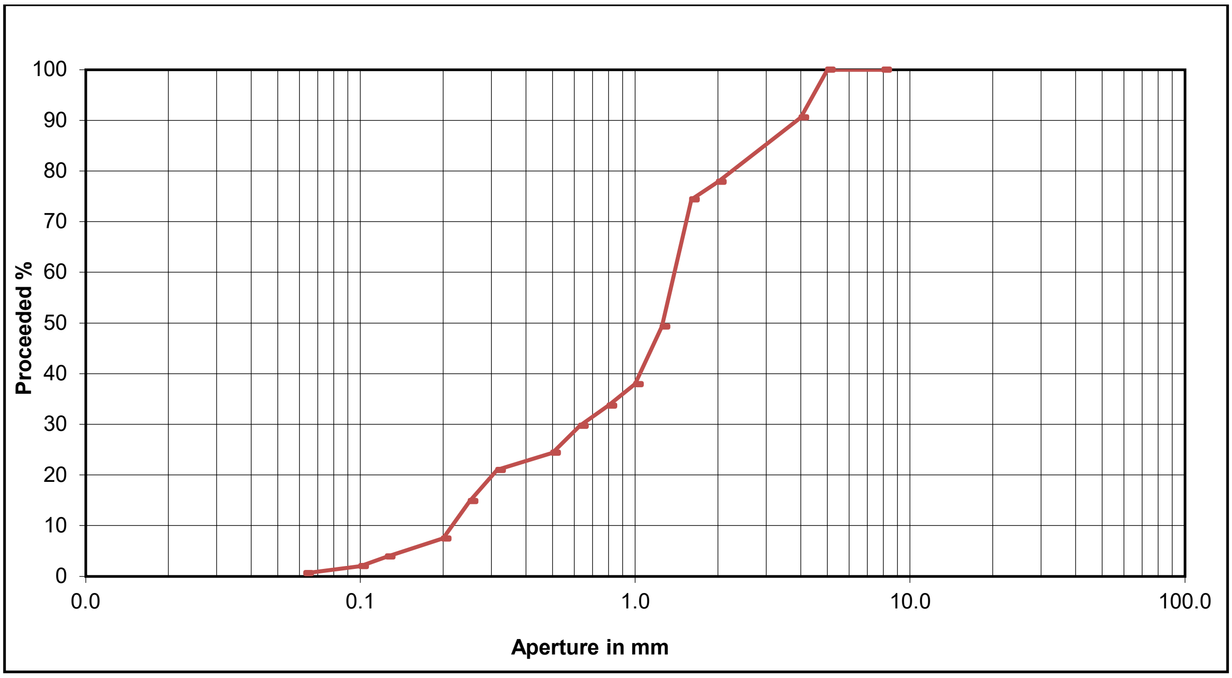

Figure 1 : Typha granulometric curve

The formulation of the specimens for the thermal characterization was done at the same time as those of the mechanical specimens for a homogenization of the characteristics of the concrete implemented. Thanks to a metallic mould of $10x10x3cm^3$, two specimens were made for each formulation, that is to say a total of 24 samples.

Figure 2: Formulation of thermal and mechanical samples

Once dry, the samples are demolded, sanded and smoothed on both sides that are in contact with the polystyrene blocks, to limit the contact resistances. Thus, the measurement of thermal properties is performed for each formulation.

Figure 3 : Samples for thermal characterization after sanding and smoothing

Thermal characterization method

The device used allows to perform an asymmetric hot wire assembly model as shown in Figure 4 below. It consists of a data acquisition module type TC-08, a stabilized power supply type Base Tech and a laptop computer with the required programming.

Figure 4 : Measurement device

The sample to be characterized is placed between two blocks of extruded polystyrene of the same size (10x10cm²) and thickness of 5 cm. A heating wire of the same length as the aluminum block is inserted between the sample and the insulator as well as thermocouples on the same side for the temperature measurement. The contact resistance at the interface does not increase with the presence of the thermocouples and the heating resistor because the polystyrene is an insulator and the medium is deformable.

This entire assembly is placed between two 3 cm thick aluminum blocks, for the maintenance of a constant temperature. A significant mass is placed on the upper part of the aluminum block in order to keep the device intact, to minimize contact resistances, to avoid thermal losses and lateral losses so that the transfer is assumed to be unidirectional.

The plot $T_0(t) - T_0(t = 0)$ as a function of ln (t) is therefore a straight line with a slope $\frac{\varphi_0}{4\pi\lambda L}$, the determination of which allows us to calculate the thermal conductivity λ.

Modeling the hot wire method

The heat equation is written in the sample for heat transfer by conduction:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{a}\frac{\partial T}{\partial t}$$

Modeling the system using the quadrupole formalist allows us to write [6]:

$$\boldsymbol{\theta_0} = \frac{\varphi_0}{p}\frac{A_0 + (A_0 R_C + B_0)/Z}{C_0 + (C_0 R_C + D_0)/Z}$$

$$\text{with : } \begin{cases} A_0 = 1 \\ B_0 = \frac{1}{2\pi\lambda L q r_0}\frac{I_0(qr_0)}{I_1(qr_0)} - \frac{1}{\rho c \pi {r_0}^2 L p} \\ C_0 = \rho c \pi {r_0}^2 L p \\ D_0 = \frac{q r_0}{2}\frac{I_0(qr_0)}{I_1(qr_0)} \\ \frac{1}{Z} = 2\pi\lambda L q r_0 \frac{K_1(qr_0)}{K_0(qr_0)} \end{cases}$$

Where:

θ_0: Laplace transform of the difference T_0 (t) - T_0 (t=0)

θ: Laplace transform of the difference T (t) – T_0 (t=0)

Rc: Contact resistance at the interface heating resistor / sample

C: Heat capacity of the thermocouple + resistance

λ: Thermal conductivity of the sample

A: Thermal diffusivity of the sample

p: Laplace variable

r_0: Radius of the heating wire

L: Length of the heating wire

φ_0: Power dissipated in the heating resistor

I_0, I_1, K_0, K_1: Bessel functions

Sensitivity study

Determining the sensitivity of a model's quantity allows us to measure the relative influence of its parameters on the quantity. The reduced sensitivity consists of scaling the sensitivity by multiplying it by the nominal value of the parameter so that it can be compared with the reduced sensitivities of other parameters [7]. Thus, the reduced sensitivity of temperature with respect to a parameter k_i is calculated by $k_i\frac{\partial T}{\partial k_i}$. This quantity represents the variation of T (in °C) induced by a relative variation of k_i of 100% [8]. The following Figure 5 gives the reduced temperature sensitivity curve with respect to the different thermal properties for the case of the control concrete of series 1.

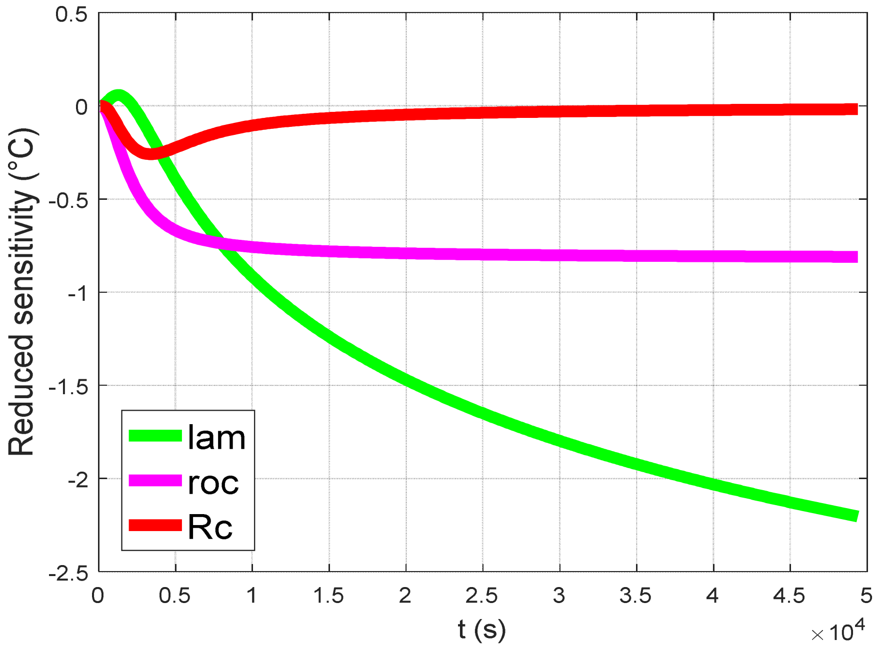

Figure 5 : Reduced temperature sensitivity curve for different thermal properties S1-0% Typha

Results

When the experimental reference conditions are respected and after iteration with respect to the reference value, the approximate curve and the asymmetric model curve should lie one above the other. Thus, the experimental and theoretical thermograms should overlap as shown in Figure 6 :

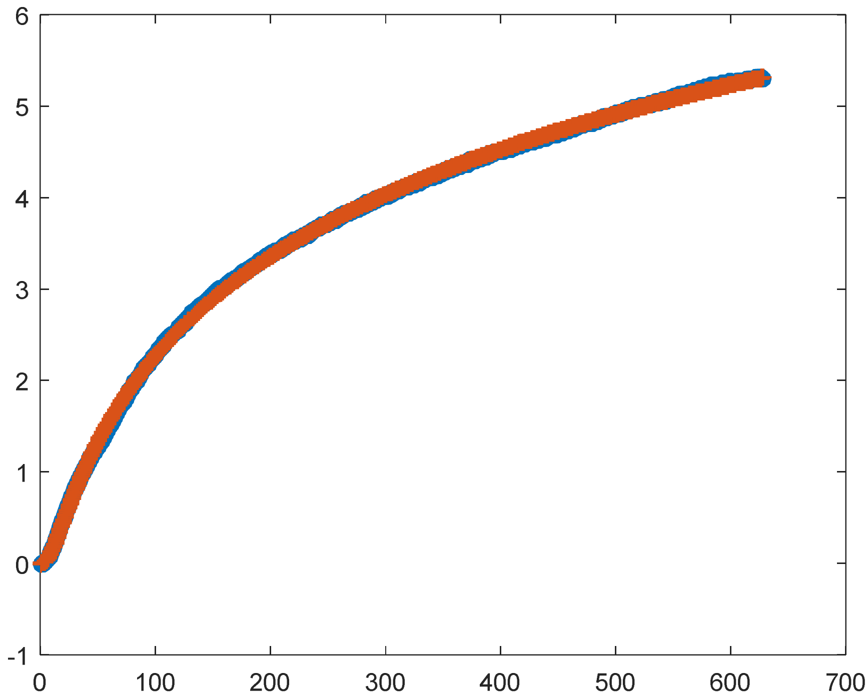

Figure 6 : Superposition of the theoretical and experimental thermograms S2 - 60% Typha- Temperature versus time

The residual curve in Figure 7 below also gives us an idea of the relevance of the estimated properties. This curve should oscillate as much as possible on the 0 ordinate axis.

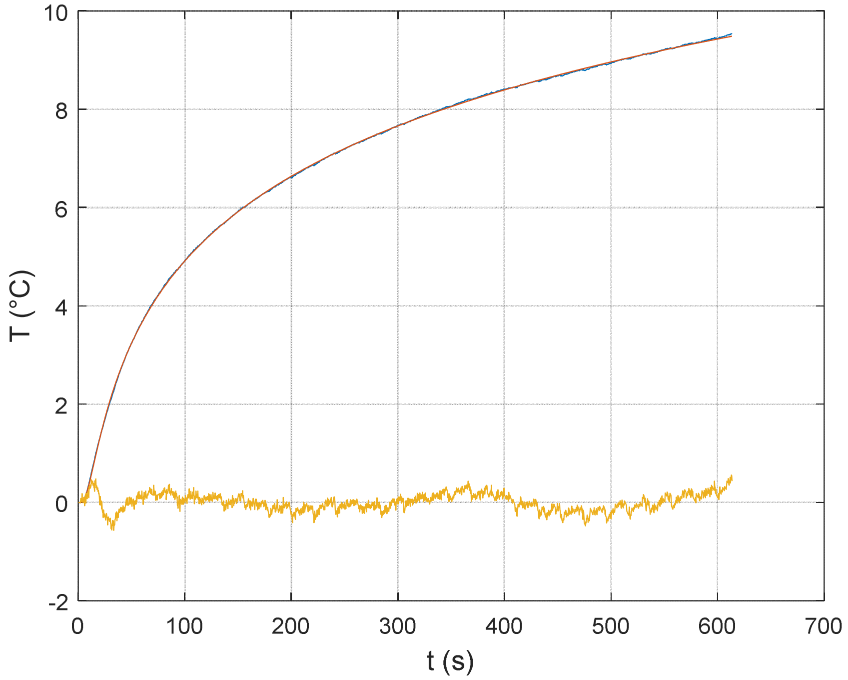

Figure 7 : Residual curve S2-0% Typha

The figure above illustrates the overlap between the theoretical and experimental curves and the residual curve. The latter, well centered around the horizontal axis of value 0, informs us about the superposition errors and shows us the squared deviation of these two curves.

A slight oscillation, noticed on the residual curve at the beginning of the experiment, can be explained by the beginning of the powering up.

This experiment, carried out on the S2-0% sample, can then be validated as the two curves overlap and the residual curve tends to cancel out for a maximum absolute value approximately equal to 0.5°C.

The results of the measurements of the thermal conductivity of the dry samples of the two series are summarized in the following le Table 3 :

Table 3: Thermal conductivity measurement

Thermal conductivity λ ($W.m^{-1}.K^{-1}$)	**Control concrete**	**Concrete dosed with 10% Typha**	**Concrete dosed with 20% Typha**	**Concrete dosed with 30% Typha**	**Concrete dosed with 40% Typha**	**Concrete dosed with 50% Typha**	**Concrete dosed with 60% Typha**
S1	1.72	1.68	1.63	1.58	1.5	1.42	1.14
S2	1.79	1.75	1.71	1.67	1.61	1.57	1.25

The graphical exploitation of these results allows to draw the curves of Figure 8 below:

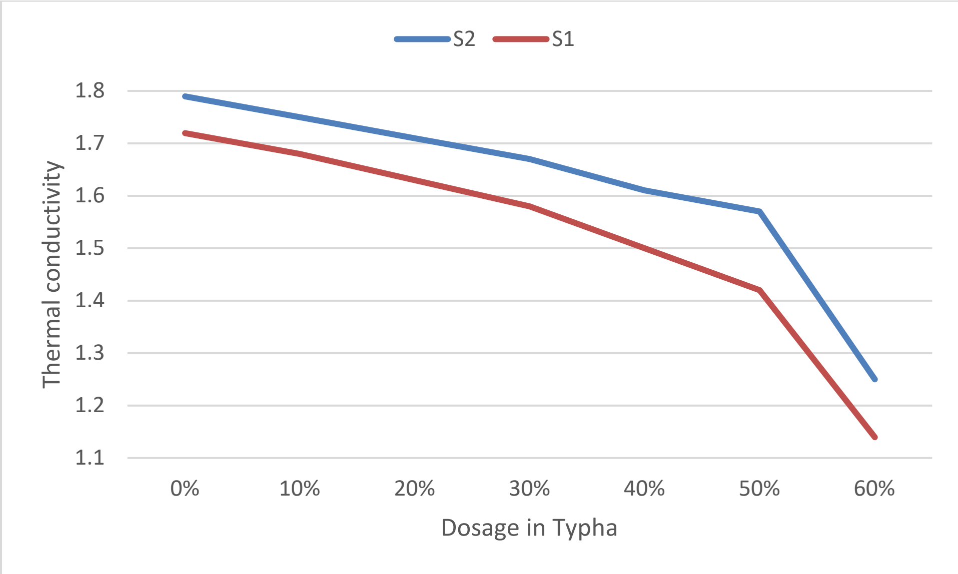

Figure 8 : Thermal conductivity of the series S1 and S2

Since most of our local constructions are made with 15 cm thick agglomerates, we can better corroborate these elements, by calculating the thermal resistance for a width of structural elements of 15 cm. Thus, the thermal resistance curve is shown in Figure 9 below:

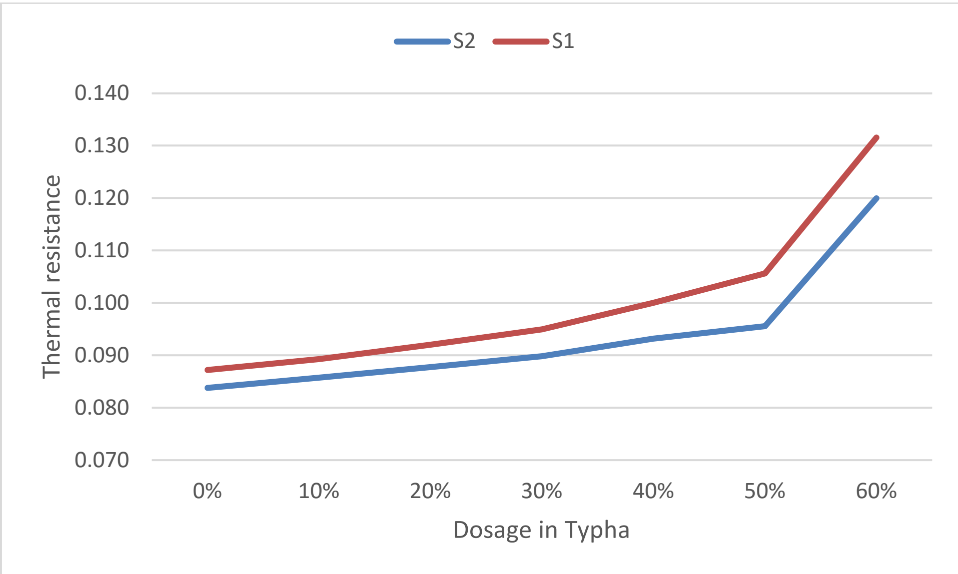

Figure 9 : Thermal resistance of the series S1 and S2

Discussions

The results of the experimental measurements showed that the thermal conductivity of the concretes with Typha Australis decreases progressively with the mass of Typha added compared to the control concretes. This decrease can be explained by the fact that Typha Australis, which has an average thermal conductivity alone of 0.045 $W.m^{-1}.K^{-1}$ when chopped into small pieces [9], contributes to the decrease of ordinary concretes which have higher thermal conductivities.

On the other hand, this decrease in thermal conductivity also leads to an improvement in thermal resistance as shown in Figure 9. The thermal resistance increases by 51% for the S1 series and 43% for the S2 series compared to the reference concretes.

It is also noted that the resistance of the S1 is much higher than that of the S2 series. This can be explained by the presence of a greater quantity of basalt aggregates in the second series. Indeed, it is logical to expect that the concrete containing the largest amount of aggregates will have the highest thermal conductivity value since the thermal conductivity of aggregates is the highest of the concrete constituents [10]. Similarly, increasing the amount of basalt aggregate affects the density. The higher the density, the higher the thermal conductivity of the mixture [11].

The mechanical study of these Typha concretes allowed us to obtain concretes with a strength class of C20/25 or C25/30 according to the exposure class of the NF EN 206-1 standard, with the exception of Typha concrete dosed at 60% of Typha from the S1 series [12]. Thus, they can be used as concretes of a supporting structure with improved thermal properties.

Conclusion

This work has allowed us to valorize the Typha Australis in ordinary concrete. This invasive grass, available in large quantities with a relatively low operating cost and ease of implementation, is characterized by a high porosity. This property, allows to reduce considerably the thermal conductivity of the ordinary concrete so that they can better associate with the bricks of cement and Typha [13] or of clay and Typha [14]. All this, allows a reduction of the differences of thermal resistances between the materials used in the construction and to assure to have low losses of heat by the junctions, with the aim of an energetic efficiency of the buildings.

References

[1]. Commission de Régulation du Secteur de l’Electricité (CRSE), « RAPPORT ANNUEL 2018 », p. 80.

[2]. Commission de Régulation du Secteur de l’Electricité (CRSE), « RAPPORT ANNUEL 2015-2016 », p. 76.

[3]. PNUD - GEF, « Transfert de Technologie : Production de Matériaux d’Isolation thermique à base de Typha au Sénégal », p. 112.

[4]. Direction de l’Environnement et des Etablissements Classés (DEEC), « TROISIEME COMMUNICATION NATIONALE DU SENEGAL », p. 204.

[5]. Abdessamad Akkaoui, « Bétons de granulats de bois : étude expérimentale et théorique des propriétés thermo-hydro-mécaniques par des approches multi-échelles », p. 231.

[6]. Yves JANNOT, *Métrologie thermique et quadripoles*, vol. Annexes de livre.

[7]. Vincent Félix, « Caractérisation Thermique de Matériaux Isolants Légers Application à des Aérogels de Faible Poids Moléculaire », Thèse de Doctorat, INSTITUT NATIONAL POLYTECHNIQUE DE LORRAINE- INPL, 2011. [En ligne]. Disponible sur: https://hal.univ-lorraine.fr/tel-01749491

[8]. Yves Jannot, *Théorie et pratique de la métrologie thermique*. Laboratoire d’Energétique et de Mécanique Théorique et Appliquée (LEMTA), 2011.

[9]. Marthe Tatiana Diatta, S. Gaye, A. Thiam, et D. Azilinon, « Détermination des propriétés thermo-physique et mécanique du typha australis. », p. 6.

[10]. K.H. Kim, S.E. Jeon, J.K. Kim, et S. Yang, « An experimental study on thermal conductivity of concrete », *Cement and Concrete Research*, vol. 33, nº 3, p. 363-371, mars 2003, doi: 10.1016/S0008-8846(02)00965-1.

[11]. K.Y. Shin, S.B. Kim, J.H. Kim, M. Chung, et P.S. Jung, « Thermo-physical properties and transient heat transfer of concrete at elevated temperatures », *Nuclear Engineering and Design*, vol. 212, nº 1-3, p. 233-241, mars 2002, doi: 10.1016/S0029-5493(01)00487-3.

[12]. A. Gaye *et al.*, « Optimization of the Mechanical Formulation of Typha Concrete », *IJITEE*, vol. 10, nº 3, p. 54-58, janv. 2021, doi: 10.35940/ijitee.C8377.0110321.

[13]. A. S. Diaw, H. M. Bal, M. Wade, et S. Gaye, « Utilisation de Typha Australis dans l’Habitat pour l’Amélioration de l’Efficacité Energétique des Bâtiments », p. 8, 2018.

[14]. A. Diop, M. B. Ndiaye, H. M. Bal, M. Thiam, et S. Gaye, « Thermal Characterization of Dry Soil/Typha australis Materials for Improving the Energy Performance of Buildings », p. 8, 2020.