Design of a measuring device for the implementation of a method for simultaneous determination of conductivity and diffusivity of building materials

Summary

The thermo-physical characterization of building materials is essential to evaluate their energy performance. In developing countries such as Senegal, the measuring devices available on the market are often expensive and not easily accessible. This work presents the design and experimental validation of a lightweight and economical device allowing the simultaneous determination of the thermal conductivity (λ) and the thermal diffusivity (a) of building materials. The method is based on a simplified physical model integrating the transient and permanent regimes. The measurements carried out on reference materials such as plaster and extruded polystyrene allowed to obtain respectively: for plaster, a = 2.9 10 m 2/s and λ = 0.25 W/m °C, and for extruded polystyrene, a = 6 10 m 2/s and λ = 0.023 W/m °C. These results, consistent with the literature, validate the reliability of the proposed device.

Keywords: characterization, thermal conductivity, thermal diffusivity, plaster, extruded polystyrene, transient.

1. Introduction

Faced with the challenges of climate change and global warming, the energy performance of buildings constitutes a major challenge. In Africa, the energy consumption of buildings represents a significant part of the national bill. Improving energy efficiency requires the development of new building materials adapted to the local climate and offering good thermal insulation properties. The thermo-physical characterization of these materials is then essential to evaluate their ability to meet these requirements. The main methods for measuring thermo-physical properties are the hot plate method, the hot wire method, the hot plane method and the box method. The latter is known for its simplicity and the reliability of its results, but the available devices remain expensive. In this perspective, our study proposes the design of a more accessible measuring device allowing simultaneous determination of thermal conductivity and diffusivity. This device is intended to characterize both conventional materials and bio-sourced materials (laterite, typha, straw, etc.).

2. Methodology

2.1. Theoretical modeling

The thermal field of the studied material is governed by the heat conduction equation (Equation 1) with the appropriate boundary conditions.

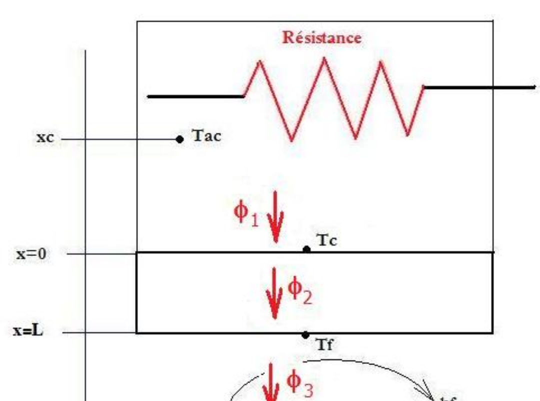

Figure 1: schematization of the model

The thermal field of this sample (**figure 1**) is governed by the equation **[1] [7] [16] [17]**

$$\frac{\partial^2 T(x,t)}{\partial x^2} = \frac{1}{a}\frac{\partial T(x,t)}{\partial t} \tag{1}$$

With the boundary conditions:

- At the front face (x=0):

$$\lambda \frac{\partial T(x,t)}{\partial x}\bigg|_{x=0} = RI^2 - C(Tac - Ta) \tag{2}$$

- At the rear face (x=L):

$$\lambda \frac{\partial T(x,t)}{\partial x}\bigg|_{x=L} = hf(Tf - Ta) \tag{3}$$

Where: $T_{ac}(t)$: ambient temperature on the high side depending on the parameter *t.*

Tf: temperature of the lower face

Ta: ambient temperature on the low side, constant.

R: heating resistor

I: current passing through the resistance

The resolution by the Duhamel method allows obtaining the evolution of temperature and deducing the thermal diffusivity from the experimental slopes. The thermal conductivity λ is then determined in the steady state, after stabilization of temperatures.

2.2. Experimental design

The device designed is a calorimetric box composed of insulating layers in polystyrene. Heating is provided by a film heater, generating a unidirectional flow of heat. The temperature sensors are positioned on both sides of the sample in order to follow the thermal evolution. The lateral insulators ensure minimization of heat losses. (Figures 1 and 3)

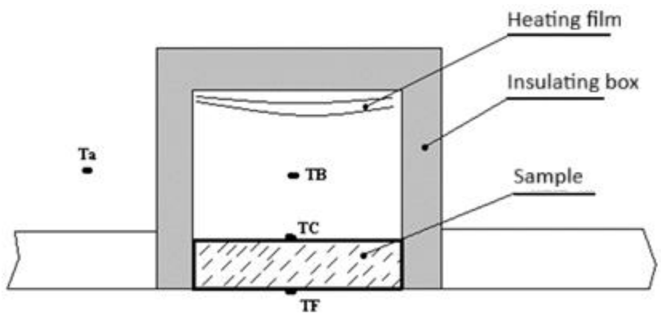

Figure 1: Experimentaldevice

Figure 2: Photo of the experimental

3. Experimental results

3.1. Thermal conductivity

The experimental results are presented in the table below:

Table 1: Different conductivities obtained

Material	Voltage (V)	Speed time	Conductivity λ (W/m·K)

Plaster	220	3 h 30	0,2649
Plaster	220	3 h 00	0,2443
Plaster	200	2 h 30	0,2540

The average conductivity of plaster is λ = 0.25 W/m K with a relative uncertaintyestimated at 7%.

3.2. Thermal diffusivity

Table 2: Different diffusivities obtained

Material	Voltage (V)	Measurement time	Diffusivity a (m 2/s)
Plaster	220	1 h 40	$2{,}89\times10^{-7}$
Plaster	220	1 h 45	$3{,}00\times10^{-7}$
Plaster	200	55 min	$2{,}89\times10^{-7}$

The average diffusivity obtained is a = 2.9 10 m 2/s, with a relative uncertainty of 6%.

4. Discussion

The results obtained are in good agreement with the literature values for plaster and extruded polystyrene. The designed device demonstrates its ability to faithfully reproduce the thermo-physical properties of materials. However, to ensure the reliability of measurements, the following precautions must be observed: use at least three representative samples, condition the samples before testing, ensure good sensor-sample contact. These recommendations will strengthen the accuracy of the device and allow its extension to the characterization of local bio-sourced materials (typha, straw, laterite).

5. Conclusion

The device developed allows the simultaneous determination of the thermal conductivity and diffusivity of building materials. Lightweight, economical and reproducible, it is a credible alternative to expensive commercial devices. The results obtained with plaster and extruded polystyrene confirm the validity of the model and the device. Future perspectives include its application to the characterization of local bio-sourced materials for sustainable construction in Senegal.

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