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Research Article

Determination of the Critical Thermal Mass Capacity of Building Materials of Building Envelope

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Abstract The thermal requests of the outside environment of the building are applied generally directly on the envelope. The latter must then have a behaviour which allows to oppose the spread of heat from the outside to the indoor environment. This present work joins within the framework of a thermal study of the characteristics of the envelope of the constructions through the study of characterization of materials. The study was specifically directed to a justification of the existence of a minimal specific heat, a proposal of method of determination of its value but also towards an analysis of the influence of the material's porosity on the minimal value of the specific heat. This is the way this work succeeded on a proposal of a method of calculation of the critical value of specific heat which allowed to do the calculation for certain materials. On this base, we also made an analysis of the variation of minimal specific heat under the influence of the porosity.

Keywords Thermal inertia, minimal specific heat, maximum penetration depth of heat, porosity, thermal conductivity, diffusivity, effusivity

Nomenclature

b : Thermal effusivity	$J.s^{-1/2}.m^{-2}.K^{-1}$
c : material specific heat	$J.kg^{-1}.K^{-1}$
c_{min} : minimum specific heat	$J.kg^{-1}.K^{-1}$
t: heat propagation time	s
Greek symbols	
α : Thermal diffusivity	$m^2.s^{-1}$
δ : Penetration depth of heat	m
δ_{max} : maximum penetration depth of heat	m
λ : material thermal conductivity	$W.m^{-1}.K^{-1}$
λ_{app}: apparent thermal conductivity ofgranular media	$W.m^{-1}.K^{-1}$
$\boldsymbol{\lambda_f}$ **:** fluid thermal conductivity	$W.m^{-1}.K^{-1}$
λ_s : solid thermal conductivity	$W.m^{-1}.K^{-1}$
ε : material porosity	-
ρ : material density	$Kg.m^{-3}$
ρ_{app} : apparent density of granular media	$Kg.m^{-3}$
ρ_s : solid density	$Kg.m^{-3}$
ρ_f : fluid density in atmospheric pressure	$Kg.m^{-3}$

1. Introduction

The envelope is the part of the building which is in direct contact with the external environment and it is therefore through it that the mass and heat transfers are carried out between the inside of the building and the outside.

The transmission of heat through the walls of the enclosure is done by radiation, convection and conduction.
The thermal inertia given by the product of two intrinsic characteristics of the material, namely the density and the specific heat of the material, represents all the thermo-physical characteristics which allow it to withstand the Variation of the heat fluxes exerted on it [1]. Indeed, a building with a high thermal inertia will withstand the variations of the outside temperature and have an internal temperature which varies very slowly. Thus the building therefore the casing is carried out with high inertia materials can provide a summer comfort without air conditioning by resisting heat from the external environment especially for the tropical climate [2-4]. The specific heat is a very important parameter in the thermal behavior of the material. Indeed, its increase is a good thermal inertia. Building materials are generally granular media; thus the structure of the material according to the arrangement of the grains and the presence of the pores has a great influence on the intrinsic physical characteristics. [5-8].
It is therefore important to characterize the building materials in order to know the thermal behaviour of the building beforehand. Because of its easy application, the method of the boxes remains a very effective technique for the characterization of the materials [9-10].
In this work, we first give, for a building material, a method of determining the minimum (or critical) value of the specific heat. We then study the influence of the porosity of the material on this critical value.

2. Existence of a minimum wall thermal capacity of a building envelope

In Figure 1 below, we will take as example clay and represent the graphs of diffusivity and effusivity according to the thermal capacity mass for different values of conductivity and density.

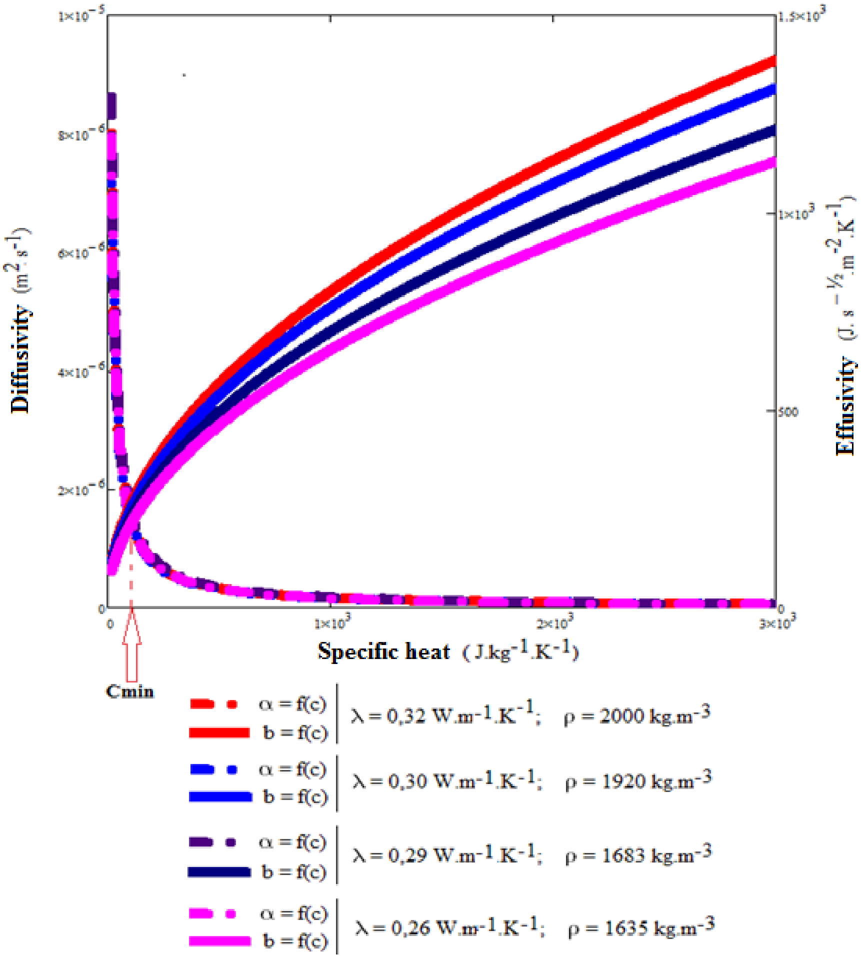

Figure 1: Influence of the specific heat on the diffusivity and effusivity of the material for different values of conductivity and density

We note in Figure 1 above that the variation in conductivity and density has a negligible influence on diffusivity.Everything happens as if there was compensation between the conductivity and the density. But their increase increases the effusivity. We also find that diffusivity decreases for a specific heat increase.

Through this same figure 1, we notice that the effusivity increases with the specific heat. We can also see that there is a minimum value of the specific heat (cmin), below which the thermal inertia of the wall is low (large diffusivity with low effusivity).

So for the material to be usable as a building material, its specific heat willhave to be greater than that minimum value.

3. Determination of the minimum specific heat

We will determine the minimum specific heat from the penetration depth for a given wall thickness.

We have below the relationship giving depth of penetration:

$$\delta = \sqrt{\alpha t} \tag{1}$$

The maximum penetration depth is equal to the thickness of the envelope wall. Indeed a depth of penetration substantially less than the thickness of the wall of the building envelope does not increase the thermal inertia of the building.

Then we can however consider a maximum penetration depth equal to a reasonable wall thicknessto avoid an un necessary increase in the amount of material used for the constructionof the envelope.

The objective of the characterization would then be to determine the minimum specific heat that will give for a given time of heat diffusion from the outside to the interior of the building, a maximum penetration depth equal to the thickness of reasonably considered wall.

We have from the equation (1):

$$\delta = \sqrt{\frac{\lambda}{\rho c} t} \tag{2}$$

And to avoid overheating of the premises inhabited by the heat from the outside, the thermal inertia of the building envelope must allow the situation defined by the following relationship (3):

$$\sqrt{\frac{\lambda}{\rho c} t} \leq \delta_{\max} \tag{3}$$

In fact $\delta_{\max}$ is equal to the thickness of the material considered.

The relationship (3) Entrains:

$$c \geq \frac{\lambda t}{\rho (\delta_{\max})^2} \tag{4}$$

So for a given material thickness, we can always determine the minimum specific heat ($c_{\min}$) to obtain a good inertia of the building envelope.

$$c_{\min} = \frac{\lambda t}{\rho (\delta_{\max})^2} \tag{5}$$

In a project for the improvement of a building material, it will be, with δ_{max} and the duration of the heat diffusion defined, to take the standard values of references of λ and ρ of the material for the calculation of the minimum specific heat. These values can be derived from the literature or from the technical documentation of a material manufacturer when it is in an unconditioned state (example: λ and ρ value of powdered clay).

The heat diffusion period throughthe wall of the building envelope is from 6:00 a.m. to 6:00 p.m. during the day, So time t is equal to 12 hours [4].

One of the physical quantities influencing both density and thermal conductivity is the porosity of the material. This is given by the following relationship

$$\varepsilon = 1 - \frac{\rho_{app}}{\rho_s} \tag{6}$$

From the equation (6), we have:

$$\rho_{app} = \rho_s (1 - \varepsilon) \tag{7}$$

On
the other hand, we give the expression of the thermal conductivity of the material from the model of Hashin and Shtrikman where the material is considered to be composed of a solid phase and a fluid
phase (air) in the pores. We have:

$$\lambda_{app}(\lambda_f, \lambda_s, \varepsilon) = \lambda_f \left(1 + \frac{1-\varepsilon}{\frac{1}{\frac{\lambda_s}{\lambda_f} - 1} + \frac{\varepsilon}{3\lambda_f}} \right) \tag{8}$$

From there, we integrate the porosity into the formula of calculating the minimum specific heat:

$$c_{\min}(\lambda_f, \lambda_s, \rho_s, \varepsilon, t, \delta_{\max}) = \frac{\lambda_f t}{\rho_s (1-\varepsilon)\delta_{\max}^2} \left(1 + \frac{1-\varepsilon}{\frac{1}{\frac{\lambda_s}{\lambda_f} - 1} + \frac{\varepsilon}{3\lambda_f}} \right) \tag{9}$$

4. Results and Discussions

The table below gives, for δ_{max} and t defined the value of $\mathbf{c_{min}}$ for some building materials.

Table 1: Thermal characteristics of a few building materials used in the building

δ_{max}= 200 mm, with time t is equal to 12 hours			
Materials	$\rho(kg.m^{-3})$	$\lambda(W.m^{-1}.K^{-1})$	$c_{min}(J.kg^{-1}.K^{-1})$
Sand or gravel	1950	2	1108
clay	1600	1,5	1013
Solid concrete with river sand or quarry	2200	1,4	687
Reinforced concrete (with 1 < % steel≤ 2)	2350	2,3	1057
Stone	2700	3,5	1400
Granite	2600	2,8	1163
Woodchips concrete	550	0,16	314
Baked clay	2300	0,98	460
Lava	1600	0,55	371

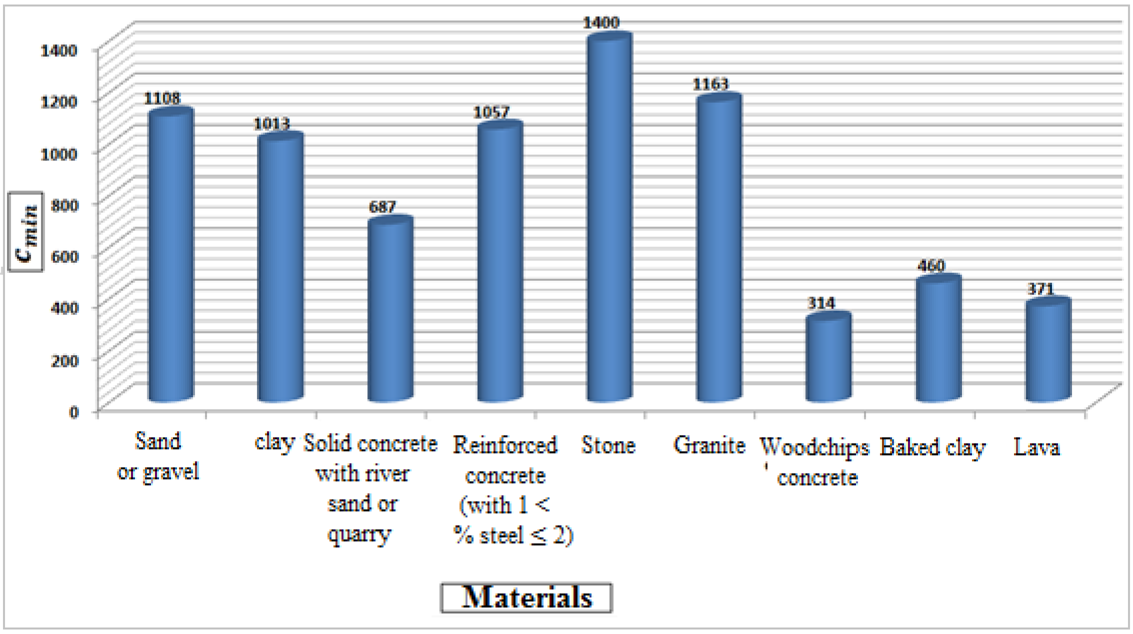

Figure 1: Value of Cmin according to the material

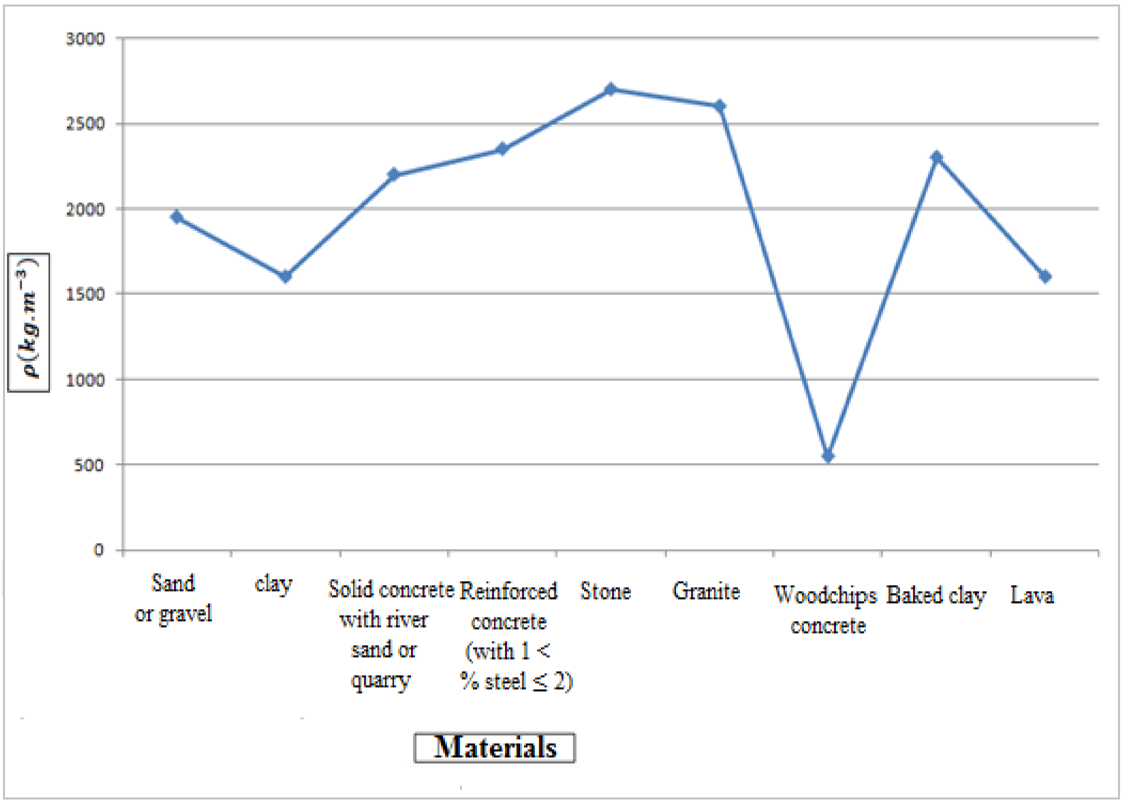

Figure 3: Value of density as a function of material

The combined analysis of the diagram in Figure 2 and the curve in Figure 3 shows that the minimum specific heat changes with the density.

Construction materialswith a high density have a high minimum specific heat.

This means that heavy materials must have a good heat stock capacity to curb its diffusion through the thickness of the material.

The graph in Figure 4 below represents the 3d tracer of Cmin according to t and δ_{max}

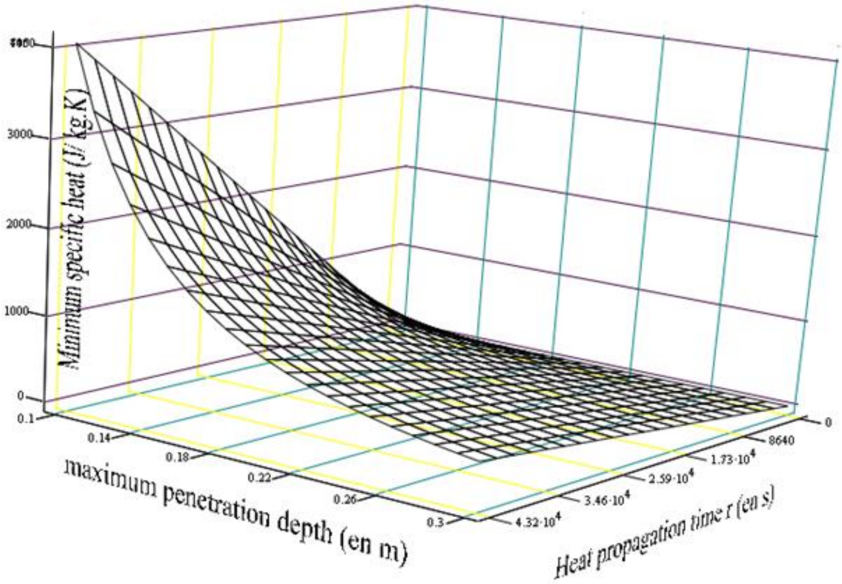

Figure 4: Influence of depth of penetration and heat propagation time on minimum specific heat: for $\boldsymbol{\lambda} = \mathbf{1,5W.m^{-1}.K^{-1}}$; $\boldsymbol{\rho}$ *= 1600 kg.m*$^{-3}$

From Figure 4, we find that the minimum specific heat decreases for an increase in the maximum penetration depth. However, it increases with the duration of heat propagation. This observation allows us to say that if a material does not meet the requirements of thermal inertia, an increase in the thickness of the material can be an alternative. However, the disadvantage is the use of a larger amount of material and therefore more important expenses, for example for the realization of the building envelopes.

On the other hand, to have a good thermal inertia of the walls, the building materials must have a higher specific heat when the heat propagation time increases.

At the end, for a good thermal inertia of the building, the building material must be conditioned in such a way as to obtain a specific heat value greater than Cmin under the fixed conditions of wall thickness and the propagation time of the Heat.

We represent in Figure 5 below the graph of the minimum specific heat according to the porosity for different values of λ_S et ρ_s

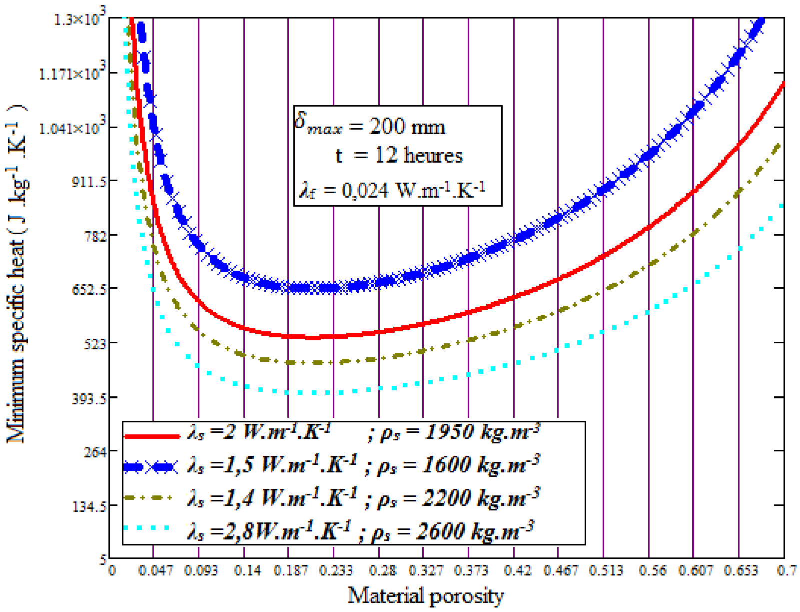

Figure 5: Influence of porosity on the minimum specific heat for different values of λ_S *et* ρ_s

Let's remember first that in our case of study, the fluid that fills the pores is air.
The analysis of the graphs in Figure 5 shows that the minimum specific heat is even higher if the porosity of the material is low to about 20% porosity.
From 20% porosity, the minimum specific heat increases as in the case of low porosity values. In fact, beyond 20% porosity, there may be the presence of open pores in the material, thus increasing the share of convection in the heat transport. In such a situation, it will take a high heat storage capacity to have a good thermal inertia when the material is used in a building envelope.
The advantage we have of the presence of pores in the material is the reduction of the minimum specific heat. The material can then give a good thermal inertia without having to have a large capacity to heat storage. However, it will be necessary to take into account the fact that the presence of pore reduce the mechanical resistance of the material. Figure 5 shows that a porosity of 20% would be optimum for non-insulating construction material. The graphs in Figure 5 also show that in the presence of pore in the material, the minimum specific heat is reduced for an increase in the density of the solid phase of the material.

5. Conclusion

In order to understand the thermal behavior of the building envelope, one is led to study the building material. This study was usedto justify the existence for any construction material, of a minimum mass thermal capacity. Analysis of the simulation results revealed that in the absence of pores, which is the case when the material is purely in its solid phase, the minimum specific heat increases with the density. However, the presence of pores, at least up to a maximum value of 20%, is an advantage as it decreases the value of the minimum specific heat. Furthermore, for a material to have a good thermal inertia, an increase in the maximum depth of penetration would be an alternative to failing to reach the minimum specific heat under given conditions of use.

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