INFLUENȚA DIFUZIVITĂȚII TERMICE A MATERIALELOR DE CONSTRUCȚII ASUPRA COMPORTĂRII TERMICE A PLĂCILOR MONOSTRAT DE GROSIME MARE LA UN SEMNAL TERMIC DE TIP TREAPTĂ

INFLUENCE OF THE BUILDING MATERIALS THERMAL DIFFUSIVITY OVER THE BEHAVIOUR OF SINGLE-LAYER THICK PLATES TO A THERMAL EXCITATION OF IMPULSE-TYPE

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The mathematical model of the semi-infinite massif was used to characterise building materials in case of thermal conduction in unidirectional non-stationary thermal regime. There were obtained informations about the evolution in time of the temperature inside the construction element. Thermal response was analyzed for the following building materials: cellular concrete block GBN35 masonry with thin joints, cellular concrete block Ytong A+ masonry with thin joints, solid brick masonry, reinforced concrete and cellular polystyrene. The results are useful for assessing the thermal insulation performance of building materials and improving the thermal comfort.

În lucrare s-a utilizat modelul matematic al solidului semiinfinit pentru a caracteriza materialele de construcții din punctul de vedere al conducției termice unidirecționale în regim nestaționar. Astfel s-au obținut informații despre evoluțiile în timp ale temperaturilor în interiorul elementului de construcție. Răspunsul termic a fost analizat pentru următoarele materiale de construcții: zidărie de beton celular autoclavizat GBN35 cu rosturi subțiri, zidărie de beton celular autoclavizat Ytong A+ cu rosturi subțiri, zidărie de cărămidă plină presată, beton armat şi polistiren expandat. Rezultatele obținute sunt utile pentru evaluarea performanțelor termoizolatoare ale materialelor de construcții şi îmbunătățirea confortului termic.

Keywords: *thermal diffusivity, non-stationary thermal regime, thermal excitation of impulse-type*

1. Introduction

The ability of a building to use, in winter time, various types of free contributions directly depends on the feature commonly called "thermal inertia" [1, 2]. The concept is still diffusely defined, but by analogy with the well known mechanical characteristic could be described as "the tendency of an element / building subassembly or construction as a whole to maintain the existing thermal state at the time of occurrence the disturbing thermal excitation". This trend appears clearly in non-stationary thermal regime and is more or less significant depending on the thermophysical characteristics of the construction element material [3].

One way to highlight the influence of these "material" characteristics on the performance of thermal inertia of building elements is to study the thermal behavior of building materials currently use to temperature changes. Further, it will consider the classic case of homogeneous semi-infinite solid whose free surface is subjected to a thermal disturbance of impulse-type. Physical phenomenon studied is unidirectional. The capacity problem of heating / cooling in time the inside elements of a building is of great interest [4, 5].

The multitude of construction materials available today makes possible to choose a solution as rational as possible, capable to simultaneously solve both the problem of thermal comfort in enclosed spaces of a building and energy needed to satisfy this requirement [6 - 8].

2. Mathematical model, parameters considered in the analysis

The study takes into account five different materials, very commonly used for the interior walls: cellular concrete block GBN35 masonry with thin joints, cellular concrete block Ytong A+ masonry with thin joints, solid brick masonry, reinforced concrete and cellular polystyrene.

For calculations, the values of the main thermophysical characteristics of these materials were considered those shown in Table 1. The values are indicated by the producers in the technical data of the materials or by the "Reglementation regarding the thermotechnical calculation of construction elements of the building" C107/3-1997 [9].

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Table 1

Thermophysical characteristics of the materials / *Caracteristicile termofizice ale materialelor*

The material *Materialul*	Thermal conductivity *Conductivitatea termică* λ	Mass heat *Capacitatea calorică masică* c	Apparent density *Densitatea aparentă* ρ	Thermal diffusivity *Difuzivitatea termică* a
	W/mK	J/kgK	kg/m^3	m^2/h
Cellular concrete block masonry GBN35 *Zidărie BCA GBN 35*	0.27	870	675	1.654x10^{-3}
Solid brick masonry *Zidărie CPP*	0.80	870	1800	1.838x10^{-3}
Reinforced concrete *Beton armat*	1.74	840	2500	2.980x10^{-3}
Cellular concrete block masonry Ytong A+ *Zidărie BCA Ytong A+*	0.15	870	450	1.378x10^{-3}
Cellular polystyrene *Polistiren expandat*	0.044	1460	20	5.420x10^{-3}

The physical-geometrical model of the semi-infinite massif, very thick, homogenous and isotropic, is associated with different analytical mathematical models designed to characterize the behavior of materials in a non-stationary unidirectional thermal conductive process [1, 8].

The free surface of the material, that is subjected to a temperature variation, is considered as plane x = 0 of the reference system of the model (Fig. 1). Obviously, the temperature variation of the surface will be "received / felt" weaker as the plan of abscissa "x" is getting away from the surface x=0. Also, the temperature variation will be "recorded significantly later in time as the plane “x” is away from the plane x = 0.

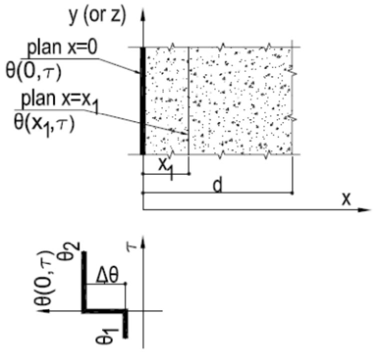


Fig. 1 – The semi-infinite massif reference system.
Sistemul de referință al masivului semiinfinit .

The massive layers of materials analyzed were exposed to a thermal excitation impulse-type, therefore the free surface temperature has suddenly increased from the initial temperature value θ_1, considered to be zero, to the temperature θ_2 which was kept constant for a very long period of time.

The mathematical model used to determine the temperature field θ(x, τ) is:

$$\begin{cases} \dfrac{\partial\theta}{\partial\tau} = a\dfrac{\partial^2\theta}{\partial x^2} \\ \theta(0,\tau) = \theta_1 = 0 \text{ for every } \tau < 0 \\ \theta(0,\tau) = \theta_2 = \Delta\theta \text{ for every } \tau > 0 \\ \theta(x,\tau) = \theta_1 = 0 \text{ for every } \tau < 0 \text{ and every } x \end{cases}$$

One analytical method uses the variable change:

$$U = \frac{x}{2\sqrt{a\cdot\tau}}$$

and finally leads, for function θ(x,τ), to the expression:

$$\theta(x,\tau) = \theta_2 - \Delta\theta\cdot\operatorname{erf}\left(\frac{x}{2\sqrt{a\cdot\tau}}\right)$$

The semi-infinite massif, submitted to a thermal excitation, gradually changes its temperature, reaching that for every time sequence τ_j , any infinitesimal layer of abscissa x_k has its own temperature θ_k (τ_j).

3. Thermal response analysis. Results and discussions.

The specific analysis of the thermal response took into account a positive leap Δθ for the temperature θ(0,0) with the value of 3°C, which led for the function θ(x, τ) to the expression:

$$\theta(x,\tau) = 3 - 3\cdot\operatorname{erf}\left(\frac{x}{2\sqrt{a\cdot\tau}}\right)$$

The only characteristic of the material that appears in the expression of θ(x, τ) is the coefficient a = λ / ρc of thermal diffusivity, whose physical significance is the speed of spreading the heat in the solid mass.

A review of the value "a" for the most commonly used building materials indicates many relatively close values and, as exception, reinforced concrete and cellular polystyrene, two materials with very different thermophysical characteristics.

Since the characteristic "a" appears in the denominator of the mathematical function "erf" and also in the square root, it is difficult to analytically show how $\theta(x, \tau)$ varies by "a" and at the same time by "τ". Parametric studies are therefore required.

The first parametric analysis consists in determining the values of temperature variation in different plans $\Delta\theta(x)$, parallel with the free surface of the solid, for certain values of the variable τ and for each of the five types of analyzed material.

In Figure 2 a)-d) are graphically shown the results obtained for τ=6h, τ=12h, τ=24h, respectively τ=48 hours.

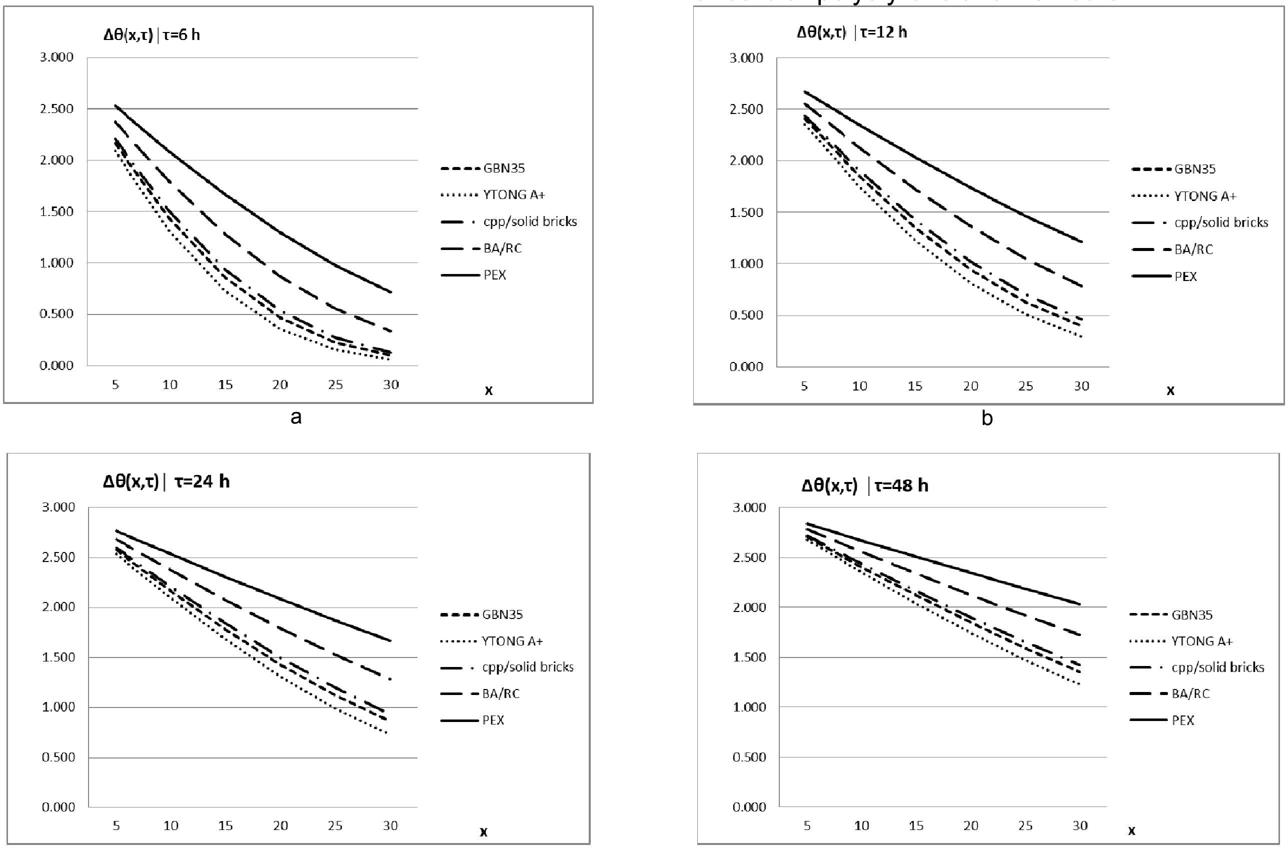
The analysis of these graphical representation shows the following:

- for every value of the time "τ" all analyzed solids are heated in a set section "x" in the same order; the fastest heating, from this point of view, occurs into the polystyrene; the slowest heating $\Delta\theta$ occurs, with small differences, in the two cellular concrete block masonries and in the case of solid brick masonry
- rapid heating of the cellular polystyrene occurs for relatively large thicknesses
- at a moment closer to the beginning of thermal excitation (eg. τ=6 hours) the allure of variation for $\Delta\theta(x)$ has, for all five materials considered, a relatively pronounced curvature; in exchange, for a later moment (eg. τ=48 h) the variation of $\Delta\theta(x)$ is closer to a linear one;

A second parametrical analysis consists in determining the values of $\Delta\theta(\tau)$, showing the way that changes the temperature in different plans "x" parallel to the free surface of the solid, in each of the five types of analyzed material.

For analyses it was used an impulse for thermal excitation of 3°C from $\Delta\theta(0,0)$ and a continuously variation of time τ from 1 hour to 48 hours, for different thickness "x" of material. In this case, the values of the parameter x used for calculating $\Delta\theta$ were taken from x=5cm to x=30cm, with an increment of 5 cm. In Figure 3 a) and b) are graphically represented the curves of variation of the functions $\Delta\theta(\tau)$, in two characteristic sections, for the five analyzed materials.

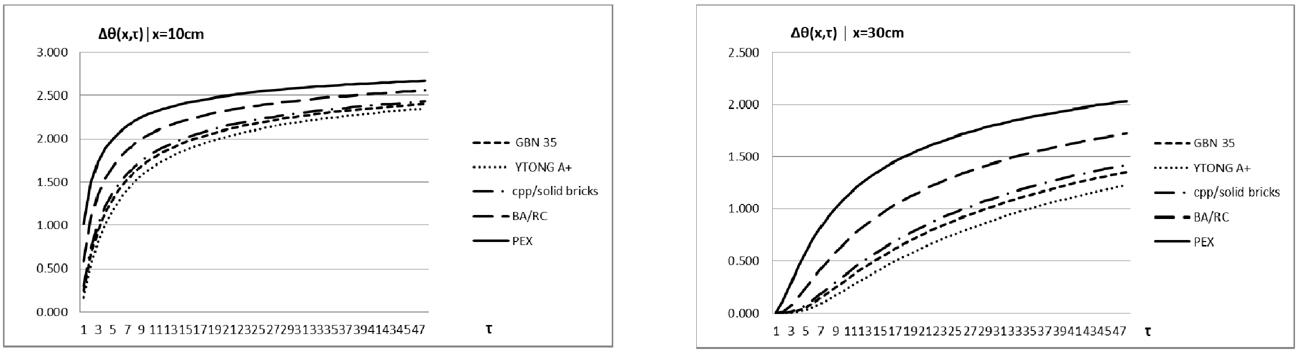
It can be noticed that in the plan x=10cm the increase of temperature "feels" very quickly and at a value quite close to the thermal excitation of the plan "zero": about 55% for Ytong masonry and 78% for cellular polystyrene at the moment τ=12 hours and about 78% for Ytong masonry and 89% for cellular polystyrene at τ=48 hours.



a b c d

Fig. 2 – Graphical representation of the temperature variation $\theta(x)$ at the time a) τ=6h, b) τ=12h, c) τ=24h, d) τ=48h

Graficele variației de temperatură θ(x) la momentul a) τ=6h, b) τ=12h, c) τ=24h, d) τ=48h.



a b

Fig. 3 – Graphical representation of the temperature variation $\theta(\tau)$ in the section plan a) x=10cm, b) x=30cm
Graficele variației de temperatură θ(τ) în planul a) x=10cm, b) x=30cm .

By comparison, in the plan x=30 cm the increase of the temperature "feels" less significant: about 10% for Ytong masonry and 40% for polystyrene at the moment τ=12 h and 40% for Ytong masonry and 68% for polystyrene at τ=48 hours.

In the first hours, the heating process is almost insignificant, almost inexistent in the more distant sections from plan x=0. Therefore:

- after 2 hours, the heating of the plan x = 10 cm is 1,49°C for cellular polystyrene, 1,08°C for reinforced concrete and below 0,7°C for the 3 types of masonry considered;
- also after 2 hours, the heating of the plan x=30cm is practically zero for all five material considered;
- even after 4 hours, the heating of the plan x=30cm is very small: 0.45°C for polystyrene, 0.16°C for reinforced concrete and under 0.04°C for the 3 types of masonry considered.

In conclusion, the thermal diffusivity is the aptitude of the materials that influences in a decisive way the thermal behavior and the temperature range inside a solid element subjected to a temperature variation on one side. The larger is the value of the thermal diffusivity, the faster and deeper is the heating of the material.

4. Conclusions

After the analysis, the following main conclusions can be stressed out:

- A wall made of a material with high thermal diffusivity, after starting a heat source:
  - it increases the inner temperature along its thickness faster than a wall made of a material with low thermal diffusivity;
  - it reaches relatively quickly a temperature of the inner surface θ_{si} closer to the thermal comfort.
- Among the studied materials, the highest values of the thermal diffusivity have cellular polystyrene and reinforced concrete, two materials with thermo-physical characteristics ρ and λ very different, but mutually compensating each other in the thermal diffusivity "a" definition.

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