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Characterization of the thermal behavior of a kapok-plaster material by studying the temperature in frequency dynamic regime.

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Abstract:

We present a study of one-dimensional heat transfer through a kapok-plaster material. We show the temperature behavior in the material subjected to an external faced to the climate solicitation in the frequency dynamic regime. The Kapok-plaster material used has a thickness of 10cm, and an average thermal conductivity λ=0,1W.m^{-1}K^{-1}.

We highlight the impact of the exciting pulse, the convective heat exchange coefficient at the front and the thermal diffusivity on the temperature inside the material.

We show the influence of these variables on the optimal thermal insulation thickness.

Keywords: frequency dynamic regime; kapok; plaster; pulsation; thermal diffusivity; convective heat exchange coefficient; optimal insulation thickness (O.I.T).

1. Introduction:

Saving energy in the habitat is a prerequisite for good control of thermal insulation [1] buildings. Numerous materials (polystyrene, glass wool, rock wool etc.) are very polluting. Thus, the plant materials such as kapok [2] related to plaster and waste from the processing olive industry, as well as paper and cardboard (cellulose) occupy an important place in the quest for an alternative solution.

We propose a characterization of the thermal behavior of the kapok-plaster material by studying the temperature throughout the material. The influences of the exciting pulse from external climatic solicitations to the material, the heat transfer coefficient at the front and the thermal diffusivity on the transfer of heat in the kapok-plaster material are highlighted. The influences of these parameters on optimal thermal insulation thickness (O.I.T) are shown.

2. Schema and description of the study device

The material is of parallelepiped shape whose thickness is of length L. The material is subjected on two faces parallel to from external climatic constraints. We consider the heat transfer in the direction perpendicular to the faces subject to climatic constraints.

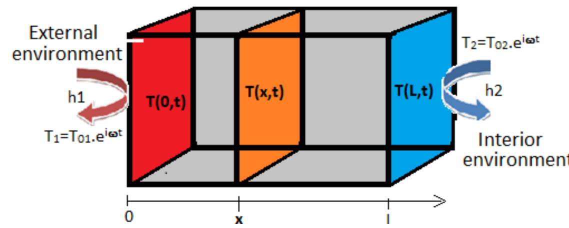

Figure 1: the plan kapok-plaster wall subjected to external climatic solicitations.

T_{01}=318K, T_{02}=273K.

- h1 and h2 are respectively the heat transfer coefficients at the outer and inner side.
- T1 and T2 are respectively the temperatures in frequency dynamic regime of the ambient indoor and outdoor environments.

3. Temperature expression in the homogenous material kapok plaster

The equation of the heat for the transfer of heat in the wall is given by the equation (1) :

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha} \cdot \frac{\partial T}{\partial t} = 0 \qquad \textbf{(1)}$$

With : $\alpha = \dfrac{\lambda}{\rho \cdot C}$ **(2)**

α is the thermal diffusivity.

The boundary conditions (3) and (4) are the conditions of heat exchange on the wall faces.

$$\lambda \frac{\partial T}{\partial x} = h_1 [T(0,t) - T_1] \qquad \textbf{(3)}$$

$$\lambda \frac{\partial T}{\partial x} = h_2 [T(L,t) - T_2] \qquad \textbf{(4)}$$

The solution of equation (1) is:

$$T(x,\omega,h1,h2,\alpha,t) = \begin{bmatrix} A_1 \cdot \sinh(r(\omega,\alpha)\cdot x) + \\ A_2 \cdot \cosh(r(\omega,\alpha)\cdot x) \end{bmatrix} e^{i\omega t} \qquad \textbf{(5)}$$

ou

$$r(\omega, \alpha) = \sqrt{\frac{\omega}{2\alpha}}(1 + i) \qquad \textbf{(6)}$$

The expressions A1 and A2 coefficients are determined from the boundary conditions. [3,4]

A_1=f(x,ω, h1, h2, α) **(7)**

A_2=f(x,ω, h1, h2, α) **(8)**

4. Results:

The curves below show the evolution of the temperature as a function of the depth of the kapok-plaster material. Respectively we are highlighting the influences of external excitation pulse, the heat transfer coefficient and thermal diffusivity. The optimal thermal insulation thickness (O.I.T) is defined as the distance between the face of the material in contact with the external medium and the position within the material from which the temperature takes a minimum value of the neighboring environmental condition of the inside face of the material.

Figure 2 shows the influence of the external excitation pulse on the optimal thermal insulation thickness. The comparison of the curves shows that this thickness depends on the energizing pulse so period of climatic stresses. Table 1 gives some illustrations; for a pulsation 10^{-3}rad.s^{-1} corresponding to a biasing period of about 2 hours with an external temperature of 318K, the O.I.T is of the order of 10 cm to a temperature variation ΔT = 45K . Given the constraining conditions resulted by the significant variation of temperature, the kapok-plaster material thus used is a good thermal insulator.

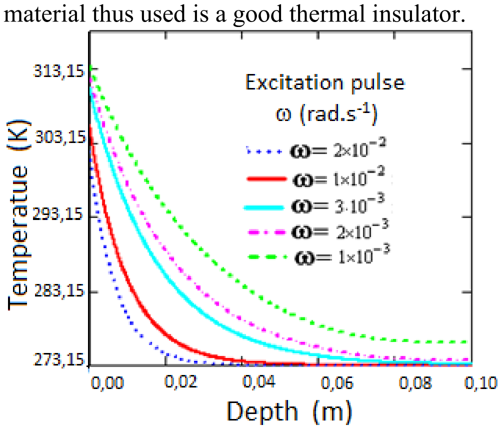

Figure 2 : Evolution of the temperature as a function of depth; influence of pulsation.
h1=30W.m^{-2}.K^{-1} ; h2=30W.m^{-2}.K^{-1} ; α=4,73.10^{-7}m^{2}.s^{-1}.

Table 1: Values of the optimal thermal insulation thickness (O.I.T) for different values of the excitation pulse.

Excitation pulse ω (rad.s^{-1})	*Optimal thermal insulation thickness (O.I.T)*
10^{-3}	O.I.T $\geq 10^{-1}$m
2.10^{-3}	O.I.T $\geq 10^{-1}$m
3.10^{-3}	O.I.T $\geq 10^{-1}$m
10^{-2}	$4.9.10^{-2}$m
2.10^{-2}	$3.4.10^{-2}$m

The curves of Figure 3 emphasize the influence of the thermal exchange coefficient on the optimal thermal insulation thickness. Table 2 provides some illustrative values; for a heat exchange coefficient of the order of 200W.m^{-2}.K^{-1}, the O.I.T is approximately 3cm. The treatment of the outer surface to reduce the heat transfer coefficient will reduce the amount of materials to be used in the design of cold rooms.

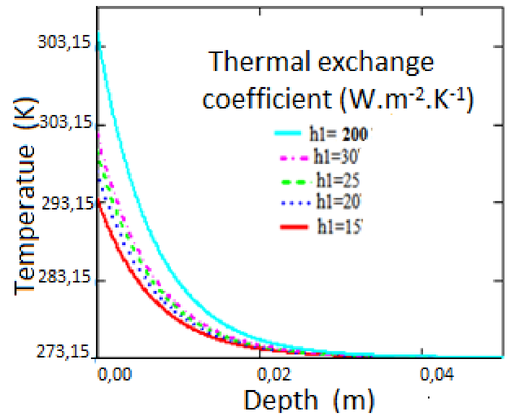

Figure 3 : Evolution of the temperature as a function of depth; influence of the heat transfer coefficient.
ω=2.10^{-2}rad.s^{-1} ;h2=0,5W.m^{-2}.K^{-1} α=4,73.10^{-7}m^{2}.s^{-1}.

Table 2: Values of the optimal thermal insulation thickness (O.I.T) for various values of the thermal exchange coefficient.

thermal exchange coefficient h1 (W.m^{-2}.K^{-1})	*Optimal thermal insulation thickness (O.I.T)*
15	$2.86.10^{-2}$m
20	$2.95.10^{-2}$m
25	$3.05.10^{-2}$m
30	$3.09.10^{-2}$m
200	$3.33.10^{-2}$m

The curves of Figure 4 show the influence of the thermal diffusivity of kapok-plaster material on the optimal thermal insulation thickness. Thermal diffusivity depends on the thermal conductivity, density and thermal capacity of the material. So we can deduce that the thermal diffusivity also depends on the compaction rate used for the realization of the kapok-plaster material.

Table 3 shows that the smaller values of thermal diffusivity allow to obtain an optimum thermal insulation minimum thickness. Equation (2), however, shows the need for a study to determine the optimal mix of kapok and plaster to have good thermal diffusivity of the material without sintering.

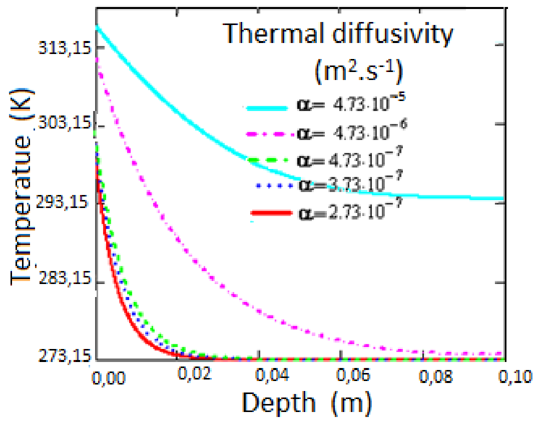

Figure 4 : Evolution of the temperature as a function of depth; influence of the thermal diffusivity.
$\omega=2.10^{-2}$rad.s^{-1} ; h1=30W.$m^{-2}K^{-1}$; h2=0,5W.$m^{-2}.K^{-1}$.

Table 3: Values of the optimal thermal insulation thickness (O.I.T) for different values of the thermal diffusivity.

Thermal diffusivity α ($m^2.s^{-1}$)	***Optimal thermal insulation thickness (O.I.T)***
$2,73.10^{-7}$	*$2.5.10^{-2}$m*
$3,73.10^{-7}$	*$3.0.10^{-2}$m*
$4,73.10^{-7}$	*$3.4.10^{-2}$m*
$4,73.10^{-6}$	*E.I.O>10^{-1}m*
$4,73.10^{-5}$	*E.I.O>10^{-1}m*

5. Conclusion

The study shows that the choice of the composition of the kapok-plaster material for good thermal insulation requires a mastery of parameters:

-intrinsèques: density, thermal conductivity and specific heat capacity of the material;

- Extrinsic: pulse excitation relative to the period of external climatic stresses, the heat transfer coefficient which also depends on the shape of the contact surface and climate constraints.

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