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RESEARCH ARTICLE

INFLUENCE OF EXCITATION PERIOD ON THERMAL TRANSFER OF TOW-PLASTER THERMAL INSULATION PLATE ATTACHED TO WALL: APPLICATION TO COLD ROOM

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Abstract

Composite wall consisting of three layers placed from outside to inside in concrete, plaster and plexiglass, is subject to external climatic constraints evolving in frequency dynamic regime. Goal is to maintain indoor environment at lower temperature for thermal comfort in homes or thermal insulation of cold rooms. By means of excitation pulse, periods of external climatic stresses for which thermal insulation is effective for this wall system are determined

Introduction:-

African countries in general, especially Senegal, are major producers of fruits and vegetables.

However, a part of the harvest is lost either at the place of production or at the level the markets because of a notorious lack of means of transformation but especially a lack of means of conservation such as cold rooms.

Indeed, the number of cold storage rooms for fruit and vegetables is very limited compared to demand because of the exorbitant cost of these installations linked, among other things, to the cost of thermal insulation.The insulators used are generally synthetic types imported from Europe or Asia, hence the need to find alternatives locally. However, several characterization studies [1], [2] on various local materials, such as tow, kapok, kenaf ..., have shown that these can be used for effective thermal insulation of buildings [3], [4] and refrigeration equipment.

It is with this in mind that we opt to study the tow-plaster composite material for thermal insulation of a positive cold room for storing tropical and European fruits in order to reduce the cost of acquiring cold rooms.We are studying the influence of the excitation period on heat transfer through tow-plasterattached to a wall.

Theory :

Study Model:

The study device is composed of a tow-plaster material attached to a concrete wall whose thermophysical properties [5] (coefficient of thermal conductivity, coefficient of thermal diffusivity) are determined.

A cold room (Figure 1) is a special room equipped with a refrigeration machine [6] which keeps the temperature and relative humidity [7] of the air at constant values.It consists of four side walls, a ceiling and a low floor. The

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particularity of these local insulators is based on the type of thermal insulation [8,9] used which is a determining factor for maintaining a low temperature at a reasonable energy cost.The insulation in question is subjected to external climatic stresses [10] as shown in Figure 1 (convection, radiation, etc.). Figure 2 is a section on one of the side walls of the cold room showing the composition of the materials and their different thermophysical parameters.

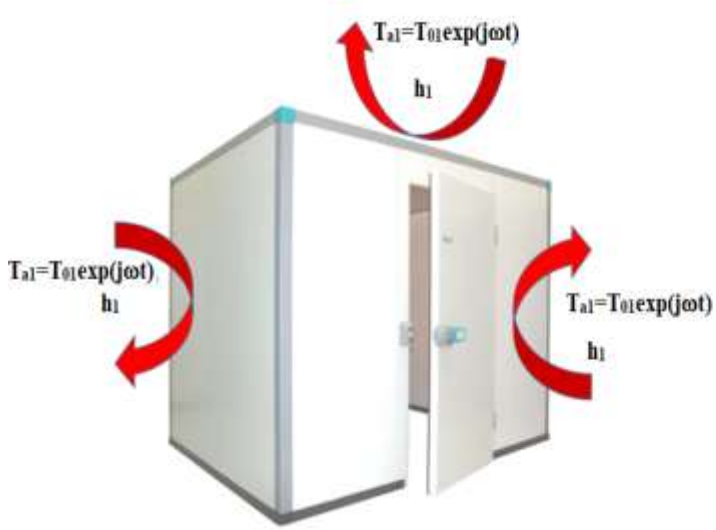

FIG. 1:- Modeling of climatic stresses outside the cold room.

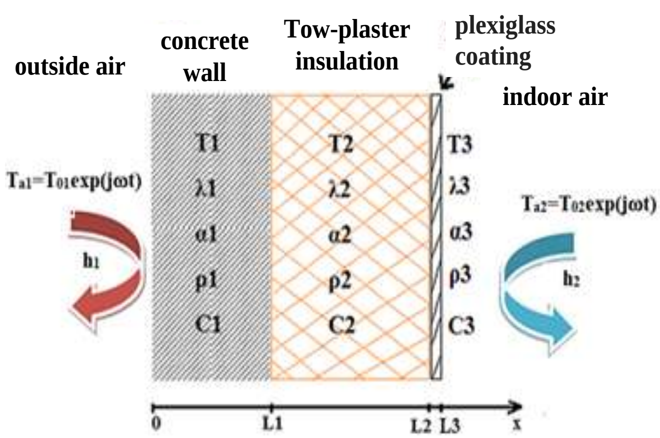

FIG. 2:- Sectional view of the different layers making up the side walls of the cold room.

T_{a1} and T_{a2}: respective temperatures, in complex modulation, of the air outside and inside the cold room.
T_1, T_2 and T_3 : respective temperatures of the concrete wall, the tow-plaster insulation and the plexiglass
T_{01} et T_{02} : Respective maximum temperatures of the external and internal environments of the cold room.
h_1 et h_2 : respective convective exchange coefficients of the outside and inside air of the cold room
λ_1, λ_2 et λ_3 : respective thermal conductivities of the concrete wall, the tow-plaster insulation and the plexiglass.
α_1, α_2 et α_3 : respective thermal diffusivity coefficients of the concrete wall, the tow-plaster insulation and the plexiglass coating.
C_1, C_2 et C_3: respective mass heat capacitiesof the concrete wall and the tow-plaster and plexiglass insulation.

Study Hypotheses:
For a period of 2 to 4 weeks of average fruit conservation in general, the constraints are defined by:

the interior conditions of the cold room: 7 ° C and a relative humidity of 85%;

outdoor conditions: a room is generally installed in a warehouse to minimize the external heat gains linked to sunlight. The cold room will be installed in a warehouse located in Dakar with an ambient air temperature of 27 ° C with a relative humidity of 70%.

The use of a wall consisting of:

Thermal insulator, in particular plaster-plaster material, a prototype manufactured in the Semiconductors and Solar Energy laboratory of the Faculty of Sciences and Techniques of the Cheikh Anta Diop University, Dakar, [11] having a thermal conductivity $\lambda = 0.17\ Wm^{-1}K^{-1}$, a coefficient of thermal diffusivity $\alpha = 2.03\ 10^{-7}\ m^2.s^{-1}$ and an average mass of 3.29 kg including 40g of tow.

Concrete [12], consisting of cement, aggregates (sand and gravel) and water. The concrete used has a thermal conductivity $\lambda = 1.3\ W.\ m^{-1}K^{-1}$ and a coefficient of thermal diffusivity $\alpha = 5.02\ 10^{-7}\ m^2.s^{-1}$.

And plexiglass: it is a vapor barrier, in the form of a coating, it is installed inside the room in contact with the plaster-plaster insulation to prevent the humidity of the air from affecting the latter. This coating consists of polymethyl methacrylate [13] with a thermal conductivity $\lambda = 0.19\ W.m^{-1}K^{-1}$ comparable to that of the plaster plaster material and density $\rho = 1.19\ kg.m^{-3}$.

The thicknesses of the different materials (Figure 2) are: L1 = 0.100 m; L2 = 0.200m and L3 = 0.205m.

Mathematical Formulation:

In the cold room wall, the expressions for temperature and heat flux density are obtained respectively from the resolution of equation (1) of heat and the equation of quartermaster (14).

$$\rho \cdot C \cdot \frac{\partial T(x,h_1,h_2,\omega,t)}{\partial t} = \lambda \cdot \Delta T(x,h_1,h_2,\omega,t) + Pp \qquad (1)$$

Where :

λ : thermal conductivity of material($W.m^{-1}K^{-1}$) ;

C : specific heat of the material($J.Kg^{-1}.K^{-1}$) ;

P_p : internal heat supply (heat sink) of material($W.\ m^{-3}$) ;

ρ : density of material($Kg.\ m^{-3}$) ;

T : Temperature in material(K).

In the absence of an internal heat source (Pp = 0) and in one dimension, the heat equation becomes:

$$\frac{\partial^2 T(x,h_1,h_2,\omega,t)}{\partial x^2} - \frac{1}{\alpha} \cdot \frac{\partial T(x,h_1,h_2,\omega,t)}{\partial t} = 0 \qquad (2)$$

$$\text{With}\ \alpha = \frac{\lambda}{\rho \cdot C} \qquad (3)$$

α ($m^2.s^{-1}$) is thermal diffusivity coefficient of the material[**14**] .

The resolution of equation (2) makes it possible to obtain the expression of the temperature in the wall: layer 1, concrete; layer 2, tow plaster; layer 3, plexiglass. Thus, in the different layers, we have:

$$\frac{\partial^2 T_i(x,h_1,h_2,\omega,t)}{\partial x^2} - \frac{1}{\alpha_i} . \frac{\partial T_i(x,h_1,h_2,\omega,t)}{\partial t} = 0 \qquad (4)$$

$i = 1, 2$ or 3respectively for the layers1, 2 ou 3.

Taking into account the initial conditions of the materials, we note:

T_i^0= 25°C : initial temperature condition ;

$\overline{T}_i(x,h_1,h_2,\omega,t)$: « addition Temperature » material

$T_i(x,h_1,h_2,\omega,t)$: Material temperature at the moment(t) ;

We have:

$$T_i(x,h_1,h_2,\omega,t) = \overline{T}_i(x,h_1,h_2,\omega,t) + T_i^0 \qquad (5)$$

From the addition temperatures, equations (4) become:

$$\frac{\partial^2 \overline{T}_i(x,h_1,h_2,\omega,t)}{\partial x^2} - \frac{1}{\alpha_i} . \frac{\partial \overline{T}_i(x,h_1,h_2,\omega,t)}{\partial t} = 0 \qquad (6)$$

To solve equation (6), we use the variable separation method. The solutions, in dynamic frequency regime for the different layers, are in the form:

$$T_i(x,h_1,h_2,\omega,t) = \left[A_i(h_1,h_2,\omega,t) \cdot \sinh(\beta_i \cdot x) + B_i(h_1,h_2,\omega,t) \cdot \cosh(\beta_i \cdot x)\right].\ e^{j\omega t} + T_i^0 \qquad (7)$$

$$\beta_i = \sqrt{\frac{\omega}{2.\alpha_i}}(1 + j) \qquad (8)$$

Where : $i = 1, 2$ or 3respectively for the layers1, 2 or 3 et $j^2 = -1$

The expressions coefficients A_i and B_i are determined from the boundary conditions defined by equations (9):

$$\begin{cases} -\lambda 1 \cdot \left.\dfrac{\partial \overline{T}_1(0,h_1,h_2,\omega,t)}{\partial x}\right|_{x=0} = h_1\left(T_{a1} - (\overline{T}_1(0,h_1,h_2,\omega,t) + T_i^0)\right) & (9) \\ \overline{T}_1(L_1,h_1,h_2,\omega,t) = \overline{T}_1(L_2,h_1,h_2,\omega,t) & (10) \\ \lambda 2 \cdot \left.\dfrac{\partial \overline{T}_2(x,h_1,h_2,\omega,t)}{\partial x}\right|_{x=L2} = \lambda 3 \cdot \left.\dfrac{\partial \overline{T}_3(x,h_1,h_2,\omega,t)}{\partial x}\right|_{x=L2} & (11) \\ \overline{T}_2(L_2,h_1,h_2,\omega,t) = \overline{T}_3(L_2,h_1,h_2,\omega,t) & (12) \\ -\lambda 3 \cdot \left.\dfrac{\partial \overline{T}_3(x,h1,h2,\omega,t)}{\partial x}\right|_{x=L3} = h_2(\overline{T}_3(L_3,h_1,h_2,\omega,t) + T_i^0 - T_{a1}) & (13) \end{cases}$$

The heat flux density [15] is given by equation (14) in the in the different layers:

$$\phi_i(x,h_1,h_2,\omega,t) = -\lambda_i \frac{\partial T_i(x,h_1,h_2,\omega,t)}{\partial x} \quad (14)$$

$i = 1, 2$ or 3respectively for the layers1, 2 or 3.

Resultats and discusions:-

thermal behavior of the wall under impact the excitation pulse:

Figures 3, 4 and 5 respectively show the thermal behavior of the different layers of the wall: concrete, plaster and plexiglass, for h_2= 10W.m^{-2}.K^{-1} and x = 0.10m; the series of curves in a figure show the influence of the heat exchange coefficient h_1.

Table 1 below gives an indication of the correspondence between the excitation pulse and the period of external climatic stresses.

Table 1:- Period of external climatic stresses.

excitation pulse (rad/s)	3,16.10^{-6}	10^{-5}	3,16.10^{-5}	10^{-4}	3,16.10^{-4}	10^{-3}	3,16^{-3}
Périod excitation (Hours)	552	174	55,2	17,4	5,52	1,75	0,55

For$\omega < 10^{-4}$rad.s^{-1}, the temperature of the concrete increases with the exciting pulse which means that the thermal conductivity of the concrete is an increasing function of the pulse: λ = f (ω). A similar phenomenon is observed with the plaster tow. On the other hand, in plexiglass, we have a reduction in thermal conduction phenomena with pulse, which gives it a considerable propertyof thermal insulation.

For a pulse fixed in this pulse band $\omega < 10^{-4}$rad.s^{-1}, we have a considerable heat retention during the crossing of the concrete-tow line interface. plaster which results in a decrease in the temperature of ΔT by comparing Figures 3a and 4a. In the same pulse band, we have a decrease in the heat flux ϕ at the interface (by comparing Figures 3b and 4b). Contact resistance Rc is a function of the excation pulse ; $R_c = \frac{\Delta T}{\phi} = g(\omega)$.

At the tow-plaster-plexiglass interface, the comparison of FIGS. 4a and 5a shows a considerable retention of heat which results in a drop in temperature at a fixed pulse. The comparison of FIGS. 4b and 5b shows a different evolution of the heat flux in the plexiglass and tow plaster insulation. We have a dynamic thermal resistance Rc(ω).

Around$\omega = 10^{-4}$rad.s^{-1}, we have a maximum temperature in concrete around 26 ° C (figure 3a), an inflection point in the tow-plaster around 20 ° C (Figure 4a) and between 6 ° C and 7 ° C in the plexiglass (Figure 5a). We thus have at the interfaces thermal resistance of dynamic contact Rc(ω).

For $\omega > 10^{-4}$rad.s^{-1}, the thermal conduction in concrete (figure 3a and 3b) is practically independent of the excitation pulse.The heat flow decreases considerably (figure 3b); the regime is quasi-static. On the other hand in the plaster plaster and in theplexiglass we have considerable variations of flux at the plaster plaster - plexiglass (figure 4b) and plexiglass- interior medium (figure 5b) interfaces; these phenomena are linked to heat exchangeswith the external environment via the heat exchangecoefficient h_2.

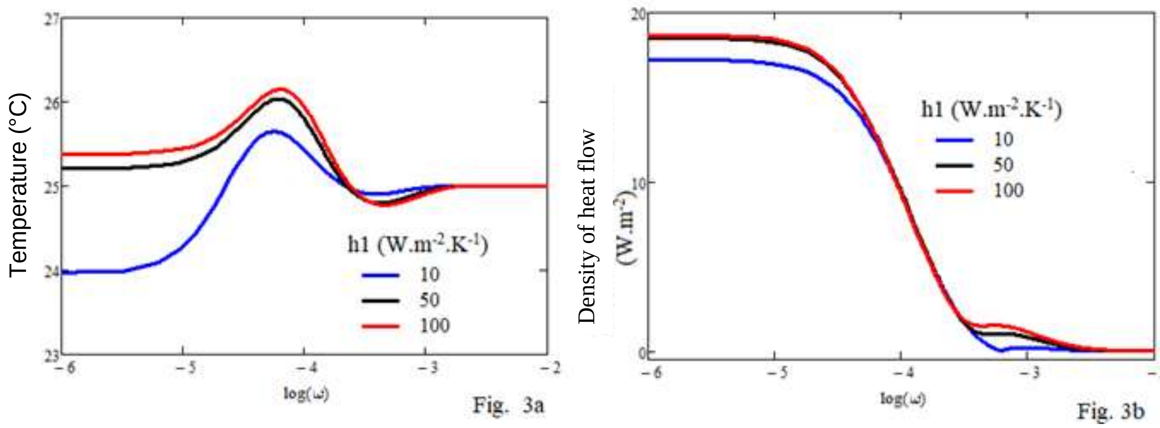

Fig. 3.(a):- Temperature evolution, (b): evolution of the heat flow density as a function of the excitation pulse in the concrete wall; influence of h_1; $h_2 = 10W.m^{-2}.K^{-1}$ and x = 0.10 m.

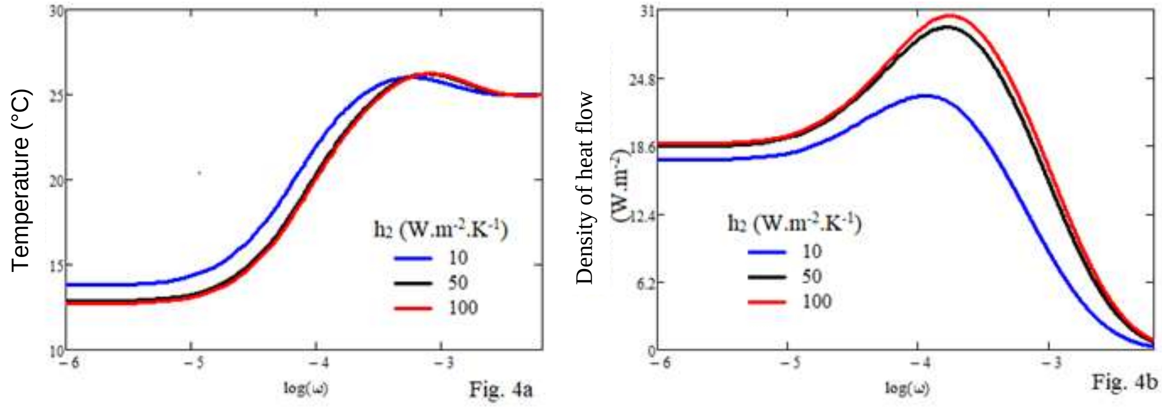

Fig. 4.(a):- Evolution of the temperature, (b): evolution of the tensity of heat flowas a function of the excitation pulse in the tow-plaster insulation **-** influence of h_2; $h_1 = 10W.m^{-2}.K^{-1}$ and x = L2 = 0.20 m.

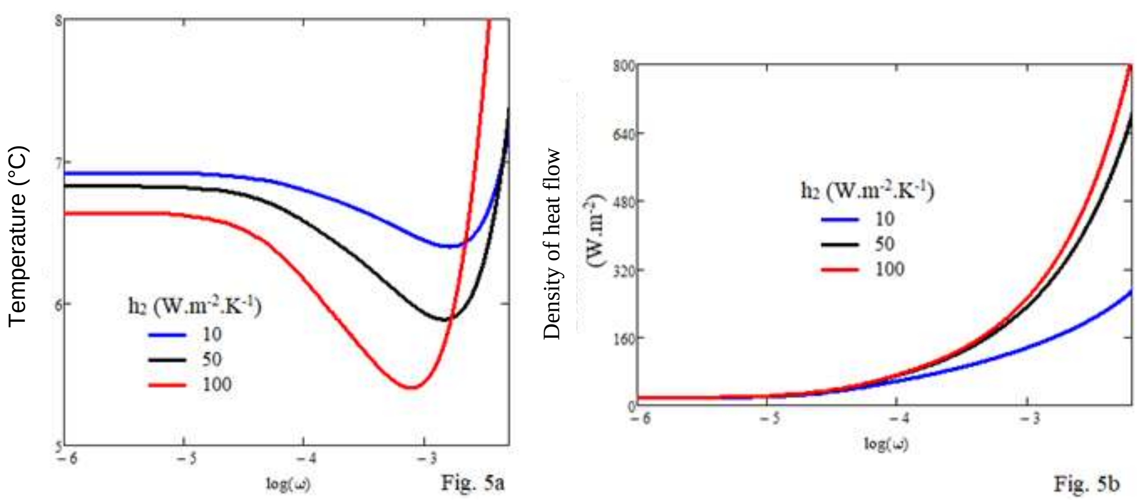

Fig. 5. (a):- Evolution of the temperature; (b): evolution of the heat flux density as a function of the excitation pulse in the plexiglass; influence of h_2; $h_1 = 10W.m^{-2}.K^{-1}$ and x = L3 = 0.205 m.

Influence of the excitation period on the thermal behavior of the wall:

Figure 6 shows the evolution of the thermal behavior through the composite wall for different values of the excitation pulse.

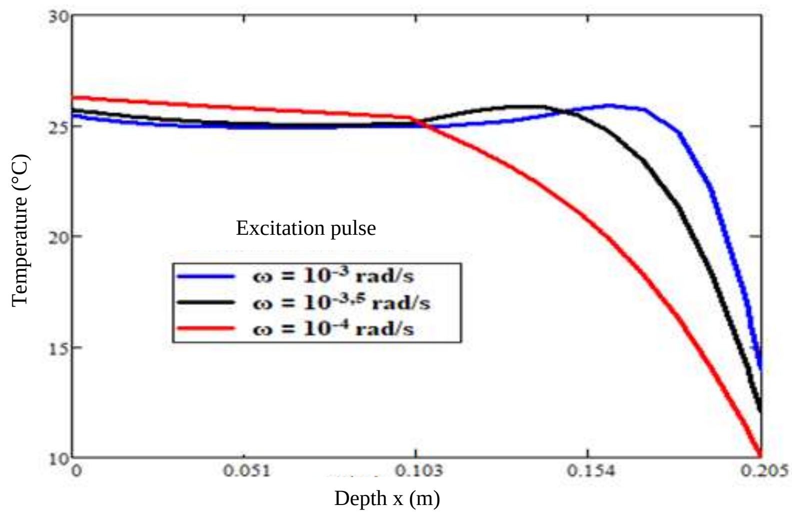

Fig. 6:- Evolution of the temperature through the composite wall (concrete / plaster / plexiglass); influence of the excitation pulse;h_1 =20W.m^{-2} .K^{-1} and h_2 =10W.m^{-2} .K^{-1}.

In the concrete wall, the thermal conduction is considerable; the temperature drop is relatively small. The wall has a low heat storage capacity per unit of mass which results in a slight drop in temperature.

The plaster and the plexiglass have comparable thermal conductivities and thermal behavior. This part of the wall has a considerable thermal mass capacity which allows it to store significant amounts of heat in thin layers. The diffusion of heat through this part is weak.

In concrete, conduction phenomena are important when the excitation pulse is weak, that is to say when there is an excitation period greater than 17 hours. On the other hand, in the insulating part, there is an inversion of the phenomenon for the large pulses, that is to say the relatively short periods, less than 17 hours; there is a decrease in the capacity of heat storage. This is explained by the relaxation phenomena of the insulating material.

Conclusion:-

The thermal transfer studied on a composite wall made up of three layers: concrete, tow-plaster and plexiglass, has shown considerable interest in the use of local materials such as plaster plaster in the thermal insulation of domestic buildings and cold rooms. However, it is necessary to use protective envelopes against moisture from matrices containing vegetable fibers using moisture-resistant materials such as plexiglass.

For periods of climatic stress less than 17 hours, we have good behavior of the thermal insulator. Given the average duration of sunshine in our tropical zones of less than 12 hours, the system thus studied appears to be favorable to good thermal comfort in homes and good insulation of cold rooms.

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