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Research Article

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Thermal Study of a Composite Wall (Concrete/typha-plaster) of a Cold Room in Frequential Dynamic Regime

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Abstract A cold room whose walls are made up of two layers arranged from the outside to the inside of concrete brick and typha-plaster, is subjected to external climatic constraints evolving in frequential dynamic regime. Our study focuses on the thermal behavior of this wall based on Typha (local of thermal insulation material) while maintaining the interior environment at a lower temperature. The objective of our study is to improve energy efficiency in building techniques for thermal insulation. By means excitatrice pulsation, the periods of external climatic stresses for which the thermal insulation is effective for this wall system, was determined.

Keywords Cold room, typha-plaster, excitatrice pulsation, period, thermal insulation

Introduction

Due to a lack of processing and conservation industries, fruit and vegetable producers lose 60 to 70% of their production in Casamance in a southern region of Senegal [1].

To deal with this problem, the producers would like to have means of transformation but especially to have a system of conservation like the cold rooms. Because of the exorbitant cost of its facilities, the number of cold storage rooms for fruit and vegetables is very limited [2]. However, researchers have worked on several local materials of plant, animal or synthetic [3] origin for thermal comfort. Among these materials of plant origin, we have typha [4] often associated with a binder [5] to improve its mechanical behavior**.**

In order to reduce the cost of acquisition of cold rooms, we study the thermal behavior of a typha-plaster composite wall in frequential dynamic regime.

First, we study the thermal behavior of a typha-plaster board attached to a concrete wall as a function of the excitation period under the influence of depth; and then depending on the depth of the concrete wall and the typha-plaster under the influence of the heat exchange coefficient and the excitatrice pulsation.

Theoretical Study

Study Model

A cold room is a particular room equipped with a refrigeration machine [6] which maintains the temperature and relative humidity [7] of the air at constant values. It is subject to external climatic stresses (Figure 1) [2].

The particularity of local insulators is based on the type of thermal insulation [8,9] used, which is a determining factor in maintaining a low temperature.

Figure 2 [10] is a section on one of the side walls of the cold room showing the composition of its materials.

The study device (Figure 3) is composed of a typha-plaster material attached to a concrete wall whose thermo-physical parameters (coefficient of thermal conductivity, coefficient of thermal diffusivity) are determined.

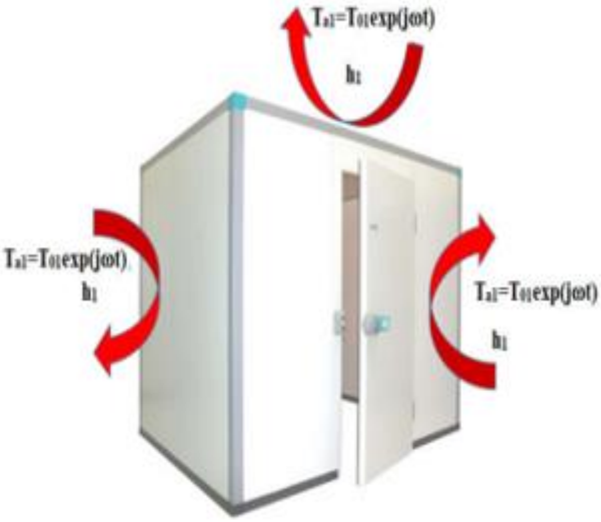

Figure 1: Modeling of external climatic stresses in the cold room

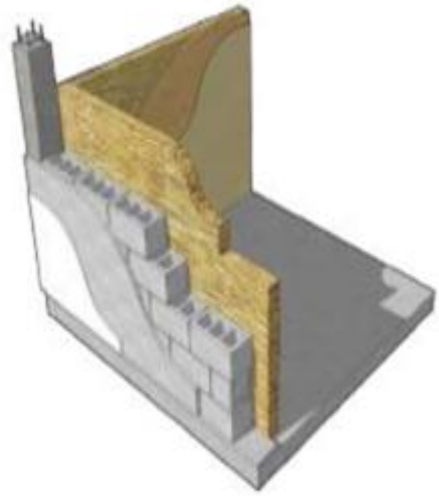

Figure 2: Section of a side wall of the cold room

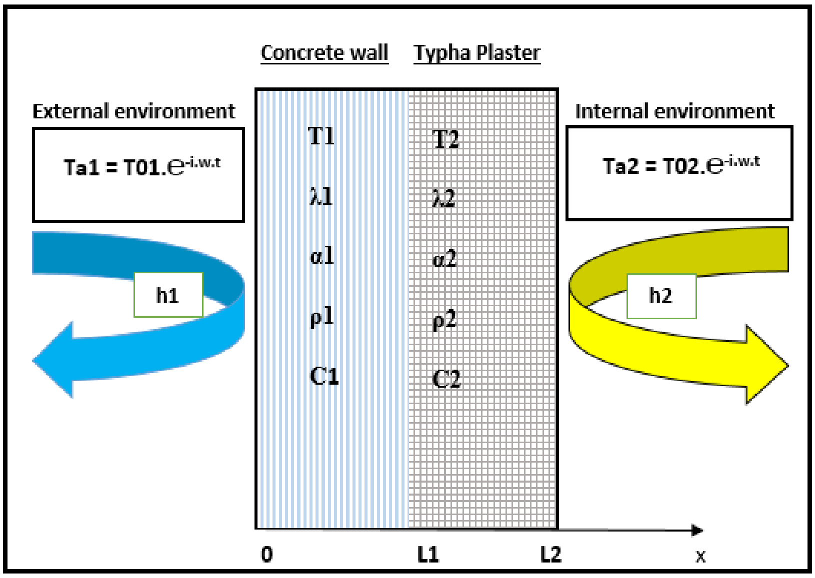

Figure 3: Profile view of the material subjected to exciting temperatures in the frequential dynamic regime

- Ta1 and Ta2: respective temperatures, in complex modulation, of the air outside and inside the cold room.
- T1 and T2: respective temperatures of the concrete wall and typha-plaster insulation.
- T01 and T02: Respective maximum temperatures of the external and internal environments of the chamber.
- h1 and h2: respective convective exchange coefficients of the air outside and inside the chamber.
- λ1 and λ2: respective thermal conductivities of the concrete wall and typha-plaster insulation.
- α1 and α2: respective thermal diffusivity coefficients of the concrete wall and typha-plaster insulation.
- C1 and C2: respective specific heat capacities of the concrete wall and typha-plaster insulation.

Study Assumptions

- External conditions: a cold room is generally installed in a warehouse to minimize external heat gains linked to sunshine. The cold room will be installed in a warehouse located in Diacounda having an ambient air temperature equal to 35°C with a relative humidity of 70%.
- The use of a wall made up of:

-Thermal insulation, in particular the typha-plaster material, [10,11], having a thermal conductivity $\lambda = 0.045$ $W.m^{-1}.K^{-1}$, a coefficient of thermal diffusivity $\alpha = 1.81.10^{-5}.m^2.s^{-1}$.

-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 thermal diffusivity coefficient $\alpha = 5.02.10^{-7}$ $m^2.s^{-1}$.

Mathematical Formulation

When a unidirectional flow is imposed on the wall of the cold room, the thermal transfer is governed by the heat equation (in the absence of an internal heat source) at a dimension given by the following relationship:

$$\frac{\partial^2 \overline{T}_j(x,t,w,h1,h2)}{\partial x^2} - \frac{1}{\alpha_j}\cdot\frac{\partial \overline{T}_j(x,t,w,h1,h2)}{\partial t} = 0 \qquad (1)$$

j = 1, 2 respectively for layers 1, 2.(layer 1: concrete ; layer 2: Typha-plaster)

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

$T_j(x,t,w,h1,h2) = \overline{T}_j(x,t,w,h1,h2) + T_{0j}$: Material temperature at time t (K) ;

$T_{0j} = 20°C$: initial temperature of the material;

$\overline{T}_j(x,t,w,h1,h2)$: "Additional temperature" of the material (K)

$$\text{with:} \quad \alpha_j = \frac{\lambda_j}{\rho_j . c_j} : \qquad (2)$$

α_j : the thermal diffusivity of the material ($m^2.s^{-1}$)

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

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

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

We have :

$$T_j(x,t,w,h1,h2) = \overline{T}_j(x,t,w,h1,h2) + T_{0j} \qquad (3)$$

To solve the equation **(1)**, we use the method of separation of variables. The solutions, in frequential dynamic regime for the different layers, are in the form:

$$T_j(x,t,\omega,h1,h2) = [Aj(t,\omega,h1,h2).\sinh(\beta j.x) + Bj(t,\omega,h1,h2).\cosh(\beta j.x)].e^{i\omega t} + T0j \qquad (4)$$

With :

$$\beta_j = \sqrt{\frac{i.\omega}{\alpha_j}} = = \sqrt{\frac{\omega}{2.\alpha_j}}.(1+i) \qquad (5)$$

The expressions of the coefficients Aj and Bj are determined from the boundary conditions defined by the equations:

$$\begin{cases} -\lambda 1.\left.\frac{\partial \overline{T}_1(x,h1,h2,w,t)}{\partial x}\right|_{x=0} = h1\,[Ta1 - T1(0,h1,h2,w,t)] & (6) \\ \lambda 1.\left.\frac{\partial \overline{T}_1(x,h1,h2,w,t)}{\partial x}\right|_{x=L_1} = \lambda 2.\left.\frac{\partial \overline{T}_2(x,h1,h2,w,t)}{\partial x}\right|_{x=L_1} & (7) \\ T1(L1,h1,h2,\omega,t) = T2(L1,h1,h2,\omega,t) & (8) \\ -\lambda 2.\left.\frac{\partial \overline{T}_2(x,h1,h2,w,t)}{\partial x}\right|_{x=L_2} = h2\,[\,T1(L2,h1,h2,w,t) - Ta2\,] & (9) \end{cases}$$

The heat flux density is given by equation **(10)** in the different layers:

$$\varphi_j(x, h_1, h_2\omega, t) = -\lambda_j \frac{\partial T_j(x, h_1, h_2, \omega, t)}{\partial x} \qquad (10)$$

Results

Thermal Behavior of the Wall as a Function of the exciting pulsation under the influence of the Depth of the Wall

Figures 4, 5, 6 and 7 give the modules of the temperature and heat flux density as a function of the decimal logarithm of the excitatrice pulsation in the concrete wall and typha-plaster under the influence of the depth of the wall and of the heat exchange coefficient.

Table 1 represents the correspondence between pulsation and excitatrice period of external climatic stresses.

Table 1: Correspondence between the pulsation and the period

Excitatrice pulsation (rad/s)	10^{-6}	10^{-5}	$10^{-4,5}$	10^{-4}	10^{-3}	$10^{-2,5}$	10^{-2}
Excitation Period (Hours)	1745.328	174.5328	55.19212	17.45328	1.745328	0.5519212	0.1745328

For different depths of the wall, the curves look the same with three parts:

- For $w \leq 10^{-4.5}$ rad/s (low frequency), the temperature remains practically constant and maximum rotating around that of the external environment (T = 35°C). These low pulsation values correspond to relatively low heat flux densities (high heat transmission). Thus, the wall behaves as a conductor.
- For moderate pulsations ($10^{-4.5} \leq w \leq 10^{-2.5}$rad/s), we notice a temperature drop in the different layers. The material reacts more to climatic stresses reflecting the variable regime. The heat flux density reaches its maximum value. This magnitude of heat flux density decreases as the depth of the wall increases. Thus a large thickness of the wall (concrete or typha-plaster) has a better thermal insulation property.
- For $w \geq 10^{-2.5}$rad/s (low period), the temperature is almost constant and minimal. The density tends towards a zero value. This means that the wall does not have time to respond to excitations favoring low energy.
- Through the concrete wall, the temperature increases with the heat exchange coefficient at the front face h1. On the other hand, the temperature transmitted at the level of the typha-plaster is all the more important as the heat exchange coefficient on the back face h2 is low. We notice an inverse situation for these coefficients with respect to the heat flux density curves.

The variable regime is bounded on either side by two quasi-static regimes, that is to say between a very high and too low period of stress.

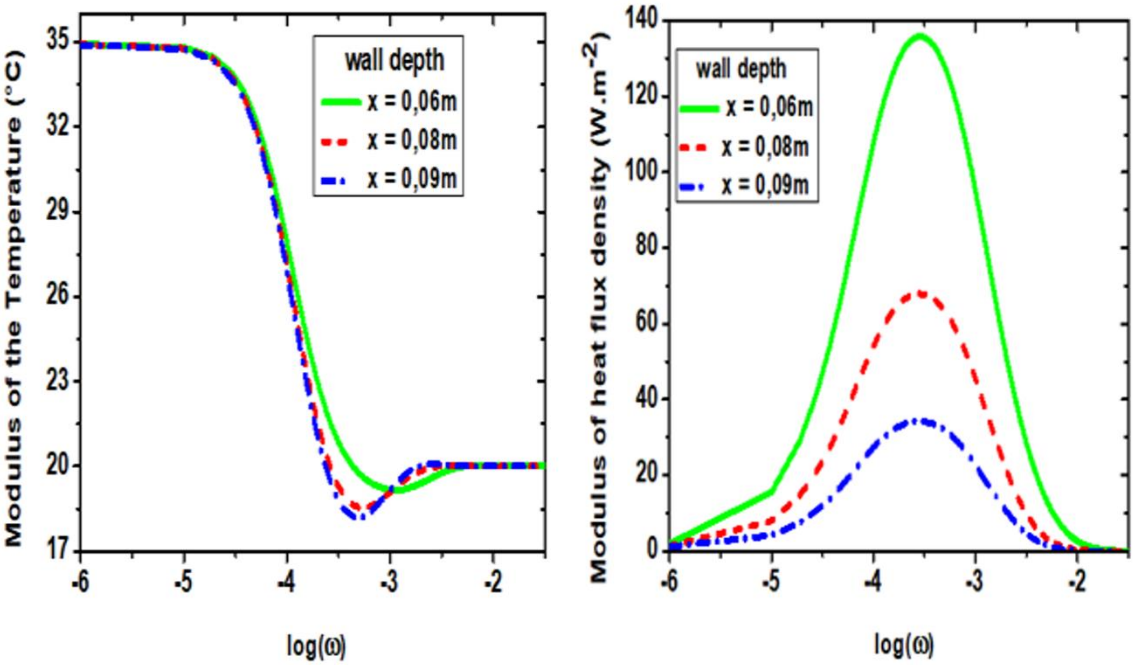

Figure 4: (a): Evolution of the temperature; (b): Evolution of the heat flux density as a function of the decimal logarithm of the pulsation in the concrete wall: influence of the depth of the wall; h1 = 100W.m^{-2}.K^{-1} ; h2 = 0,05W.m^{-2}.K^{-1} ; t = 10s.

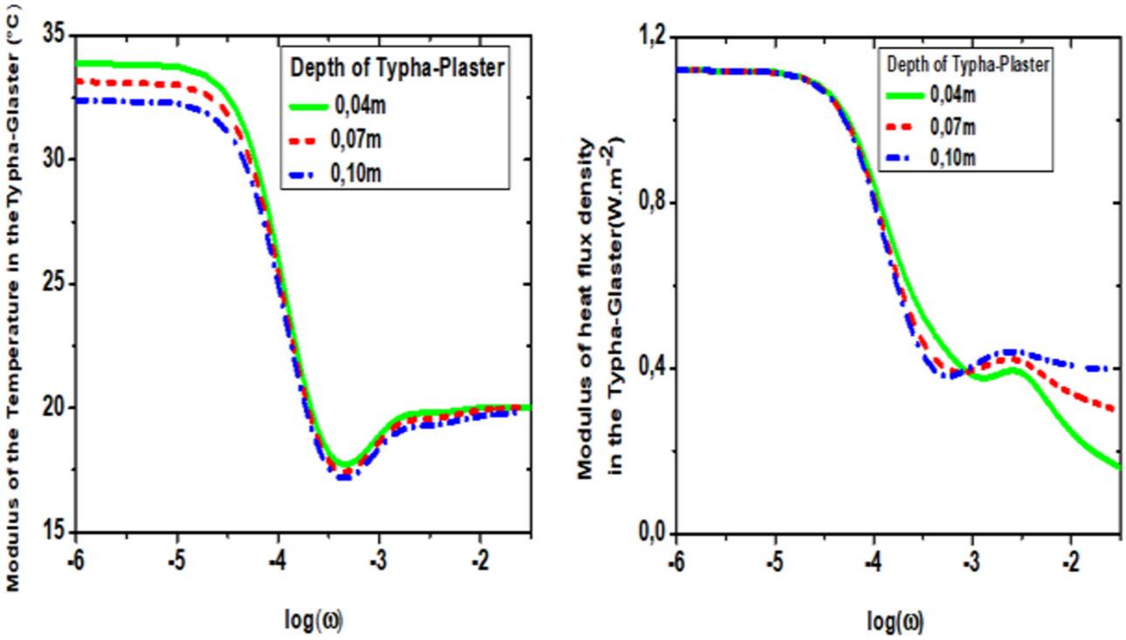

Figure 5 :(a): Evolution of the temperature; (b): Evolution of the heat flux density as a function of the decimal logarithm of the pulsation in the Typha-Plaster: influence of the depth of the Typha-Plaster; h1 = 100W.m^{-2}.K^{-1}; h2 = 0.05W.m^{-2}.K^{-1}; t=10s.

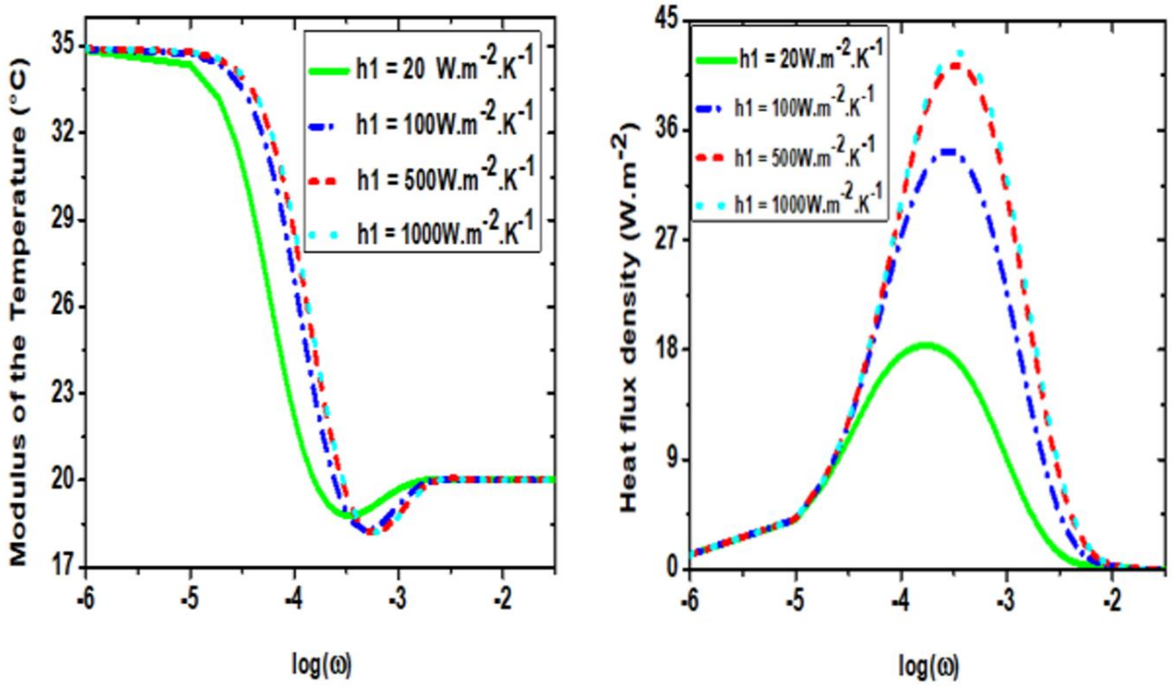

Figure 6: (a) : Evolution of the temperature; (b): Evolution of the heat flux density as a function of the decimal logarithm of the pulsation in the concrete wall: influence of the heat exchange coefficient at the front face h1 ; x = 0.1m; h2 = 0.05W.m^{-2}.K^{-1}; t = 10s.

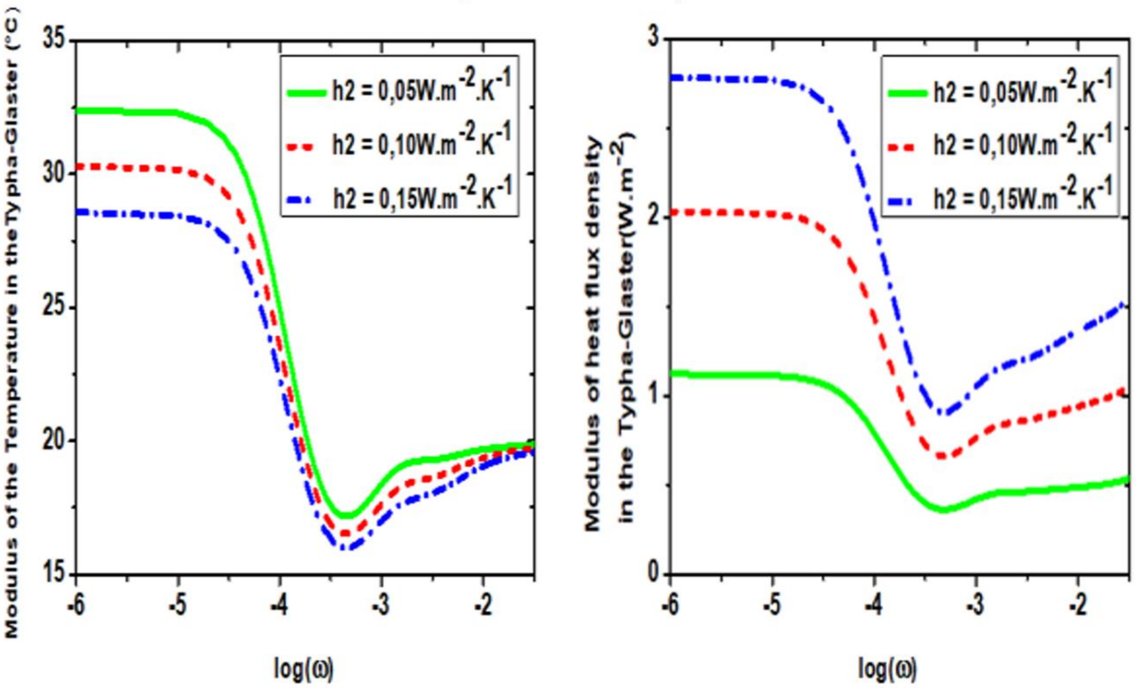

Figure 7: (a): Temperature evolution; (b): Evolution of the heat flux density as a function of the decimal logarithm of the pulsation in the concrete wall: influence of the heat exchange coefficient at the rear face h2; x = 0.2m; h1 = 100W.m^{-2}.K^{-1}; t=10s.

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

Figure 8 gives the modulus of the temperature as a function of the depth of the Concrete/Typha-Plaster composite wall for a low value and an average value of the excitatory pulsation.

For Figure 8: In the concrete, if the exciting pulsation is low, the conduction phenomena are significant (excitation period greater than 17 hours). On the other hand, in the typha-plaster, for a moderate pulsation (relatively short periods: less than 17 hours), there is an inversion of the phenomenon (a reduction in the capacity for storing heat). This is explained by the phenomena of relaxation of the insulating material.

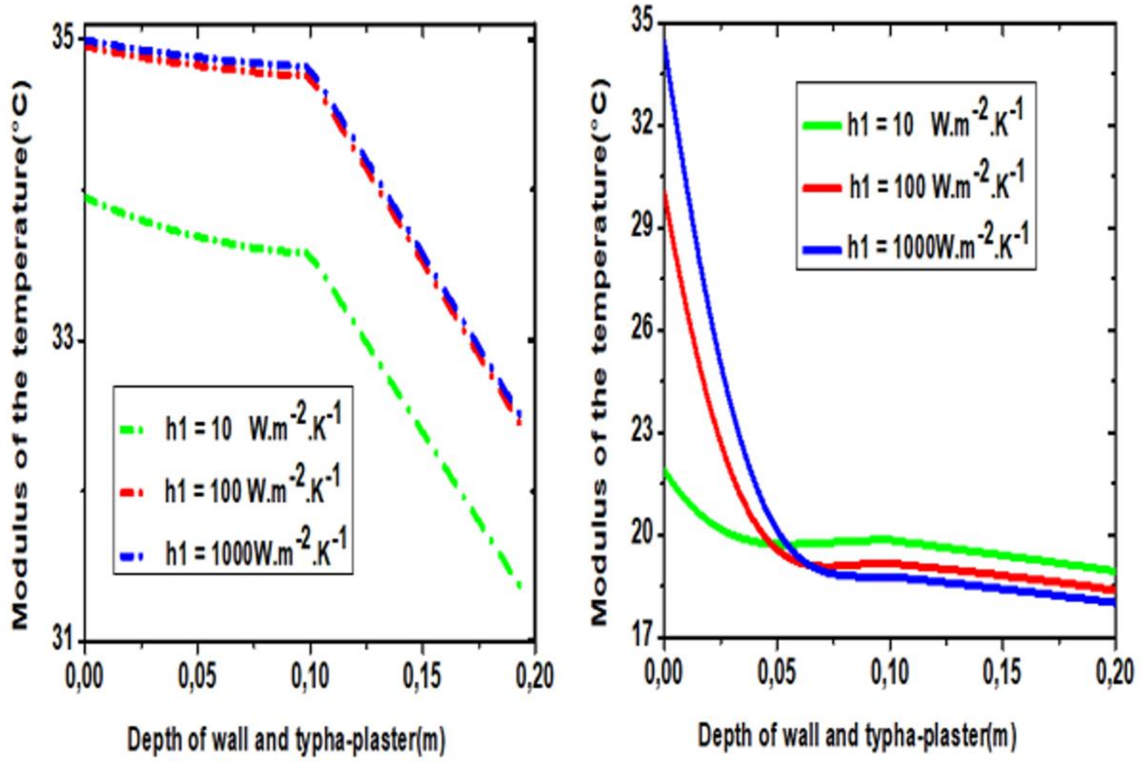

Figure 8 : Evolution of the temperature through the composite wall (Concrete/Typh-Plaster) : (Fig a) : $\omega = 10^{-5} rad.s^{-1}$(low frequency) ; (Fig b) : $\omega = 10^{-3} rad.s^{-1}$(average frequency) : influence of the heat exchange coefficient at the front face h1 : $h2 = 0.05 W.m^{-2}.K^{-1}$; t = 10s.

Conclusion

The study of the thermal behavior, in frequency dynamic regime, of a composite wall made up of two layers: concrete brick, typha-plaster, through a modeling of the temperature and the density of heat flow, made it possible to put highlights the quality of the material in terms of thermal insulation. However, its thermal comfort depends mainly on the values of the depth of the wall and the heat exchange coefficients.

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