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A study on the thermal comfort inside a flat under arid climate zone in Algeria

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Abstract - *The use of naturally materials improves to reduce the life-cycle cost of building (initial cost plus lifetime energy cost). In this paper, looking for the thermal comfort inside an apartment located in an arid climate zone in Algeria, in Biskra city (35.56 N, 6.16 E) by comparing the use of two materials: the concrete (C) and the stabilized earth-concrete (SEC). The temperature variations through the walls are determinate and analyzed. In this study the wall is exposed to the maximum temperature in the two cases: transient and steady state. The mathematical formulation of the problem leads to a parabolic equation. The equation is resolved analytically and numerically by setting the appropriate boundary conditions. The resulting model applied for both materials (concrete, and SEC). The comparison of the results obtained, analytically and numerically, show that the SEC has the higher thermal resistance than concrete and the temperature difference between these two materials can reach about 5.5 °C in steady state. We have also performed the calculation of wall insulation dimensions by resolving a nonlinear system, which corresponds to the optimum thickness to ensure an adequate thermal comfort in side the flat.*

Résumé – *L'utilisation de produits naturels permet d'améliorer le coût du cycle de vie des bâtiments (coût initial et coût énergétique). Dans cet article, nous nous intéressons au confort thermique à l'intérieur d'un appartement situé dans une zone aride en Algérie, à Biskra plus précisément (35.56 N, 6.16 E) en comparant l'utilisation de deux matériaux: le béton (B) et le béton en terre stabilisée (BTS). Les variations de température à travers les murs sont déterminées et analysées. Dans cette étude, le mur est exposé à des températures maximales dans deux cas: état transitoire et état stable. La formulation mathématique du problème mène à une équation parabolique. L'équation est résolue de façon analytique et numérique en mettant les conditions limites appropriées. Le modèle résultant est appliqué aux deux matériaux (béton, et béton en terre stabilisée). La comparaison des résultats obtenus, analytiquement et numériquement, montre que le béton en terre stabilisée a une résistance thermique plus élevée que celle du béton, et la différence de température entre ces deux matériaux peut atteindre 5.5°C en état stable. Nous avons aussi mis au point le calcul de dimensions des isolations murales en résolvant un système non-linéaire, qui correspond à l'épaisseur optimum pour assurer un confort thermique adéquat à l'intérieur de l'appartement.*

Keywords: Thermal comfort - Arid climate - Mater - P - Nonlinear system stabilized - Earth concret.

1. INTRODUCTION

The most manufacturing processesof building materials are energy intensivethereby causing negative effects to the environmentin addition to the waste of energy resourcesare becoming increasingly scarce. However, the natural materials can prevent

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a lot of these problems in their manufacture and contribute to the creation of a healthy atmosphere in the interior of an apartment. The earth material requires minimal energy to be produced).

The benefits of natural earth used as a building material are known, natural materials such as earth require that 5 to 10 kWh per cubic meter, it is more less that production of one cubic meter of concrete which requires 400 to 800 kWh [1]. To improve the thermal comfort in a building and save energy, it is necessary to implement materials particularly efficient, providing good thermal insulation. Indeed, a good thermal insulation causes the choice of air conditioning equipment less powerful therefore more economical.

Unlike cement, concrete or steel, the earth in its natural state can be used as a building material with apparently no energy expenditure. It has many environmental benefits, social and cultural. The earth was widely used in the construction of buildings, however it is very sensitive to water. Earth blocks are produced by the compressive of raw earth in a mechanical or hydraulic press.

The earth is retained in a mould where it is compressed between two plates that are slowly approaching. The compression reduces the volume of air in the block, thereby decreasing its sensitivity to water and increases its compressive strength, more detailed are reported in [2]. The low thermal conductivity justifies their use for improving the thermal insulation of buildings such as brick and hollow brick packs. The heat transfer is the physical phenomena most studied, much work and approaches have been used to model the phenomenon. Our work falls into this logic, and given that the problem studied is still topical [3, 4].

In some previous works [5-8], studies are focused on case of a single wall exposed to solar flux. One model to evaluate the behaviour of the heat and moisture transfer in porous materials was presented by Qin *et al.* [9], where they proposed an analytical method. Henrique dos Santos and Mendes [10] proposed a 2D model considering the coupled heat, air and moisture transport through the earth brick, they performed hygro thermal simulation to evaluate the performance of solid bricks, cavity and insulating.

Tamene *et al.* [11] proposed a numerical model based on finite differences method,in their study heat transfer in a multilayer wall exposed to solar radiation on the outside and convection on both sides.

According Abdesselam [12], it is more practical to use the appropriate low-priced local materials to increase the thermal insulation of buildings. Recently the use of air conditioning was largely propagated in hot country, but the natural ventilation contributes to limiting the use of air conditioning and it is an economic solution for the all hot countries. It is noted that, traditional techniques recede in favour of imported architectural standard have a negative consequences. SEC is characterized by their low thermal conductivity. However, the thermal conductivity of bricks depends on the nature of the soil itself.

Adam *et al.* [13] obtained conductivity values between 0.38 and 0.88 W/m.K, whereas the values found by Lamkharouet *et al.* [14], for bricks cement stabilized, vary between 0.71 and 1.53 W/m.K. Today, there are several numerical models to describe the coupled transfer of heat and moisture in building envelopes [15-17].

These models develops theories used in the coupled heat and moisture transport to investigate the hygro thermal behaviour of composite materials, they present the advantage of similarity between the equations of the transient heat transfer equation and moisture (vapour or liquid phases).

Experimental and numerical studies have been developed in Building Research Institute in Japan, that deal with coupled heat and mass transfer in building components [18].

Shengwei *et al.* [19] present a transient heat flow model that allows analyzing the heat flow through an envelope, evaluates the response factors and the conductivity coefficients..The thermal conductivity of bricks decreases with the addition of cement, lime and slag [20].

In the same context, Meukam *et al.* [21, 22] have studied the evolution of the thermal properties of compressed earth bricks and cement stabilized with the addition of natural pozzolana or wood sawdust as a function of water content. These works concluded that the potential of thermal comfort is improved by mineral additions to the ordinary compressed earth bricks.

This work aimed to determining the temperature variation through the walls of an apartment exposed to a maximum temperature for the both regimes (transient and steady state). The established mathematical model applies to wall with different dimensions and thermal characteristics, for the both materials (concrete and stabilized earth concrete (SEC)) in order to make to the comparison between the use of these materials.

The comfort depend on: temperature, relative humidity, air movement in another hand the comfort depend on the occupant itself (age, nutrition, gender and constitution), this study focus on the more important parameter, the temperature.

2. DEFINITION OF CASE STUDY

An apartment building with concrete exterior walls are exposed to a maximum temperature T_{max} (most unfavorable case) is considered. The mathematical formulation of the problem leads to a parabolic equation whose solution is the temperature variation along a solid wall (C, SEC).

The temperature profile for the two regimes (transient and permanent) is obtained by solving the problem analytically by using the Fourier series and numerically the system resolution of equations above is performed by the finite difference method, according to the numerical scheme (Cranck-Nicolson) [23].

The assembling of all these equations leads to a tridiagonal system whose resolution is performed at each time step, by algorithm known (Thomas) [24].

The dimensioning of the insulating layer is obtained by solving the nonlinear system equations using the method of (Newton-Raphson). Thermo physical characteristics of the materials used are grouped in **Table 1**.

Table 1: Thermo physical characteristics of materials

Materials	**Thermal conductivity K (W/m°C)**	**Specific heat Cp (k_j/kg°C)**	**Density ρ (kg/m³)**
C	1.30	0.90	2.20×10^3
SEC	0.46	0.85	1.90×10^3

It should be noted that the wall thickness of the concrete for most constructions of buildings in the region of Biskra is about 25 cm. As for the preferred temperature in the interior of room is T_f = 25 °C.

3. GOVERNING EQUATIONS OF THE PROBLEM

For a differential volume element dV, the governing equation is the thermal problem of the form:

$$K.\nabla^2 T.dV + q.dV = C_p.dV.(\partial T/\partial t) \quad (1)$$

This equation can be simplified to:

$$(\partial T/\partial t) = a.\nabla^2 T + q/\rho.C_p \quad (2)$$

In the absence of internal sources (no chemical reaction or electrical resistance), while the term contained in the equation (2) will be negligible and the equation has the following form:

$$\nabla^2 T.(1/a).(\partial T/\partial t) \quad (3)$$

4. RESOLUTION METHOD

4.1 Linear part

In this part we will try to show the approach used to determine the temperature at any point of the thickness of the outer wall using two methods:

4.1.1 Analytical method

Assume

$$T(x,t) = (x) + \Psi(x,t) \quad (4)$$

with: $\Psi(x,t) = \tau(t).\xi(x)$ (5)

From where:

$$T(x,t) = \Phi(x) + \tau(t).\xi(t) \quad (6)$$

4.1.2 Numerical method

We choose the scheme of 'Cranck-Nicolson', we can write:

$$\left(1/2\Delta x^2\right)\left[T_{i+1,j+1} - 2T_{i,j+1} += T_{i-1,j+1} + T_{i+1,j} - 2T_{i,j} + T_{i-1,j}\right] = (T_{i,j+1} - T_{i,j})/\Delta t \quad (7)$$

After arrangement, the previous equation takes the following form:

$$\left\lfloor -MT_{i-1,j+1} + (2/a + 2M)T_{i,j+1} - MT_{i+1,j+1} = MT_{i-1,j} + (2/a + 2M)T_{i,j} + MT_{i+1,j} \right\rfloor \quad (8)$$

$$i = 1.9 \text{ and } j = 0.3$$

$$-K/\Delta x(T_{i,j+1} - T_{i-1,j+1}) = h(T_{i,j+1} - T_f) \quad (9)$$

$$i = 10 \text{ and } j = 0.3$$

With, $M = (\Delta t/\Delta x$

4.2 Nonlinear part

In this part, the dimensioning of the insulating wall by adding a thickness of cork well calculated to minimize the temperature in the interior of the apartment. The mathematical formulation of the problem provided:

$$\begin{cases} T_1 X(1) - X(1).X(2) - e_1.X(5) = f_1 \\ K_2 X(2) - K_2.X(3) - e_2.X(5) = f_2 \\ K_3 X(3) - K_3.T_4.X(4)(X_5) = f_3 \\ 2X(1) - \alpha T_1 - 2\alpha X_2 - 2\beta = f_4 \\ (T_1 - T_4)K_2 K_3 X(1) - e_1 K_2 K_3 X(5) - e_2 K_3 X(1) X(5) - K_2 X(1) X(4) X(5) = f_5 \end{cases} \quad (10)$$

The physical solution of this system is of the form:

$$X(1) = K_1 = 1.30641\ \text{W/m°C} \qquad f_1 = 1.9070\ 10^{-6}$$

$X(2) = T_2 = 35.04400\ °C$ $\qquad f_2 = 8.1630\,10^{-7}$

$X(3) = T_3 = 33.92750\ °C$ $\qquad f_3 = 3.6088\,10^{-8}$

$X(4) = e_3 = 0.00468\ m$ $\qquad f_4 = 0.0000E\ 0$

$X(5) = \varphi = 78.15400\ W/m^2$ $\qquad f_5 = 0.0000E.0$

5. BOUNDARY CONDITIONS

For solve the {Eq. (3) it is necessary to specify the boundary conditions where:

a. The exterior surfaces of the dwelling are exposed to a maximum temperature such that:

$$T(0,t) = T_{max} \tag{11}$$

b. The conductive flux on the surface to the interior surface is equal to the convective flux which results in:

$$-K.\partial T/\partial x\,\big|_{x=e} = h(T - T_f) \tag{12}$$

These conditions to limits are written in terms of functions (Φ and Ψ) by:

$$\Phi(0) = T_{max} \quad -K.\partial T/\partial x\big|_{x=e} = h(\Phi - T_f) \tag{13}$$

$$\Psi(0,t) = 0 - K.\partial \Psi/\partial x\big|_{x=e} = h.\Psi\big|_{x=e} \tag{14}$$

The analytical solution using the model (6) is of the form:

$$T(x,t) = -h\left[(T_{max} - T_f)/(h.e + K)\right]x + T_{max} + \sum_{m=1}^{\infty} C_m \sin\lambda_m x.\exp - \lambda_m^2 a t \tag{15}$$

The numerical solution is obtained by solving a system of linear equations whose matrix is tridiagonal.

6. RESULTS AND DISCUSSION

The variation in temperature along the wall thickness constructed in concrete and the SEC for case a transient regime (t = 2 h) as shown in figures 1, 2, the temperature gap calculated for the case shown is of the order of 2.7 °C. This gap reaches its maximum value for the permanent regime as shown in figure 3.

Figures 4 and 5 explain the convergence of the numerical solution to the analytical solution of a percentage error more or less small.

The velocity of the heat propagation in the interior the two materials illustrated in figures 6, 7, 8 and 9that translate thermal resistance of the SEC relative to concrete. The dimensioning of the insulating layer showed that the thickness of the cork is a few millimeters which show the concordance of our results with the practical or real side.

It is important to note that the cork sheets available on the market have a thickness of about 3.5 mm that we do not know the origin of their dimensioning.

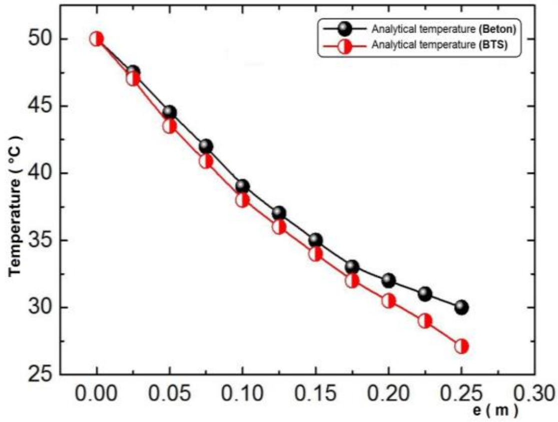

Fig. 1: Variation of analytical results of temperature along the concrete wall and the SEC wall

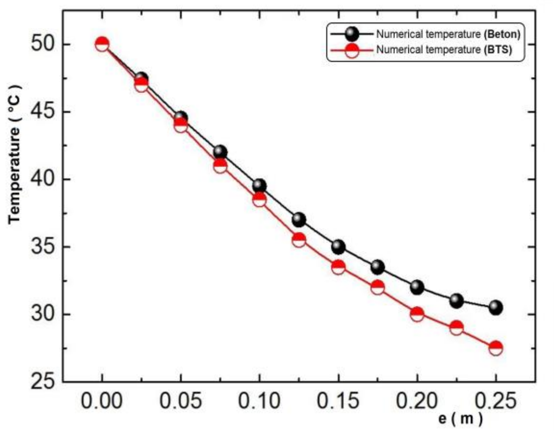

Fig. 2: Variation of numerical results of temperature along the concrete wall and the SEC wall

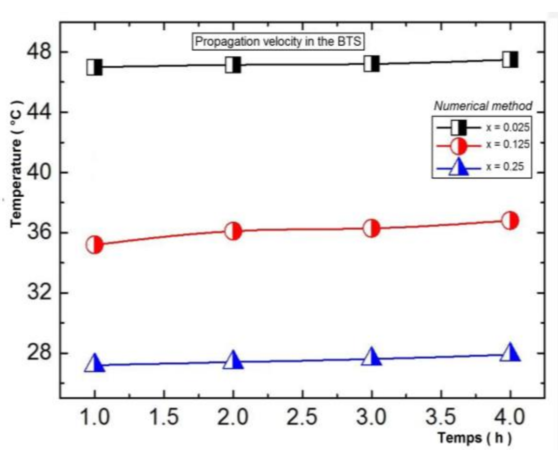

Fig. 3: Time variation of numerical results of temperature in the SEC wall

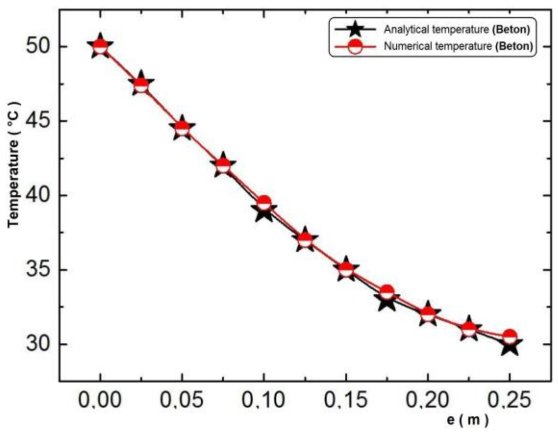

Fig. 4: Comparison of numerical analytical results of temperature along the concrete

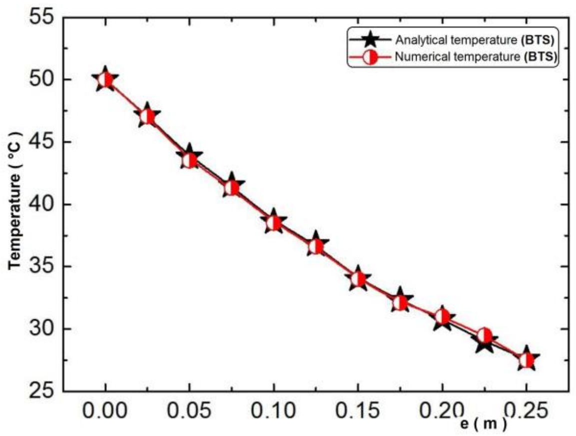

Fig. 5: Comparison of numerical and analytical results of temperature along the SEC wall

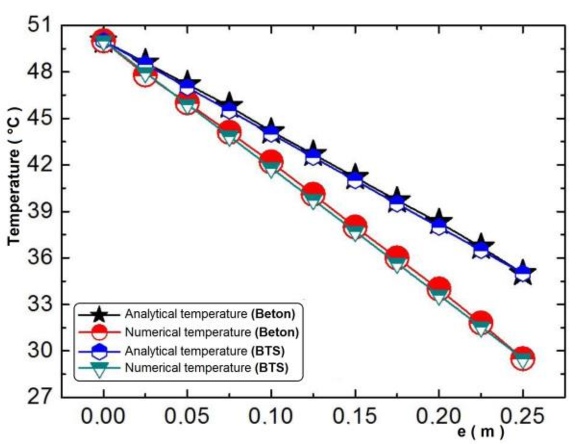

Fig. 6: Heat propagation along the wall depth Analytical and numerical for concrete and SEC

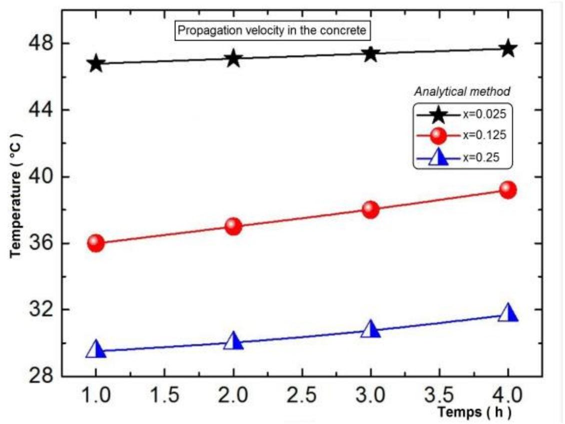

Fig. 7: Transient analytical result for different concrete wall depth

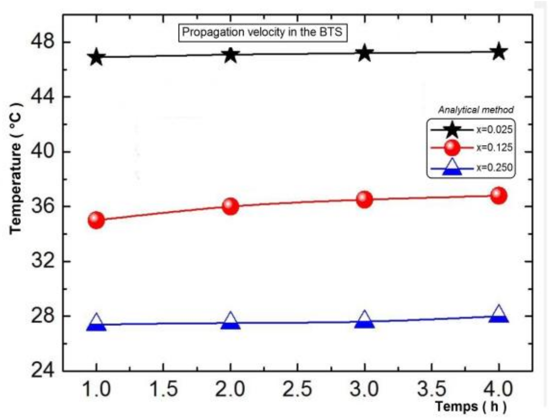

Fig. 8: Transient numerical result for different SEC wall depth

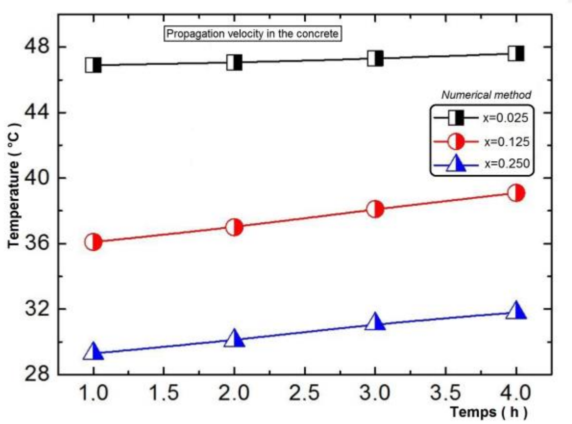

Fig. 9: Transient numerical result for different concrete wall depth

7. CONCLUSION

The main objective of this paper aimed to study the transfer of heat through the thickness of the walls of an apartment located in a hot area to determine one of the factors affecting thermal comfort, which is the temperature. Based on the results of this study, the following conclusions could be drawn:

- The results obtained using the proposed mathematical model are in good concordance to those computed numerically.
- The advantage of the analytical solution lies partly in the combination of the permanent solution and transient solution and secondly in its generalization for all solid walls exposed to the same conditions chosen in our case.
- The judicious choice of the estimated facilitates the convergence of the nonlinear system to the physical solution resulted essentially from the optimum thickness of the insulating material.
- Finally, we can say that it is recommended to construct walls the SEC because indicated material has a thermal resistance three more than concrete.

The complete study of the thermal comfort in the interior the apartments isolated or located in a building will reflect this study alongside the introduction of the effects of humidity coefficient and the velocity of the air.

NOMENCLATURE

C_p, Specific heat; K, Thermal conductivity; T, Temperature; a, Thermal diffusivity; ρ, Density; φ, Flux density; e, Thickness; $\alpha - \beta$, Constants; $X(j)$, Variables; $f_i - \Phi - \Psi$, Functions; $\lambda_m - C_m$, Fourier coefficients; h, Heat transfer coefficient by convection.

REFERENCES

[1] H. Houben, '*For a New Architecture*', Ecodecision, 1997.

[2] R. Gupta, '*Characterizing Material Properties of Cement-Stabilized Rammed Earth to Construct Sustainable Insulated Walls*', Case Studies in Construction Materials, Vol. 1, pp. 60 – 68, 2014.

[3] I. Marincic, J.M. Ochoa, M.G. Alpuche and I. Gonzalèz, 'Comparative Analysis of the Thermal Behavior between Cellular Concrete Blocks and Stabilized Earth Blocks as Wall Materials', Energy Procedia, Vol. 57, pp. 1783 – 1791, 2014.

[4] P. Talukdar, S.O. Olutmayin, O.F. Osanyintola and C.J. Simonson, '*An Experimental Data Set for Benchmarking 1-D, Transient Heat and Moisture Transfer Models of Hygroscopic Building Materials*', International Journal of Heat and Mass Transfer, Vol. 50, N°25-26, pp. 4527 – 4539, 2007.

[5] S.A. Al-Sanea, M.F. Zedan and S.A. Al-Ajlan, '*Effect of Electricity Tariff on the Optimum Insulation Thickness in Building Walls as Determined by Dynamic Heat Transfer Model*', Applied Energy, Vol. 82, N°4, pp. 313 – 330, 2005.

[6] E. Wurtz, L. Mora, K.C. Mendonca and C. Maalouf, '*Modeling of Heat Transfer and Mass in the Simulation Environment Simspark*', Journée INES-LAMA, 2004.

[7] N. Mendes, P.C. Philippi and R. Lamberts, '*A New Mathematical Method to Solve Highly Coupled Equation of Heat and Mass Transfer in Porous Media*', International Journal of Heat and Mass Transfer, Vol. 45, N°3, pp. 509 – 518, 2002.

[8] N. Mendes and P.C. Philippi, '*A Method for Predicting Heat and Moisture Transfer through Multilayered Walls Based on Temperature and Moisture Content Gradients*', International Journal of Heat and Mass Transfer, Vol. 48, N°1, pp. 37 – 51, 2005.

[9] M. Qin, R. Belarbi, A. Ait-Mokhtar and A. Seigneurin, '*An Analytical Method to Calculate the Coupled Heat and Moisture Transfer in Building Materials*', International Communications in Heat and Mass Transfer, Vol. 33, N°1, pp. 39 – 48, 2006.

[10] G. Henrique dos Santos and N. Mendes, '*Heat, Air and Moisture Transfer through Hollow Porous Blocks*', International Journal of Heat and Mass Transfer, Vol. 52, N°9-10, pp. 2390 – 2398, 2009.

[11] Y. Tamène, S. Abboudi and C. Bougriou, '*Simulation of Transient Heat Transfer through a Multilayer Wall Subjected to Conditions of Solar Flux and Convection*', Revue des Energies Renouvelables Vol. 12, N°1, pp. 117 – 124, 2009.

[12] M. Abdesselam, '*A New Approach to the Climate Design of Buildings*', Liaison Energies Francophone N°42, 1999.

[13] E.A. Adam and P.J. Jones, '*Thermophysical Properties of Stabilized Soil Building Blocks*', Build Environ, Vol. 30, N°2, pp. 245 – 253, 1995.

[14] N. Lamkharouet, S. Boussaid, H. Ezbakhe, A. El-Bakkouri, T. Ajzoui and A. El-Bouardi, '*Thermal Study of the Larache Earth to Cement Stabilized*', Forum International sur les Energies Renouvelables, Actes du Forum, Tome II. Tétouan, Maroc, 541, 2002.

[15] M.P. Deru and A.T. Kirkpatrick, '*Ground-Coupled Heat and Moisture Transfer from Buildings Part 1- Analysis and Modeling*', Journal of Solar Energy Engineering, Vol. 124, N°1, pp. 10 – 17, 2002.

[16] P.T. Tsilingiris, '*On the Transient Thermal Behaviour of Structural Walls-The Combined Effect of Time Varying Solar Radiation and Ambient Temperature*', Renewable Energy, Vol. 27, N°2, pp. 319 – 336, 2002.

[17] P. Meukam and A.N. Noumowe, '*Modeling of Heat and Mass Transfer in Lateritic Building Envelopes*', Heat and Mass Transfer, Vol. 42, N°2, pp. 158 – 167, 2005.

[18] A.N. Noumowe, T. Ohkudo, M. Makatayma and L. Watanabe, '*Coupling Heat and Mass Transfers in Building*', 8th International Conference on Durability of Building Materials and Components, May 20-June 3, Vancouver, Canada, 1999.

[19] W. Shengwei and C. Youming, '*Transient Heat Flow Calculation for Multilayer Constructions Using a Frequency-Domain Regression Method*', Build Environ, Vol. 38, N°1, pp. 45 – 61, 2003.

[20] J. Akinmusuru, '*Thermal Conductivity of Earth Blocks*', Journal of Materials in Civil Engineering, Vol. 6, N°3, pp. 341 – 351, 1994.

[21] P. Meukam, A. Noumowe, Y. Jannot and R. Duval, '*Thermophysical and Mechanical Characterization of Stabilized Mud Bricks for Thermal Insulation of Building*', Materials and Structures, Vol. 36, N°7, pp. 453 – 460, 2003.

[22] P. Meukam, Y. Jannot, A. Noumowe and T.C. Kofane, '*Thermophysical Characteristics of Economical Building Materials*', Construction and Building Materials, Vol. 18, N°6, pp. 437 – 443, 2004.

[23] F.G. Curtis, '*Applied Numerical Analysis*', Addison-Wesley Educational Publishers Inc, 1978.

[24] M. Boumahrat and A. Gourdin, '*Numerical Methods Applied*', Office des Publications Universitaires, Algérie, 1993.