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Thermal resistances of air in cavity walls and their effect upon the thermal insulation performance

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Abstract
The optimum thickness in cavity walls in buildings is determined under steady conditions; the heat transfer has been calculated according to ISO 15099:2003. Two forms of masonry units are investigated to conclude the advantage of high thermal emissivity. The paper presents also some results from a study of the thermal insulation performance of air cavities bounded by thin reflective material layer "ε = 0.05". The results show that the most economical cavity configuration depends on the thermal emissivity and the insulation material used.

Keywords: Air cavity; Thermal resistance; Thickness; Thermal emissivity.

1. Introduction
The concept of sustainable building incorporates and integrates a variety of strategies during the design, construction and operation of building projects. The use of building materials represents one important strategy in the design of a building. An assessment of green materials may involve an evaluation of energy efficiency. The evolution of construction entails the application of new building materials in the envelopes of buildings. Apparently, the high thermal resistances of building envelopes were qualified as an indicator of high energy efficiency of these buildings. The calculation of equivalent thermal resistances leads to deduce immediately the values of thermal resistances of walls. It will be respected to acomply with Ohm's law but with a thermal analogy. The application of these concepts based on arrangements of layers and materials relative to the direction of the heat flow [1-5].
In Ghardaïa region, stone, cinderblock and hollow brick are the most used construction materials due to their availability. The walls were fitted with air cavities which the masonry unit has the same shape of a cinder block and a hollow brick. In order to increase the thermal resistance in a closed air cavity bounded by ordinary building materials, various studies are employed to predict Grashof number in enclosed cavities with vertical angles of inclination. The emissivity influence of the cavities inner surfaces on the thermal resistance of the masonry unit was also studied.

2. Natural convection in a cavity filled with air

A literature search showed that in the case of natural convection in a cavity filled with air, for Ra < 10^3, conductive heat transfer is the dominated heat transfer mode. Increasing the Rayleigh number intensifies the air the flow of air loop in the boundary layer near the vertical walls. The flow changes from laminar "10^3 < Ra < 10^9" to turbulent flow which is accompanied by a significant increase in the Nusselt number. This search covers over 40 different items to derive correlations between Nu and Ra in a closed cavity empty. The choice of the Nusselt number is deduced according the value of the Rayleigh number. However, according to Rayleigh expression, Ra depends on air temperature T and the temperature difference Δθ between surface and air in the cavity. A suggested methodology to solve these problems requiring calculations of convective heat transfer coefficient using empirical correlations is as follows:

$$If\ 10^{-3} \langle\ Pr\ \langle 10^{5} \quad 1 \langle H/L \langle 2 \quad 10^{3} \langle \frac{Ra\,Pr}{0.2+Pr} \quad Nu = 0.18\left(\frac{Pr}{0.2+Pr}Ra\right)^{0.29} \tag{1}$$

Convection heat transfer may be classified according to the nature of the flow for free or natural convection the flow is induced by buoyancy forces, which arise from density differences caused by temperature variations in the fluid. So in these cavities, the heat is first transferred from the wall surface to the air by convection, then by convection to the second wall surface [6-8].

2.1 Cinderblock

The cinderblock is a molded masonry unit which has a facing on each of two opposite sides of a wall. This is the case of a real material consisting of several layers. Figure 1 gives a detailed sizing to calculate the equivalent thermal resistance of a cinderblock.

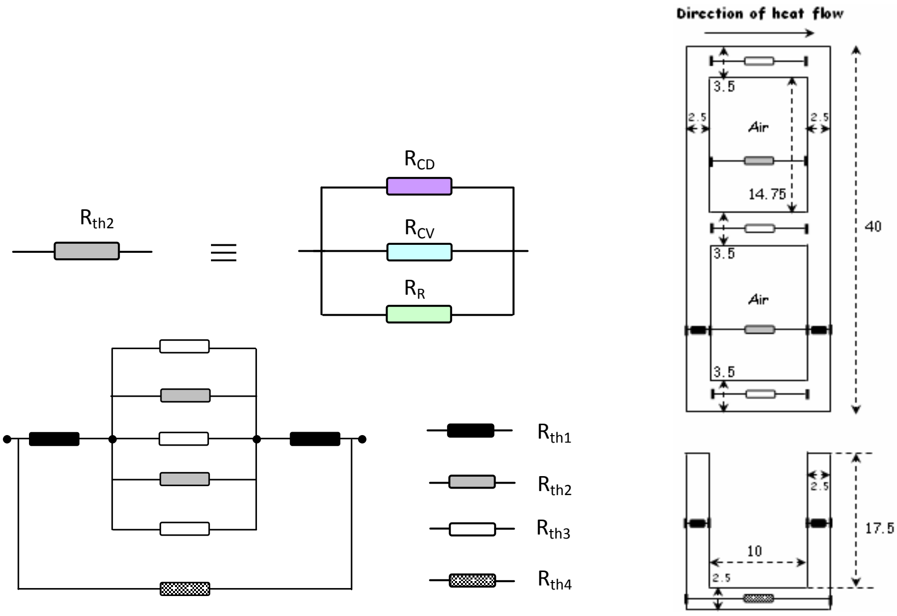
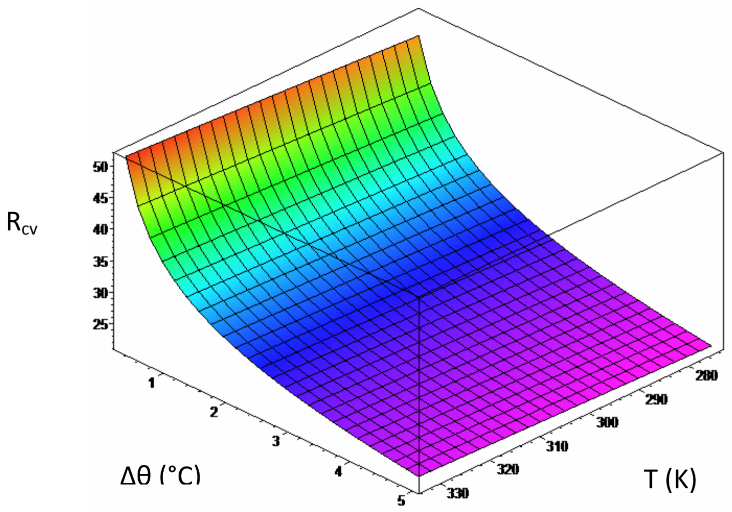


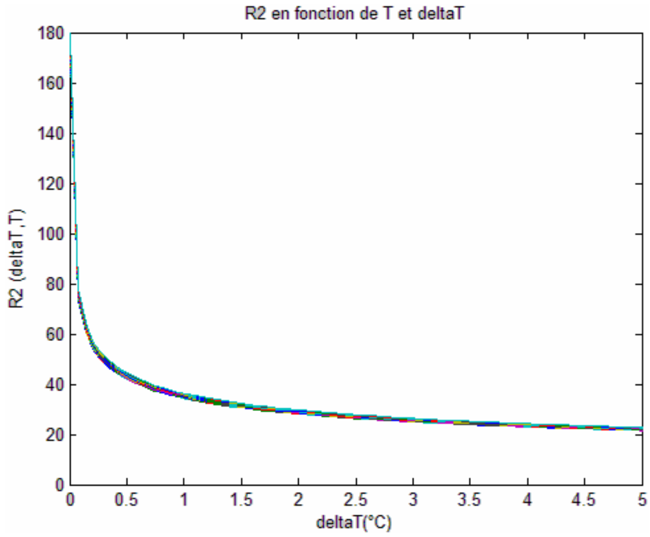
Figure 1. Dimensions (in centimeters) and equivalent circuit of a cinderblock

The convective resistance R_{CV} is related to a parameter called Heat Transfer Coefficient. To calculate R_{CV}, we must calculate the convective transfer coefficient h in the cinderblock. This coefficient depends entirely on the Grashof number Gr. A mathematical study was made, provides simplified diagrams to describe succinctly the variation of the convective resistance, and which will serve us for the choice and proper use of the heat transfer coefficient. Figure 2 (a, b, c) were obtained by considering that the air temperature inside the cavity is between 0 and 60 °C.

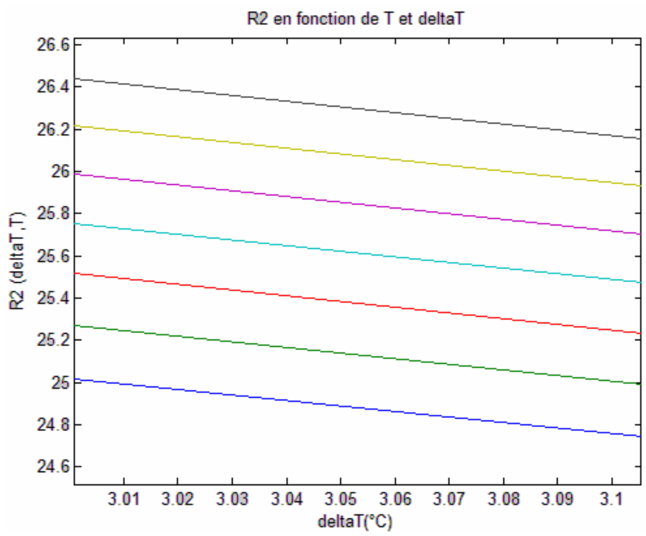
The convective resistance of the air cavity depends particularly on the temperature difference between the air and the wall. The temperature effect is not very important compared to Δθ. The movement of trapped air due to temperature gradient starts in increased the coefficient of heat transfer. This increase in heat transfer takes place due to convective heat transfer taking place in addition to conductive heat transfer.



(a)



(b)



(c)

Figure 2. (a) variation of R_{CV} as function of T and Δθ; (b) R_{CV} as a function of Δθ for T ranging from 0 to 60 ° C; (c) zoom

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2.2 Hollow brick

The hollow brick is used as building material and it is a rectangular parallelepiped of raw clay and sun-dried or baked it. The clay is often mixed with sand. Therefore, environmental and structural performance may be different in elements constructed of hollow brick from those constructed of structural cinderblock or solid brick. The dimensions and the equivalent circuit diagram of a hollow brick are given below in Figure 3.

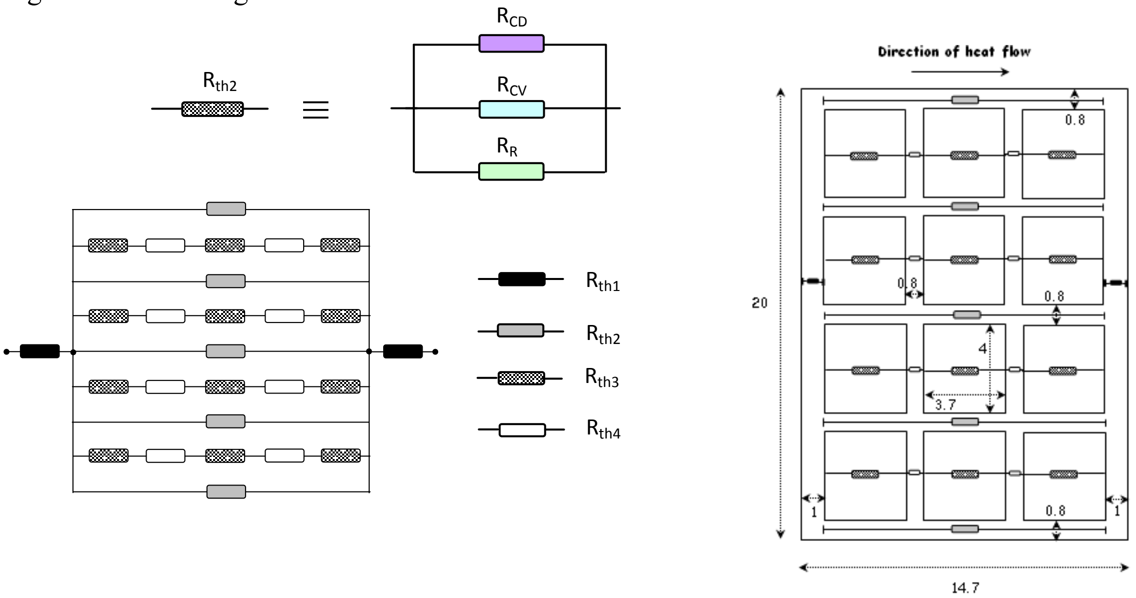
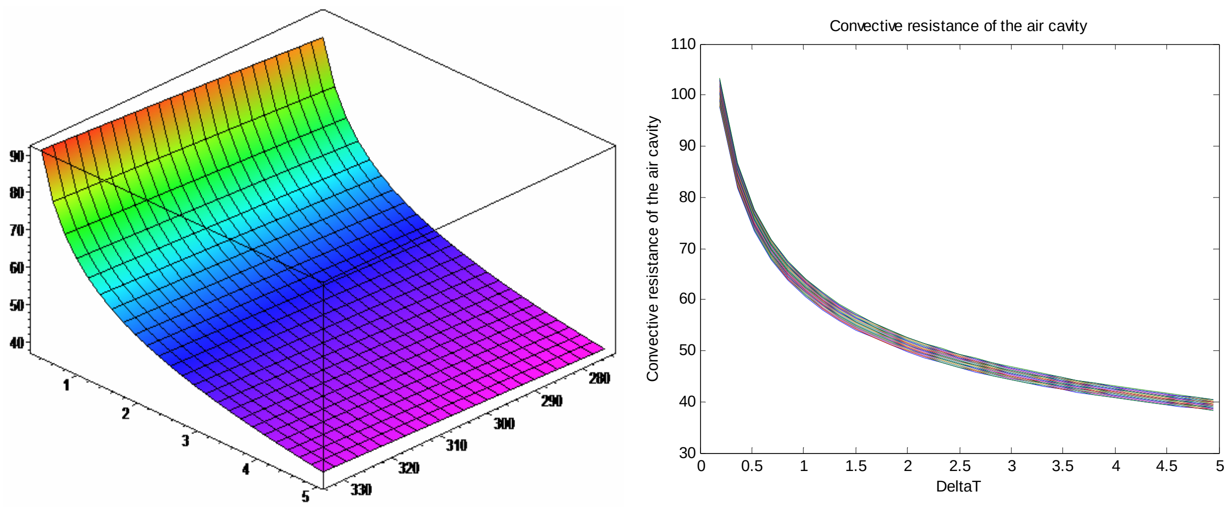


Figure 3. Dimensions (in centimeters) and equivalent circuit of a hollow brick

This following study addresses an idea on the laminar natural convection within this shape of cavity. Similarly to the previous example, Figure 4 (a, b) drawn below describe the thermal resistance of the air cavity in the hollow brick according to the air average temperature in the cavity and the temperature difference Δθ.



(a) (b)

Figure 4. (a) variation of R_{CV} as function of T and Δθ; (b) R_{CV} as a function of Δθ for T ranging from 0 to 60 ° C

We note from these results that the resistance of the convective air cavity in the hollow brick is greater than that in the cinderblock. On the other hand, the influence level of the temperature T on the convective resistance is more important compared to the first case, but we always keep in mind that this resistance depends primarily on the temperature difference Δθ.

3. Heat transfer mechanisms and emissivity effect in air cavities

Heat is transferred across an air space by a combination of conduction, convection and radiation. Heat transfer by conduction is inversely proportional to depth of the air space. Convection is mainly dependant on the height of the air space and its depth. Heat transfer by radiation is relatively independent of both thickness and height, but is greatly dependent on the reflectivity of the internal surfaces. All three mechanisms are dependent on the surface temperatures. The mathematical treatment of air cavity would be similar to that of insulation if natural convection in air is neglected. The thickness of air cavity is a very important design parameter that governs its effectiveness by controlling the heat transfer coefficient as in case of insulation.

As shown in Figure 5 long wave radiation is the dominating heat transfer mechanism in closed air cavities bounded by ordinary building materials with emissivity ≈ 0.9. By use of a reflective foil, with emissivity 0.05, at one face of the cavity the heat flow by radiation is dramatically reduced to approximately 5 % as shown in Figure 6. The heat transfer by convection does increase with the thickness of the cavity and will limit the thermal resistance values of such cavities in roofs and walls. The heat transfer has been calculated according to ISO 15099:2003. Main conditions for the calculation are:

- Total thickness of conventional insulation and air cavity is constant 200 mm
- Thermal conductivity of the conventional insulation are 0,037 W/mK
- No air leakages through the cavity or the structure
- The emissivity of the reflective layer has been set to 0.05.
- Indoor and outdoor temperatures are +20 °C and 0 °C respectively [9, 10].

4. Optimization of the cavity thickness

Cavity walls are among the types of wall structures used in Algeria. Cavity walls are lighter and have higher thermal resistance than solid masonry walls. Without insulation, the whole cavity becomes essentially an air space of finite thickness across which heat is transferred by conduction, convection and radiation. Therefore, the effective thermal resistance of the air space is usually much less than that of an air layer in a pure heat conduction mode. To increase the resistance of an air space, air must not be allowed to circulate in order to suppress convection which is not easy to achieve.

In the majority of cases considered, an insulation material of certain type is installed either at the middle of the cavity or on one side; the optimum thickness of this insulation layer will be determined by the calculations. In the present study, this wall assembly is enclosed by a 10 mm thick cement mortar on each side. We seek the optimum thickness of the air cavity of these two types of building materials under these conditions, taking into account whenever the emissivity. Figures 7 and 8 show explicitly the thickness effect of the cavity on the thermal resistance of these building elements according to ISO 15099:2003.

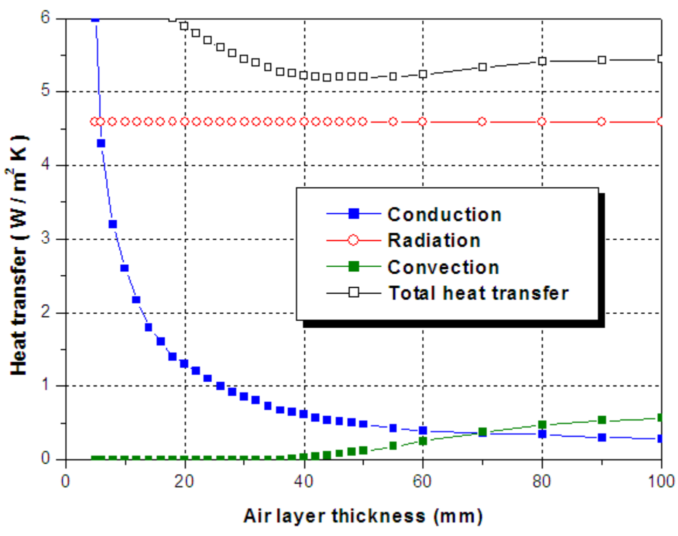


Figure 5. Estimated heat transfer in a closed air cavity bounded by ordinary materials ε = 0.9

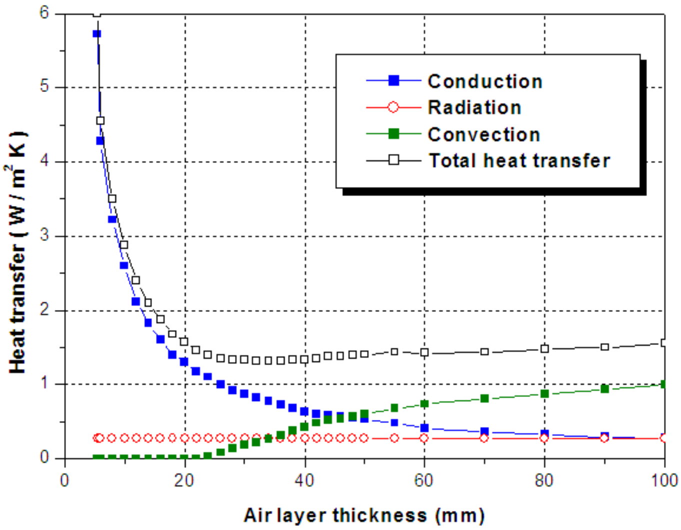


Figure 6. Estimated heat transfer in a closed air cavity bounded by a reflective material at one face ε = 0.05

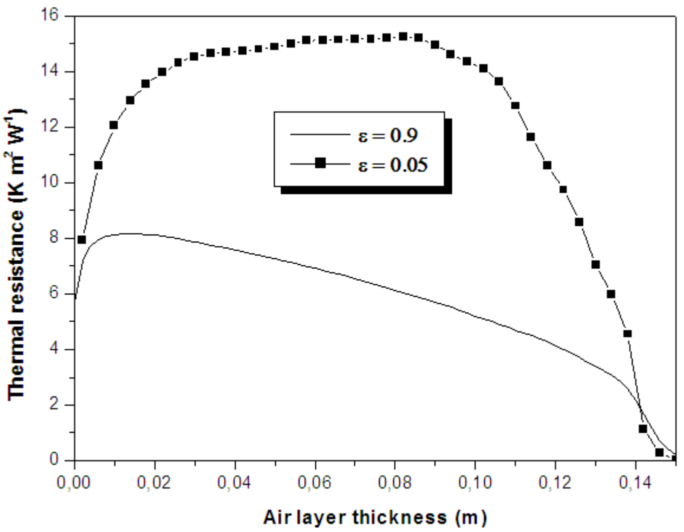


Figure 7. Thermal resistance as a function of the air cavity thickness, case of a cinderblock

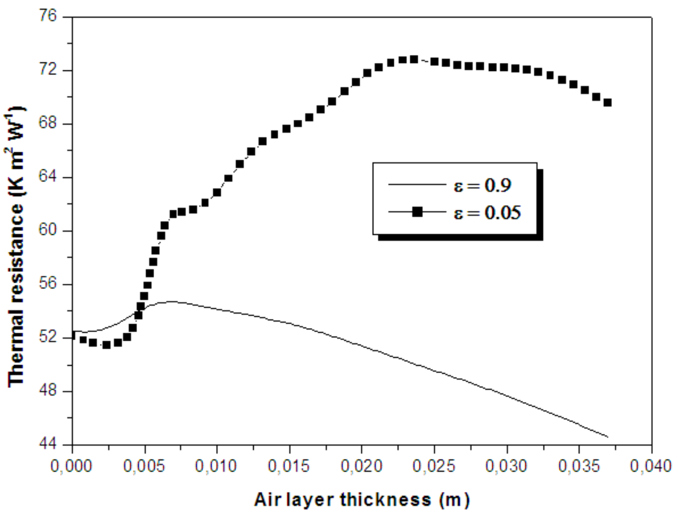


Figure 8. Thermal resistance as a function of the air cavity thickness, case of a cinderblock

In Figure 7, an attenuation of the thermal resistances, caused by increasing the air thickness is observed that from the optimum thickness e = 1.4 cm if the emissivity is of the order of 0.9. However, if the wall of the cavity is low emissivity or provided for example with a reflective film "ε = 0.05", the optimum thickness increases to have a value equivalent to 8.2 cm. If we place ourselves in the second case (Figure 8: air cavity in hollow brick bounded by ordinary materials "ε = 0.9"), the maximum thermal resistance is achieved for an optimal thickness of 0.68 cm. However, when the closed air cavity is bounded by a reflective material at one face "ε = 0.05", the optimal thermal resistance corresponds to the thickness of 2.36 cm.

5. Conclusion

The most performant type of insulation and its optimum thickness were determined for cavity walls under steady conditions. Besides, when selecting insulation material can be very important according to type of application and must be considered. When aluminum foil for example is used as the facing material, reflective thermal insulation can stop 97% of radiant heat transfer.
The resistance of a closed air cavity can be equivalent with a conventional thermal insulation layer, with a thickness that depends on the used building materials. Increasing the air cavity thickness beyond these limits will not increase the thermal resistance of the cavity due to the development of natural convection.
The thermal resistance of concrete block and brick hollow depend mainly on thermal emissivity, the thickness of the air cavity and on the temperature difference between surface and air of this cavity.
Therefore, cavities broader than a calculated threshold are normally not preferred. However, if more thickness of air cavity is required for getting heavy insulation, by putting partitions in the main broad cavity multiple cavities can be used as an alternative.

References

[1] Ana-cristina Tudora, Assessments criteria of building materials from ecological point of view, buletinul institutului politehnic din iaşi, Publicat de Universitatea Tehnică Gheorghe Asachi din Iaşi, Bul. Inst. Polit. Iaşi, t. LVII (LXI), f. 4, 2011.
[2] S. M. A. Bekkouche, T. Benouaz, M. R. Yaiche, M. K. Cherier, M. Hamdani, F. Chellali, "Introduction to Control of Solar Gain and Internal Temperatures by Thermal Insulation, Proper Orientation and Eaves ", Elsevier, Energy and Buildings vol.43 pp. 2414 – 2421, 2011.
[3] S. M. A. Bekkouche, T. Benouaz and A. Cheknane, "A Modelling Approach of Thermal Insulation Applied to a Saharan Building ", Thermal Science: Vol. 13, No. 4, pp. 233-244, 2009.
[4] S. M. A. Bekkouche, T. Benouaz, M. K. Cherier, M. Hamdani, R. M. Yaiche, R. Khanniche, Influence of building orientation on internal temperature in Saharan climates, building located in Ghardaïa region (Algeria), International Scientific Journal, Thermal science, Article in press, http://thermalscience.vinca.rs/online-first/646.
[5] S.M.A. Bekkouche, T.Benouaz, A. Cheknane, "Simulation and Experimental Studies of an Internal Thermal Insulation of two Pieces of Rooms Located in Ghardaïa (Algeria)", International Journal of Advanced Computer Engineering, January, Volume 2, issue 1 pp 1-9, June 2009.
[6] S. Ben Amara, Ecoulements et Transferts Thermiques en Convection Naturelle dans les Milieux Macro-poreux Alimentaires, Application aux Réfrigerateurs Ménagers, Thèse de Doctorat, Institut National Agronomique Paris-Grignon, Février 2005.
[7] A.J.N. Khalifa, Natural Convective Heat Transfer Coefficient - a Review II. Surfaces in Two and Three-Dimensional Enclosures, Energy Conversion and Management, vol. 42, p. 505-517, 2001.
[8] A.J.N. Khalifa, Natural Convective Heat Transfer Coefficient - a Review I. Isolated Vertical and Horizontal Surfaces, Energy Conversion and Management, vol. 42, p. 491-504; 2001.
[9] EN ISO 6946:1996, Building components and building elements, Thermal resistance and thermal transmittance, Calculation method. CEN.
[10] ISO 15099:2003, Thermal performance of windows, doors and shading devices - Detailed calculations.

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