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IMPROVING OF INTERIOR TEMPERATURES BY REINFORCED THERMAL INSULATION OF THE BUILDING ENVELOPE IN GHARDAÏA CLIMATE

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ABSTRACT

An inventory has been made for improving the interior temperature of a typical building located in Ghardaïa region. Through the mathematical studies, it has been shown that the design of passive houses in an arid region is based on some principles, namely: the correct choice of building materials and the strengthening of the thermal insulation. The experimental results indicate that in Saharan zone, the level heat gain through the walls is the main cause of a building overheating. The analysis of passive house solutions shows high priority with regard to the performance of the thermal envelope, such as high insulation of walls, roofs, floors, windows, doors and thermal bridge-free construction. Consequently, the realization of attics and eaves constitute the second phase in the passive design of these houses.
Keywords: Temperature – Hollow Brick – Cinderblock – Stones – Thermal Resistance

RESUME

Un inventaire a été réalisé pour améliorer les températures intérieures d'un bâtiment typique situé dans la région de Ghardaïa. A travers les études mathématiques, il a été démontré que la conception des maisons passives dans une région aride est basée sur certains principes, à savoir: le choix correct des matériaux de construction et le renforcement de l'isolation thermique. Les résultats expérimentaux indiquent que, dans la zone saharienne, le niveau de gain de chaleur à travers les murs est la principale cause des surchauffes du bâtiment. L'analyse des solutions de maisons passives montre une priorité élevée à l'égard de la performance de l'enveloppe thermique, comme l'isolation renforcée des murs, toits, planchers, fenêtres, portes et ponts thermique. Par conséquent, la réalisation des greniers et gouttières constituent la deuxième phase de la conception passive de ces maisons.

1. INTRODUCTION

Current climatic disturbances associated with growing energy needs, leads humanity to question the long-term management of resources, as well as another way of consumption. These environmental concerns are applicable to all areas, and in particular how to design habitat for a better quality of ambiances associated with a rational consumption of energy. The use of thermal insulation in buildings has increased significantly in recent years and has become mandatory in some countries. This was due to higher demands on human thermal comfort inside residential, commercial, and public buildings, beside the ever increasing costs of energy production and its negative impact on the environment [1].

In order to reduce the energy consumption and peak load requirement of air-conditioning in buildings, especially under severe climatic conditions, thermal insulation must be used. Insulation materials increase the thermal resistance (R value) and, hence, reduce the heat transfer rate between the outside and inside of a building. Nevertheless, the optimum R-values are subject to scientific research and depend on many parameters, including economic factors [2-3]. In Ghardaïa region, stones are the most used construction materials. It is has been used for centuries due to their availability and also due to the lack of other construction materials such as wood (low vegetation because of the climate). A typical most commonly used construction in the region had been chosen.

2. THERMAL RESISTANCE CALCULATION

Thermal resistance (R) is the reciprocal of thermal conductance. It is a measure of the resistance to heat transmission across a material, or a structure. Thermal resistance determination of simple walls (studied building material only) were conducted using the Kirchhoff's law. So, assuming that the transfer is unidirectional and perpendicular and taking into account the axis of symmetry, one can calculate the flow and the equivalent thermal resistance R through walls.

Knowing that: λ_{Stone} = 2.8 $Wm^{-1}K^{-1}$, λ_{Air} = 0.026 $Wm^{-1}K^{-1}$, $\lambda_{Cinderblock}$ = 1.1 $Wm^{-1}K^{-1}$ and $\lambda_{Hollow\ Brick}$ = 0.5 $Wm^{-1}K^{-1}$.

h: is the exchange coefficient by convection ($Wm^{-2}K^{-1}$) between the cavity of air and the vertical surface, it is calculated by equations given in reference [4-5]. We consider that the choice of the Nusselt number is deduced according the value of the Grashof number:

for $Gr < 1700 + 47.8\,i,\ Nu = 1.013$ (First case), (1)

for $Gr > 8104,\ Nu = 2.5 + 0.0133(90 - i)$ (Third case), (2)

else $Nu = (0.06 + 310 - 4(90 - i))\,Gr^{0.33}$ (Second case), (3)

where i is the tilt angle (degrees) and Gr the Grashof number.

3. DIMENSIONS AND EQUIVALENT CIRCUIT OF A 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. To calculate R_{th2}, we must calculate the convective transfer coefficient h in the cinderblock, this coefficient depends entirely on the Grashof number Gr. For this reason, the Nusselt number was chosen according to the value of Gr [6]. A mathematical study was made, provides a simplified diagram to describe succinctly the variation of the Grashof number, and which will serve for the choice and proper use of the heat transfer coefficient. These diagrams were obtained by considering that the air temperature inside the cavity is between 0 and 60 °C.

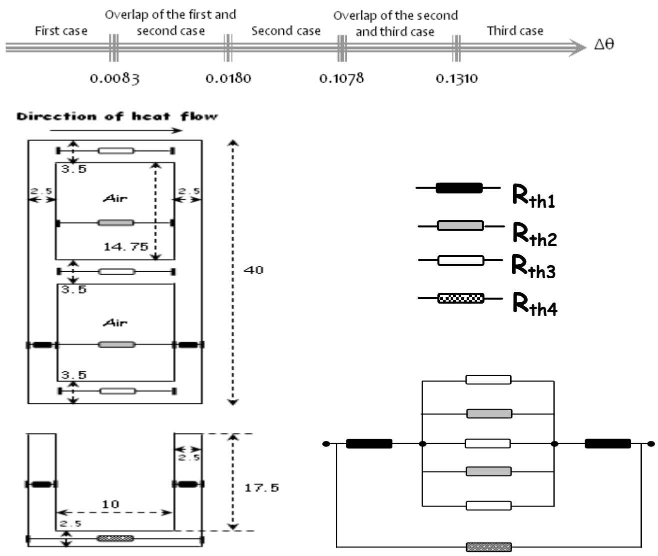

Fig. 1: Dimensions (cm) and equivalent circuit of a cinderblock.

Taking into account these considerations and applying Kirchhoff's law, we find the values of thermal resistances for a cinderblock.

R_{th1} = 0.3247 K m^2 W^{-1}

R_{th2} = 257.3602 K m^2 W^{-1} if Gr < 6002

R_{th2} = 131.6194 K m^2 W^{-1} if Gr = 40000 (i.e., T ~ 30.1100 °C and Δθ ~ 0.0597 °C)

R_{th2} = 104.2824 K m^2 W^{-1} if Gr > 80000

R_{th3} = 14.8423 K m^2 W^{-1}

R_{th4} = 13.6364 K m^2 W^{-1}

Consequently, the equivalent resistances of the cinderblock are given by the following values:

$R_{cinderblock}$ = 3.8760 K m^2 W^{-1} if Gr < 6002

$R_{cinderblock}$ = 3.7922 K m^2 W^{-1} if Gr = 40000 (i.e., T ~ 30.1100 °C and Δθ ~ 0.0597 °C)

$R_{cinderblock}$ = 3.7481 K m2 W-1 if Gr > 80000.

4. DIMENSIONS AND EQUIVALENT CIRCUIT OF A HOLLOW BRICK

The hollow brick is used as building material, 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. To complete our studies, we will choose the two dispositions most commonly used; the horizontal and vertical position. The dimensions and the equivalent circuit diagram of a vertically disposed hollow brick are given below in figure 2.
In order to determine the coefficient of convective transfer, we will follow the same method for the case of a cinderblock.

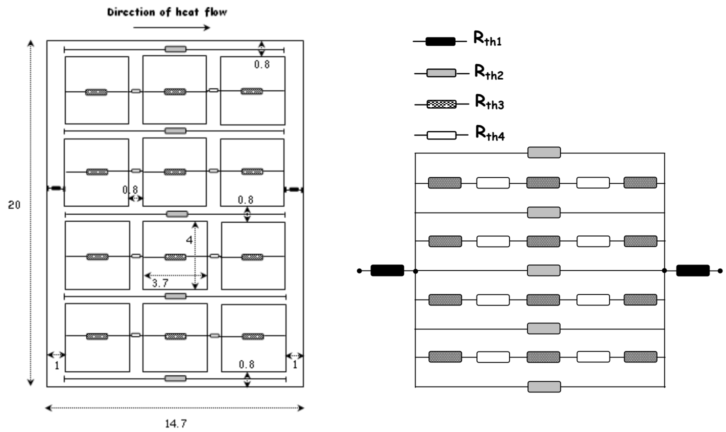

Fig. 2: Dimensions (cm) and equivalent circuit of a hollow brick.

Consequently, the equivalent resistances in this case are given by the following values:

$R_{hollow\ brick}$ = 17.9976 K m2 W-1 if Gr < 6002

$R_{hollow\ brick}$ = 15.4814 K m^2 W^{-1} if Gr = 40000 (i.e., T ~ 30.11 °C and Δθ ~ 5 °C)

$R_{hollow\ brick}$ = 14.4029 K m^2 W^{-1} if Gr > 80000.

The same steps are followed to calculate the equivalent thermal resistance of a horizontal hollow brick. Therefore, the characteristic dimensions remain the same but the equivalent circuit changes completely. The equivalent resistances in this case are given by the following values:

$R_{hollow\ brick}$ = 30.4878 K m^2 W^{-1} if Gr < 6002

$R_{hollow\ brick}$ = 26.1097 K m^2 W^{-1} if Gr = 40000 (i.e., T ~ 30.11 °C and Δθ ~ 6.3175 °C)

$R_{hollow\ brick}$ = 24.3309 K m^2 W^{-1} if Gr > 80000.

5. RESULTS AND NUMERICAL SIMULATION

The calculation of equivalent thermal resistances leads to deduce immediately the values of thermal resistances of walls. It will be conform 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. The equivalent thermal resistance of any wall is calculated by considering that the thermal resistance of each cinderblock (respectively for hollow brick) is parallel to another of the cinderblock (hollow brick) wall. The next step is devoted to present a new configuration model which, not only simulates Indoor temperatures of the building taking into account constituents of the envelope, but also applies numerical optimization techniques to propose the solution, which achieve the best thermal comfort conditions [7-8].

We consider that the sun-facing walls are composed in addition of two layers of hollow brick arranged horizontally, an air gap of 1 cm and 6 cm layer of polystyrene ($\lambda = 0.041$ $Wm^{-1}K^{-1}$). So the equivalent thermal resistance of walls equals to the sum of thermal resistances of layers. The used equations for calculating the Nusselt number are those given in reference [9-13]. We use these values to insert in the program and to simulate the indoor temperatures. Figure 3 shows the internal temperatures of the air in room 2 in the case of a building stone compared with temperatures predicted for this configuration. The obtained temperatures show that the proposed configuration allows to maintain more indoor temperatures.

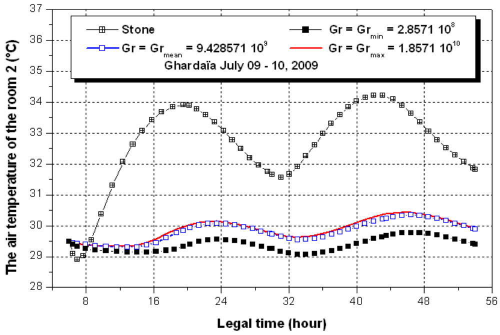

Fig. 3: Air temperatures of the room 2, July 09 – 10, 2009.

Figures 4 and 5 explain the immerging behaviour and present temperature curves of internal air of respectively room 1 and 2 in different cases.

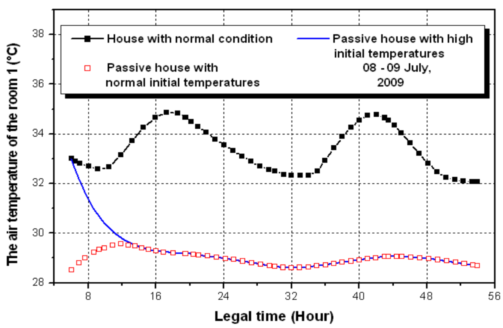

Fig. 4: Air temperatures of the room 1, July 08 - 09, 2009.

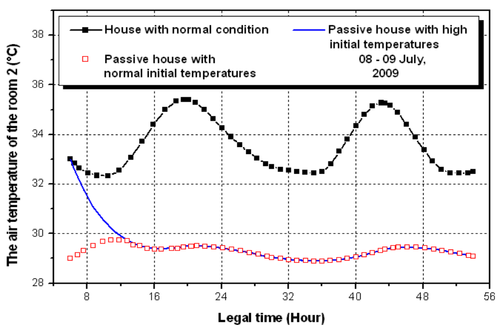

Fig. 5: Air temperatures of the room 2, July 08 - 09, 2009.

The obtained temperatures show that the proposed configuration allows maintaining more indoor temperatures. However, the diminution of interior temperatures can reach the value of

6°C but we have not yet reached the desired temperature 27 ° C, because the two main causes of overheating buildings in Ghardaïa region are due firstly to the used construction materials and partly to the absence of Sun-protections. The design does not need to be complex, but it does involve knowledge of solar geometry, window technology, localisation and local climate. We propose as another alternative solution in this region the construction of a house with two facades better than a house with four facades. Passive solar design increase energy efficiency and comfort in homes by incorporating passive solar design features. Therefore, the east and west facades will not be exposed to the sun. The indoor environment parameters such as air temperature are also affected by the situation of housing in rural areas. The problem is to seek and to set-up of prerequisites for modernising the degree of comfort in rural areas.

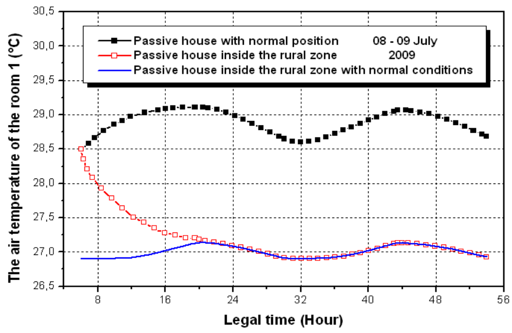

Fig. 6: Air temperatures of the room 1, July 09 - 10, 2009.

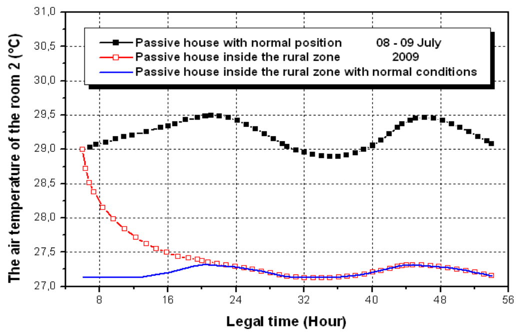

Fig. 7: Air temperatures of the room 2, July 09 - 10, 2009.

Figures 6 and 7 show simulated temperatures of rooms 1 and 2 by considering the house in a rural area so that only the south and north facades are exposed to sun. According the previous graphics heat gains through the walls for a rural housing with two exposed walls (north and south) consumes less energy by comparing it against another of the same plane with four facades. One can win sometimes more than 2 ° C. The thermal resistances of east and west walls have been improved by protecting them from overheating in summer and by adding at the same time, other additional layers. Consequently, the level heat gain through the walls is the main cause of a building overheating. The analysis of passive house solutions shows high priority with regard to the performance of the thermal envelope, such as high insulation of walls and roofs.

6. CONCLUSION

Providing thermal comfort conditions is very important for the residents especially in hot areas. The energy simulation in buildings can offer a valuable tool for engineers and architects to evaluate building energy consumption before the building is built. The results indicate that in Saharan zone, heat gains through the walls are certainly the main cause of overheating in this kind of buildings. The analysis of passive house solutions shows high priority with regard to the performance of the thermal envelope, such as high insulation of walls, roofs, floors, windows, doors and thermal bridge-free construction. Consequently, the realization of attics and eaves constitute an essential phase in the passive design of these houses.

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