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The improving energy efficiency using unfired clay envelope of housing construction in the south Morocco

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Abstract

Unfired clay is widely used in Moroccan's rural areas as a building material especially in the hot an arid climate regions. The unfired clay bricks offer a cost-effective form of construction and are selected for their low environmental impact. In order to valorize this ecological material in building efficiency energy, this work deals with experimental measurements of the thermal diffusivity and the specific heat unfired clay based on the flash method and the use of differential scanning calorimeter, respectively. After, the thermal conductivity can be deduced from a simple formula relating the thermal properties of unfired clay. A residential dwelling constructed using unfired clay bricks was simulated by Design builder software with the climate data for south Morocco location. This project is devoted to the investigation of the ways to use less energy by showing the impact of using the unfired clay on the thermal comfort and the building energy consumption according to the variation of the outside temperatures.

1. Introduction

Due to the increasing of energy consumption of population and the pollution caused by the manufacture of binders such as cement and plaster, it became necessary to promote a natural and local materials being more insulating, less energy-consuming and respecting the environment. To improve the energy performance of buildings, shutter material of construction and more exactly the envelope of heat insulation displays as big deposit of improvement and control.

Many studies have been published concerning the thermal proprieties characterization of clay such an insulation building material. The clay is one of the best materials can be used in order to build a sustainable construction. It is usually added to straw, sand, and then water in order to make bricks that are used in walls.

The thermal properties of brick materials based on fired clay have been measured by Laaroussi et al. [1,2] through the use of different methods to improve the reliability of the results. Cherki et al. [3] evaluated an experimental study of thermal properties of a sample characterization of insulating cork-gypsum composite. The properties requirements and the possibilities for traditional and future thermal building insulation materials and solutions, with their advantages and disadvantages, have been investigated by Jelle [4]. The sustainability and the qualities of the earth on construction in real conditions is demonstrated by El Fgaier et al. [5]. The study of Ball et al. [6] has underlined the strong influence of the water content on the thermal conductivity of laterite based bricks and it has been shown that the adding millet waste may strongly decrease the thermal conductivity of bricks.

Osseni et al. [7] research dealt with the development of new composite materials made of banana fibers-cement mortar which could be used as thermal insulator in building to valorize of agricultural waste. Merzougui et al. [8] conducted a relevant study with the objective of showing the laws that control heat in the atmosphere of local architecture of Biskra region for improved thermal yield of the building and control of energy consumption. A series of experimental studies were performed on composite clay-plastic in [9] . The obtained results indicate that the composite presents interesting characteristics in term of insulation and thermal Inertia.

Mounir et al. [10] conclude that the thermal transmittance of the Composite Illite Clay -Cork blocks is reduced considerably in comparison to traditional walls and can be used for the construction of standard Moroccan walls. Fahmy et al. [11] investigated the building envelope optimization both in the present and future time climate conditions. The simulated buildings showed gradual energy consumption reduction using GRC-foam sandwich.

Recently, The work of Tilioua et al. [12] reports the numerical and experimental studies of physical and thermal properties of polyester batting insulator. The material is consisting of recycled plastic waste based polyester fibers with constant diameters. The inverse method was introduced to determine the radiative properties of the studied material.

This work is a contribution to valorize the using of unfired clay as an environmental construction material resisting to the hard climatic conditions by improving its thermal proprieties and its impact on the energy performances and the thermal comfort of the occupants. Therefore, two different studies were treated; the experimental investigation concerned the thermal diffusivity and the specific heat determination using the flash method and the calorimeter respectively. Also, the thermal simulation was done to study the impact of clay on the energy efficiency in buildings.

2. Composition of used materials

The studied material of unfired clay is taken from Slaoui's Bricks company [13], it is the decomposition of four types of rock extracted from two different Moroccan's sites Rommanie and Khmisset, it is prepared by mixing 22% of water and 78% of clay. The chemical decomposition of unfired clay, described in Tables 1 and 2, reports of the substances relative proportions.

The sample, shown in Figure 1, is prepared by mixing small pieces of unfired clay and compacting them into a mold to have a circular sample having diameter 10.07 cm and thickness 3 cm. It was covered by a thin black painting and introduced in a strove for 72 h to remove its moisture. Finally, the sample was packed in plastic bag to maintain zero humidity until experimental measurements use.

Table 1:Chemical composition of the used clay [14]

Percent composition of mass	Redclay (Rommanie)	gray clay (Rommanie)	Yellowclay (Khmisset)	Claycellars
SiO_2	49.45	51.27	34.19	65.76
M_2O_3	14.24	14.55	9.75	14.56
Fe_2O_3	5.03	9.66	3.73	8.82
CaO	3.76	9.01	23.97	1.08
MgO	12.97	9.39	2.70	0.37
K_2O	2.77	0.33	1.65	1.01
TiO_2	0.78	1.42	0.56	0.89
P_2O_5	0.10	0.15	0.17	0.09

Table 2 : Percent of composition of the used clay

Type of clay	Red clay (Rommanie)	gray clay (Rommanie)	yellow clay (Khmisset)	clay cellars
Composition of mass	50%	10%	30%	10%

Figure 1: View of the unfired clay sample

Knowing the dimensions and dry mass of the sample, the measure of the density can be easily deduced as it is presented in Table 3.

Table 3 : Dimensions and density of studied sample

dimensions (mm^3)	$47.2^2 \times 29$
Mass (g)	425.67
Density [kg m^{-3}]	2097.20

3. Methodology for thermal characterization of unfired clay

3.1. *Flash method*

The flash method permits to estimate the thermal diffusivity of solids, its principal scheme is described on Figure 2. We send on the sample upper face a luminous flow of strong power P= 1000 W during a short time (t=3s), a thermocouple in contact with the lower face allows to register the rise of its temperature from the moment the lower face received the flash.

The same procedure is repeated many times until we get three satisfactory experimental termograms, shown in Figure 3, permitting to determine the thermal diffusivity of the sample using two theoretical models:

Parker model: This method was developed by Parker [15], it's applied only in the case which the duration of flash is short (impulse of Dirac) and where the heat losses on the various faces of the sample are unimportant (h=0).The thermal diffusivity is calculated as a function of time and the thickness (e) of the sample.

The part-times model was developed by Degiovanni [16] and [17],considering the thermal losses. It is based on the use of four temperatures $T_{max}/2$, $T_{max}/3$, $2T_{max}/3$, $5T_{max}/6$ corresponding to times $\frac{t1}{2}$, $\frac{t1}{3}$, $\frac{t2}{3}$ and $\frac{t5}{6}$ respectively. The numerical models of the thermal diffusivity calculation is described in [9,10,11].

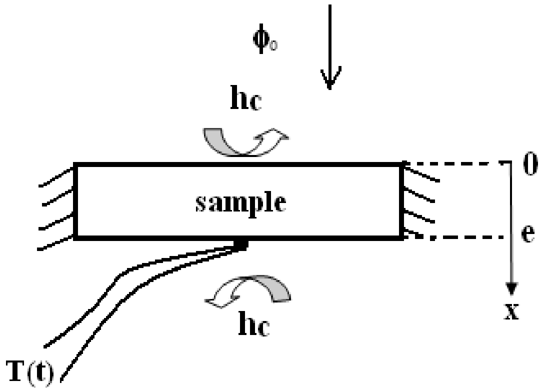

Figure 2: Scheme of the flash method

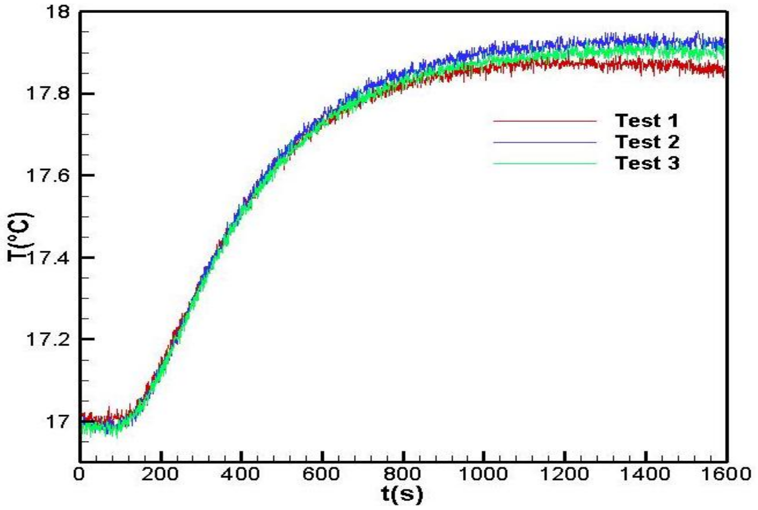

Figure 3: Tree favorable thermograms resulted from the flash method of unfired clay

Table 4: Thermal diffusivity values of unfired clay bricks

Test	$a \times 10^{-7} (m^2s^{-1})$ Parker	measurement deviation (%)	$a \times 10^{-7} (m^2s^{-1})$ Degiovanni	Measurement deviation(%)
1	3.531	2.347	3.504	2.907
2	3.434	2.985	3.385	0.587
3	3.387	1.826	3.326	2.320
Mean value	3.450		3.405	

3.2. Calorimeter method

The measurement of the specific heat unfired clay is based on the use of the differential scanning calorimeter (μDSC7Evo) designed for the study of samples in isothermal or/and scanning modes over a wide temperature range [18]. Since thermal properties tests are conducted at ambient conditions, an average value of specific heat capacity close to 980 $J.kg^{-1}K^{-1}$is retained corresponding to a temperature range of [10°C,40°C].

The thermal conductivity λ of the unfired clay sample can be determined from the measurement of the thermal diffusivity, as shown in Table 5, provided that volumetric heat capacity $\rho.Cp=2.055\times 10^6$ $J\ m^{-3}\ K^{-1}$ is known.

Table 5: Thermal conductivity values of unfired clay bricks

$a \times 10^{-7} [m^2s^{-1}]$ Parker	$\lambda\ (Wm^{-1}\ K^{-1})$ $(\lambda= a.\rho.Cp)$	$a \times 10^{-7} (m^2s^{-1})$ Degiovanni	$\lambda (Wm^{-1}\ K^{-1})$ $(\lambda= a.\rho.Cp)$
3.450	0.708	3.405	0.699

The input thermal properties of the unfired clay adopted in the simulation are (C_p=980 $J.kg^{-1}K^{-1}$, λ= 0.703Wm^{-1} K^{-1}, a=3.427 $\times 10^{-7}$ m^2s^{-1}).

4. Thermal simulation of building

The building studied is a residential housing with an approximate area of 73 m^2, oriented south and divided into six thermal zones. The choice of zones is made according to the location, the occupation and the use. The simulation is carried out under the climatic conditions of Errachidia.

The ventilation rate including infiltration is 36m^3/h per person, corresponding to an air change rate between 1h^{-1} and 0.4h^{-1}, in conditions where the cooling and the heating system is off. The envelope specifications used in the simulation study are presented in Table 6.

Table 6: unfired clay envelope composition

External wall (case 1)	external wall (case 2)	roof	floor
Unfired clay e=50cm	Unfired clay (e=30cm) Air gap (e=10cm) Unfired clay (e=30cm)	Bitumen Unfired clay wood-softwoods	Stone Slate Unfired clay Interior coating
U=1.12 $Wm^{-2}.k^{-1}$	U=0.82 $Wm^{-2}.k^{-1}$	U=0.604 $Wm^{-2}.k^{-1}$	U=1.65$Wm^{-2}.k^{-1}$

The average number of occupants per housing which represent the inhabitant occupancy rate is equal to four persons. The studied building floor model is shown in Figure 4. The simulation is carried out using Design Builder interface software [19] based on Energy Plus system.

Figure 5 shows that the average annual outdoor air temperature is 21°C and July and August are the hottest months of the year; air temperature during these months can reach 42.1°C while the lowest temperature recorded in Errachidia is -1.6 °C on Junary.

Figures 6 and 7 illustrate the results of the dynamic simulation of the air temperature evolution inside building of the two external walls construction (case 1, case 2).

An analysis of the indoor temperatures variation revealed that during the hottest and coldest months, the unfired clay bricks reduce the fluctuations of the outside temperature, as shown in Figures 6 and 7 for the two external walls. Indeed, the simulation results demonstrate that the indoor temperature remained quite stable over the two periods. Its variation range did not exceed ΔT_{in} =2°C, compared to the difference between the minimum and maximum values of outdoor temperatureΔT_{out} =16°C, the decrement factor was equal to ($\Delta T_{in}/\Delta T_{out}$=0.15).

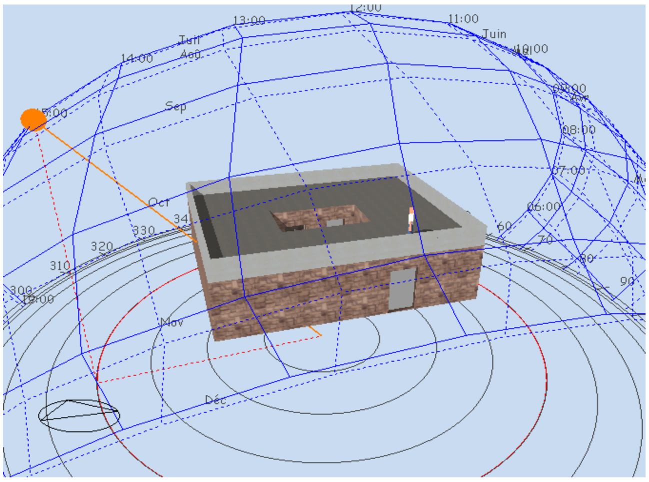

Figure 4: Simulated building model

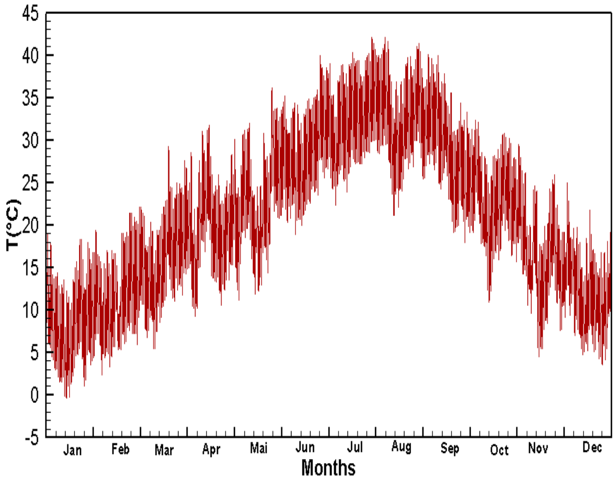

Figure 5: Outdoor temperature evolution for the Errachidia region on the full year 2012

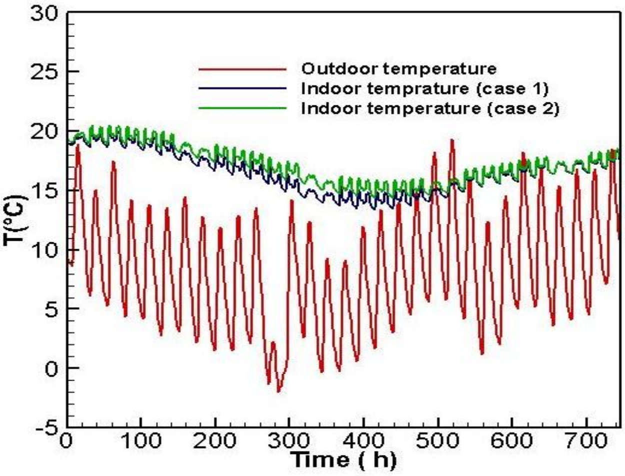

Figure 6: variation of indoor and outdoor temperatures for the two cases during January

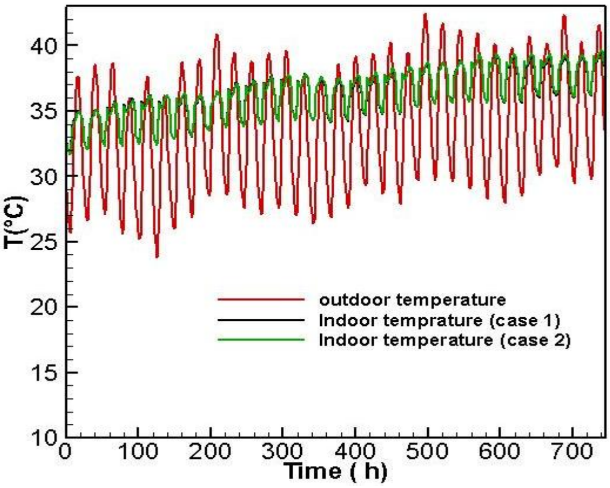

Figure 7: variation of indoor and outdoor temperatures for the two cases during July

These results highlight the thermal inertia of unfired clay bricks is able to guarantee the occupants comfort on coldest season, especially on the January. However, the occupants aren't feeling the fluctuations of the external heat flow.

From the thermal comfort point of view, the results of the simulations can be analysed for the two used external walls as follows:

- During the coldest months, the two external walls used in building construction achieved moderately the required thermal comfort without heating. The indoor temperature exceed 16°C and could attain 21°C during winter, consequently the unfired clay bricks is a good insulating material.
- During the hottest months, for the two cases studied, the outdoor temperature may reach levels above 42.1°C. However, the indoor temperature did not exceed 37°C, revealing that the unfired clay have a considerable thermal inertia. The decrease in the indoor temperature by an approximately 5.1°C during the hottest period created an increased feeling of comfort. In summer, the room temperature is higher and the thermal comfort conditions are not satisfied, hence, a system of cooling should be used.

Conclusion

In this paper, an experimental study of the thermophysical properties of unfired clay bricks is presented. A good envelope optimized design can improve the thermal performance through passive solar techniques based on the deep role that the earth materials like unfired clay bricks play in this process. It is shown that ensures a reduction of the fluctuations of the outdoor temperature and a limitation of the risk of overheating the building. however, the study demonstrated the thermal performance of unfired clay bricks and their contribution in creating thermal comfort in buildings in cold weather which represents the predominant climate for Errachidia.

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