4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Pol.16, pp.104 - 110

Environment and Thermal Impacts of Stabilized Earth Blocks for Residential Building in Mediterranean Climate

FatihaMokhtari#,*1, Larbi Loukarfi**2, Nachida Kasbadji Merzouk#3, Mourad Chikhi#4

#*Unité de Développement des Equipements Solaires UDES/Centre de Développement des Energies Renouvelables CDER, Bou-Ismail 42415, W. Tipaza, Algérie.*
1mokhtari.fatiha@gmail.com
3*nkmerzouk@gmail.com*
4*chikhimourad06@yahoo.fr*
**Department of Mechanical Engineering, University of Oran, Algérie*
***Department of Mechanical Engineering, University of Chlef, Algérie*
2*l.loukarfi@yahoo.fr*

***Abstract*— In modern societies, vast amount of energy are consumed to maintain, regularly used, buildings (residential, commercial, industrial and institutional) at temperatures which ensure an acceptable level of indoor comfort. Consequently, the past few decades have seen tremendous efforts geared towards reducing energy consumption for indoor heating and cooling thus leading to the development of improved insulation material and energy efficient HVAC systems. This reduction which is a pre-requisite for sustainability is commonly achieved by combining energy efficient building envelops with smart devices for energy consumption monitoring. From the perspective of building envelops, despite the tremendous progress that was made in building material, remote rural residents are still relying on traditional techniques to build their homes either because the cost of energy efficient materials is too high or because of limited accessibility. As a result, this contribution explores the effect of using Stabilized Earth Bricks (SEB), a common material used in Algeria's rural communities, on the indoor temperature. The study which uses a prototype house equipped with sensors to collect indoor temperature during the winter and summer seasons. These data are used to calibrate a thermal model which is then used to conduct a comparative study of three typical building envelops (as used in Algeria) from the standpoint of cost, embodied energy and thermal comfort. The result of this study will help to provide a scientific base to educate rural communities which often associate SEB based construction to a lower social status.**

Keywords*— Building envelop, Thermal performance, Embodied energy, Indoor temperature modelling, TrnSys

I. INTRODUCTION

Over the past few decades, the demand on non-renewable energy has increased dramatically worldwide which raised serious concerns with regards to the long term impacts of the current energy consumption rates on the availability of energy commodities and on their environmental effects such as ozone layer depletion, global warming and climate change to name a few. Buildings account for almost a third of final energy consumption globally and are an equally important source of CO2 emissions.

Currently, both space heating and cooling, as well as hot water are estimated to account for roughly half of global energy consumption in buildings, [1]. Energy-efficient and low/zero-carbon heating and cooling technologies for buildings have the potential to reduce CO2 emissions. Over the past few years, several studies ([2],[3],[4]- [6]) were conducted in order to gain insight into the energy consumption dynamics around the world with the aim to developing solutions that will keep it under control and by the same token will help reduce greenhouse gas emissions. Recent research ([7], [8]) helped gain further insight into occupancy factors including preferred comfort, 'take-back' from thermal efficiency improvements, and patterns of electricity use. Space heating is on a downward trend and is low in new dwellings.

Balaras et al, [9] conducted an investigation in which heating energy consumption data were collected during an audit that involved 193 European residential buildings from five different countries. Among other objectives, the authors have examined the influence of the thermal insulation of the envelope, the age and condition of the heating system on heating energy consumption and the resulting environmental impact. About 38% of the audited buildings had a yearly heating energy consumption above the European average (174.3 kWh/m^2 year), 30% had airborne emissions exceeding the European average and 23% had higher solid waste emissions than the European average. Polish buildings had the highest average heating energy consumption (63% of the buildings were found to be above the European average). French and Polish buildings had the highest production of airborne emissions with Poland leading the way with respect to emissions of solid wastes.

The study of Tan, [10] is motivated by the need to increase energy efficiency in existing buildings. The author confirms that identifying and investing in the right energy saving technologies within a given budget helps the adoption of energy efficiency measures in existing buildings. He uses a mathematical programming approach to select the right

ISSN 2356-5608

energy efficiency measures among all the available ones to optimize financial or environmental benefits subject to budgetary and other logical constraints in single-and multi-period settings. Through numerical experiments using the case data, he investigates and quantifies the effects of using environmental or financial savings as the main objective ,the magnitude of benefit of using a multi-period planning approach instead of a single-period approach, and also feasibility of offering energy saving technologies as a service. He shows that offering energy efficient technologies as a service can be a win arrangement for a service provider, its client, and also for the environment.

Even though Algeria is considered as rich in terms of non-renewable (fossil) energy resources (oil and natural gas), it is however well understood, in the light of available research, that short- and long-term energy strategies are necessary in order to build energy efficient structures in anticipation of the fateful date at which all its fossil resources are exhausted [11].

In this respect a new energy policy, [12] was recently proposed and included the following objectives: (*i*) use of construction material that require less energy to produce and (*ii)* improve the insulation of the envelope and (*iii*) use of intelligent systems to regulate energy consumption.

As a result, this work is the investigation based on an experimental house built using (Compressed) Stabilized Earth Bricks (SEB), which is often chosen as the material of choice for rural construction since it circumvents many difficulties including transportation, which is particularly challenging in mountainous or remote regions, [13]. The pilot house model is studied using TRNSYS software for performing a series of simulations aiming at analyzing its thermal behavior. The calibration of the model is performed through a comparative study of numerical temperature results with experimental data which are obtained from two monitoring campaigns carried out in the climatic conditions of Algiers (the pilot house location).

In the latter part of this work, a comparison study between traditional burnt clay bricks and (compressed) SEB is carried out. Numerical simulations are developed for testing different building external wall configurations. These configurations are based on changing walls construction materials using Stabilized Earth Blocks (SEB) and Clay bricks. Thermal characteristics such as indoor temperature are determined for each configuration.

II. CASE STUDY

The prototype is a rural house with approximately 80 m^2 of living space located in the municipality of Souidania (west of the metropolitan city of Algiers) whose geographic coordinates are respectively (latitude: 36°24' 25.2”, longitude: 2°54’50.4”, Altitude: 137 m).

The dwelling is designed for good energy efficiency based on optimal insulation of the envelope and use of solar energy for space heating and domestic hot water production. Its enhanced thermal efficiency reduces energy demand for heating and cooling. The house is equipped with four thermal solar collectors with a total area of 8 m2. This solar system provides domestic hot water and space heating through the floor, (Fig.1).

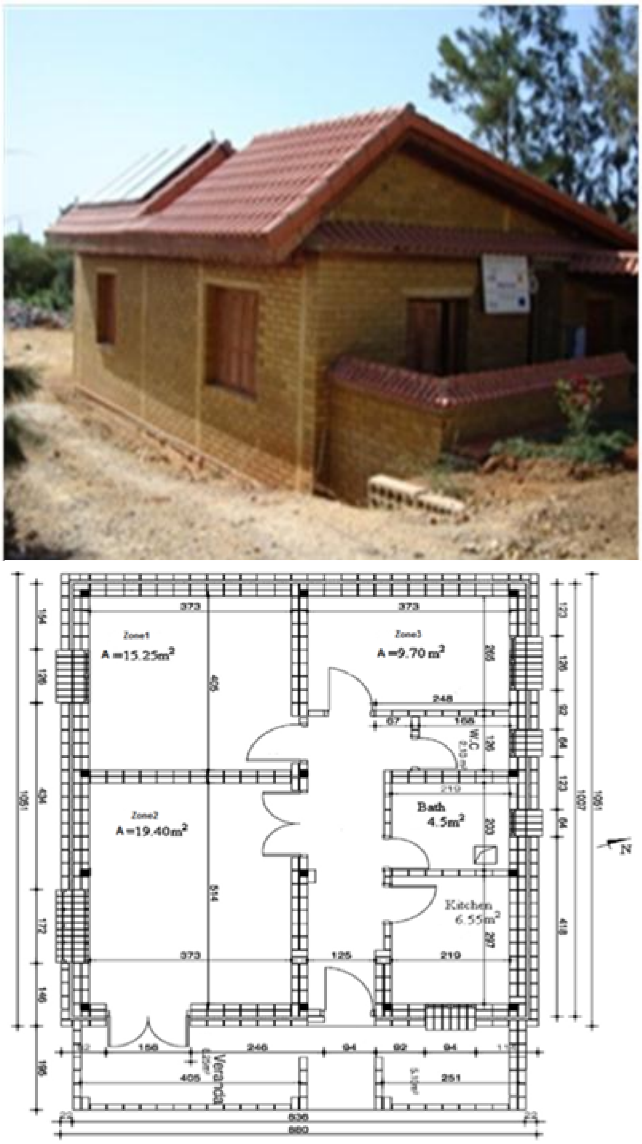


Fig. 1. An as-built view of the project and the plan of the prototype house showing the details of the living area.

However, the space heating system was turned off for the duration of the research reported in this contribution since the thrust of this paper is the analysis of the experimental dwelling from the perspective of material selection and thermal comfort in the context of a passive mode. The thermal characteristics and the materials that made up the elements of the house prototype are summarized in Table 1, [14]. It is instructive to compare the indoor temperatures of the above mentioned zones under three different layouts (commonly used in Algeria) for the exterior walls: (*i*) burnt clay bricks with EPS insulation, (*ii*) burnt clay bricks with air gap insulation and (*iii*) SEB with EPS insulation. The comparison of the simulated heat loss between SEB and burnt clay bricks based construction is motivated by the fact that the latter is probably the most widely used building material around the Mediterranean Sea. The thermal properties of the walls corresponding to these three experiments are summarized in Table 2.

TABLE I
HOUSE WALLS MATERIAL AND THERMAL PROPERTIES

	Composition	**Thickness (m)**	**λ (W/mK^{-1})**	**U (W/m^{2}K^{-1})**
External wall	SEB (BTS) EPS SEB	0.14 0.09 0.29	1.3 0.04 1.3	0.36
Floor	Concrete XPS Concrete Mortar + sand Tiling	0.05 0.06 0.15 0.03 0.02	1.75 0.04 1.75 1.15 1.7	0.54
Ceiling	Mortar EPS Concrete Plaster	0.03 0.16 0.08 0.04	1.60 0.04 1.75 0.35	0.23

TABLE 2
EXTERIOR WALLS LAYOUT COMMONLY USED FOR RESIDENTIAL CONSTRUCTION IN ALGERIA.
THE EXPERIMENTAL HOUSE IN FIG1 WAS BUILT ACCORDING TO SETUP 3

Exterior Walls	**Setup 1:Burnt Clay Bricks + EPS**				
	Plaster	Clay Brick	EPS	Clay Brick	Cement Coating
Thickness (Cm)	2	10	9	10	2
U (W/m^2 K)	0.34				
Setup 2: Burnt Clay Bricks + Air Gap					
Layout	Plaster	Clay Brick	Air Gap	Clay Brick	Cement Coating
Thickness (Cm)	2	10	4	10	2
U (W/m^2 K)	0.876				
Setup 3: SEB + EPS					
Layout	SEB	EPS	SEB		
Thickness (Cm)	14	9	29		
U (W/m^2 K)	0.36				

III. RESULTS AND DISCUSSIONS

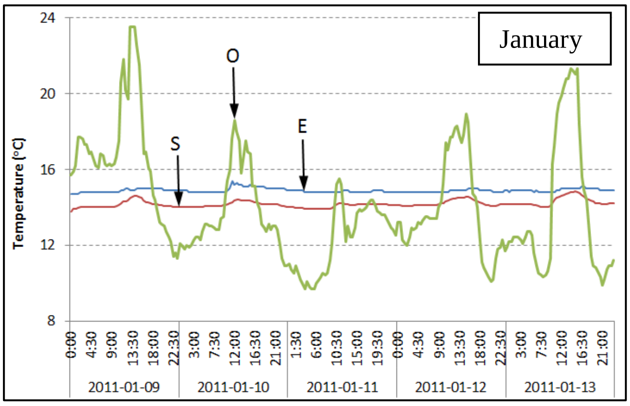
Using the layouts described in Table 2, the effect of the building envelopes on the indoor temperatures was studied. Given that this contribution is based on a single experimental house built using SEB, the comparison between the actual (existing) prototype and hypothetical dwellings built according to setup 1 and 2, cf. Table 2, will be conducted using TrnSys software.

A. Validation Model

However, as a first step it is imperative to verify that the model built within TRNSYS is sufficiently accurate so to be used for subsequent comparisons.

The experiments are taken at the prototype house. A weather station WMR918 is installed near the prototype at 7 m from the ground. This station is used to measure wind velocity, external air temperature and external relative humidity. The wall temperatures are tested using a set of type-k thermocouples which takes recording every 30 min. Indoor temperatures are measured using thermo-hygrometers (TESTO 175-H1) to each zone. Measurements were recorded over the whole year, [15].

As a result, indoor temperatures were collected during the months of August and January where the differential between indoor and outdoor temperatures is known to be extreme (for the Algerian context). These results are summarized in Fig. 2. It can be seen that the overall discrepancy between the simulated indoor air temperatures and their experimental counterparts is reasonable (≤1°C) given the (intrinsic) variability between the thermal parameters used within TRNSYS and those of real building materials, which are composition dependent. Clearly, Fig. 2 shows a stable indoor temperature, which indicates a performing building envelope, which encompasses wall insulation as well as quality doors and windows (double-glazing).



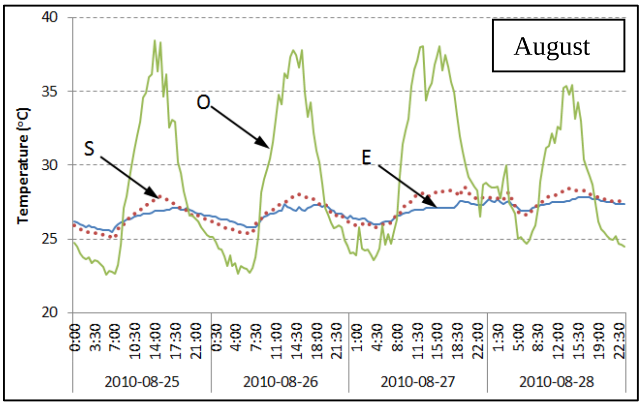
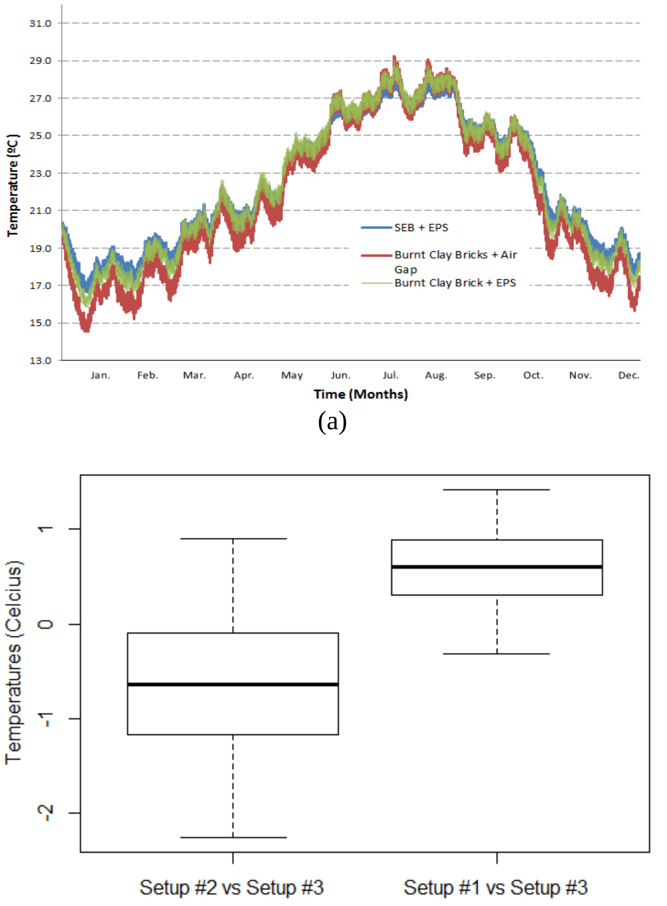


Fig. 2 Time series representing the indoor temperature (E: experimental and S: Simulated) and the outdoor temperature (O).

B. *Indoor Temperature Analysis*

Note that the curves in Fig. 3 correspond to passive modes where no additional energy sources are used for cooling or heating. At this juncture, given the stability and the level of accuracy of the models built within TRNSYS, the next step is to compare the indoor temperatures for zones 1 and 2 shown in Fig. 1. The simulated temperatures for these areas are shown in Fig. 3.



(a)

(b)

Fig. 3 (a) Indoor temperature for zone 2 for each wall layout as described in Table 2. (b) Indoor temperature differential between scenario 3 (i.e. SEB + EPS insulation) and scenarios 1 and 2, cf. Table 2.

According to Fig. 3, when EPS-insulated SEB is used for exterior walls, there seems to be a slight advantage in terms of indoor temperatures in both winter and summer seasons where the difference between the indoor temperatures ranges from 1 to 2 degrees (in favour of SEB), cf. Fig. 3b.

However, this advantage comes with a tradeoff since the thickness of the EPS-insulated SEB walls is larger than their burnt clay bricks counterparts (52cm versus 31cm and 28 cm respectively for setup 1 and 2). This of course translates into waste of living space, which, depending of the architectural complexity can be non-negligible. For instance in the case of the prototype in Fig. 1, the waste of living space due to the exterior walls alone amounts to approximately 3.5m^2 and 4.5m^2.

However, even though loss of living space may seem important, it must be understood that the choice of building material is first dictated by the local geographic, economic and to some extent the environmental realities may shift the balance in favour of locally available building materials such as SEB.

C. *Impact on Environmental and Cost*

It is noted that the cost which is probably the main motivator for choosing SEB as the main building material in rural areas as well as the environment impact of SEB-based construction as compared to burnt clay bricks. It is important to note that even though the cost is determined using the Algerian context, the factors underlying this cost analysis should be applicable in other areas of the world. In table (3), the costs of the building materials required for SEB and burnt clay bricks construction are summarized.

According to the costs provided in Table (3), it is clear that from the perspective of, SEB-based construction is undeniably far more affordable than its burnt clay brick counterpart. This, as mentioned above, often weighs onto the decision of adopting SEB in rural areas where road accessibility remains an issue. However, despite many advantages including comfort and cost, SEB is still underused for rural construction in Algeria as well as in other neighbouring countries for two main reasons:

(i) burnt clay bricks are traditionally believed to be more resistant to weather wear and
(ii) culturally, there is higher social status associated with building with burnt clay bricks which pushes rural individuals to strive for adopting burnt clay bricks even if that means putting tremendous pressure on their (usually) limited budget just to avoid using SEB as a building material.

To address the above-enumerated issues, two elements were taken into account during in the early planning stages of this project:

TABLE 3
COST OF THE WALL STRUCTURE EXPRESSED IN ALGERIAN DINARS (DA) FOR THE PROTOTYPE HOUSE IN FIG. 1: (1) USING STABILIZED EARTH BRICKS AND (2) BURNT CLAY BRICKS.

Brick type	Walls area (m^2)		Bricks	Brick cost(1)	Cement cost(3)	Sand cost	Labour	Total
	Exterior	Interior						
SEB: (29cm*14cm*9cm)	182.08	59	6.027	36.162(2)	15.000	10.000	20.000	81.162
Clay: (30cm*20cm*10cm)			4.098	81.960	42.000		60.000	193.960

(1)The cost of a burnt brick (excluding transportation to construction site) is approximately 20 DZ as sold by the manufacturer, i.e. excluding shipping.
(2)The cost of SEB bricks is estimated from the cost of labour. The daily wage for a labourer is about 500 DZ for an approximate production of 85 bricks per day. As a result the cost of an SEB brick is approximately 6 DZ.
(3)Cement is usually delivered in 25 kg bags costing approximately 600DA per bag.

(i) the prototype house was purposely built in a region known for its humidity (since close to shores of the Mediterranean Sea) to test the long term impact of humidity on its structural integrity and
(ii) the house was designed with architectural features, usually encountered in urban housing, see fig.1, that can showcase the beauty of SEB based construction hence contributing to improve the cultural view of future homeowners about this building material.

As mentioned in the beginning of this contribution, SEB not only is advantageous from a financial perspective but also from an environmental perspective since SEB-based construction usually have comfortable indoor temperatures and the production of this particular type of bricks has marginal environmental footprint. Indeed according to Venkatarama and Jagadish, [16] burnt clay bricks use huge amounts of energy since each brick (of size 23cm x 11cm x 7 cm) uses between 3.75 MJ to 4.75 MJ whereas a cement stabilized earth block with the same size requires 2.75 MJ o 3.75 MJ.

In the context of Algeria, since energy is mainly produced from natural gas a burnt clay brick generates approximately 189 to 239 tons of CO2 (assuming 100% efficiency), [17]. Even though economies of scale may reduce, to some extent, these numbers pose serious concern to decision makers especially given the fact that many brick production plants are not energy efficient.

IV. CONCLUSION

Currently, many underdeveloped countries are facing serious challenges in terms of housing since manufactured building materials are costly and in many instances are very difficult to ship to remote rural areas. As a result, alternative building materials, especially those relying on earth available everywhere (and at practically no cost), become a solution of choice that allows individuals to build their own dwellings within a short period hence increasing their quality of life.

However, culturally SEB-based construction is perceived negatively since it is commonly associated with a lower social status since homeowners prefer to use burnt clay bricks (traditionally used in the Mediterranean region).

In this work, it is shown that from the perspective of thermal comfort SEB-based dwellings can offer an indoor thermal comfort comparable to that obtained with burnt clay bricks provided the brick thickness is appropriately sized.

Although an increase in SEB thickness can be viewed as a disadvantage since this yields loss of living area, their low production cost and their thermal properties and their low environmental impact (low embodied energy) make these bricks a building material with a high sustainability potential.

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ISSN 2356-5608