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Sustainable Building Envelopes (Ecobuildings, Retrofit, Performance Gap)

Vernacular housing practices in Burkina Faso: representative models of construction in Ouagadougou and walls hygrothermal efficiency

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Abstract

In Burkina Faso, particularly in Ouagadougou, the walls of the houses are made of several local materials. The choice of a material implies a suitable constructive technique and an appropriate architecture. The walls are either earth-based, i.e. Compressed Earth Blocks (CEBs) or Adobe, or based on cement-based materials such as hollow concrete blocks. This paper proposes a description of the vernacular construction practices according to the material used for the walls and tries to explore the hygrothermal behaviour of various wall compositions. A hygrothermal simulation of a hollow concrete blocks wall and a CEBs wall using the WUFI®Pro software is carried out in order to compare the humidity flux passing through interior surface of each wall and to analyze the influence of integrated moisture in the calculation of heat flow. It is shown that, for CEBs wall, both thermal and hygrothermal simulation of heat flow give similar results.

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Keywords: Earthen bricks; Compressed earth blocks; Hollow concrete blocks; Hygrothermal properties;Climate; Building materials;Architecture

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1. Introduction

Materials used by humans in building construction require energy for their production or extraction. According to the World Business Council for Sustainable Development, the construction sector uses 40% of the total energy produced in the world. The building sector alone accounts for over half of the world's CO2 emissions [1]. To reduce these emissions, housings must be adapted to the climatic context, and to some extend based on local materials. In Burkina Faso, the government has initiated some research and promotion programs on so-called “friendly materials”. One of the government's projects was LOCOMAT, from 1991 to 2011. The LOCOMAT project's strategies included the promotion of local building materials, i.e., earth-based materials. The choice of wall materials is influenced by various factors including climatic response, availability, cost, and socio-cultural parameters. The traditional architecture of Burkina Faso, due to populations’ values, cultures and climate, is characterized by earth-based techniques [2] but there is an increase of constructions made with imported material like cement. 2006 statistics show that 69.4% of the dwellings have adobe walls, and 13.8% have walls in hollow cement blocks [3]. Cement-based constructions are gaining popularity despite the fact that their “modern” materials and architecture are not adapted to the local climate and are suspected to create discomfort. On the opposite, recently developed earth based techniques such as compressed earth blocks (CEBs) or clay bricks are supposed to improve the comfort in housing due to their high thermal inertia and capacity to regulate the moisture [4].

It is possible by means of a hygrothermal simulation to show the efficiency of the materials of the walls in hot and dry climate. Many studies focus on predicting the indoor thermal climate and use a thermal or hygrothermal simulation of building envelope. Fati Z. and al.[5] modeled a dwelling and studied the time lag of several building materials from Burkina Faso including earth materials according to the geographic orientation of each walls. In [6], a dynamic thermal simulation is carried out using TRNSYS in dry and hot climate and gives, for dwelling made with CEBs, interior temperature and humidity during one year. In [7], a combined heat and moisture simulation is being conducted with different types of CEBs walls. This paper is part of a more comprehensive research on earthen habitat in a hot and dry climate. In addition to the previous research, this paper shows the influence of humidity gradient in dynamic environment on the calculation of thermal transfer through a CEBs wall and the moisture flow through compressed earth blocks wall and hollow concrete blocks wall.

2. Objective and method

Several materials are used in vernacular architecture to build the walls in Burkina. These walls’ energy efficiency aspect particularly deserves to be studied in this hot and dry climate. Previous researches have investigated the energy efficiency of different walls in this environment. We try to integrate the effect of the hygric properties of materials on mass and on heat transfers through the walls and see how this can have an impact on indoor climate. Therefore, we need to classify the architecture according to the nature of the walls. We can distinguish three types of houses described below: *Modern cement block houses; houses from Adobe blocks* and *houses whose walls are made of compressed earth blocks*. This distinction has been established through contacts with local actors, field immersion and literature review. Four architects, two associations, one builder and *several* construction sites were surveyed. The description of each case is based on field observations supported by the literature[2, 8, 9].

2.1. Modern cement block houses

This type of dwellings represents 48% of the buildings in Ouagadougou[3]. These buildings’ envelopes are made of cement materials (Fig. 1). The envelopes are usually composed of a cement exterior coating of 2 cm, a hollow concrete blocks wall of 15 or 20 cm and a cement interior coating of 2cm. For esthetical finishing, a layer of paint can be applied on interior and exterior coating. The bricks are built using a cement mortar of vertical thickness between 3 and 8 cm. The roof can be heavy or light. In the first case, it consists of reinforced concrete floor. In the case of a light roof, the frame is made of wooden rafters or metal tubes directly supported by the walls or reinforced concrete beam. The whole is covered by a sheet metal. When the walls are load-bearing, the foundations are made of cement concrete and cement cyclopean concrete. When the walls are not load-bearing, the stability is ensured by a system of beams, poles, or reinforced concrete soles. In all cases, the excavation depths are between 0.40 and 1.20m, depending of the type of soil.

2.2. *Houses from molded earth blocks or Adobe*

The houses in Adobe blocks represent 24.7% of the buildings in Ouagadougou[3] (Fig.2). This mode of construction is issued from traditional architecture but is influenced by new materials such as steel sheet. The bricks are made using a wooden mold. The earth used comes from spontaneous quarries. *The selected earth must be rich in clay.* The percentage of clay in the earth intended for the production of adobe is between 10 and 40%[10]. For bricks production, the mixture is composed of earth material and water but to limit cracks, the bricks are sometimes made with an addition of straw. The wall is built with earth mortar. Sometimes, walls received a coating of a mixture of earth, straw and cow dung or a coating of cement. The earth mortar used to mason these bricks has a thickness of 2 to 5 cm. The roof is either thatched either made of sheet metal. The thatched roof is now very marginal in the capital. When the roof is in thatch, the form can be conical, pyramidal or with two slopes depending on the shape of the dwelling. When the roof is made of sheet metal, the structure is a summary structure made of wooden rafters with a section varying between 8x15 cm to 6x 8cm depending on the range to be crossed [2]. The walls are load-bearing and the foundations depth does not exceed 0.30 meters.

Fig.1 Construction of cement blocks dwelling in Ouagadougou

Fig.2 Dwelling made of molded earth blocks in Ouagadougou

2.3. *Houses whose walls are made with compressed earth blocks.*

The compressed earth block is the modern descendent of the molded earth block, more commonly known as the adobe block (fig.3). The idea is to compact the earth with a press to improve the quality of the material[11]. The particle size range recommended of earth for production of CEBs is given by CRAterre[12]. These blocks can be assembled using cement mortar or without mortar. The usual dimensions of the blocks used are 29.5 × 14 × 9 cm^3 or 22 × 14 × 11.5 cm^3. These blocks' dimensions allow the thickness of the walls to vary according to the adopted apparatus: 14, 22 or 29.5 cm. The walls are generally not coated. The roofing system is the same as the one used in modern construction. The walls are rarely load-bearing and the stability is ensured by a reinforced concrete frame.

Fig.3 Construction of CEBs building

3. Hygrothermal simulation

3.1. Hypotheses

We first evaluate the influence of moisture on the calculation of the heat flow of a CEBs wall. For the simulation we used the Heat, Air and Moisture Transfer model referred HAMT, used by WUFI®PLUS software [13]. The general equations for humidity transfer and storage are presented in (1) and for thermal conduction in (2). A sinusoidal curve model representing the exterior climate is established based on Typical Meteorological Year data (TMY 2) of Ouagadougou. The average minimum and maximum temperature and humidity are used to define the sinusoidal curve of exterior climate. Indoor temperature and relative humidity are set respectively to 28°C and 34,5%. Then, we compare the moisture flow between two components, from the outside to the inside. Component A is a typical concrete wall composed with coating and hollow concrete blocks illustrated in figure 4.a. Component B is a CEBs wall (fig.4.b). For CEBs, thermal conductivity can be found in [14], specific heat in[7], vapor diffusion resistance factor (μ) in [15], free water saturation, dry density and porosity in [6] and reference water content (kg/m³) in [16]. For component A, the hollow bricks are decomposed and are modeled by a succession of concrete-air-concrete layers. Concrete, air layer and concrete coating parameters are issued from WUFI®PLUS database. Table 1 summarizes the walls parameters.

Table 1: Hygrothermal properties of materials

hygrothermal properties	CEB	Concrete layer	Air layer	Concrete coating
Dry density (kg/m³)	1959	2315	1,3	2000
Thermal conductivity (W/m.K)	0,9	0,733	0,59	1,2
Porosity (m³/m³)	0,29	0,13	0,999	0,3
Specific heat (J/kg.K)	1003,33	800	1000	850
Vapor diffusion resistance factor (μ)	9	182,5	0,15	25
Reference water content (kg/m³)	11,9	50	-	35
Free water saturation (kg/m³)	165	64,82	-	280

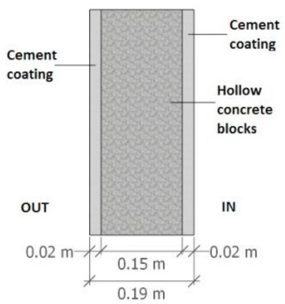

Fig. 4.a Component A: concrete wall

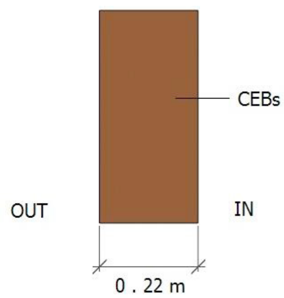

Fig. 4.b Component B: CEBs wall

$$\frac{du}{d\phi}\frac{d\phi}{dt} = \delta_{perm}\frac{d(p_{sat}\phi)}{dx} \quad (1)$$

$$\lambda\Delta T + P = \rho c\frac{\partial T}{\partial t} \quad (2)$$

du/dϕ: slope of moisture sorption curve ($kg_{moisture.}$ Kg^{-1}_{dry}); ϕ: relative humidity; δ_{perm}: vapor permeability ($kg.m^{-1}.s^{-1}.Pa^{-1}$); p_{sat}: saturation vapor pressure (Pa); T: temperature (°C); P:internal energy ($W.m^{-3}$); ρ: density ($kg.m^{-3}$); c: specific heat ($J.kg^{-1}.K^{-1}$); t: time (s); x: distance into wall (m).

3.2. Results and discussion

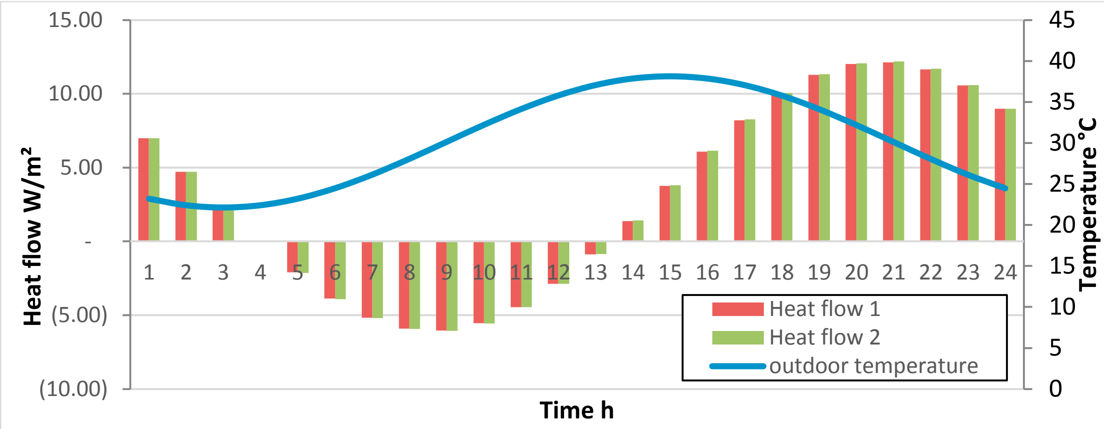

Fig. 5 Heat flows through interior surface of component B

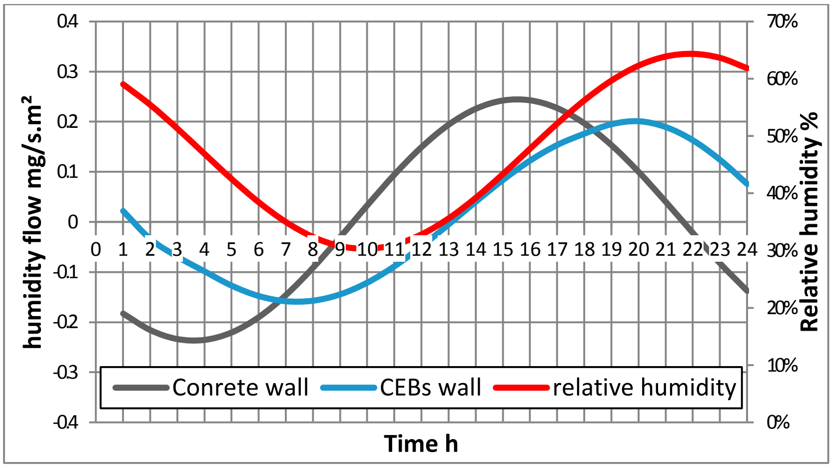

Fig. 6 Moisture flow through interior surface of component A: concrete wall, and component B: CEBs wall

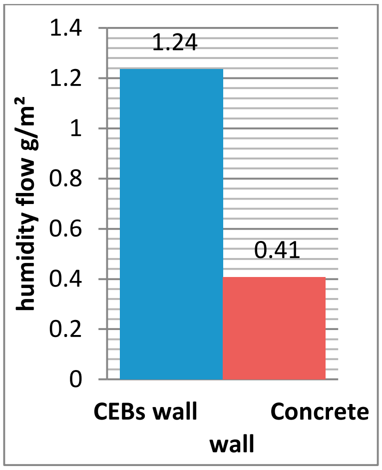

Fig.7 Daily moisture add in indoor environment

Figure 5, *Heat flow 1* represents the heat passing through the inner surface of CEBs wall and calculated without the influence of humidity gradient on the thermal behavior. *Heat flow 2* is calculated using temperature and humidity gradient between outdoor and indoor environment. These two curves of heat flow are almost the same. Thermal simulations of building envelope without influence of humidity show a good estimate of the walls' behavior.

Fig. 6 shows daily evolution of humidity flow through the inner side of each component and the relative humidity of exterior environment. The average value of humidity flow for concrete wall is $4{,}72.10^{-3}$ mg/s.m², with a minimum of -0,24 mg/s.m² and a maximum of 0,24 mg/s.m². The average value of humidity flow for CEBs wall is $1{,}43.10^{-2}$ mg/s.m², with a minimum of -0,16 mg/s.m² and a maximum of 0,20 mg/s.m². Figure 7 shows the amount of moisture discharged in interior environment for component A and B. In the same exterior environment during one day, component B lets in 0,83 g/m² more water into the indoor environment than component A. It represents an increase of relative humidity from 34,5% to ≈38% for 4x5x2.8m³ sized house whose walls are made of CEBs and 34,5% to ≈36% for a concrete house with same dimensions.

It could be considered to use the earthen bricks buffer storage potential put forward in this study to regulate radiant temperature of walls, which could possibly have an impact on the indoor climate. The objective is to see how we can use this surface humidity flow to improve radiant temperature of walls. We can also consider an adiabatic cooling of indoor hot air through its contact with the wetter wall.

4. Conclusion

The vernacular architecture of dwellings in developing countries involves the use of local materials. The choice of these building materials for the wall by the populations is mainly influenced by financial, social and sustainable factors. Cement based or earthen materials are used for building walls in Burkina Faso. We focus on exchanges between these walls and their environment, in particular on mass exchanges and the influence of these mass exchanges on heat transfer. Thermal simulations to predict the indoor temperature and heat flow through the walls of dwellings give similar results to those of hygrothermal simulation for CEBs wall. The hygrothermal models nevertheless allow calculating the flow and storage of moisture through the material. Walls made of compressed earth blocks are more permeable to mass transfer than walls made of hollow concrete blocks. This result is predictable when we consider the values of vapor diffusion resistance of the elements composing each wall (table1).

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