Impact de la nature des matériaux utilisés dans l'enveloppe des bâtiments au Burkina Faso sur la consommation énergétique et le confort thermique

Impact of the type of materials for building envelopes on thermal comfort and energy consumption in Burkina Faso

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Résumé - Cette étude examine expérimentalement les performances thermiques et la consommation énergétique de trois bâtiments identiques à Ouagadougou, au Burkina Faso, ne différant que par les matériaux des murs extérieurs : parpaings de ciment creux, briques de terre comprimée stabilisés au ciment et briques de terre comprimée stabilisés au géopolymère. Lorsque le système de climatisation est éteint, le bâtiment en briques de terre comprimée stabilisés au géopolymère présente la plus faible variation de température moyenne quotidienne, indiquant une meilleure inertie thermique. Lorsque le système de climatisation est en marche, le bâtiment en briques de terre comprimée stabilisés au géopolymère consomme le moins d'énergie pour le refroidissement.

Abstract - This study experimentally investigates the thermal performance and energy consumption of three identical pilot buildings in Ouagadougou, Burkina Faso. The main difference is only in the external wall materials: hollow concrete blocks (HCB), cement-stabilized compressed earth blocks (cement CEB), and geopolymer-stabilized compressed earth blocks (geopolymer CEB). When the air conditioning system is off, the geopolymer CEB building exhibited the lowest variation of average daily temperature, indicating better thermal inertia. When the air conditioning system is on, the geopolymer CEB building consumes the least energy for cooling to reach 27 °C.

Nomenclature

e	Thickness, m
E	Thermal effusivity, W.m^{-2}.K^{-1}.s$^{0.5}$
c	Specific heat, J.K^{-1}kg^{-1}

Greek symbols

α	Thermal diffusivity, m².s^{-1}
λ	Thermal conductivity, W.m^{-1}. K^{-1}
ρ	Density, kg.m^{-3}

Index and exponent

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1. Introduction

The management of the energy sector is essential to achieving sustainable development, whether human or economic [1]. A well-performing energy sector promotes growth, attracts investment, fosters innovation, and improves well-being. Global primary energy consumption increased by 12.6% from 12.62 Gtoe in 2012 to 14.21 Gtoe in 2021 [2]. Similarly, for non-OECD countries, energy consumption increased by 23.2% during the same period, reflecting the growing demand driven by rapid economic development and population growth [2]. Sub-Saharan Africa continues to face energy challenges, despite increased production capacity in recent years. By 2022, only 51% of the population in sub-Saharan Africa was projected to have access to electricity [3]. One of the challenges is to rationalise and optimise available energy resources.

In the buildings sector, measures to optimise energy use can have a significant impact, as buildings account for an estimated 34% of global energy demand. [4]. A significant proportion of this energy is used for air conditioning. For example, in Ouagadougou, the capital of Burkina Faso, 40% of average household electricity consumption was used for cooling in 2023 [5]. In such a hot climate, reducing energy consumption for air-conditioning requires appropriate building design and the selection of appropriate materials for the building envelope. Several studies have addressed this challenge.

In north-eastern Algeria, a study on the impact of building envelopes on energy demand was carried out using a thermal simulation model. The results showed that the reflectivity of the material influences the energy demand of buildings and that clay bricks offer more advantages than concrete blocks [6].

In Burkina Faso, Hema et al. investigated the effect of the design of wall systems, mainly made of compressed earth blocks (CEB), on the indoor thermal comfort of naturally ventilated houses in the hot climate of Burkina Faso. The results of the simulation show that the thermal discomfort profiles vary depending on the wall design and the building spaces [7]. In another study, Hema et al. highlighted the importance of layer positioning in wall, emphasising that placing a thermal mass layer, such as CEB, on the inside of a double-layered wall significantly reduces internal temperature variations [8].

Moussa et al. carried out a simulation of a naturally ventilated building with CEB and cement block external walls in the Ouagadougou climate. The thermal discomfort in the building with CEB masonry was 400 hours lower than in the building with cement block masonry. Taking into account the air conditioning system, an annual saving of 310,000 CFA francs (about 472 euros) in energy consumption for cooling was achieved in favour of the CEB model [9]. However, Neya et al. demonstrated through a dynamic thermal simulation study under the climatic conditions of Ouagadougou that the studied CEB buildings remain hot, with daily discomfort hours ranging from 19 to 15 hours [10].

The above studies highlight the influence of external wall materials on indoor temperatures and thermal comfort in hot climates. Earth materials appear to have thermal advantages over cement blocks. However, these studies are mostly based on thermal simulations and often do not consider energy consumption. The present study aims to compare the thermal performance of three identical pilot buildings, differing only in the materials used for their external walls. An experimental approach was used to simultaneously measure temperature and cooling energy consumption in three buildings constructed with (i) hollow concrete blocks (HCB), (ii) compressed earth blocks stabilised with 8% cement (cement CEB) and (iii) compressed earth blocks stabilised with 15% geopolymer (geopolymer CEB).

2. Materials and Methods

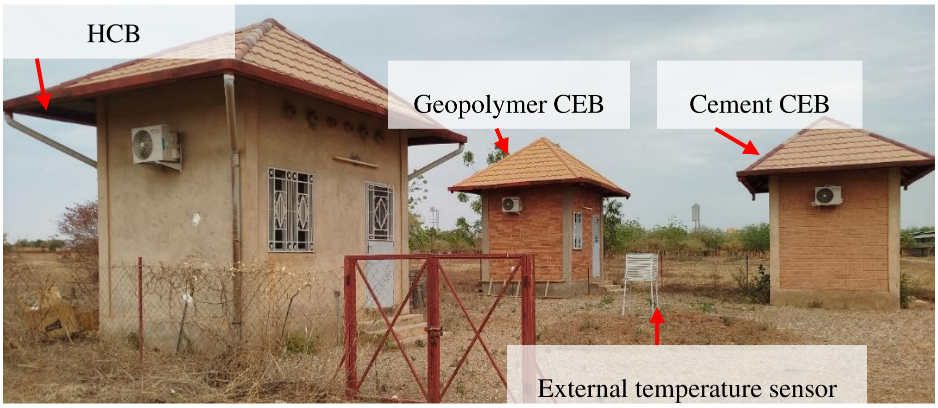
2.1. Overview of the climate

Burkina Faso, located in sub-Saharan Africa, has a hot and dry climate. The country has three main climatic regions: the desert in the north, the Sudan-Sahelian in the centre, and the savannah in the south. This study was conducted in Ouagadougou, which is in the central Sudan-Sahelian zone. The city has an average monthly temperature ranging between 25°C and 34°C and an average relative humidity ranging between 14% and 58%, except during the rainy season when humidity can reach 80% [11].

2.2. Description of experimental buildings

The study was carried out on three pilot buildings located in Ouagadougou, exclusively built for instrumentation on the campus of the international institute for water and environmental engineering (2iE). These pilot buildings are intended for research by the laboraboire eco-matériaux et habitats durables "Eco-materials and Sustainable Housing Laboratory" of the 2iE. The buildings were identical in geometry, differing only in the materials used for their external walls: compressed earth blocks stabilised with 8% cement (Cement CEB), compressed earth blocks stabilised with 15% geopolymer (Geopolymer CEB) and hollow concrete blocks (HCB).

Each building had a single room of 10 m² with a ceiling at a height of 2.7 m. The main facade, with one door and one window, faced south, while the opposite façade had a single window. The east and west facades had no openings. A ventilated attic separated the 3 mm plywood ceiling from a 0.35 mm aluminium roof. The buildings were empty throughout the study and had no internal heat sources. Figure 1 shows the experimental buildings. The thermal properties of the wall materials are detailed in Table 1. [7], [9], [12].



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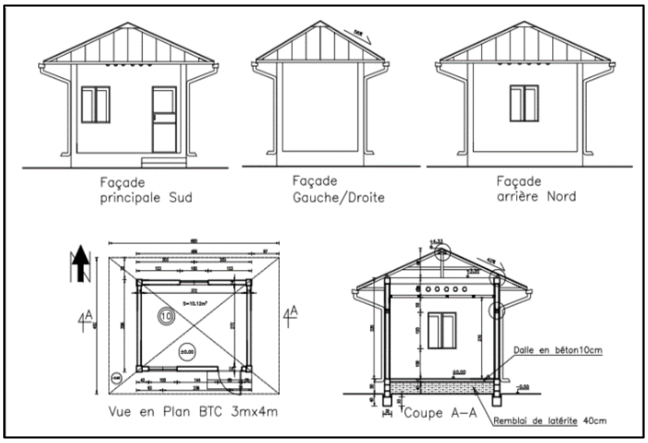


(b)

Figure 1: *Experimental buildings: (a) photography of the buildings; (b) plan view and facades of tested building*

Materials	e [m]	λ [W.m^{-1}. K^{-1}]	ρ [kg.m^{-3}]	c [J.kg^{-1}.K^{-1}]	α [m².s^{-1}]	E [W.m^{-2}.K^{-1}.s$^{0.5}$]
HCB	0.19	0.95	2068	648.82	7.08^{E}-07	1129
Cement CEB	0.14	0.78	1860	846.00	4.95^{E}-07	1108
Geopolymer CEB	0.14	0.71	1730	1027.14	4.00^{E}-07	1122

Table 1: *Thermal characteristics of wall material*

2.3. Sensors and equipment

Programmable sensors from Waranet Solutions were used to record temperatures, operating in the range of -40°C to +85°C with a sensitivity of ± 0.06°C. These sensors can store up to 8,000 readings. Measurements were taken hourly. Inside each building, one sensor was placed in the centre of the room, 1.2 m above the floor, to measure the indoor temperature. Additional sensors were placed on the inside and outside of the north wall to measure surface temperatures. An external sensor in a protected box recorded outdoor temperatures. For the purposes of this study, the results relating to surface temperatures will not be presented.

Air-cooling systems in the 3 buildings are of the inverter type, which allows the useful cooling capacity to be progressively adjusted. It is a SHARP model AU-X9ZMVP of 735.50 W using R32 refrigerant, with a cooling capacity of 2.70 W, and a control range of 16°C to 30°C.

Single-phase energy meters, according to IEC 620532-1, were used to quantify the energy consumption of the air conditioners. These energy meters were installed at the switch of each air conditioner. Energy consumption was recorded at every hour.

2.4. Experimental approach

The measurements in the 3 buildings were simultaneous and synchronised with a recording interval of one hour. The measurements took place discontinuously from 02 October 2024 to 26 December

2024. The period of the experiment was the cold season in the Sudano-Sahelian climate of Ouagadougou. The doors and windows of the three buildings remained closed throughout the measurement period.

In the first setting, the measurements were taken without the air conditioning system in operation. In this setting, measurements were taken from 02 October 2024 to 04 October 2024. In the second configuration, the temperature of the air-conditioning system was set to 27 °C. This choice of temperature was based on a previous study of the comfort operating temperature for air-conditioned buildings in Burkina Faso, which is between 26.3°C and 26.5°C [15]. The air conditioning system was kept running from 23 December 2024 to 26 December 2024. The outdoor temperature was measured in each configuration.

3. Résultats et discussion

3.1. Evolution of the temperature without air conditioning

Figure 2 shows that the outdoor temperature ranged between 22.58 °C and 37.51 °C. The temperatures inside the pilot buildings ranged from 27.62 °C to 36.14 °C. The differences in temperature values inside the buildings are small. As a result, the curves showing changes in indoor temperatures are largely overlapping. In addition, the indoor temperatures are above the comfort threshold.

On day 1 of the experiment, temperatures ranged from 28.12°C to 33.64°C, giving a daily temperature variation of 5.00°C4.50°C, and 5.50°C for cement CEB building, geopolymer CEB, and HCB buildings, respectively. On day 2, the daily temperature variation was 7.50°C for each of the buildings. On day 3, the daily temperature variation was 8.00°C, 7.50°C, and 7.99°C for the cement CEB, geopolymer CEB, and HCB buildings, respectively. Thus, the average daily temperature variation over the 3 days of the experiment shows that the geopolymer CEB building performed better (6.50°C), followed by the cement CEB building (6.83°C), then the HCB building (7.00°C). Based on the average thermal amplitude, the geopolymer CEB building offers the best performance.

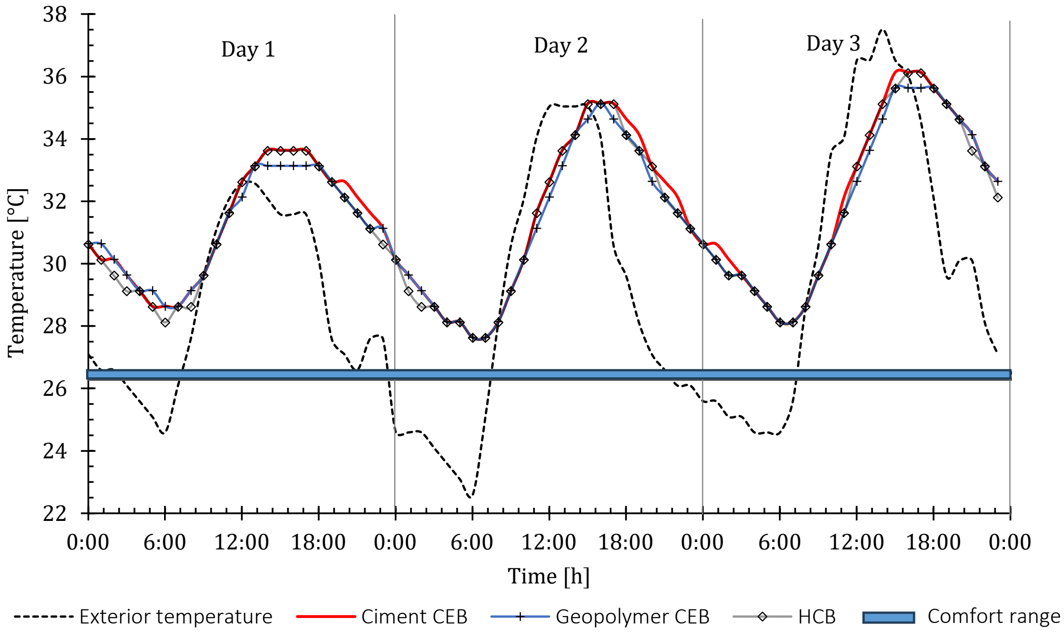


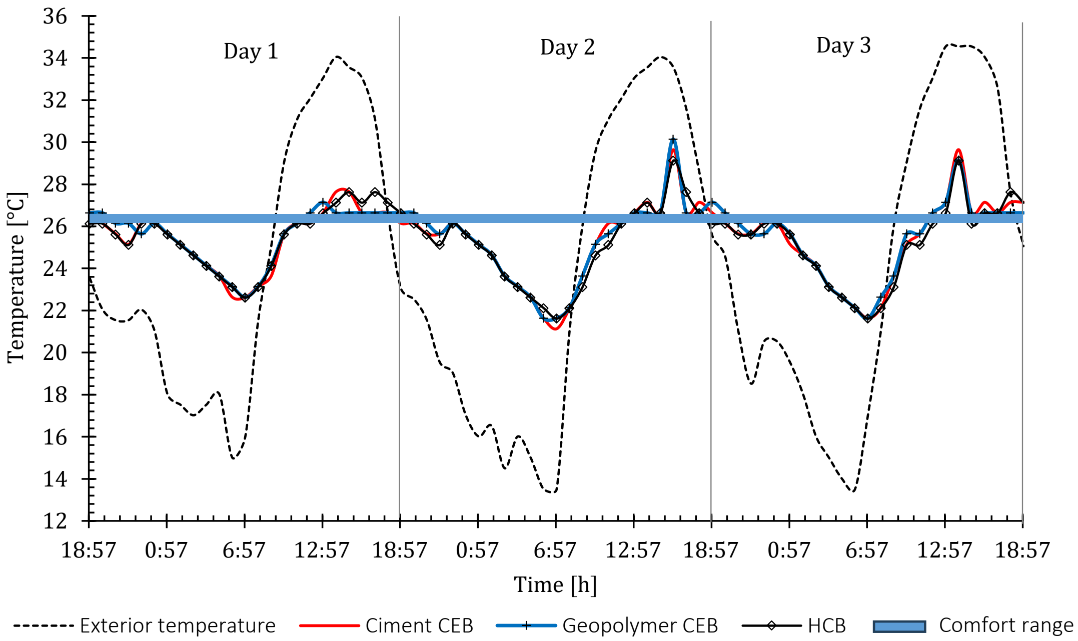
Figure 2: *Evolution of air temperature without air conditioning system*

3.2. Evolution of the temperature and energy consumption with air conditioning

Figure 3 shows the evolution of the indoor and outdoor temperatures of the 3 pilot buildings when the air conditioning system is switched on with a setpoint of 27°C. The outdoor temperatures ranged from 13.5°C to 34.55°C during the test, while the indoor temperatures ranged from 21.16°C to 30.14°C. Overall, the indoor temperatures in the 3 buildings followed a similar pattern, so that the curves were mostly superimposed.

On day 1 of the experiment, indoor temperatures ranged from 22.63 °C to 27.64 °C, giving a daily temperature variation of 5.01°C for the cement CEB building, and 4.51°C and 5.01°C, respectively, for the geopolymer CEB and HCB buildings. On day 2, the daily temperature variation was 8.51 °C, 8.51°C, and 7.51°C, respectively, for the cement CEB, geopolymer CEB, and HCB buildings. On day 3, the daily temperature variation was 8.01 °C, 7.51 °C, and 7.51 °C, respectively, for the cement CEB, geopolymer CEB, and HCB buildings. The average daily temperature variation over the 3 days of the experiment shows that the HCB building performed better (6.68 °C), followed by the geopolymer CEB building (6.84 °C) and finally the cement CEB building (7.18 °C).

Figure 3 (b) also shows the evolution of energy consumption in the 3 buildings. It follows a similar pattern in the 3 buildings. However, two trends can be observed: a horizontal linear trend when indoor temperatures are below 25.8 °C; and an increasing linear trend above 25.8 °C, reflecting an increase in cooling demand. Over the course of the experiment, the geopolymer CEB building consumed the least energy for cooling at almost all times. This resulted in a total energy consumption of 7.3 kWh for the geopolymer CEB building, while the cement CEB and HCB buildings consumed 7.6 kWh and 7.5 kWh, respectively. This performance of the geopolymer CEB building can be attributed to its enhanced thermal insulation properties, which reduced the cooling demand (Table 1). These results suggest that using geopolymer stabilized CEB could improve energy efficiency in building designs for hot climates, making them a sustainable choice for reducing energy consumption.



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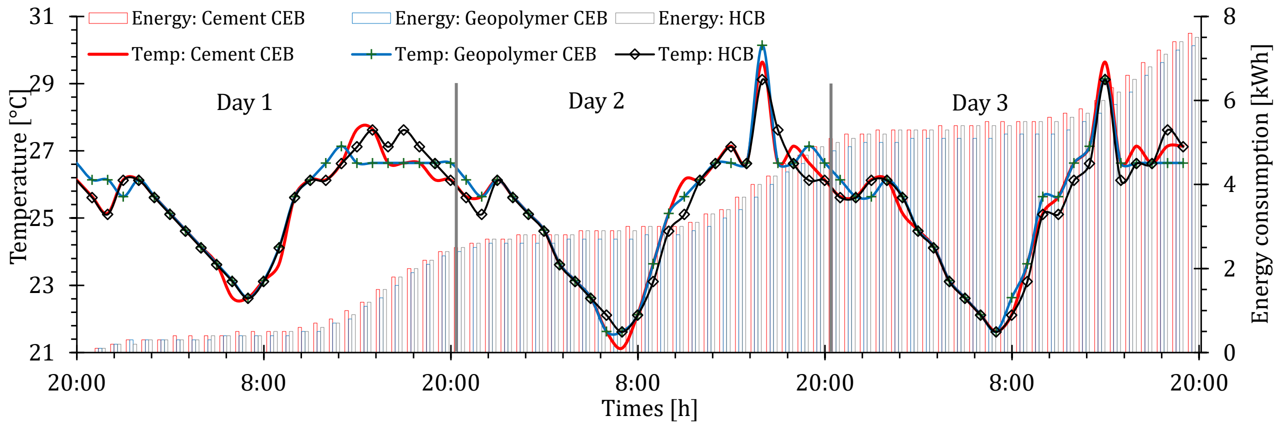

(b)

Figure 3: *Evolution of thermal parameters with conditioning system: (a) interior and exterior temperatures; (b) interior temperatures and energy consumption.*

4. Conclusion

This study highlights the role of wall material selection in improving the energy efficiency and interior temperature of buildings in hot climates. Through an experimental comparison of three buildings constructed with hollow concrete blocks (HCB), cement stabilised compressed earth blocks (Cement CEB) and geopolymer stabilised compressed earth blocks (Geopolymer CEB), it was shown that the geopolymer CEB building demonstrated the best energy performance. This material reduced energy consumption for cooling and maintained more stable indoor temperatures, outperforming both HCB and cement CEB. The results suggest that geopolymer CEB offers a sustainable and energy-efficient alternative for building construction in Ouagadougou. These results are in line with the global need to optimise energy use and improve thermal comfort. Future studies could investigate the long-term experimentation, including the hot period, and coupling with the insulation systems.

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