Journal of Energy and Power Engineering 15 (2021) 231-242
doi: 10.17265/1934-8975/2021.07.001

Comparative Study of the Thermal Comfort of Four Materials Type Used in the Construction of a Building

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Abstract: This research work consisted in making a comparative study of the thermal comfort of four materials types used in the construction of a building. A simulation of the building with the various materials on the KoZiBu software in reference and optimized situation was carried out. A study on the sensitive and air-conditioning loads as well as the curves of temperatures on a building of type F2 in situation of reference and in optimized situation was made on the one hand and the other hand a study on the same building without air-conditioning in reference and optimized situation. Finally, the analysis of the results favorizes the choice of the material having the best thermal comfort. The conclusions of these works show that the material that can give the best comfort and the most economics in terms of energy is the adobe which offers temperatures (301.40K or 28.40°C) and a good indoor thermal environment compared to BLT (blocks of cut laterite), BTC (blocks of compressed earth) and cinder block. Dwellings built with earthen materials offer a better indoor thermal environment than those built with modern construction materials, which are used more and more in the construction of houses in Burkina Faso.

Keywords: Materials, thermal comfort, modeling, air conditioning loads, sensitive loads, KoZiBu.

1. Introduction

The scarcity of energy is today more than ever a topical issue, but to this phenomenon we have to add the climate changes of recent decades, alarming the scientific community, which calls for a change in the population's behavior. Burkina Faso is a country with a dry and hot tropical climate, which means that air conditioning needs are high, which increases the demand for electricity. However, this demand is not fully covered by production. The construction domaine is very energy intensive, accounting for 60% to 75% of energy consumption [1]. The energy consumption of buildings in the public sector, particularly for the operation of air conditioning equipment (air conditioners, fans, etc.) in 2012 is estimated at 30,000 MWh/year, with an estimated financial cost of F CFA 3.4 billions/year [2]. This situation leads to overbilling, over-consumption of energy in buildings and irregularities in the supply of electricity. In addition, it would be wise to propose new constructions based on materials that take account the thermal comfort of the inhabitants and consequently reduce electricity bills. The different building materials studied are such as adobe or banco, BLT (blocks of cut laterite), BTC (blocks of compressed earth) and agglos or cement blocks. Thus we proceeded to numerous analyses and a simulation in order to characterize them. The results of these analyses make it possible to find for each material, the optimal formulation which reconciles the best the technical aspects while having a good thermal resistance which constitutes a convincing criterion for the choice of a material in construction.

Given the relevance of this theme, research of works has been carried out on building materials, such as: V. Prodjinonto et al. [3] led in 2016 a comparative study on the thermal retention capacity of some building materials existing in Benin. This study focused on a frantic search for the improvement of the energy's

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performance of the building. During this study, four materials: composite cement and fibers of ronier, composite cement and balls of rice, agglomerate and composite cement and earth of bar, were designed under the same conditions and according to the same mixture. The ranking of the materials in decreasing order of retention capacity is as follows: composite cement and rice balls, composite cement and rice fibers, composite cement and bar soil and agglomerate.

Nusrat Jannat et al. [4] studied in 2020, a comparative simulation study on the thermal performance of building envelope materials under tropical climate. This study evaluated in detail the different aspects (thermophysical properties, thickness, exposure to solar heat gain, etc.) of building construction materials affecting the indoor thermal environment and energy efficiency.

M. Saidi et al. [5] led in 2019, comparative studies on the sorption capacity of earth-based building materials. This study allowed analyzing the effect of chemical stabilization on the sorption capacity of SEB (stabilized earth bricks). The chemical binders used were cement and lime. The stabilizer contents added are 0%, 5%, 8%, 10% and 12% of the soil mass. The sorption isotherms are determined by a gravimetric method at a temperature of 25°C and fitted by three models: Halsey, Henderson and Oswin. The results obtained show that the sorption isotherms of these materials are of type II.

O. Coulibaly et al. [6] have carried out work on the influence of building materials and building orientation on the thermal load of buildings in a hot and dry tropical climate. This study focuses on the determination of the thermal energy performance of individual houses built with “H” shape bricks in a hot and dry tropical climate (different cities in Burkina Faso and the city of Bamako in Mali). The results show that houses built with clay bricks can have positive effects on the environment. In addition to their economic and environmental benefits, houses built with clay-filled H-bricks show approximately the same energy consumption patterns as empty cement bricks. In contrast, houses built with H-bricks filled with a mixture of clay and grass, which have low thermal conductivity, have a reduced air-conditioning load.

Chaffa, Awanto et al. [7] studied the improvement of indoor environmental conditionsin the northern zone of Benin, precisely in Kandi. This study allowed analyzing the thermal responses of the building envelope, as well as the resulting indoor environmental conditions for walls made of traditional materials of different thicknesses such as hollow block walls (12 cm), solid brick walls (18 cm) and clay walls (25 to 30 cm). After simulations, they obtained results that show that in a dry tropical region, clay buildings protect well from sunlight and support better environmental conditions during the day and night.

O. Coulibaly et al. [8] carried out work on eco insulation materials to reduce the cooling loads of a house built of breeze block or laterite in a dry tropical climate. This study investigated the influence of eco-materials for roof insulation and fibre-reinforced mortar cladding on the cooling loads of a house in a dry tropical climate. The walls of the house are made of breeze blocks or laterite and the insulation material of a roof panel is composed of lime (24%), cement (6%), water (50%), hibiscus sabdariffa plant fibres (16%), a tree widely grown in Burkina Faso, and sugarcane bagasse (4%). The results obtained show that in the hottest months of the year, i.e. in March and April, the relative differences between the thermal gains of the “cinder block rendered mortar and uninsulated roof” and “lateritic fibre rendered mortar and insulated roof” configurations vary between 15% and 20% and the “insulated roof” configuration varies between 15.6% and 16.8%. The configuration “laterite fibre reinforced mortar cladding and insulated roof” results in a reduction in annual thermal gains of 15.5% compared to the configuration “breeze block cladding mortar and uninsulated roof”.

The objective of our study is to perform a comparative study of the thermal comfort of four materials, in order to determine the material with the good thermal comfort while reducing energy consumption. In our work, we will first model the building on the KoZiBu software using the thermal characteristics of each type of material to determine the thermal behavior and the different loads (sensitive and air conditioning) of the building, then study the evolution of temperatures, humidity and loads sensitive and air conditioning according to the different materials (04) used, giving analysis and interpretation of the results obtained, finally deduce the most economical material.

2. Material and Method

2.1 KoZiBu Model Description and Material Properties

2.1.1 KoZiBu Software

KoZiBu is simulation software for the dynamic analysis of the thermal and hydric performances of a building. In addition, it is intended to conduct studies of heating and cooling, air conditioning and ventilation, and the choice of insulation materials. The main objective of KoZiBu is the prediction of energy consumption, and of the amplitude of variation of temperature and humidity. KoZiBu allows estimating the heating or cooling power needed to maintain a given set point, or to determine the evolution of temperatures when the heating or cooling system is insufficient. Humidity is treated in the same way. KoZiBu is based on the assembly of simple bricks to form a complex building with its equipment. Using the graphical interface, the user builds a model of his building using basic elements (air volumes, walls, windows). The user can add internal loads and control elements to the building model and then perform thermal calculations [9].

2.1.2 Material Properties

Table 1 summarizes the composition and properties of the different types of walls and openings that were considered for the hollow block building.

The thermo-physical properties of the materials used are in Table 2 below.

2.2 Modeling the House with KoZiBu

2.2.1 Description of the Building

The study that we carry out concerns a dwelling of approximately 28.08 m² of surface, a volume of 84.24 m^3, with its principal frontage directed towards the east. It is a building of type F2 composed of a room, a living room, a release and a toilet.

The uninsulated exterior walls are 25 cm thick brick for all materials with exterior and interior cement

Table1 Thermo-physical properties of hollow block materials [10-12].

Designation	Materials	Thermal conductivity (W/m·K)	Heat capacity (J/ kg·K)	Density (kg/m^3)	Thickness (m)
Exterior walls	Gypsum plaster	0.520	1,000	1,300	0.025
	Hollow block	0.670	880	1,250	0.200
	Cement plaster	0.870	105	2,200	0.025
Slab (roof)	False ceiling STAF	0.450	900	1,200	0.050
	Concrete	1.750	653	2,100	0.160
	Bitumen	0.230	800	1,000	0.020
Interior partitions	Gypsum plaster	0.520	1,000	1,300	0.025
	Hollow block	0.670	880	1,250	0.200
Floor	Sandstone tiles	1.200	1,000	2,000	0.005
	Concrete	1.750	653	2,100	0.150
Front door	Metallic	50.000	450	7,800	0.150
Interior doors	Wood	0.120	2,510	593	0.150
Windows (Single glazing)	Glass	1.150	1,000	840	0.004

Table2 Thermo-physical properties of the materials used [10-12].

Material	Thermal conductivity (λ, W/m·K)	Density (ρ, kg/m^3)	Diffusivity (α, m^2/s)	Effusiveness (E, J/m^2·K·s$^{-1/2}$)	Thickness (m)
Block	0.670	1,250	6.7×10^{-7}	858	0.2
BLT	0.469	1,853	2.7×10^{-7}	898	0.2
BTC	0.541	1,960	2.3×10^{-7}	1,401	0.2
Adobe	0.650	1,700	2.7×10^{-7}	872	0.2

renderings, white paint on the interior and dark yellow on the exterior (i.e., 20 cm with 2.5 cm of interior rendering and 2.5 cm of exterior rendering); the partitions are 20 cm thick brick with cement renderings for the cinder blocks and white paint on both sides for the other materials.

The slab consists of 15 cm of concrete, covered with 5 cm thick tiles on solid ground and a tin roof.

The interior doors are made of wood and the exterior doors are made of metal, double sash with iron frame. The glazing is single and 4 mm thick with iron frame, with a conductance out of surface resistance equal to 5.7 W/(m²·K) and solar factor equal to 0.85. The height under floor is 3m. The average temperature of the ground in Ouagadougou is 26°C.

2.2.2 Multizone Modeling

The multi-zone building model is used. The simulations are performed over the year with a time step of 1 h (0 to 8760h) in the KoZiBu simulation environment. In order to have a finer modeling of the habitat (Fig.1) according to its use, we subdivided it into four (4) zones in order to describe it in the KoZiBu software. The four (04) zones described in KoZiBu are:

Zone 1: Staying

Zone 2: Clearance

Zone 3: Room

Zone 4: Toilets

2.2.3 Meteorological Data

As the building is located in the city of Ouagadougou, METEONORM meteorological data of this city are used for the simulation.

2.2.4 Internal Loads and Control Devices

We assume that the air conditioner is turned on when the indoor temperature rises above 26°C with a relative humidity of 50%. Ventilation and infiltration are set at one volume per hour. Weekday and weekend occupancy scenarios corresponding to the bedrooms and the living room have been created. The number of occupants is 4 for the living room and 2 per room. For the lighting, 06 fluorescent lamps of 9W/m^2 are used in total for the building. The living room has a 175W television and a 60W Canal+ decoder, a 100W refrigerator and an 80W laptop computer, each with a usage coefficient of 100%.

3. Results and Discussion

3.1 Comparison of the Maximum Temperature Curves of Living Room and Bedroom

Figs. 2 and 3 show respectively the variations of the living and room temperatures of the building with air conditioning in the reference situation of four (4) types of materials.

We can see in Fig. 2 that the evolutions of the temperatures in the living room are identical. The maximum temperatures of the room in BLT, breeze block, BTC and adobe are respectively: 36.10°C; 36.80°C; 35.80°C and 35.60°C. These maximum temperatures are observed in April. We also note that BLT, BTC and adobe are respectively 0.70°C; 1°C and 1.20°C lower than cinder block.

The graphs in Fig.3 show that the evolutions of the temperatures in the chamber are identical. A decrease of the temperature for the different materials is noted at the level of the chamber with maximum temperatures for the chamber in BLT, in cinder block, in BTC and adobe are respectively: 35°C; 35.70°C; 34.80°C and 34.70°C. The differences in temperature between the breezeblock room and the BTC, BLT and adobe rooms

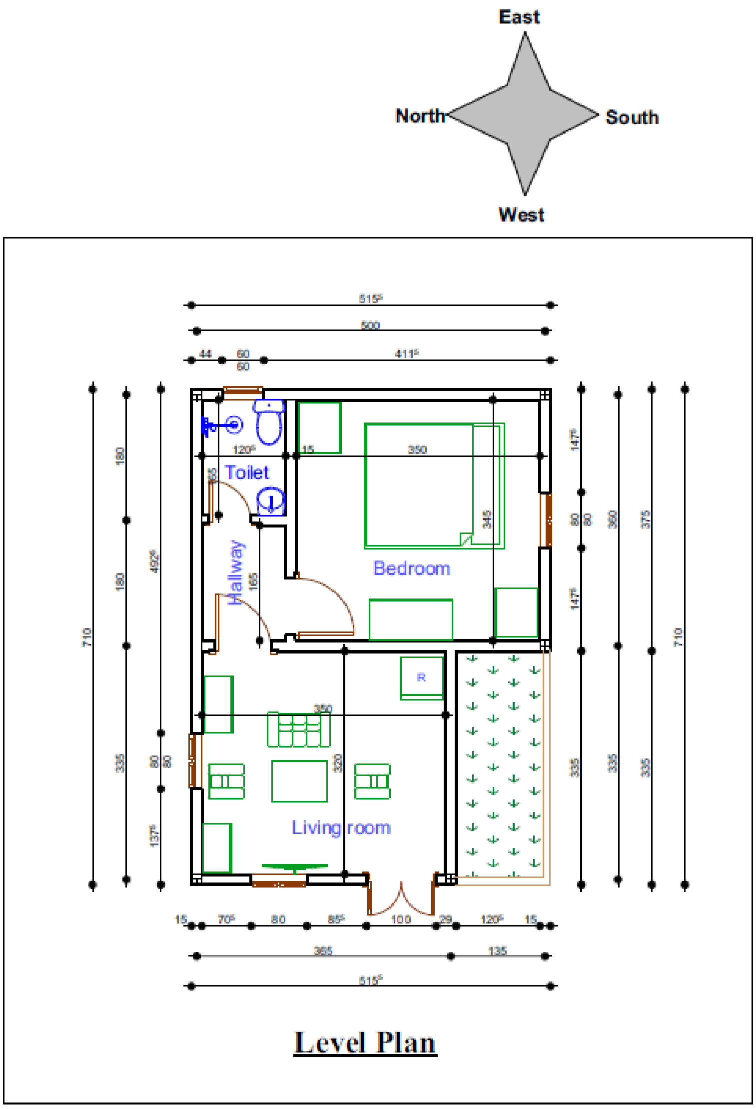

Fig. 1 Plan of the typical F2 building.

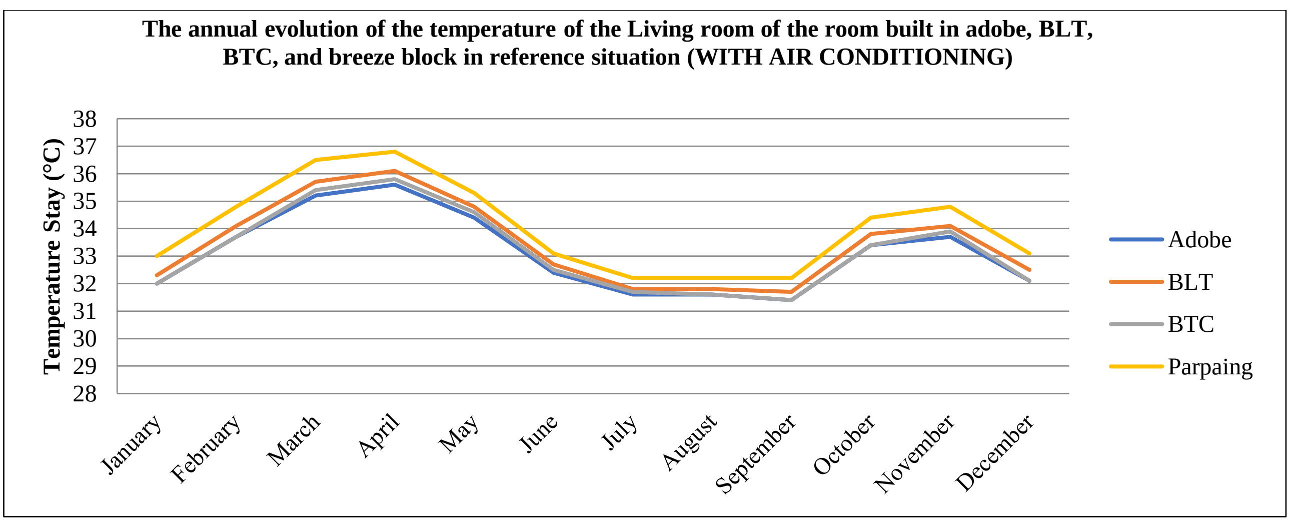

Fig. 2 Temperature curve for the living room for the reference building with air conditioning.

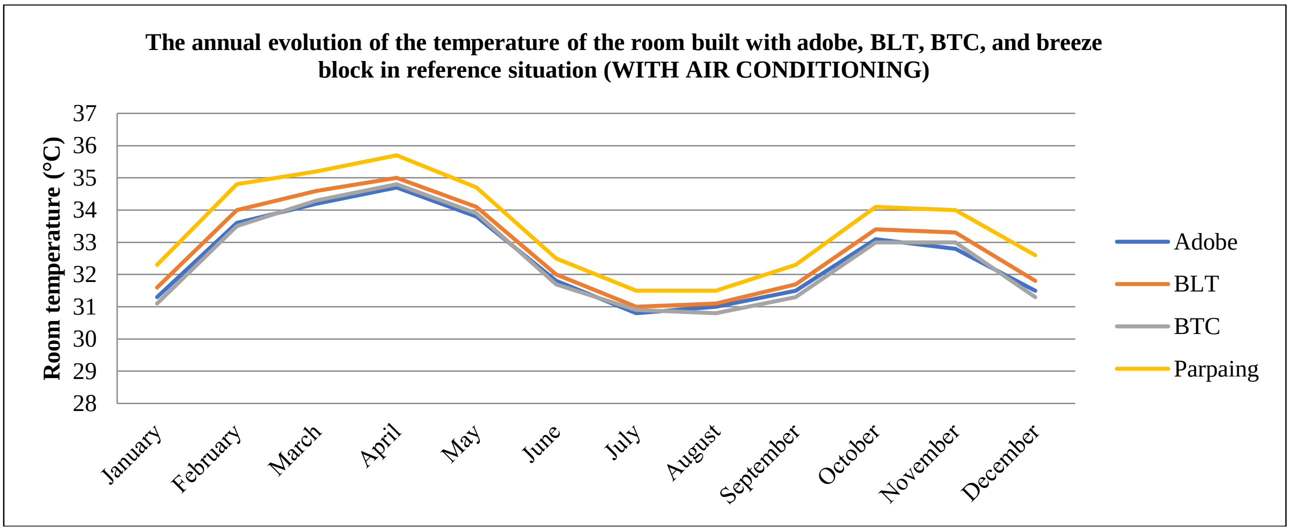

Fig. 3 Temperature curve for the room for the building with air conditioning.

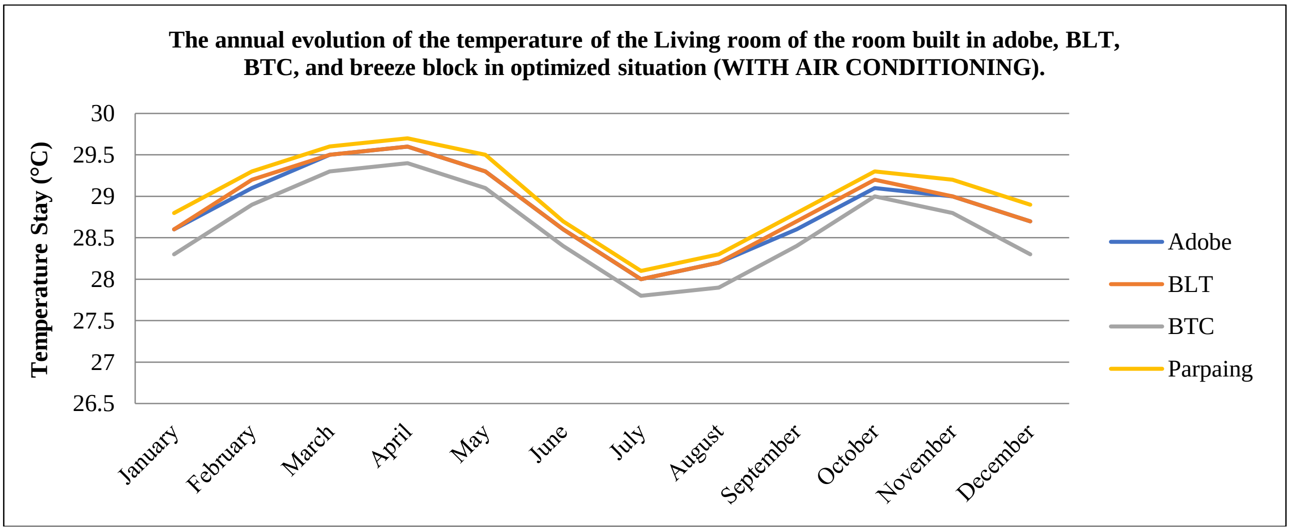

Fig. 4 Temperature curve for the living room for the building in optimized situation.

are 0.90°C, 0.70°C and 1°C respectively. This can be explained by the fact that BTC, BLT and Adobe have the ability to absorb sudden fluctuations in temperature.

Figs. 4 and 5 show respectively the temperature variations of the living room and the bedroom of the building with air-conditioning in an optimised situation of the same four (4) material type.

The temperature trends in Fig. 4 are identical. A considerable drop in temperature for the different materials is observed. The maximum temperature of the room in BLT, in cinder block, in BTC and adobe being respectively of: 36.10°C; 36.80°C; 35.80°C and 35.60°C in the reference situation went respectively to: 29.60°C; 29.70°C; 29.40°C and 29.60°C in optimized situation. However, we obtain a gain of temperature going from 7.10°C for the breeze block, 6°C for the adobe, 6.50°C for the BLT and 6.40°C for the BTC.

The graphs in Fig.5 show that the temperature evolution is identical. A considerable drop in temperature for the different materials is observed. The maximum temperature of the room in BLT, breeze block, BTC and adobe being respectively of: 35°C; 35.70°C; 34.80°C and 34.70°C in April reference situation has decreased respectively to: 29.60°C; 29.70°C; 29.40°C and 29.60°C. However, a gain of temperature is then

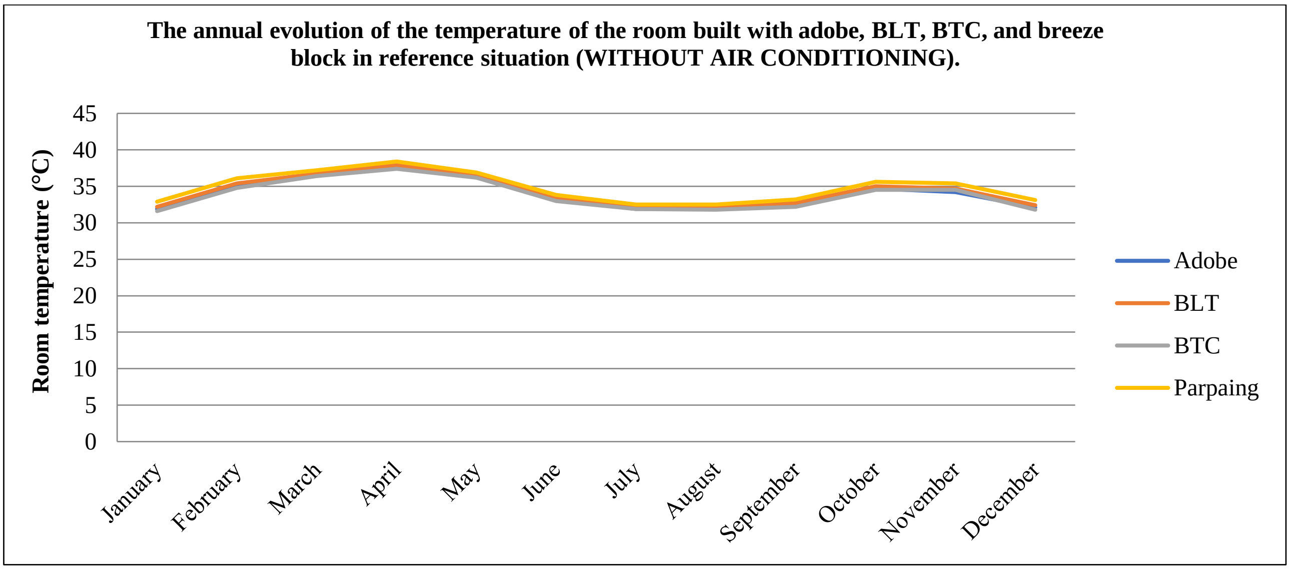

Fig. 5 Temperature curve for the room for the building in optimized situation.

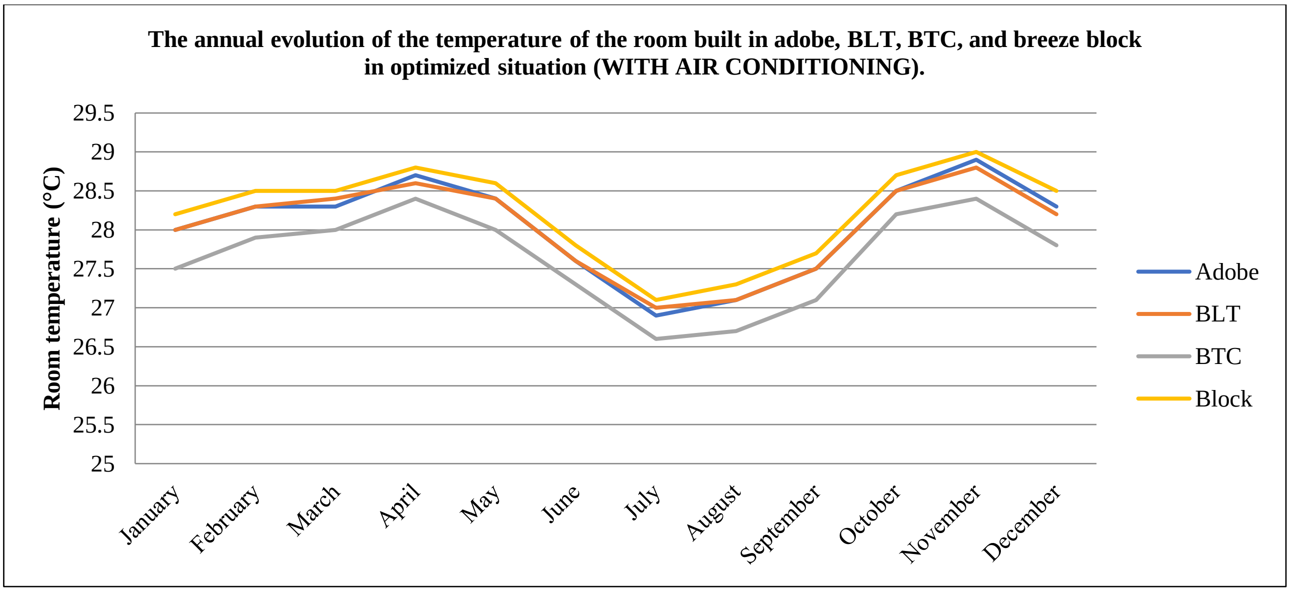

Fig. 6 Temperature curve for the living room for the building in reference situation.

recorded between the situation of reference and that optimized going thus of 6.90°C for the breeze block, 6°C for the adobe, 6.40°C for the BLT and 6.40°C for the BTC.

The maximum temperature is observed in November.

Figs. 6 and 7 present respectively the variations of the living and room temperatures of the building without air conditioning in the reference situation of four (4) types of materials.

The graphs of Fig. 6 show us that the evolutions of the temperatures are identical and a little confused. The maximum temperatures of the room in BLT, in breeze block, in BTC and adobe are respectively: 39.70°C; 40.20°C; 39.20°C and 39.50°C. We note that BLT, BTC and adobe are respectively 0.50°C, 0.70°C and 1°C lower than cinder block.

The graphs of Fig.7 show us that the evolutions of the temperatures are identical and a little confused. The maximum temperatures of the room in BLT, in cinder

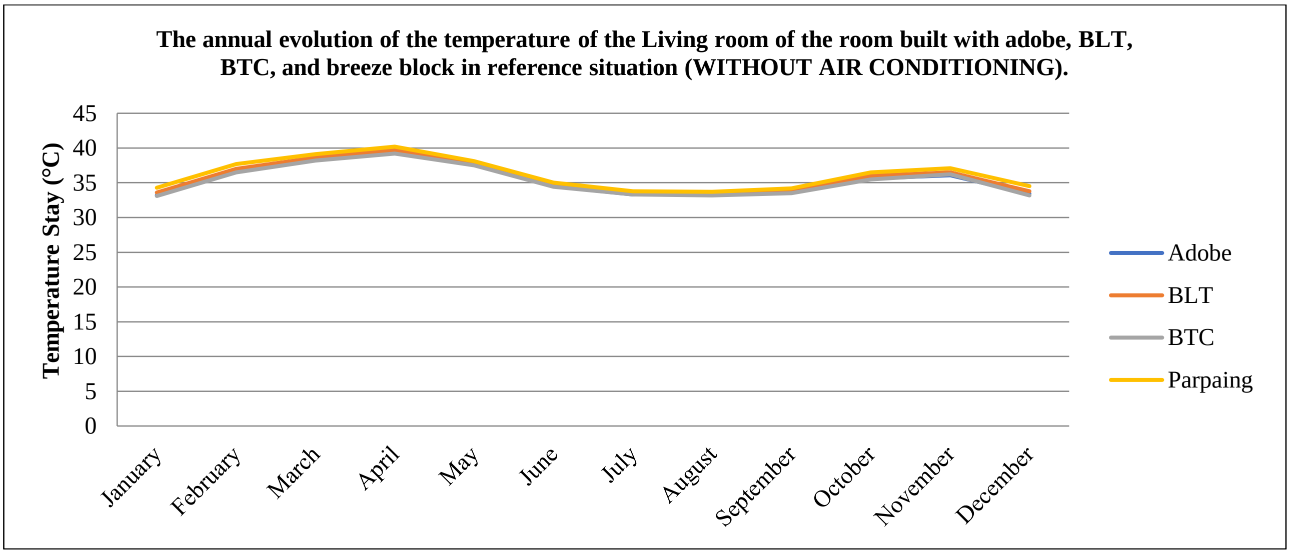

Fig. 7 Temperature curve for the room for the building in reference situation.

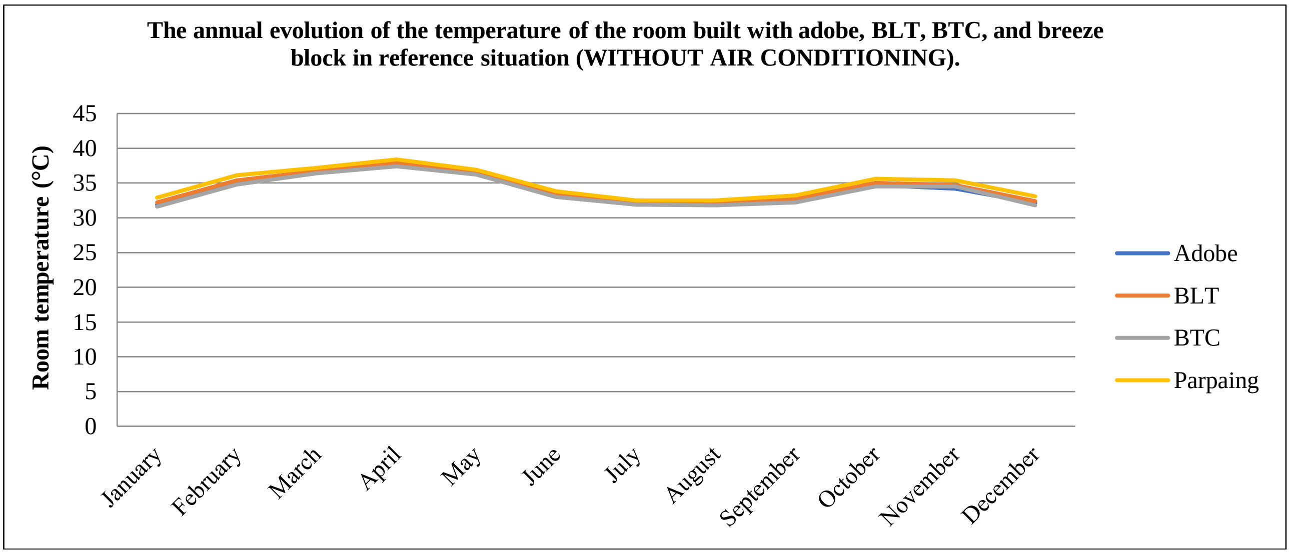

Fig.8 Temperature curve for the living room for the building in optimizedsituation.

block, in BTC and adobe are respectively of: 37.90°C; 38.40°C; 37.40°C and 37.70°C. We note that BLT, BTC and adobe are respectively 0.50°C, 1°C and 0.70°C lower than cinder block.

Figs. 8 and 9 show respectively the variations of the living and room temperatures of the building without air conditioning in an optimised situation of four (4) types of materials.

The patterns of temperature evolution are identical and somewhat confounded in Fig.8. A considerable decrease of the temperature for the different materials is noted. The maximum temperatures of the room in BLT, in cinder block, in BTC and adobe being respectively of: 39.70°C; 40.20°C; 39.20°C and 39.50°C in the reference situation goes respectively to: 34°C; 34.30°C; 33.30°C and 33.90°C in the optimized reference situation. A gain of temperature is then recorded going from 5.90°C for the breeze block, 5.60°C for the adobe, 5.70°C for the BLT and 5.90°C for the BTC.

The graphs in Fig.9 show us that the evolution of the temperatures is identical and a little confused. A considerable decrease of the temperature for the different materials is noted. The temperature of the room in BLT, in cinder block, in BTC and adobe being

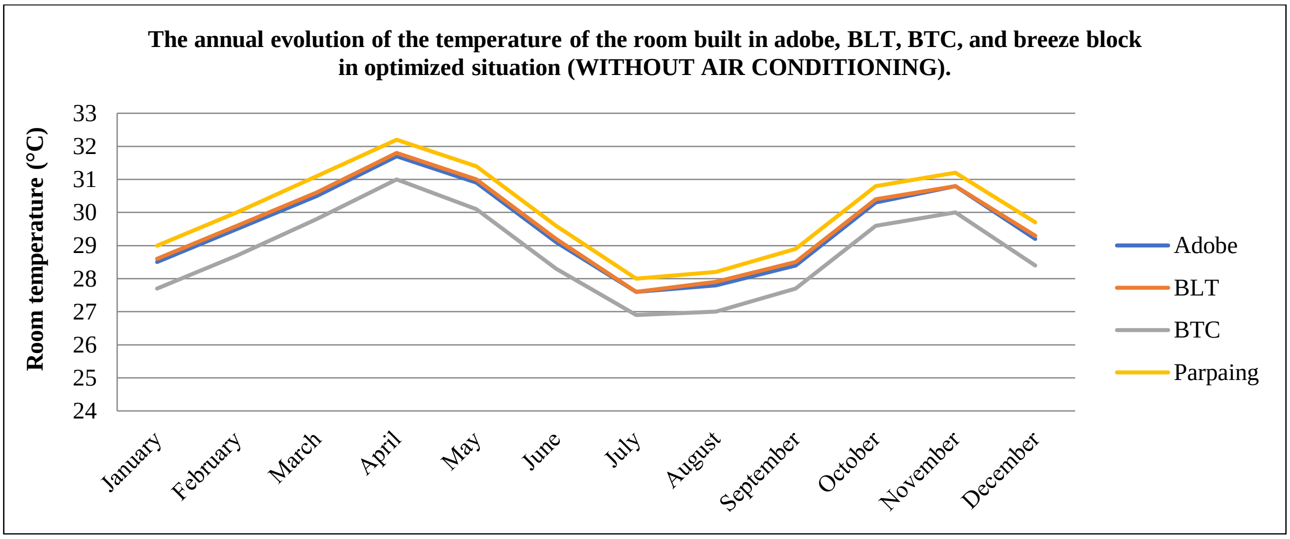

Fig. 9 Temperature curve for the chamber for the building in optimized situation.

respectively of: 37.90°C; 38.40°C; 37.40°C and 37.70°C in the reference situation in April goes respectively to: 31.80°C; 32.20°C; 31°C and 31.70°C in optimized situation. A gain of temperature is then recorded going thus from 6.20°C for the breeze block, 6°C for the adobe, 6.10°C for the BLT and 6.40°C for the BTC.

The maximum temperature is recorded in November.

3.2 Sensitive Loads, Latent Loads and Total Cooling Loads

Figs.10-12 compare the sensible loads, as well as the total air conditioning loads of the building in the reference situation and in the optimized situation.

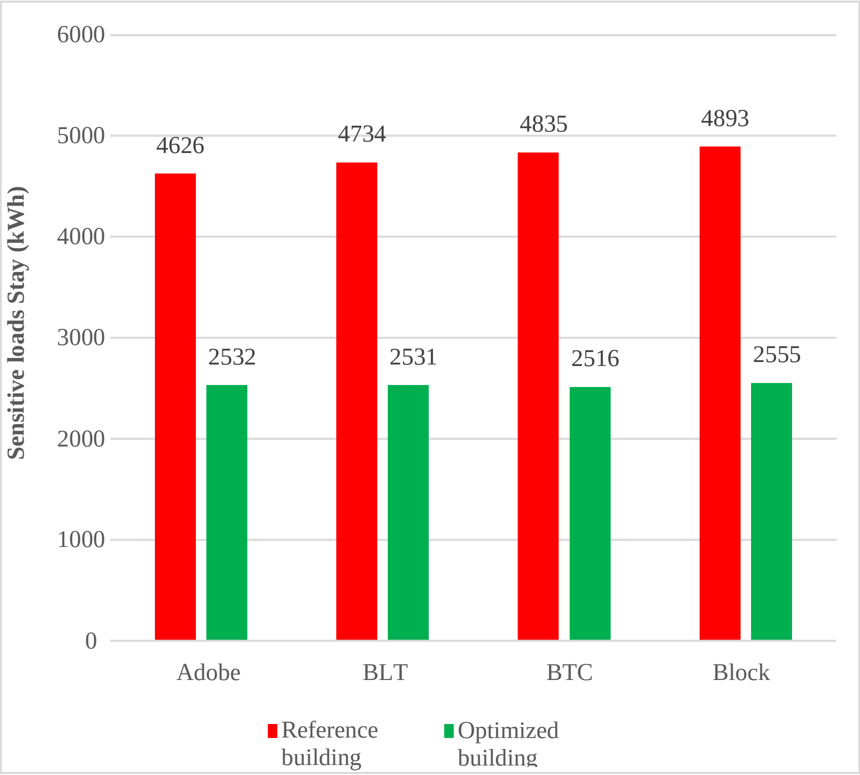

Fig. 10 Sensitive loads stay.

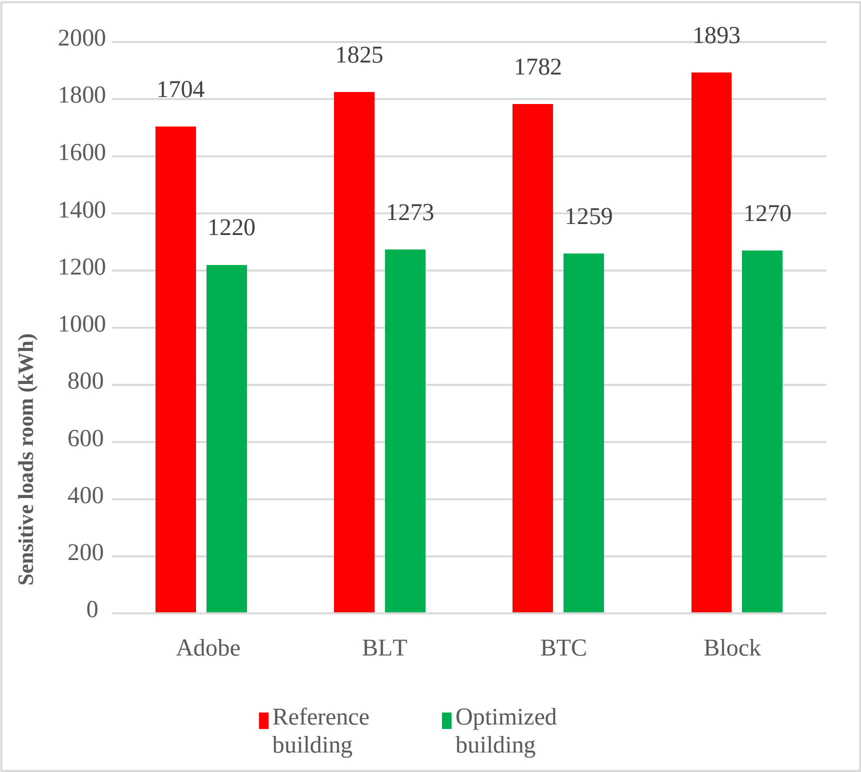

Fig. 11 Sensitive loads room.

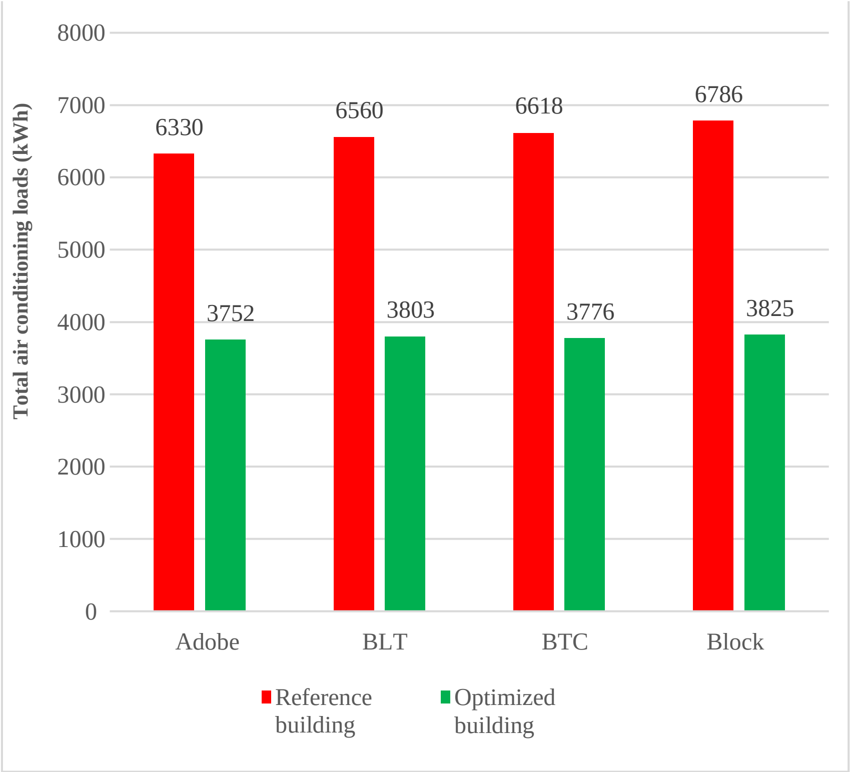

Fig. 12 Air conditioning loads.

Fig. 10 shows the sensitive loads of the living room. We notice a considerable variation in the sensitive loads between the reference and the optimized building. The sensitive loads of the reference building are much higher than those of the optimized building.

The difference in sensitive loads between the building in the reference situation and in the optimized situation is: 2,094 kWh or 45.26% for adobe; 2,203 kWh or 46.53% for BLT; 2,319 kWh or 52.04% for BTC; 2,338 kWh or 52.21% for cinder block.

Fig. 11 shows the sensitive loads of the chamber. We can see that the sensitive loads of the reference building are much higher than those of the optimized building.

The difference in sensitive loads between the building in the reference situation and in the optimized situation is: 484 kWh or 28.40% for adobe; 552 kWh or 30.25% for BLT; 523 kWh or 70.65% for BTC; 623 kWh or 67.09% for cinder block.

Fig. 12 shows us that the total air conditioning loads in the reference situation are much higher than those in the optimized situation.

The difference in air conditioning loads between the building in the reference situation and in the optimized situation is: 2,578 kWh or 40.73% for adobe; 2,757 kWh or 42.03% for BLT; 2,842 kWh or 57.06% for BTC; 2,961 kWh or 56.37% for cinder block.

4. Conclusion

This study compared the thermal comfort of four (4) types of materials in the construction of a building. The modeling and simulation of the building under the KoZiBu software with the meteorological data relative to the city of Ouagadougou made it possible on the one hand, to characterize the interior atmosphere of the building (in reference situation, in optimized situation which presenting a saving of energy); and on the other hand, to study the influence of the various materials on the loads of air-conditioning.

The results obtained allowed us to propose the material that can give the best comfort and the most economics in terms of energy. It emerges from this study that this material is the adobe which offers temperatures (301.40K or 28.40°C) and a good interior thermal environment compared to the BLT, BTC and the cinder block. Dwellings built with earthen materials offer a better indoor thermal environment than those built with modern construction materials, which are increasingly used in the construction of houses in Burkina Faso.

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