



Developing Double Walls System to Improve Building Energy Performances in Dry Tropical Climates

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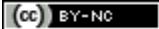
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ABSTRACT

This paper deals with building envelope thermal performance through a comparative study of the use of two types of construction materials, such as CEB and cement blocks, in order to introduce the use of double walls in sustainable buildings construction. The building envelope participates in providing thermal comfort to users and in the optimal management of building energy consumption. This study begins with a survey of public preferences for building materials used in Burkina Faso. The results indicate that 76% of the people surveyed opt for cement blocks over local materials. Concerning the thermal and specific energy performance, three variants of building envelope were studied: CEB walls, cement blocks and the double-wall (CEB + Cement blocks). It appears that the CEB walls are more efficient than the cement block walls. The introduction of double envelopes leads to the thermal resistance of 357.37m².K/W and reduces the heat flow from 85.32% to 90.24% compared to the wall made with CEB and cement blocks. This approach, which consists in mixing construction materials for good thermal insulation, allows improving the envelope thermal performance and the overall building energy performance.

Keywords: Numerical study, Building energy performances, Compressed Earth Block, Conventional Cementitious material, double walls envelope.

1. Introduction

The country development level is linked to the infrastructures (monuments, bridges, buildings, etc.) quantities and qualities and their ability to meet the population needs. In this context, the rapid growth and strong expansion of infrastructure has an environmental impact and is accompanied by increasing energy needs. The construction sector offers opportunities for action to address this energy and environmental pressure, provided that certain options are adopted in the design, construction and operation of infrastructure in general and housing in particular. Considering that one measure for more cost-effective and rational use of energy resources in individual residential buildings is the application of passive solar systems with a sunspace (Vukadinović, Radosavljević, Petrović, & Đorđević, 2019).

The building sector has great potential to improve energy-efficient and reduce the ecologic impact (Bahrar, 2018). To contribute to this, we are interested in the thermal comfort of the building which is related to several aspects, including construction materials. The mechanical, physical and thermal performances differ from constructions materials and therefore influence the building design options. Indeed, a good building envelope design contributes to reducing effectively building energy consumption and the associated CO₂ emissions (Bahrar, 2018) and the behaviour of the envelope is highly influenced by the materials used. Therefore, the management of building envelope becomes essential to carry efficient construction (GOSSARD, BONTE, LARTIGUE, & THELLIER, 2001) This study aims to identify appropriate material and propose an alternative approach of mixed material construction (local and modern materials) for more performance of building envelope. Building thermal comfort became a very important issue for development. Therefore, building techniques that reduce environmental impacts by minimizing industrial processes and using locally available materials, such as earth, are receiving a new impetus. (Ávila, Puertas, & Gallego, 2020). Indeed, nowadays we are witnessing a constructions standardization that consists in building in cement blocks with a corrugated iron roof and a non-ventilated attic and not taking into account the climate. While the former constructions taking into account the climate (use of local materials) associating a local adapted spatial organization. However, the choice of building materials is also essential to have a building with low energy consumption contributing to sustainable development.

This study's aim is to optimize the building external wall and make it more efficient from an energy and thermal comfort point of view. In the energy efficiency field, there are several approaches, each with its strategy that targets a particular aspect (Boursas & Mehri, 2012). The aim is to exploit two appropriate materials and propose a double-wall design integrating the two materials in order to reduce building heats gains.

2. Material & Method**2.1 Material Choice Survey**

Construction materials are an important link in the building sector. Their availability is crucial to the achievement of development goals and the buildings constructed cost. (Khawla, Dada, & Bassoud, 2016). To contribute to the promotion of appropriate materials, a survey was conducted in this study. Thus, the public opinions on their constructions projects were collected with the main question: Which material would you like to use for building walls construction; cement blocks, earth bricks, or cut stone blocks?

➤ **Sampling to the information collection**

The information collection was operated with survey forms filled out by a sample of 110 individuals (99 men and 11 women), engaged in different activities such as student, trader, the government employed, agricultural agent, artisan, and accountant. The data collected concerned the following elements: gender, age, occupation, material choice, and choice justification. They are more quantitative and will be entered and processed with Excel software.

➤ **Survey conduct and period**

This survey was conducted from August 1st to 10, 2017 in the three districts in Bobo-Dioulasso: Yeguere, Accar Ville and district 22. The administration of the form was done from 8:00 am to 12:00 am and 2:00 pm to 6:00 pm each day during the period of the survey.

2.2 Energy Performance Optimization Method

The study framework is described in Figure 1. The originality of this work is the introduction to housing double wall system construction in the dry tropical climate. The research work has shown that the envelope influences building overall performance and the wall assembly performance depends on each wall components specific performance (Lacasse, 2003). To do this, it will be essential to study separately each construction material thermal performance and then combine them for a building envelope wall alternative option.

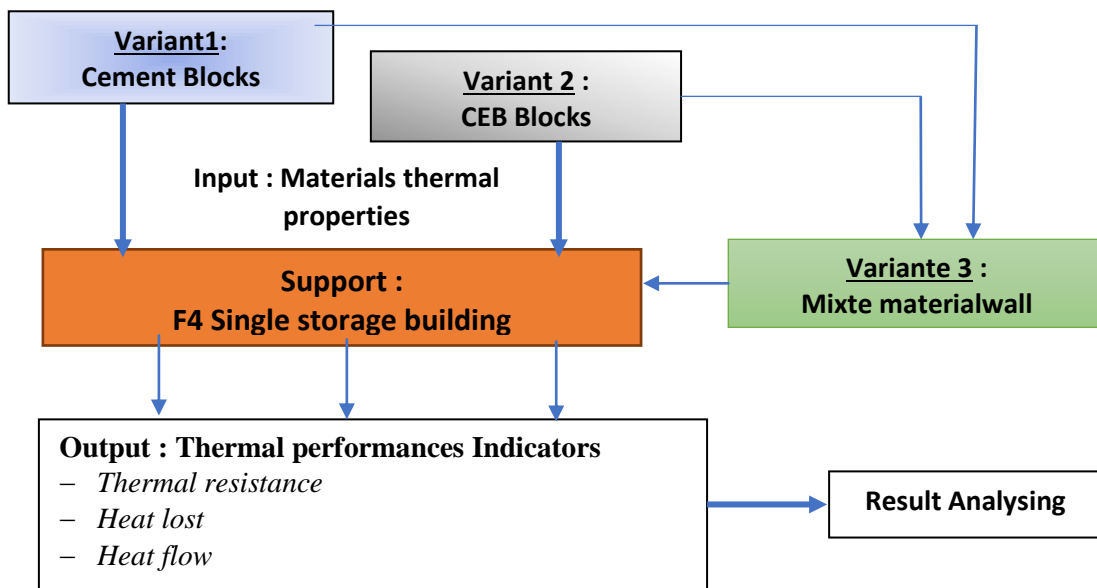


Figure 1: Study framework

2.2.1 Building Choice and Description

The building sector is considered a major energy consumer (almost half of the global consumption) and is also responsible for 25% of greenhouse gas emissions. This consumption reduction is the builder's main preoccupation who inscribe their reflection within the framework of sustainable development or of the high environmental quality (Sotehi, 2010) The the study will focus on thermal performances comparison of two types of constructions materials, the CEB and cement blocks in an F4 single storage building (Figure 2).



Figure 2: Plot and building layout

From architecture design, the building consists of a single bloc composed built on a plot of 240m² and a living area of 125.39m² divided into 9 rooms.

2.2.2 Envelope Components and Material Description

The building envelope components and constructions materials used are described in tables 1 and 2.

Table1: Envelope components and material description

N°	Building part	Variant 1: Conventional material	Variant 2: Local materials
1	Roof	Galvanized sheet 35/100	Vibrated mortar tile
2	False ceiling	Plywood thick 5mm	Plywood thick 5mm.
3	Wall	Cement blocks 15 × 20 × 40 cm.	CEB thick 20cm
4	Internal and external coating	Cement mortar thick 2.5cm	Lime plaster thick 5cm
5	Windows	aluminium single glazing thick 6mm	aluminium single glazing thick 6mm

Below Table 2 presents materials thermal and physicals properties used in this study. The control of these properties allows the precise evaluation of construction thermal comfort and energy performances.

Table 2: Constructions materials properties

Material	λ (W/m.k).	ρ (Kg/m ³)	C_p (kJ/kg.K)	Ep. (cm)
Metal sheet roof	70	7800	0.800	0.3
Plywood	0.14	600	2.72	0.5
Cement blocks	0.95	1250	0.88	15
Cement mortar	1,15	2200	1.05	5
Vibrated mortar tile	1,15	1800	0.900	1.2
CEB	1	1700	0.900	20
Lateritic earth plaster	0.900	1600	0.900	5
Lime plaster	0.87	600	0.900	1
Glazing	1	2500	750	0.6

2.2.3 Thermal Performance Calculation Principle

For building envelope thermal performance study, several physical parameters are to be considered. It is important to define suitable descriptive indicators. Indeed, criteria allowing to evaluate the energy performance are defined, like Building annual energy performance and occupants thermal comfort (GOSSARD, BONTE, LARTIGUE, & THELLIER, 2001) For this purpose, these parameters and quantities are described in the following paragraphs.

1) The thermal resistance of each material component (R_T)

The thermal resistance (RT) characterizes the material ability to slow down heat transfer by conduction. It is calculated with the following equation:

$$R_T = \frac{e}{\lambda} \quad (1)$$

With:

- R_T , in m².K/W Thermal resistance ;
- e , thickness in m
- λ , thermal conductivity in W/ (m.K).

2) Wall global thermal resistance (R_{tP})

It characterizes the sum of heat transfer by conduction within the material and surface heat exchange by convection and radiation.

$$R_{tP} = R_{si} + R_{se} + \sum(e/\lambda), \text{ in m}^2.\text{K/W} \quad (2)$$

3) Heat lost (U_p)

The thermal transmittance (UP) reflects the heat quantity escaping through a wall. It is the inverse of the overall thermal resistance. It is expressed in W/ (m².K) or in W/ (m². °c).

$$U_p = \frac{1}{R_p} \quad (3)$$

With :

- U_p , the heat lost;
- R_p , the sum of wall different layers thermal resistances, in m².K/W.

4) Heat flow (ϕ)

The Heat flow (ϕ) is the quantity of energy or heat passing through 1m^2 of the wall during one second when there is a temperature gap between its two sides. It is expressed in W/m^2 .

$$\phi = \lambda \times \frac{\Delta T}{e} \quad (4)$$

With :

- λ , thermal conductivity in $\text{W}/(\text{m}. \text{K})$. ;
- ΔT , temperature gap in $^{\circ}\text{K}$;
- e , thickness in m .

5) Glazing thermal transmittance: Ug ou K

The thermal transmittance coefficient **Ug** or **K** characterizes the heat quantities of heat escaping from glazing (g for glass/glazing) of 1m^2 for a differential of 1 degree. It is calculated according to the thermal resistances following the equation 5:

$$U_g = \frac{1}{\sum \frac{d_j}{\lambda_j} + \sum R_{s,k} + R_{se} + R_{si}} \quad (5)$$

With:

- d_j : glazing or material thickness j (excepted air or gas), in m ;
- λ_j : material layer or glass thermal conductivity, in $\text{W}/(\text{m}. \text{K})$;
- $R_{s,k}$: air gap or gas thermal resistance, in $\text{m}^2.\text{K}/\text{W}$;
- R_{si} and R_{se} : surface thermal resistance in $\text{m}^2.\text{K}/\text{W}$.

All calculations were performed using Excel software and the calculation principle is built in three steps:

- The material's performance;
- The building walls envelope performance by part of the structure;
- The building global performance.

2.2.4 Approach to Mix Local and Modern Material for Double Wall

The construction processes have evolved over the years as well as the materials used (Borderon, Cantin, & Virgone, 2008). To reduce buildings energy consumption, passive solutions have been developed by strongly increasing exterior wall insulation. One of the ways to improve the buildings energy efficiency is to design multifunctional facades that can capture locally available energy: this is the hybrid envelopes principle, capable of insulating and protecting, but also capturing, storing and transporting energy (Joussellin, Faure, Johannes, Pierson, & Quénard, 2008). To do this, the present study envisages finding with the same architectural plan a compromise between the two cases of materials for a double-wall option to offer more building thermal performance. The double-wall protects from rainwater infiltration thus improving the construction durability. The double wall water tightness is in fact ensured by a double barrier: the facing masonry and the air space between it and the thermal insulation (Règles de l'Art Grenelle Environnement 2012, 2014).

In this alternative approach, the envelope materials are described in Figures 3 and 4:

- Roof: reinforced concrete slab thick 20cm topped and protected by a metal sheet roofing;
- Double facade walls (thickness 40 cm) composed of 20 cm CEB and cement blocks of 15 cm separated by an air gap of 5 cm;
- Interior walls in cement blocks of 10cm (exclusively for the partitioning);
- Windows: double glazing thickness $2*6\text{mm}$ and separated by an air gap of 1cm.

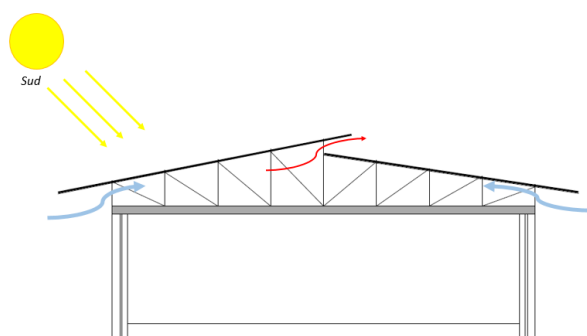


Figure 3: Roof and airflow principle (Reinforced concrete floor+Sheet metal roof)

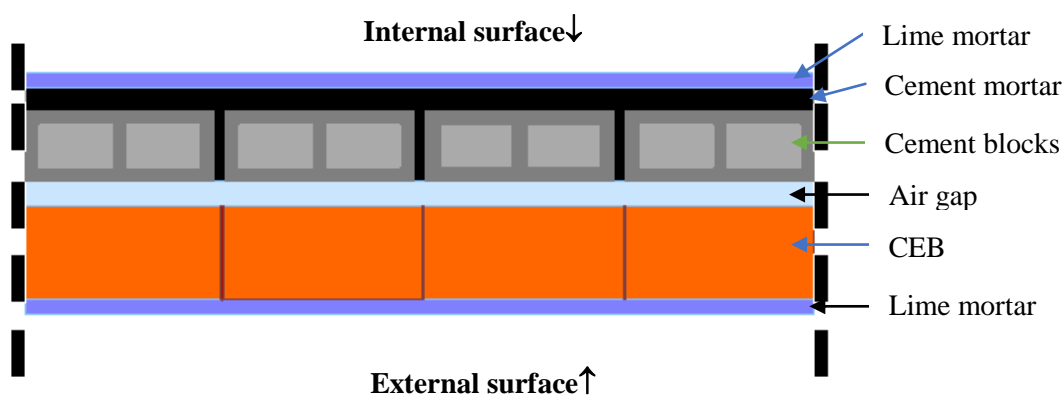


Figure 4: Description of double-wall components

3. Results

3.1 Construction Material Choice

The construction material influence in building overall performance is a reality. However, the construction material choice is a function of many factors depending on the designer and the promoter. In building material promotion, the opinion of the recipient public is not always taken into account; whereas the local population choices and preferences in terms of building materials would be an asset in the promotion of appropriate materials. Now, the new approach recommends that the building operational phase be taken into account from the design stage. The average age of the individuals surveyed is 36.53 years and the preferences of the materials are given in Figure 5.

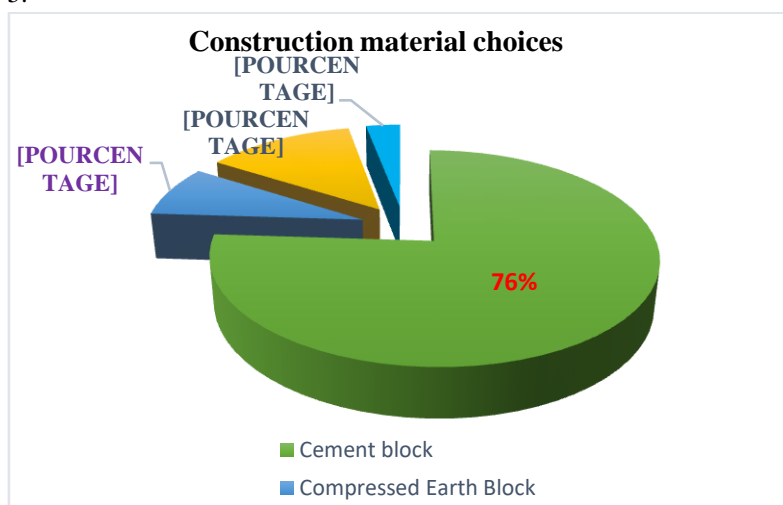


Figure 5: Construction material choice from survey

In this graph, it appears that 76% of the people surveyed opt for cement blocks. The reasons given are mainly:

- Durability and quality;
- The availability of cement and the speed in construction;
- Mastered technology and an abundance of qualified technicians;
- The modernity;
- The fear of building with another material than cement block;
- A guarantee that the house-made with cement blocks will not be maintained.

The percentage of people who opted for Cut Laterite Blocks (CLB) and Compressed Earth Bricks (CEB) are respectively 13% and 8%. The reasons given are the same and concern the economy in the construction, the quality, the aesthetics, the thermal comfort and the adaptation to the climate. However, 3% refer to designer advice.

3.2 Material Thermal Performance

Table 3 below shows modern and local building materials thermal performance in the building envelope different components studied. These results are given per unit area (m²) of each component.

Table 3: Synthesis of Thermal performances of construction materials used

Material	RT (m ² .K/W)	Up W/ (m ² .K)	(φ) W/m ²
Metal sheet	0.000043	23333.33	350000
Plywood	0.0357	28	420
Cement blocks	0.158	6.33	95
Cement mortar	0.0435	23	345
TMV	0.0104	95.833	1437.5
CEB	0.20	5	75
Lime plaster	0.0574	17.4	261
Glazing	0.006	166.67	2500

3.3 Building Envelope Component Thermal Performance

The building envelope component thermal performances are presented in Tables 4 and 5. These results take into account the layers numbers and the building of each part components.

Table 4: Summary of building envelope components thermal performances_ Variant 1

Material	RT (m ² .K/W)	S (m ²)	RT total (.K/W)	Up W/ (m ² .K)	(φ) (kW)
Metal sheet roof	0.000042	134.74	0.00576	173.40	47159
False ceiling in plywood	0.0357	108.75	3.88	0.257	45.675
Coat internal Cement blocks wall	0.245	105.965	25.95	0.039	6.491
Coat external Cement blocks wall	0.245	145.273	35.57	0.028	8.899
Glazed metal windows and doors	0.006	15.36	0.092	166.67	38.400

Table 5: Summary of building envelope components thermal performances Variant 2

Material	RT (m ² .K/W)	Surface area (m ²)	RT total (m ² .K/W)	Up W/ (m ² .K)	φ(en kW)
TMV roof	0.000042	134.74	1.40	0.711	193.689
False ceiling in plywood	0.0357	108.75	3.88	0.257	45.675
Internal wall in CEB	0.315	105.965	33.37	0.029	4.312
External wall in CEB	0.315	145.273	45.75	0.021	5.912
Glazed metal windows and doors	0.006	15.36	0.092	10.85	38.400

Table 6 presents the results of the building envelope thermals performances comparison

Table 6: Comparison of building envelope materials thermals performances

Envelope and material		RT total (m ² .K/W)	Up W/ (m ² .K)	φ (kW)
Roof	Metal sheet	0.00576	173.40	47159
	TMV	1.40	0.711	193.689
Internal wall	Cement blocks	25.95	0.039	6.492
	CEB	33.37	0.029	4.312
External wall	Cement blocks	35.57	0.028	8.900
	CEB	45.75	0.021	5.912

- Metal roofing logically has a very high heat flux compared to vibrated mortar tile (TMV), given the basic components. The ratio between the two flux quantities is about 1/200. Its thermal resistance is also low compared to the TMV. Therefore, the tile offers more thermal comfort inside the building compared to sheet metal.
- Cement block walls (φ = 6.492 kW and 8.900 kW) have higher heat flow and heat loss compared to CEB (φ = 4.312 kW and 5.912 kW) with an average difference of 2.179 kW to 2.987 kW. The heat loss coefficients are all above the limits prescribed by RT 2005 concerning vertical opaque walls in new construction: U = 0.45 W/ (m².K). All the values of thermal losses are homogeneous. The thermal loss of the cement block wall is lower than that of the CEB wall for both the partitions and the facades. The cement blocks retain less heat than the CEB. Thus the CEB has a higher thermal performance than the cement blocks (figure 6).

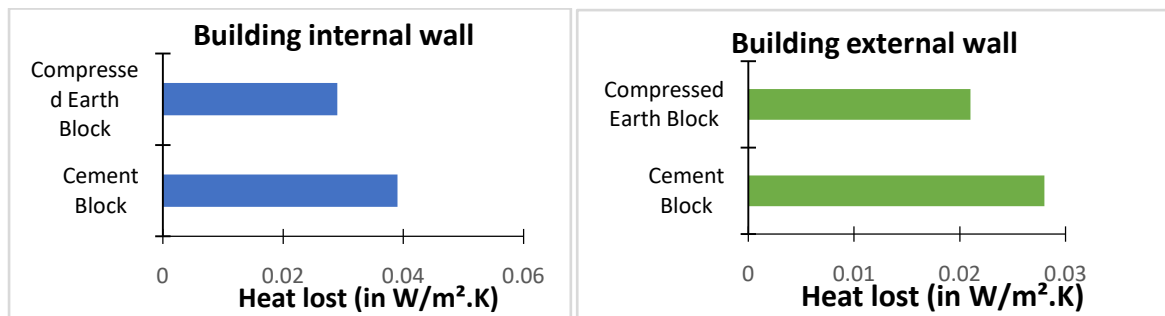


Figure 6: Heat lost coefficient U (W/ (m².K)) calculated for each type of wall

3.4 Building Global Thermal Performance

Table 7 below compares the total amount of energy (heat flow) entering the building through the envelopes (roof and walls) according to the construction materials used.

Table 7: Comparison of overall building performance by construction material used

Building	ϕ (kW) of wall	ϕ (kW) of roof	ϕ_T (kW)
Building in modern material	8.90	47159	47 167.90
Building in local material	5.912	193.70	199.600

In Table 7, it can be seen that the total amount of heat (ϕ_T) entering the modern material building is higher than that of local material building. Thus, from the thermal point of view, the building with local materials performs better than the building with modern materials. The local materials used in the basic building envelope structures allow the total heat flow to be reduced by 99.58%.

3.5 Alternative Approach Proposal

In view of the above results, an intermediate approach is envisaged by the study of double walls in mixed materials Cement blocks+CEB separated by an air gap. Table 8 presents the global results of thermal resistances, thermal losses and heat flow.

Table 8: Alternative approach envelope thermal performance

Material	RT (m ² .K/W)	Surface area (m ²)	Global RT (m ² .K/W)	Up W/(m ² .K)	ϕ (en kW)
Slab in concret	0.098	134.74	13.20	0.076	20.615
Internal walls	0.25	105.965	26.49	0.038	6.358
External walls	2.46	145.273	357.37	0.0028	0.868
Glazing	0.412	15.36	6.427	0.156	0.568

3.6 Results Comparison

The result comparison is made between the three envelope variants (double-wall, CEB, cement blocks) based on heat loss, heat flow and thermal resistance criteria. The results are summarized in below table 9.

Table 9: Thermophysical characteristics of the different envelope

Envelope and Materials	Global RT (m ² .K/W)	Up in W/ (m ² .K)	ϕ (in kW)
Exernal wall	Cement block	25.95	8.90
	CEB	45.75	5.912
	Double Wall	357.37	0.868
Glazing	Simple Glazing	0.092	38.400
	Double Glazing	6.427	0.568

4. Results Discussion

4.1 Main Results

4.1.1 Construction Materials Choice

The individuals surveyed choice and/or preference is mostly for cement blocks, which are a conventional material known as "modern". At this survey outcome, the interpretation that can be made is on two levels:

- The local materials dropping in favour of modern materials;

- The lack of consideration of certain factors related to materials such as the environmental impact and energy consumption impact in construction.

Building with cement-based materials has become a priority for many people in Burkina Faso. Indeed, according to INSD inventory in 2005, 30% to 60 % of constructions are made with cement blocks in most developed regions in Burkina Faso (Institut National de la Statistique et de la Démographie (INSD), 2005). However, this material is not specifically adapted to dry tropical or Sahelian climates and is not accessible, unlike local materials. The evaluation of air-conditioning loads to ensure thermal comfort in these habitats shows that they are higher respectively in the cement blocks, BLT, CEB, adobe constructions. We, therefore, consider that local building materials represent a good alternative for the search for buildings energy efficiency (Compaore, Ouedraogo, Guengane, Malbila, & Bathiebo, 2017) There are several reasons for this preference for modern material such as:

- The ignorance of local materials ecological qualities;
- The bias is against local materials and the modernism request;
- The lack of qualified manpower in local material technology ;
- The consideration of cement-based material as modern, more resistant and durable material.

4.1.2 Building and Materials Specifics and Global Thermal Performances

Inefficient building design, in addition, to propose less energy-consuming equipment, it is essential to control the envelope thermal exchanges (Faure, 2007) From obtained result analysis and comparison made, the following aspect appears:

- The metal sheet has a very high heat flux, compared to the tile with a total heat flux of 47159 kW while the Vibrated Mortar Tile (TMV) has a heat flux of 199.600 kW. The metal sheet is heat conductive due to its thermal conductivity of 70W/(m. K). Due to its very low thickness, it cannot oppose the temperature variations inside the building.
- Cement blocks are less efficient than CEB. In fact, cement blocks have a total heat flux of 8.90kW, while the CEB have a total heat flux of 5.912 kW. Because of its thickness (15cm) and its thermal conductivity (0.95 W/(m. K)), cement blocks alone cannot offer thermal comfort, it could be efficient if their thickness was increased.
- CEB and TMV offer more thermal and energetic performances than metal sheet and cement blocks. They are therefore appropriate for dry tropical or Sahelian climates. The earth itself does not insulate but given its properties, it is better adapted to offer to build thermal comfort in dry tropical climates. The earth becomes a very good insulator if it is mixed with plant and animal debris (straw, cow dung, rice and fonio straw...);
- The envelope thickness plays a key role in building thermal insulation. The thermal resistance is 45.75 m².K/W for the CEB (ep.=20cm) and 25.95 m².K/W for the cement block (ep.=15 cm). The more it is large, the more it opposes to the heat transfer and variations, and inversely.

4.1.3 Envelope Mixed System Development

The design of envelopes that can improve energy gains while limiting losses must contribute to reducing energy needs without affecting indoor comfort. The envelope then becomes a real heat exchanger that can be managed and adapted to the interior and exterior environments (Faure, 2007). Thus, it is possible to act on the building materials and the design. In the present study, the following aspects appear:

- The double-wall (CEB + Air Blade + cement blocks) has a lower heat loss and heat flow than cement blocks and CEB walls. With this option, the intrinsic qualities of both building materials are exploited in the same home;
- The mixed system building envelope options have respectively higher thermal performances than those in local materials and modern materials;
- Specifically, at the roof level, the slab option has a much lower heat loss and heat flow than the TMV and sheet metal options;

At these investigations completion, it is noted that this building mixed envelope approach presents a more attractive overall performance than buildings constructed with both local and modern material options.

4.2 Strengths and Limits

The results obtained in this study make it possible to appreciate the performance of the materials for an optimal choice; however, this study remains theoretical and does not take into account the occupancy and the equipment installed. Moreover, it does not integrate the dynamic variation of the site environmental conditions. A tendency, not new, but which seems to be asserting itself with more dynamism, would be to reconsider the calculation of building thermal loads by considering it in the variable regime and not in permanent as it is usually done (Huet, Castel, Amoros, & Laquerbe, 1979).

4.3 Implication on Practice and Research

This study has highlighted the quality of local building materials compared to modern materials in the search for buildings thermal performance. The introduction of the mixed wall (local material/modern material) as an approach in the construction of walls opens perspectives in the improvement of the energy performance of the building envelopes. Even if its realization is more expensive because it requires more materials and a highly qualified workforce. However, it is important to consider:

- an experimental study by instrumentation of a double wall of an existing building;
- to model the single and double walls specific thermal behaviour;
- Integrate the dynamic variation of climatic conditions in the double-wall building energy characterization.

5 Conclusion

Through the construction material survey, many people consider modern materials to be the ideal building materials in the local context. Local materials are rejected and considered to be the materials of the poor. However, modern materials are expensive and unsuitable for the dry tropical climate. Also, the implementation of local materials is delicate and requires more mastery than modern materials. On the different cases of facade walls studied, the double-wall has a heat flux of 0.868 kW while cement blocks and CEB have respectively 8.90 kW and 5.912 kW. Its thermal resistance of 357.37m².K/W is higher than that of cement blocks (25.95m².K/W) and CEB (45.75m².K/W). This approach is much better and offers more thermal and energetic performance. Even if its realization is more expensive, because it requires more materials and a highly qualified workforce, it will allow the owner to make energy savings in the long term. The thermal performance achieved by the envelopes contributes to reducing the buildings energy needs, provided that the building materials option is adapted to the climatic environment. Thus, building materials that are available and used judiciously can provide adequate thermal and building overall performance.

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Highlight

The survey of public preference of local materials over modern materials was conducted and the preference of the public was highlighted. The specific thermal performance of CEB, cement block, double wall (cement block+CEB+air gap) was characterized. This study can serve as a theoretical basis for the choice of building materials.

Nomenclature

λ	Thermal conductivity in W/m·K
a	Thermal diffusivity in m ² /s)
ρ	Density in kg/m ³
C_p	Spécific heat (kJ/kg.K)
K	Kelvin degree
°C	Celsius degree
RT	Thermal resistance en m ² .K/W ;
e	Matériau thicknessin m
Up	Heat lost W/ (m ² .K)
φ	Heat flow (in W/m ²)
Ug	Glazing thermal transmittance (in W/ (m ² .K)
ΔT	Température variation in Kelvin ;
d_j	Material layer or glass thickness (except air or gas), in m ;
Ep.	Thickness
$R_{s,k}$	Air gap or gas thermal résistance, in m ² .K/W
R_{si}	Wall internal surface thermal Resistance, in m ² .K/W
R_{se}	Wall internal surface thermal Resistance, in m ² .K/W

BA	Concrete
CEB	Compressed Earth Block
BLT	Cut lateritic blocks
INSD	National Institute of Statistics and Development
RT	Thermal Standards
TMV	Vibrated Mortar Tile