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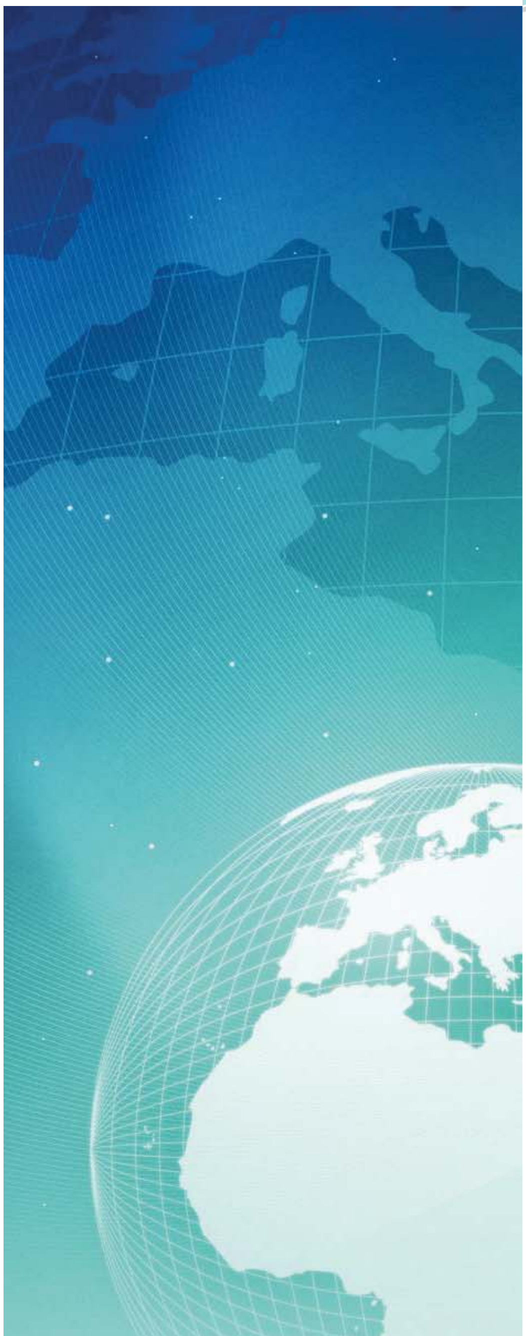

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INFLUENCES OF LOCAL MATERIALS ON THE BUILDING BEHAVIOR AND EVALUATION OF THE COOLING LOADS

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ABSTRACT

The energy demand in buildings sector is always increasing due to the climate, the economic growth, and also the need for thermal comfort. The aim of this paper is to find a way that can significantly reduce the energy demand for a building through an improvement of the design of its thermal envelope. Within this work, we utilized the thermophysical properties of four building materials: three local materials (compressed earth block (BTC), lateritic block (BLT), and raw earth), and one modern (Hollow cement). The numerical optimization of the building design has been performed dynamically by Comsol 5.3a software: the case study is Ouagadougou and the surface is 100m^2. Also, the temporal variations in the inside of the room, as well as the internal and external temperatures of the walls and the ceiling with four different materials, have been determined. The result of the simulation shows that, for BLT, the maximum of ambiante temperature is obtained 308K around 22h, for Adobe it is 308.8K around 21h, for BTC it was 309.2K at 19h30, and finally for cement block it is 310K around 17. We can safely say that BLT is the material leading to the lowest average daily indoor temperature variation, thus leading to the reduction of air conditioning load and the need for thermal comfort and around the order of 4KW of energy saving can be obtained.

RESUME

La demande énergétique dans le secteur du bâtiment est en constante augmentation en raison du climat, de la croissance économique et aussi du besoin de confort thermique. Le but de cet article est de trouver un moyen permettant reduire considérablement la demande énergétique d'un bâtiment à travers une amélioration de la conception de son enveloppe thermique. Dans ce travail, nous avons utilisé les propriétés thermophysiques de quatre matériaux de construction : trois matériaux locaux (bloc de terre comprimée (BTC), bloc latéritique (BLT) et terre brute) et un moderne (ciment creux). L'optimisation numérique de la conception du bâtiment a été réalisée de manière dynamique par le logiciel Comsol 5.3a : l'étude de cas est Ouagadougou et la surface est de 100m^2. Aussi, les variations temporelles à l'intérieur de la pièce, ainsi que les températures internes et externes des murs et du plafond avec quatre matériaux différents, ont été déterminées. Le résultat de la simulation montre que, pour BLT, la temperature maximale est obtenu vers 22h est de 308K, pour Adobe il est de 308.8K vers 21h, pour BTC il était de 309,2K à 19h, et enfin pour le parpaing de ciment il est de 310K vers 17H. Nous pouvons affirmer avec certitude que le BLT est le matériau conduisant à la variation de température intérieure quotidienne moyenne la plus faible, conduisant ainsi à la réduction de la charge de climatisation et au besoin de confort thermique et de l'ordre de 4KW d'économie d'énergie peut être obtenu.

I. INTRODUCTION

The depletion of natural resources especially fossil fuels has increased the price of energy steadily around the world [1]. Thus, the energy reserves that we have today should be conserved through efficient use in a sustainable manner to mitigate the impact on the environment and avoid energy shortages caused by the scarcity of natural resources [2]. The twenty-first century is rapidly becoming the perfect energy storm, modern society is faced with volatile energy prices and growing environmental concerns as well as energy supply and security issues. Indeed, energy is defined as the Alma and also the continuous driven power of any society wishing to develop [3]. Currently, most of the human energy consumption is based on fossil energy resources. Fossil fuels satisfy around 80% of the total energy needs, and their direct impact on the climate is alarming because they are responsible for the emissions of large amounts of greenhouse gases (GHGs) such as carbon dioxideand the depletion of the ozone layer. In response to climate change and global warming, one of the greatest threats facing the planet, it was then agreed that a lot of conventions have been set up. The objectives of all these initiatives are to reduce the CO2 emissions in the Ozone Layer [4]. Actions need to be taken especially in the building sector because it is a highlight to be significantly contributing to the increasing greenhouse gas emission in worldwide energy consumption. Knowing the importance of thermal comfort on the productivity of the human. Thermal comfort that can be achieved in both indoor environments and energy savings in warm and dry conditions has attracted recent attention. The building sector is the most energy-consuming because, the global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased, reaching around 40% worldwide and contribute for around 35% of the greenhouse gases GHG emissions (including 25% of CO_2) emissions [5] [6]. In the hottest countries such as Niger and Burkina Faso, this can be as high as as 70% [7][8]. An average, more than 50% of a building’s energy is used by the heating, ventilation, and air conditioning (HVAC) system [9] to improve this thermal comfort. Indeed, one of the biggest challenges in the construction industry around the world is to identify the development of suitable building materials that prove to be the most efficient in the long term and which will significantly reduce energy consumption. The building sector was identified as a good start in energy conservation due to it being the largest contributor in the energy consumption in Burkina Faso [10]. Indeed, the main objective of using these HVAC systems is to improve the thermal comfort in buildings. It is a real fact, and studies have shown that man spends almost all of his time, almost 90% on average according to the air quality observatory [11][12][13][5], in enclosed spaces such as buildings (amphitheaters, supermarkets, gymnasiums and swimming pools) [5][12]], and poor comfort in buildings increases the chances of sick building syndrome, such as absenteeism and cognitive degradation [14].These spaces play an essential role in the economy and society in general, but do not necessarily ensure thermal comfort and good indoor air quality [11]. Thermal comfort modeling in the building is crucial for economic performance, operation, and optimization. Thus, it is important to create a healthy and comfortable indoor space, while at the same time minimizing building energy use. Knowing the adverse environmental impacts and energy challenges facing the world in general, and in order to reduce the extensive use of energy, the building sector is positioning as a key sector to meet our national commitments on these themes. A key step towards this goal is using local materials to improve the building's indoor quality, architectural design, and renewable energies.

In Burkina Faso, this last two decades, we have witnessed multiple and intensive projects of the building that consume too much energy [13]. This high consumption in the building sector is caused, among other things, by the fact that buildings are unfortunately not subject to any energy regulations, lack of energy considerations in the design and management of buildings, lack of energy regulations in the building sector, and also there are no requirements in terms of thermal and energy efficiency [15]. This lack in the buildings sector leads to uncomfortable and energy-hungry buildings and extensive use of energy in order to improve the indoor conditions for the habitant. Our objective is to improve the thermal comfort in buildings by using local materials for energy efficiency in buildings and also the enhancement of the ecology and the protection of the environment. A building enclosure or building envelope is a passive system that has many principal requirements such as control airflow, water vapor flow, rain penetration, and light, control solar and other radiation, noise, and fire, provide strength and rigidity, be durable, be aesthetically pleasing, be economical. The valorization of local materials used in the building sector and energy performance constitute nowadays a very important field of research capital worldwide [16]. Researchers and scientists are working on energy modeling and control in order to develop strategies that will have an impact on the reduction of energy consumption in buildings.

Indeed, the objective of this study is to improve thermal comfort and the quality of the air perceived in a living cell in Burkina Faso. In order to optimize occupant comfort while preserving the environment and the climate, many parameters must be taken into account. It is in this context that we have paid special attention to the architectural construction (types of materials) of the building in order to minimize the impact of solar energy on the envelope and the ventilation air control in order to " improve human health and productivity at work. In this study, we will also assess the determination of building air conditioning loads.

II. MATERIAL AND METHODS

2.1 Climatic conditions in Ouagadougou, Burkina Faso

Burkina Faso is a Sahelian landlocked country with an area of 274,200 km^2 located in the heart of West Africa. According to the Koppen-Geiger classification of climates, Burkina Faso is characterized by a hot and dry tropical climate, with two main seasons: a dry season from mid-October to mid-March and a wet season from mid-March to mid-October [17]. Ouagadougou, the capital of the country is located at Latitude: 12°21.9396′ North and Longitude: 1°32.0328′ West. However, the country is crossed by three climatic zones.
Three distinct climatic periods can be distinguished in Ouagadougou: Hot season characterized by high temperatures from March to May, rainy season from June to October characterized by high relative humidity, and relatively colder season from November to February dominated by Harmattan of North eastern winds [18]. In the hottest months between March and May, the weather is mainly tropical in Burkina Faso, i.e., hot and dry with occasional showers or thunderstorms and creating a huge demand for air-conditioning for comfort cooling [18]. When we look at the temperature's distribution in Ouagadougou, the most frequent is between 24 and 38˚C. The hottest months are distinguished by the proportions of temperatures above 38˚C. These temperatures reach their highest levels in March, April and October, and their lowest in December, January and February. The highest and lowest levels are found in the northern part of the country giving high diurnal, monthly and annual thermal amplitudes.

2.2 Methods Procedure

For the process of reducing the extensive energy consumption in cooling service and maintaining a certain indoor comfort; we hypothesize that this can be done by improving the thermal insulation of the building and the development of appropriate materials of construction. This can be achieved by enhancing the means of additional insulation on walls, roof, combined with solutions such as the reduction of solar heat energy gains in hot season (or the increase in cold season). Thus, in the building sector, the increased use of air-conditioners, inefficient curtain walls and sliding windows, and the lack of sustainable design principles, especially in office buildings have contributed to the present energy situation [19]. In fact, several decisions and commitments are projected especially in the building sector which can significantly contribute to the increase GHG emissions in worldwide energy consumption trough the improvement of the building envelope by using local materials have been adopted in this case.

In order to attend the objectives that we set our self, we have first developed a numerical model to study the thermal behavior of a classroom oriented to the North direction in the case of study Ouagadougou. Second, the model is simulated by using the Comsol multiphysics and also the MATLAB software. The evaluation of the solar heat flow coming from the sun for each sides of the building is obtained based on Fourier equations represented by Eq.8 and calculated using MATLAB code R2018a.

$$P_i(t) = a_{0,i} + \sum_{n=1}^{4} a_{n,i} \cos(n w_i t) + b_{n,i} \cos(n w_i t) \quad \text{(Eq.8)}$$

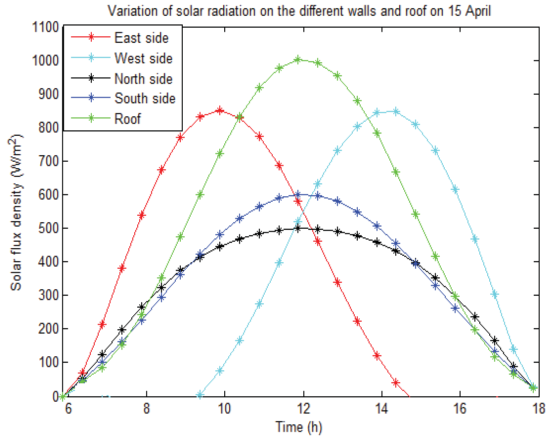

Figure 1: Evolution of solar density for each faces [13]

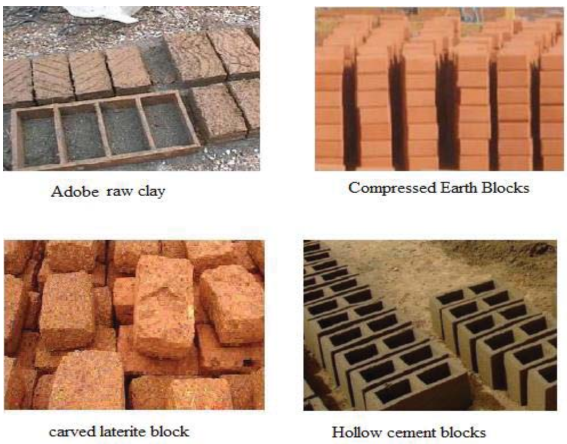

Figure 2.: Local materials used in Burkina Faso [18]

We will use four materials mostly use in our countries Niger and Burkina Faso. To simulate the program, we choose a single room like a classroom with these properties 100m^2 of surface and 400m^3 volumes. The month chosen is April because it is shown in several studies that it is the hottest month in Ouagadougou [20]. We then determine the cooling needs in each type of material and the energy that can be saved either by using this or that material.

The meshing is given by COMSOL software and we obtain the Figure 3 below.

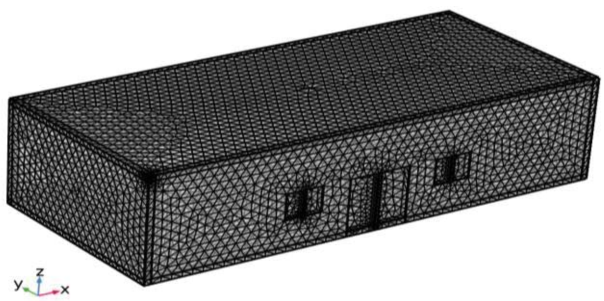

Figure 3: View of the building meshed with COMSOL.

The model chooses for the simulation is assimilated to a single room in order to simplify the complexity of the simulation. During the study procedure, we consider habitats whose walls are respectively made of the four materials previously cited such as compressed earth block, lateritic earth blocks raw earth and hollow cement block. The modeling of the cooling loads is given by taking into account the case study of the weather conditions of April and the time for the evaluation of the cooling loads is 12h(noon). The geometry selected of the local for simulation analysis is rectangular and has the followings dimensions: S=(**15*6.66**) m²; H=4m and the wall's bricks are with a thickness of 20cm [21]. The roof of the house is considered like being slab with also 20cm of thickness. In order to use simulate our building, we then need the properties of those four materials mostly use in our countries Niger and Burkina Faso. The dynamical study is already done in our previous work [13] taking into account the simplification hypothesis. The basic model of the room was built in the standard Model Builder interface of COMSOL Multiphysics 5.3a and, after the first simulation is as follow in Figure **4**

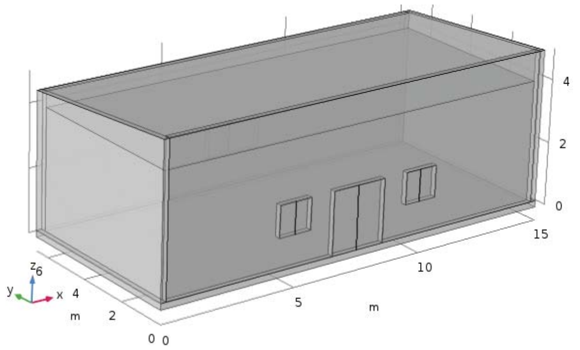

Figure 4: The model of the design of the building

The main program ability of Transient heat transfer is based on numerical solving of second order Partial Differential Equation (PDE) by finite element method (FEM). The usage of this program for similar problems, namely transient heat transfer can be found in [22]. The heat transfer is described by conduction, convection and radiation with the heat transfer module and laminar flow module of air circulation. The thermo-physical properties are considered as constant and are given in the **Table 1** below:

Table 1: Thermophysical properties of the most used local materials [15]

	λ *(W/m. K)*	ρ *(Kg. m³)*	C_p *(J/Kg. K)*
Carved lateritic block	0.655	1850	1510
Compressed earth block	0.671	1960	1492
Raw earth/ Adobe	0.556	1835	1417
Parpaing block	0.785	1250	1050

2.2. Boundaries conditions

The external conditions are taken into account by means of average temperature and the global radiation flux comes from the sun on each of its faces. We have considered some hypothesis:

- ✓ Conduction heat transfer is unidirectional;
- ✓ The air is perfectly transparent to radiation and has a uniform temperature;
- ✓ There are no domestic appliances,
- ✓ The building and the materials are assimilated to a gray body
- ✓ Take small opening that can allow air renewal.

- Heat transfer equations

The main equation of heat transfer is in the building is:

$$\nabla.q + \rho C_P u.\nabla T + \rho C_P \frac{\partial T}{\partial t} = Q \quad \text{(Eq.1) [22]}$$

Where, $q = -\lambda \nabla T$ (Eq.2)

T is the room temperature, ρ density, Cp heat capacity, u speed, t time, Q heat source. The first part of this equation refers to HT by conduction, the second to convection process and the third part to heat accumulation in the mass of specific domain.

We obtain for each of the walls, the roof and the ground an equation of the type below:

$$\rho C_P \frac{\partial T}{\partial t} + \nabla.q = Q \quad \text{(Eq.3)}$$

We make a thermal balance at all times of the volume of air in the enclosure taking into account all the flows transmitted by convection and by radiation, assuming that this volume is isothermal.

$$mC_P \frac{dT}{dt} + \int_S (n.q)\, dS = \int_V Q dV \quad \text{(Eq.4)}$$

We suppose a well-mixed fluid domain so that temperature of internal air is calculated with (Eq.4).

In the proposed model there is no internal heat production. The different heat flows on the external and internal borders:

Convective heat flux on external boundaries and boundaries related to internal air is represented by Neumann boundary condition

$$q = h_i \left(T_p - T_{\text{int}}\right) \ on\ \partial\Omega_{int} \quad \text{(Eq.5) [22] [21]}$$

Where, q means heat flux, h heat transfer coefficient (HTC), T boundary temperature and T_{inf} external temperature.

$$q = h_e \left(T_e - T_P\right) \ on\ \partial\Omega_{\text{ext}} \quad \text{(Eq.6) [23]}$$

A condition that describes heat transfer by radiation is applied on boundaries with internal air was active also second boundary equation, which describes Heat Transfer by radiation

$$q = \varepsilon\sigma\left(T_P^4 - T_{amb}^4\right) \;\; on\; \partial\Omega_{ext} \qquad \text{(Eq.7) [22][23]}$$

Where, ε means emissivity, σ Stefan Boltzmann constant, T_{amb} ambient temperature, T_p boundary temperature. These equations can easily help us to find the meshing of the model in COMSOL 5.3a Multiphysics software.

III. RESULTS AND DISCUSSION

The assessment of the heat balance is based on the estimation of the external and internal gains during the hottest month called the base month. Table 2 gives us the different base months for some sample cities in Africa [24].

Table 2: base month (hottest month) [24].

Climate zones	Countries	Reference cities	Base month
Humid tropical climate	Côte d'Ivoire	Abidjan	February
Dry tropical climate	Cameroon	Garoua	March
Desert tropical climate	Burkina Faso	Ouagadougou	April

To do this study, first, we have developed a numerical model to study the thermal behavior of a classroom oriented to the North direction in the case of study Ouagadougou. In this model, a typical base case building is selected for simulation analysis to examine the impact of the local materials on thermal comfort and energy performance. During this study, we evaluate the influence of mature of differents materials ((hollow cement blocks) and, with local building materials (BLT, BTC and raw earth) of the walls of the habitat, for the typical day of April.

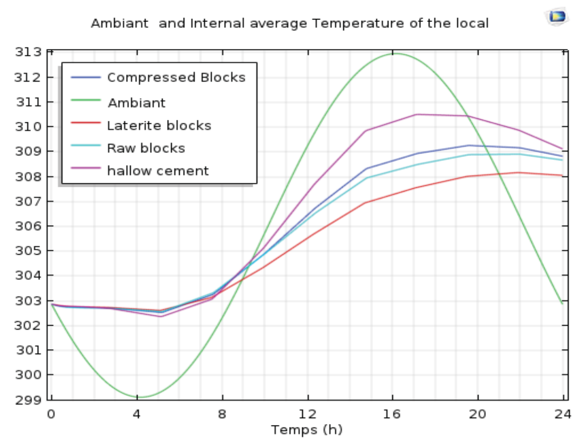

Figure 6: Internal mean temperature of each material

In the Figure 6, we can perfectly see the orders of magnitude of the internal temperature variation. The result of the simulation shows that, the maximum value of ambiente temperature is obtained around 313K at 16h. For BLT, the maximum of temperature reached is 308K(35°C) (35°C) around 22h "thermal phase shift (TPS) is around 6h", for Adobe it is 308.8K (35.8°C) around 21h "the TPS is around 5h",, for BTC it was 309.2K(36.2°C) at19h30, "the TPS is around 6h", and finally for cement block it is 310K (37°C) around 17h "the TPS is in order of 1h". The maximum value of the temperature the cement block room is 310K. Our results are similar with those obtained by [25] with the same materials by using the Fortran software and he has obtained the maximum value of the temperature reached in the cement block room is 38.5°C. They are respectively 35°C and 35.5°C, in the premises whose walls are made of raw earth and the compressed earth blocks. Our result are similar with the one done by Cédric FLAMENT [26] with BLT while he has obtained the same phase shift = 6 hours. This result can be explained by the thermal properties (density, specific heat mass, conductivity ...) of the materials. Also, the lateritic blocks and the raw earth have a high thermal inertia compared to that of the cement block. It follows that the reduction of the thermal loads of the earth constructions is greater than that of the concrete block constructions. We can therefore conclude that local construction materials such as raw earth or lateritic blocks have a higher thermal inertia than cement block. This help us to define the total cooling load and the energy saving for each material represented in the Table 3 below:

Table 3: The cooling loads and the energy concervation that can be made for each amterials

	Energy saving (KWatts)	Total of cooling loads (KWatts)
Ambient temperature	0	22,1
Hollow cement block	1,76	20,34
Compressed earth block/BTC	3,1	19
Raw earth/Adobe	3,38	18,72
Carved lateritic block/BLT	4,08	18,02

The diagram of energy saving and cooling loads is given by the **figure 7** below. We can easily see that the modern material is very energy consuming compare to the local ones. This can be explaining by the strong wall inertia of the local materials [13][21].

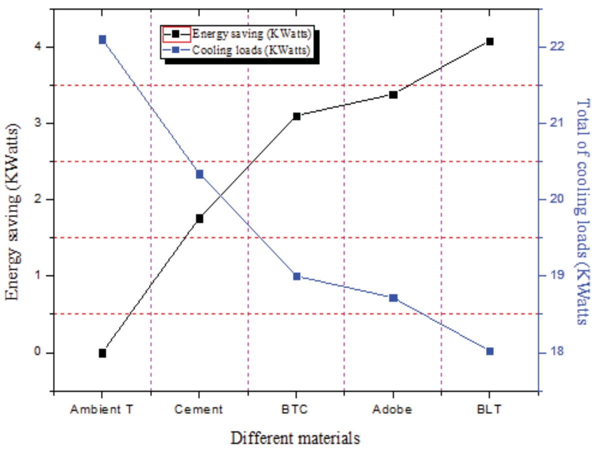

Figure 7: Cooling loads and energy saving.

This analysis of this graph in figure 7 shows that around 4kW can be saved if we constructed our building with carved lateritic where just 1.7kW is saved with the modern cement block. So that, the cooling loads are significantly higher in cement block constructions compared to local materials constructions (Adobe, BTC, BLT). The cooling load of the BTC is higher due to the fact that BTCs are mechanically stabilized with cement so that, their thermal properties, such as conductivity, increase slightly, and that is the reason why there are slightly higher air conditioning loads in BTC habitats than in other habitats (BLT and adobe). The thermal insulation in buildings does not only contribute in reducing the need of air-conditioning system size but also in reducing the annual energy cost. Moreover, it helps in extending the periods of thermal comfort without reliance on mechanical air-conditioning especially during the hot seasons.

IV. CONCLUSION

The natural use of local materials is an alternative way to reduce the energy demand in building. Thus, this paper aims to describe a passive approach to improve the thermal comfort and reduce the energy demand for an existing building through the improvement of the design of the thermal envelope. The methods used are local materials and climatic condition of Ouagadougou in April. Theses local materials are not consuming much energy because they have strong wall inertia. The study shows that among these 4 materials le BLT comes first because of the much energy saving that can be made in its room because it has strong wall inertia. Then, we conclude that, the use of local materials instead of modern one in the building design is an option for reducing the heat transfer into the room and at the same time the energy consumption. This study shows that around 4kW can be saved if we constructed our building with carved lateritic (BLT) where just 1.7kW is saved with the modern Hollow cement block. It is clear that we should turn our mind on the use of local materials to protect the environment. Based on the result of analysis we can perfectly say that the use of local materials is an alternative way to reduce the energy demand in building. Also, solar is clean and abundant. It usually occurs when cooling is needed so that, solar powered cooling systems as a green cold production technology are the best alternative.

ACKNOWLEGDMENTS

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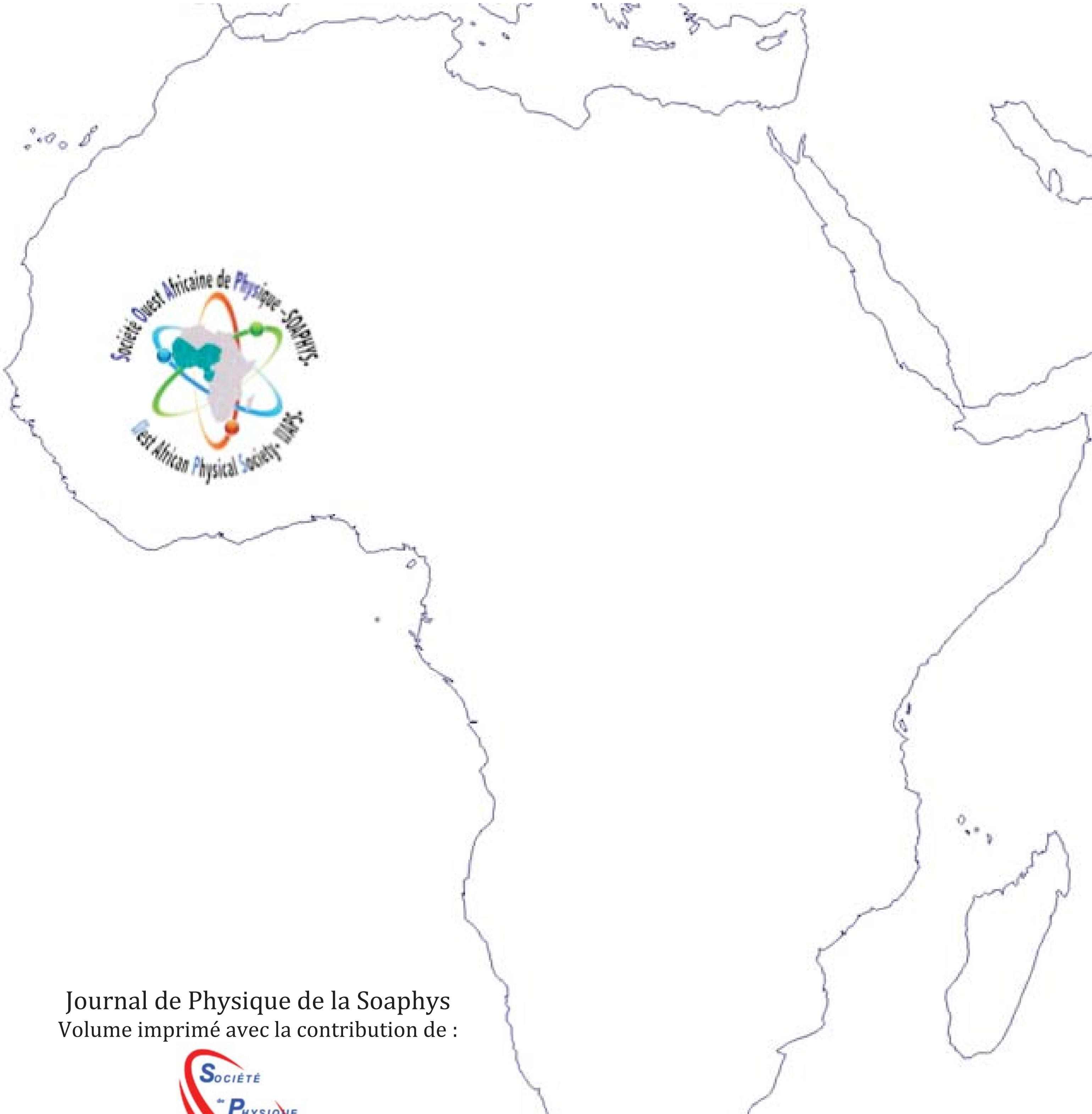

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