Two-dimensional modeling of heat transfers in a ventilated test cell built with various local materials.

_____

ABSTRACT

The lack of regulations in the thermal sector in Burkina Faso leads to the development of buildings that do not provide thermal comfort. Thermal comfort is defined as dwellers state of satisfaction with the indoor atmosphere. This study is conducted in the context of offering a material that is suitable to hot climate. During this study, a modeling and a simulation are made with the software COMSOL. The modeling is made with the building of 4m × 3m × 3m house, built successively with Cut Laterite Block (BLT), Compressed Earth Block (BTC), Hollow Concrete Blocks, and adobe. The simulation was on the evolution of the internal and external temperature of this building. Heat flows on the North and South sides were neglected given the roof over-extension. Results obtained show that the cell built with BTC reduces the temperature by 4 ° C, that built with BLT by 2 ° C and that with adobe has a temperature gain of 1.5 ° C compared to that built with concrete blocks. BTC is therefore the material that best meets the criteria.

INTRODUCTION

The first international conference on environment held in Stockholm in 1972 was the symbol of global awareness on the depletion of energy resources. The various crises experienced by systems which dependent on fossil fuels, coupled with the rise in fossil oilprice and its depletion as well as climate change call for the establishment of a global management policy to manage the planet and its ecosystem. Controlling energy consumption is becoming necessary in all the consumption sectors and notably in building industry. Building sector is one of the largest consumers of energy, nearly 40% of total global energy consumption, and a major factor of greenhouse gas releases (around 35% compared to the other sectors) ([1]).Burkina Faso is a country with a dry tropical climate characterized by high temperatures (which can reach 40° C to 45° C) for which building models require cooling systems that results in high energy consumption. The energy consumption of buildings in the public administration, notably due the use of air condition equipment (air conditioners, fans, etc.) is estimated at 30,000 MWh / year. The financial cost of this consumption is estimated atCFA F 3.4 billion/ year ([2])

Energy consumption in terms of electricity for air condition only represents 30 to 70% of the total consumption of the population ([3]). According to consumers, air condition is therefore one of the most effective alternatives for maintaining an acceptable atmosphere in buildings. This leads tooverbilling, overconsumption of energy in buildings and irregular supply of

electricity. This is partly due to the lack of thermal regulation in the building industry and the fact of not taking energy into consideration in the designing of buildings. It is therefore necessary to promote energy efficiency in buildings.

In addition, it would be advisable to offer new construction systems which promote materials that take thermal comfort into account, reduces electricity bills and CO_2 releases in the environment.

It is in the context of improving thermal comfort in a building that our study focuses on the theme: **Two-dimensional modeling of heat transfers in a ventilated test cell, built from various local materials.**
In this study, heat performances of the various local materials used for construction will be compared in order to find a typical material adapted to our climatic condition.

MATERIALS AND METHODS

1. Description of the physical method

The modeling of heat transfers in a building is very complex. Indeed, it is necessary to couple heat transfers by radiation, by convection and by conduction with mass transfers when they exist. To simplify the study, a physical model in 2D of the cell will be adopted by neglecting the releases from the lowest radiation, particularly on the Northern and Southern sides which are also supposed to receive the incident solar radiation due the roof overhangs as shown in**figure1.** The physical model of the test cell is shown in **figure 2.** It is a living cell of 3 m high and 3 m wide. The Western, Eastern walls and the roof are 10 cm thick. The terrace is 20 cm thick. The cell has two openings. A first opening of 0.1 m × 0.2 m in the wall enabling the entry of fresh air into the test cell. A second opening of 0.1 m × 0.2 m in the Western wall allows hot air to escape. Heat exchanges between the building and the external environment as well as the exchanges inside the cell are also shown in **figure 2.**
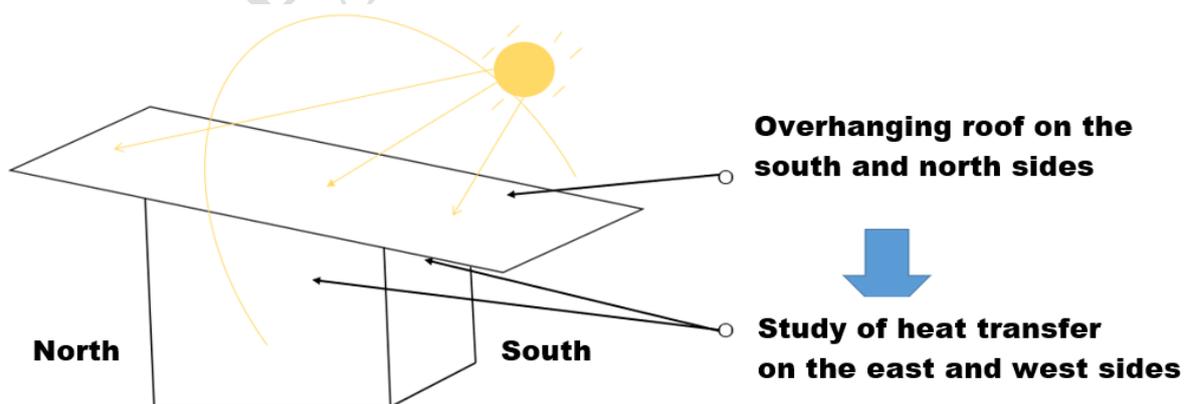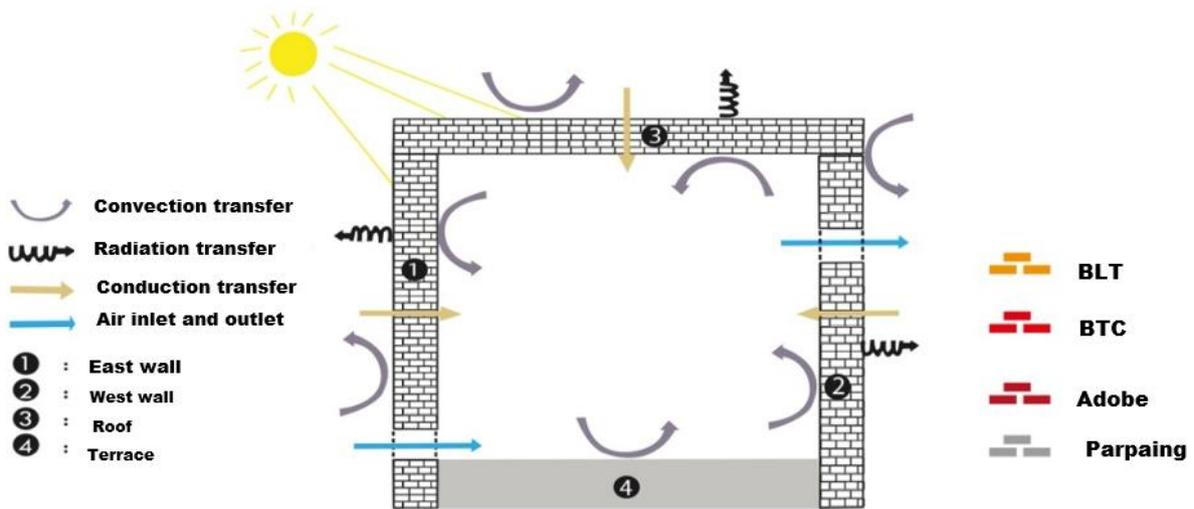

Figure 1: Perspective view

Figure 2: Geometric model showing heat exchanges

1. Materials and descriptions

The dimensions of the cell introduced with COMSOL enabled to obtain the physical model in **figure 3**. COMSOL is a simulation Software which equations are discretized by the finite element method and enables to solve any type of problem that can be described by partial differential equations ([4]). COMSOL Software provides automatic and semi-automatic 1D, 2D, and 3D meshing tools with user-controlled parameters. It has finite elements of various shapes (tetrahedral, prismatic, hexahedral or triangular, etc.) and orders (linear, quadratic, etc.). **Figure 4** shows the mesh of the model. The mesh of our field of study is triangular. It has 1661 elements and 7246 resolved degrees of freedom. The mesh area is 8.7 m^2.
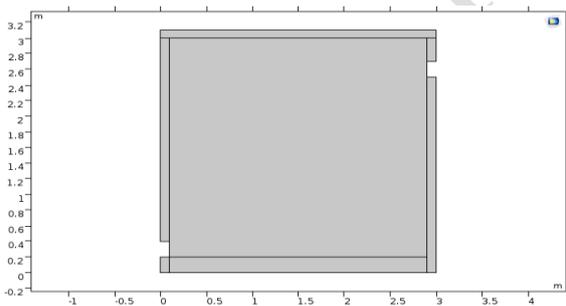

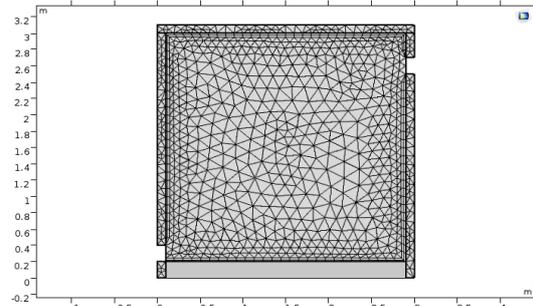**Figure 3:**Physical model conceived with COMSOL

Figure 4: Meshing of the geometric model

1. Mathematic Model of Heat and Air Transfers

The heat and air transfer equations are obtained with the COMSOL software after the definition of the physical model.

1.1. Basic equations of heat and air transfers

The equation ruling heat transfer in solids and fluids is given by:

$$\rho.C_p \frac{\partial T}{\partial t} + \rho C_p \, \text{U}.\nabla T + \nabla.\text{q} = Q + Q_{ray} \quad \textbf{(1)}$$

With: $q = -\lambda(\nabla.\nabla T)$ **(2)**; Q the term producing heat $Q_{ray} = \alpha q^{'}$ **(3)** the term showing heat transfer by radiation.

The equation showing air flow is based on Navier-Stockes' equations. Then we have:

$$\rho \frac{\partial u}{\partial t} + \rho(\text{u}.\nabla)\,\text{u} = \nabla.[-pI + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla.u)\,\text{I}] + \text{F} \quad \textbf{(4)}$$

F only exists in natural convection, where Boussinesq's approximation assumes that variations in density do not impact the flow field, except the fact that they generate buoyancy forces which are volume forces ([5]), ([6]).

1.2. Thermophysical properties and entry parameters

The thermophysical properties of the materials used are in **Table 1.**

BLT**:**Cute Laterite Block
BTC:Compressed Earth Block.

For digital simulation, there are four subdomains which are the Western wall, the Eastern wall, the roof, and the indoor air. The model used is the general heat transfer model. The **table 2** gives the input parameters taken into account in the simulation**:**

Table1:Thermophysical Properties([7])([8])([9])([10])

Property / Material	Thermal conductivity (λ) (W/m K)	Volume mass (ρ) (kg/m^3)	Thermal capacity (C_p) (J/kg K)	Diffusivity (a) (m^2/s)	Effusivity E (J/m^2 K s$^{-0,5}$)
Concrete	1,800	2300	880	$8,9.10^{-7}$	1908
Concrete blocks	0,670	1250	880	$6,7.10^{-7}$	858
BLT	0,469	1853	928	$2,7.10^{-7}$	898
BTC	0,671	1960	1492	$2,3.10^{-7}$	1401
Adobe	0,450	1394	1213	$2,7.10^{-7}$	872

Table2:Input Parameters

Parameters	Values

Wall height (m)	3
Wall thickness (m)	0.1
Roof thickness (m)	0.1
Roof length (m)	3
Terrace thickness (m)	0.2
Terrace length (m)	2.8
Input air speed (m/s)	0.294
Input air pressure (Pa)	0 Pa
Convection coefficient of the external side of the Eastern wall (W/m^{2}K)	16.16
Convection coefficient of the internal side of the Eastern wall (W/m^{2}K)	4
Convection coefficient of the external sideof the Western wall (W/m^{2}K)	16.16
Convection coefficient of the internal sideof the Western wall (W/m^{2}K)	4
Convection coefficient of the external sideof the roof (W/m^{2}K)	16.16
Convection coefficient of the internal sideof the roof (W/m^{2}K)	4
Convection coefficient of the internal sideof the floor(W/m^{2}K)	2

RESULTS AND DISCUSSION

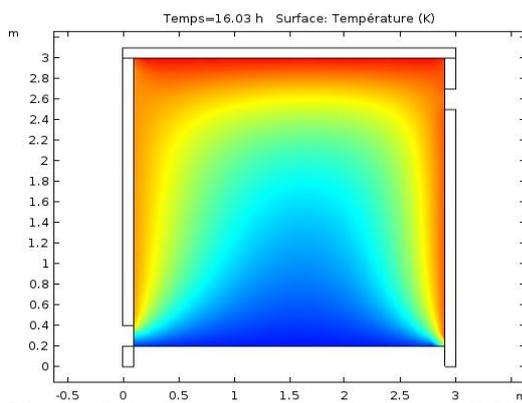### 1. Evolution of temperature, speed and pressure: case of the cell built in BLT
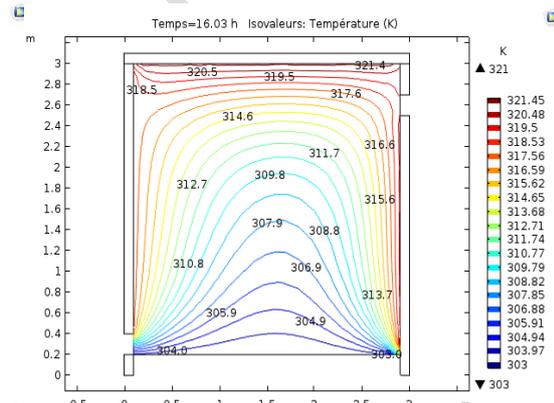

Figure 5: Surface temperature of the cell **Figure 6:** Presentation of the profile of the cell temperature iso-values
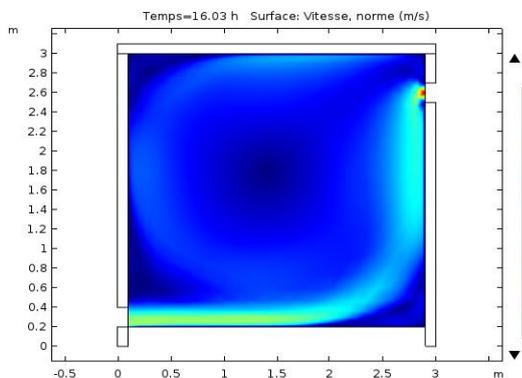

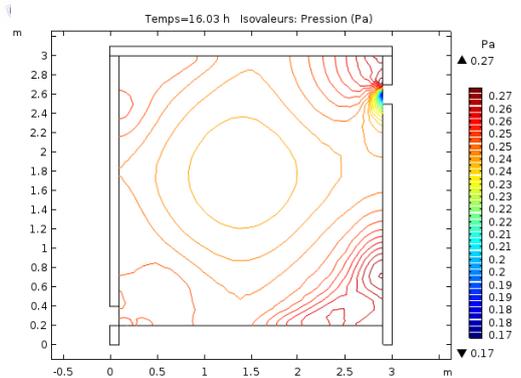
Figure 7: Evolution of the air speed in the cell**Figure 8:**Pressure iso-values in the cell

1.1. Surface temperature

These surfaces enable to determine the temperatures at any point in the cell. They are shown in Figures 5 and 6. High temperature values are recorded near the internal sidesof the walls and the roof. Temperature distribution in the center and towards the floor of the cell shows that the temperature is lower in this part of the cell. High temperatures recorded on the internal surfaces are dueto the solar radiation received by the walls and the roof during daytime. The walls and the roof will then release heat by conduction contributing therefore to their heating. The heat is then transferred to the cell by convection heating the cell. Low temperatures recorded in the center and at a low height are due to the air flow through the openings.

1.2. Temperature iso-values

Isothermal curves or temperature iso-values are distinguished by their colors and are
shown in figure 6. Isothermal curves are very dense near the internal sides of the walls and the roof. This means that high temperature fluctuations are recorded around the internal walls. In the center of the cell and for low heights, the isothermal lines are less dense and much disparate. Temperatures at this level of the cell are lower and vary very little.

1.3. Speed surfaces

Figure 7 shows the evolution of the air speed inside the cell within a day. The air flow speed inside the room near the openings is high and remains low within the rest of the cell. Speed has little impact on internal temperature. Convection due to air flow is then very weak. The high velocity values observed at the opening which constitutes the exit of the air are due to the low air pressure values recorded in this opening.

1.4. Pressure iso-values

Figure 9 shows the pressure field in the cell. Pressure lines have almost the same colors, therefore nearly the same value except in the exit. There is a slight variation of pressure.

2. Comparative study of temperature evolution in the cell built in BLT, BTC, concrete blocks and in adobe.
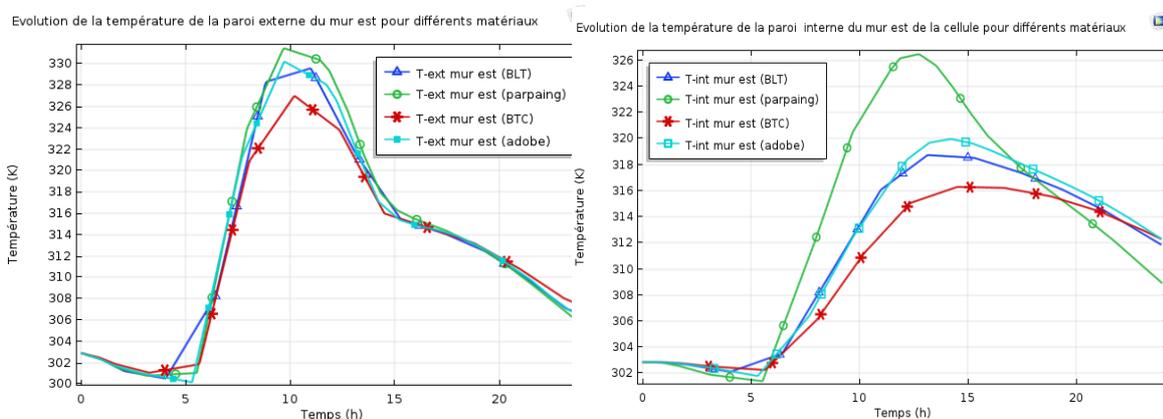

Figure 9. Evolution of temperature in the **Figure 10.** Evolution of the external temperature external side of the Eastern wall in BLT, in BTC, of the internal wall of the Eastern Wall BLT, in concrete

blocks and in adobein BTC, in concrete blocks and in adobe
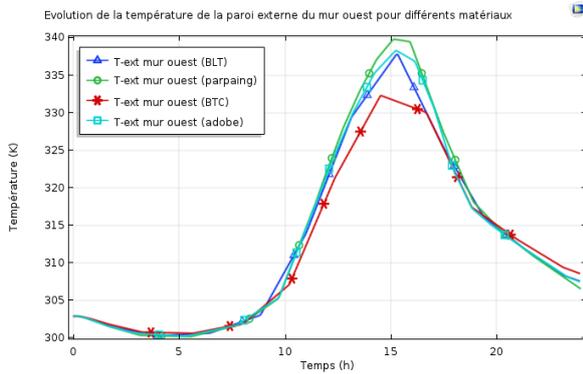
Figure 11: Evolution of temperature of **Figure 12:** Evolution of temperature of the external side of the Western wall in BLT, internal wall of the Western in BTC in BLT, in concrete block and in adobe in BTC, in concrete blocks and in adobe
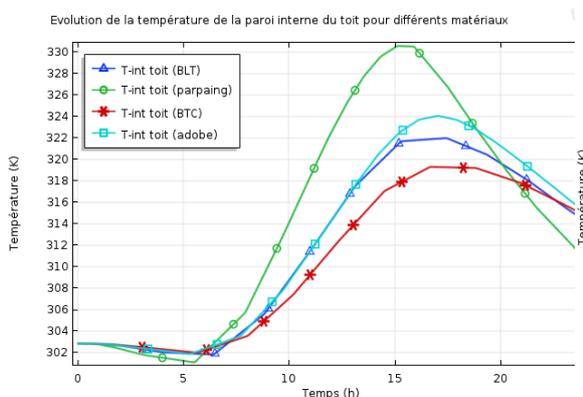
Figure 13: Evolution of temperature of **Figure 14:** Evolution of the external temperature the roof wall in BLT, in BTC, in of the internal wall of the roof in BLT, in BLC, Concrete blocks and in adobe in concrete blocks and in adobe
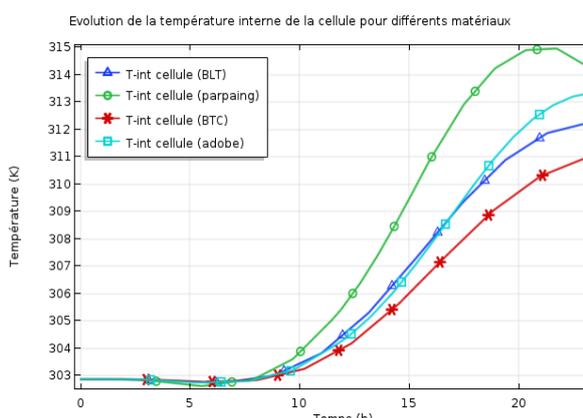
Figure 15. Evolution of the internal temperature of the cell

2.1. Evolution of the temperature of the external side of the Western wall

Figure 9 shows the temperature evolution of the external surface of the Eastern wall of the cell built in BLT, BTC, concrete blocks and adobe. It shows that the temperature trends of the external side of the Eastern wall are the same. Maximum temperature for BLT, concrete blocks, BTC and adobe wall are

329 K or 56 °C; 332 K or 59 °C; 327 K or 54 °C and 330 K or 57 °C, respectively. Maximum temperatures are reached between 9 a.m. and 11 a.m. This period is when the Eastern wall is most exposed to the sun. It should be noted that BLT, BTC and adobe have 3°C, 5 °C and 2 °C, respectively lower than concrete blocks. Temperature differences are not very high but BTC and BLT have larger differences. This means that the effusivity of these materials is higher than that of concrete blocks. Indeed, the effusivity of the concrete blocks is low (858 J / $m^2s^{-0.5}$) contributing to quickly heat its surface unlike BTC, BLT and adobe which respectively have the following effusivities: 1400 J / $m^2s^{-0.5}$; 898 J / $m^2s^{-0.5}$; 872 J / $m^2s^{-0.5}$ which surface get heated less quickly.

2.2. Evolution of the temperature of the internal side of the Eastern wall

Figure 10 shows temperature evolution of the internal surface of the Eastern wall of the cell built with BLT, BTC, concrete block and adobe. The evolutions of temperature of the internal side of the Eastern wall are the same. A decrease in the temperature of the internal wall for the various materials is noticed all the night long. In the daytime, the temperature of the internal surfaces increases from 6 a.m. to 11 a.m. and decreases from 11 a.m. to 6 p.m. At night, the internal temperature decreases considerably. The maximum temperature for BLT, concrete blocks, BTC and adobe wall are 319 K or 46 °C; 326.5 K or 53.5 °C; 316 K or 43 °C and 320 K or 47 °C, respectively. The temperature difference of the internal surfaces of the Eastern wall in concrete block and the Eastern wall in BTC, BLT and adobe are 7.5 °C, 10.5 °C and 6.5 °C, respectively. A temperature gain is then recorded for BLT, BTC and adobe compared to the concrete blocks and are 7.5 °C; 10.5 °C and 6.5 °C, respectively. The best gain is recorded with BTC. It should be noted that the temperature of the internal side of the Eastern wallin concrete blockshighly increases between 6 a.m. and 11 a.m. and decreases suddenly until 24 hours when the value is 307 K or 34 °C. Heat transfer by radiation and by conduction through materials causes an increase in the temperature of the internal side of the Eastern wall for all the materials. In the second half of the day, the Eastern wall no longer receives sunlight, which leads to the decrease in temperature for all the materials. At night, the heat stored during the day is discharged by conduction outside; therefore, the temperature at night decreases. The high temperature gaps between concrete blocks and the other materials are dueto the fact that BTC, BLT and adobe have this capacity to absorb sudden temperature fluctuations. These materials then have a high thermal inertia compared to the concrete blocks.

2.3. Evolution of the temperature of the external side of the Western wall

The change in the temperature of the external side of the Western wall of the cell built in BLT, BTC, concrete blocks and adobe is shown in Figure 11. The curves have the same appearance and vary during the day. The temperatures of the external wall for the various materials decrease all the night long. At daytime, the temperature of the external side increases from 9 a.m. to 3 p.m. and falls from 3 p.m. to 6 p.m. contrary to the temperatures of the external side of the Eastern wall which rises as from 5 a.m. The curves reach their peaks at around 3 p.m. The maximum temperature values are 337.5 K or 64.5 °Cfor BLT, about 340 K or 67 °C for concrete blocks, 332 K or 59 °C for BTC, 338 K or 65°C for Adobe, respectively. The temperature gap of the external surfaces of the Western concrete blocks wall and the Eastern BLT, BTC and adobe wall are 2.5 °C, 8 °C and 2 °C, respectively. The gapsnoticed between the temperatures of the external side of the Western wall are fairly the same as those of the temperatures of the external side of the Eastern wall which are 3 °C; 5 °C and 2 °C, respectively. It should be noted that the temperature of the concrete block wall is the highest followed by that in adobe, then that in BLT and lastly that in BTC. Temperature gaps for the various materials are not very high, as the change in the external temperature of the Eastern wall. The maximum value of the surface temperature for BTC, BLT and adobe are lower than that of concrete block. Indeed, the

effusivity of BTC is higher than that of BLT, adobe and concrete blocks, leading to the external side of BTC to heat less quickly compared to other materials.

2.4. Evolution of the temperature of the external side of the Western wall

Figure 12 shows temperature evolution of the internal side of the Western wall built with various materials including BLT, concrete blocks, BTC and adobe. The evolutions of temperature of the internal side of the Western wall are the same. It should be noted a decrease in the temperature of the internal wall for the various materials throughout the night. This decrease is much higher or even brutal for the temperature of the concrete blocks wall. In daytime, the temperature of the internal side increases from 10 a.m. to 6 p.m. for BLT, BTC and adobe except the temperature of the concrete blocks which starts falling as from 4 p.m. Maximum temperatures for BLT, concrete blocks, BTC and adobe wall are 322 K or 49 °C; 332 K or 59 °C; 319 K or 46 °C and 324.5 K or 51.5 °C, respectively. There is a decrease in maximum temperatures of the external side of the Western wall. The temperature gap of the internal sides of the Eastern side of the concrete block wall and the eastern wall in BTC, BLT and adobe are 10 °C, 13 °C and 7.5 °C, respectively. BLT, BTC, and Adobe have virtually the same gap and have lower temperatures. The sudden increase in temperature of the concrete blocks wall is due to its thermal inertia. The thermal inertia of the concrete block is lower than that of the other three materials, thus causing a strong variation in the temperature of the internal side. BTC, BLT and adobe contain temperature variation better and this is dueto their thermal inertia, which is fairly higher than that of concrete blocks. The temperature increase for materials is due,on the one hand, to heat received by convection within the cell and on the other hand, by conduction through the wall of the solar flow received during daytime. The decrease in temperature is due to the rejection of heat stored during the daytime by conduction through the wall and by convection.

2.5. Evolution of the temperature of the external wall of the roof

Figure 13 shows the evolution of the temperature of the external wall of the cell roof built in BLT, BTC, concrete blocks and adobe. Temperature evolutions of the external wall of the roof are the same. In daytime, temperatures rise as early as 5 a.m. and gets to its peak between 1 p.m. and 3 p.m. and then begin to decrease for the rest of the day. At night, there is a significant decrease in temperature for the various materials used. The maximum temperature values for BLT, concrete blocks, BTC and adobe wall are 332 K or 59 °C; 334 K or 61 °C; 329 K or 56 °C and 332.5 K or 59.5 °C, respectively less than concrete blocks. It should be noted that BTC, BLT and Adobe have 2 °C; 5 °C and 1.5 °C, respectively lower than the concrete blocks. The increase in the temperature of the external side of the roof at a precise period of the day is dueto the large solar flow received during the day. Temperature gaps are due to material effusivity. Concrete blocks have, in fact, a lower effusivity than that of BTC, BLT and adobe as shown in table 1. Thus, the surface temperature of the concrete blocks grows faster and reaches its peak before the three other materials.

2.6. Evolution of thetemperature of the internal wall of the roof

Figure 14 shows the change in the temperature of the internal side of the roof built with different materials such as BLT, concrete blocks, BTC and Adobe. Temperatures of the internal roof wall are the same. It was noticed that the temperature of the concrete blocks roof is less stable than that of the BLT, BTC and adobe roof. The temperature of the internal wall for the various materials during the whole night decreases considerably. This decrease is most noticeable for the temperature of the concrete blocks wall. Daytime is characterized by large variations in the temperature of the internal side. In daytime, the temperature increases from 6 a.m. to 5 p.m. for BLT, BTC and adobe except the

temperature of the concrete blocks which starts falling from 4 p.m. The maximum temperature values for the BLT, concrete block, BTC and adobe wall are 322 K or 49 °C; 331 K or 58 °C; 319 K or 46 °C and 324 K or 51 °C, respectively. The temperature gap of the internal surfaces of the Eastern concrete blocks wall and the Eastern BLT, BTC and adobe wall are 9 °C; 12 °C and 7 °C, respectively. BLT and BTC have virtually the same gap and show lower temperatures. Yet, the Adobe has its maximum temperature closer to that of the concrete block. The increase in the internal temperature of the roof during the day is due to the fact that the roof is exposed to solar flow throughout the day. Heat reaches the internal surface by conduction through the roof. The decrease in temperature towards the end of the day and at night is due to the release of heat from the inside to the outside of the cell by conduction through the roof and the lack of sunlight at night. The sudden rise and the rapid decrease in temperature of the internal side of the concrete blocks compared to BTC, BLT and adobe seems to be due to the thermal inertia of the concrete blocks which is lower than that of other materials. Concrete blocks poorly contain heat conduction leading to the overheating of the internal surface and the sudden fall in the temperature of the internal surface. The temperature of the internal side of the BTC roof is the most stable followed by that of BLT and adobe. Indeed BTC, BLT and adobe used have a higher thermal inertia compared to the concrete blocks, giving them this capacity to absorb these thermal losses.

2.7. Evolution of the internal temperature of the cell

The Figure 15 shows the evolution of the internal temperature of the cell built with BLT, BTC, concrete blocks and adobe. The internal temperatures of the cell all have the same pattern. It should be noted that like the internal sides of the cell, the temperature of the concrete block cell is higher than the temperature of the cell in BLT, BTC and adobe. Regardless of the type of material, the internal temperature of the cell for different materials increases throughout the day and for one part of the night. For the rest of the night, the internal temperature falls. The maximum temperature values for BLT, concrete blocks, BTC and adobe wall are 312.5 K or 39.5 °C; 315 K or 42 °C; 311 K or 38 °C and 313.5 K or 40.5 °C, respectively. The maximum temperature gaps of the cell in BLT, BTC and adobe as compared to concrete blocks are 2.5 °C; 4 °C and 1.5 °C, respectively. Temperature gaps are slight but BLT and BTC have almost the same gap and have lower temperatures.

The increase in the internal temperature of the cell constructed with BLT, BTC, adobe and concrete blocks is due to the transfer of heat from outside to inside of the cell during daytime. The diffusivity of concrete blocks ($6.1.10^{-7} m^2$ / s) is high compared to those of BTC ($2.3.10^{-7} m^2$ / s), BLT ($2.7.10^{-7} m^2$ / s) and adobe ($2.7. 10^{-7} m^2$ / s) leading the concrete block to conduct more heat. Thus, concrete blocks get quickly heated. Thermal diffusivity of the other three materials is low, that is why the internal temperature of these materials increases slowly and the cell warms up slowly. The maximum temperature gaps found are due to the thermal properties of the materials used. The thermal inertia of the concrete blocks remains low compared to that of BTC, Adobe and BLT. The concrete blocksweakly contain thermal gains, justifying the sudden fall in temperature and very high temperatures.

CONCLUSION

Bibliographic studies have been conducted to make the inventory of building materials and their thermophysical properties. In this bibliography, four materials have been identified; their performances and their production methods have been briefly presented. According to literature,several buildings are built in Burkina Faso with modern materials often causing very high electricity consumption. Taking sustainable buildings into account is promising. This study which aimed at finding material that could mitigate heat transfer and offer an acceptable indoor environment,

has successively led to a modeling and a simulation of the heat transfer in a test cell built with different local materials. The simulation of the evolution of the internal temperature of the cell and that of external and internal sides of the Eastern, Western walls and of the roof was made. The study shows that BTC (Compressed Earth Block) is the material that offers lower temperatures (varying between 303 K and 311 K) and a good internal thermal comfort compared to BLT (Cut Laterite Block), concrete blocks and adobe. The temperatures inside the cell built with BLT (varying between 303 K and 312.5 K) and adobe (varying between 303 K and 313.5 K) are lower than those of the cell built with BTC but higher than that of concrete blocks (varying between 303 K and 315 K). BTC (the maximum temperatures for the internal side of the Eastern wall, the Western wall and the roof being 316 K, 319 K, 319 K, respectively) is the material that best mitigates the transmission of heat from outside to the inside compared to BLT (the maximum temperatures for the internal side of the Eastern wall, the Western wall and the roof being 319 K, 322 K, 322 K, respectively), to the concrete blocks (the maximum temperatures for the internal side of the Eastern wall , Western wall and the roof being 326 K, 332 K, 331 K, respectively) and to adobe (the maximum temperatures for the internal side of the Eastern wall, the Western wall and the roof being 320 K, 324, 5K, 324K, respectively.The internal surfaces of the cell constructed with BTC have a temperature that slightly varies from the temperature of the internal surfaces of the cell constructed with BLT, concrete blocks, and adobe. Houses built withmud offer a better indoor thermal environment than those constructed with modern materials more and more used in the construction sector in Burkina Faso.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors

BIBLIOGRAPHIC REFERENCES

[1] IFDD, Guide to sustainable building in tropical regions. Volume 1: Design strategies
new buildings in tropical regions, Institut de la Francophonie et du
Sustainable Development, 191 p, 2015.

[2] P. Y. Gagnon and P. H. Nfaoui, "Renewable energies: Distributed and community production, Institut de la Francophonie et du Développement Durable (IFDD), Liaison Energie-Francophonie, Vol. 94, pp. 3–5, 2013.

[3] "National Communication from Burkina Faso, United Nations Framework Convention on Climate Change," p. 132, 2001.

[4] M. Mohamed, "Simulation of the effect of inserting turbulators within a fluid flow in a pipe, from the point of view of heat transfer and pressure drop, Master thesis, Merbah-Ourgla University , p.50, 2014. "

[5] P. Y. Lagrée, Thermal and mass transfers in fluids, ENSTA course, p.24, October 2018.

[6] Z. Rida, K. Sofiane, and B. Dadda, "Natural convection in an inclined rectangular cavity of different aspect ratios," Rev. renewable energies, vol. 19, no. 1, pp. 97–109, 2016.

[7] ZOMA Fati, "Experimental study of thermomechanical properties and simulation of the energy performance of composite materials formulated on the basis of clayey earth and plant reinforcements". Doctoral thesis, Joseph Ki-ZERBO University, Ouagadougou, Burkina Faso, p.250, 2016.

[8] IEPF, Energy efficiency of air conditioning in tropical regions, Volume 1: Design of new

buildings, 2006.

[9] A. COMPAORE, "Study of the thermal performance of a typical habitat in burkina faso. Application: contribution to the implementation of thermal regulations, Doctoral thesis, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso, p.168, 2018. "

[10] ISSP / UJKZ, "Scientific report, international conference on energy efficiency and thermal regulation in buildings, Ouagadougou, Burkina Faso 2015"