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Research Article

Optimization of Thermal Comfort in Compressed Earth Block (CEB) Buildings in Burkina Faso

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Abstract

The objective of this study is to evaluate the impact of orientation on the thermal comfort of bioclimatic buildings in general, and in particular those built with compressed earth blocks. A first experimental study confirmed that compressed earth blocks have good thermal inertia, and made it possible to determine the number of annual hours of thermal comfort in the room. The results showed a thermal phase shift of 6 hours with a temperature difference of 10 ℃ between the outside and the inside of the room, for an annual total of 4788 hours of comfort (54.65%) compared to 2158 hours of discomfort (49.80%), with a hygrothermal index (HIT) of 1.6 and an annual cooling requirement of 753.55 kWh. Subsequently, dynamic thermal simulations (DTS) carried out on different orientations made it possible to optimize the thermal comfort and energy consumption of the premises studied. The NORTHEAST and SOUTH-EAST orientation of the facades, with the two windows of the premises, made it possible to achieve 78.1% thermal comfort, or 6833 hours, a HIT of 0.5 and an annual power requirement of cooling of 523.78 kWh. Finally, similar work was carried out to propose optimal orientations for bioclimatic buildings in the three climatic zones of Burkina Faso.

Keywords

Orientation, Bioclimatic, Thermal Comfort, Passive Methods, Hot and Dry Climate, Thermal Simulation

1. Introduction

Since the advent of new heating and cooling technologies, building designers in this case architects and engineers seem to neglect bioclimatic design in favor of heating, air conditioning, ventilation, humidification and lighting [1]. This trend is particularly worrying in dry tropical countries like Burkina Faso, where the design of modern buildings is not sufficiently adapted to the local climatic context [2, 3]. The use of unsuitable construction materials such as concrete, glass and metals, as well as the orientation and architectural design of buildings, are the main factors responsible for this situation [4]. These factors create significant thermal discomfort and a high dependence on electronic devices to achieve comfort inside buildings [5]. This increased dependence has a significant impact on energy consumption and

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greenhouse gas emissions as shown in Figure 1.

Figure 1. *Construction using local materials unsuitable for climatic conditions (Daniel Ouezzin University Coulibaly).*

Indeed, globally, energy consumption in the building sector represents around 40% of total energy consumption and is responsible for around 25% of total carbon dioxide emissions (CO_2) [6, 7]. In sub-Saharan Africa, this consumption reaches between 50 and 70%. Between 60 and 75% of the total electricity consumption in public buildings in Burkina Faso is due to air conditioning, representing between 30 and 75% of the total low voltage electricity consumption [8-10]. It is therefore essential to act to improve the thermal comfort of buildings in order to reduce their energy consumption and their greenhouse gas emissions.

Several studies have contributed their solutions to this issue. In general, to improve the comfort and thermal performance of a building, it is possible to intervene on its physical form, its sun protection and orientation, as well as on the materials used for its envelope in order to improve its thermal inertia. Indeed, Compaoré et al. (2017) conducted a comparative study of two habitats with the same architectural form, one built with cement blocks and the other with earth material [11]. The results of this study show that the temperature inside habitats with walls made of local materials (earth materials) is lower than that of modern habitats (cement blocks). They also conclude that increasing the thickness of the walls contributes to a significant improvement in the thermal inertia of the habitat [2]. Kabore et al. (2013) studied the impact of roof type on the thermal performance of buildings in a tropical climate, showing that the use of an effective reflective insulator helps to combat heat gains [3, 12]. Ouédraogo et al. (2017) conducted a numerical study on a roof favoring ventilation in order to reduce thermal loads in a habitat in a dry tropical climate. Their results show that a north-south orientation and a 50° inclination improve ventilation [2]. A study on the characteristics of the envelope of a Malaysian building showed that a north-south orientation reduces energy consumption by 10% compared to an east-west orientation [13, 14]. In one of Bellara et al. (2020) is works, a study was conducted on the site of the new city Ali Mendjeli in Constantine, Algeria, to compare and explore the relationship between climate elements and orientation [13]. The results show that taking orientation into account offers better thermal and energy performance to the building [15]. Kiki. (2023) showed through simulations on a building in a tropical region that the thermal inertia of a compressed clay composite material allows a heat flux delay of more than 6 hours and an improvement in interior temperature of about 2℃ [16]. Gagliano et al. (2017) showed that high thermal inertia combined with natural ventilation can reduce overheating in a building, and that thermal delay can be increased by 5 hours by changing the building's orientation from west to east [2]. The results of Besbas's work (2019) show that the interior temperature of a classroom with no shading on the openings is governed by the radiation entering through a large glazed surface as well as the radiation absorbed by the entire wall [17]. Mansouri et al. (2017) conducted an evaluation on the impact of roof reflectivity combined with wall thermal insulation [18]. The results of their study show that high solar reflectivity associated with thermal insulation defines an acceptable level of comfort and reduces energy costs, and that these effects are more significant for the roof than for the walls [5, 18].

It is thus clear from the above studies that the orientation of buildings is a determining factor in the design of thermal comfort in passive habitats. Therefore, it is very instructive to conduct a thorough investigation on the influence of orientation on the thermal comfort of bioclimatic buildings in Burkina Faso. This study is motivated by the observation that construction with local materials does not necessarily guarantee optimal thermal comfort throughout the year as revealed by several studies. The present work focuses on a local bioclimatic design to reduce energy expenses for cooling (air conditioning), ventilation, and greenhouse gas emissions.

2. Materials and Methods

2.1. Materials

The hygrothermal data of the office studied was recorded using a Graphtec GL840-MW recorder and the thermophysical properties of the walls and openings were measured with the KD2-PRO device.

Table 1. *Technical specifications of measuring devices.*

Devices	Measuring ranges		Errors or clarifications
Graphtec GL840-MW recorder	Tension	$20mV \leq U \leq 250V$	±(0.15% val.read)
	Temperature (type K thermocouples)	$-100 \leq T_S \leq 1370°C$	±(0.5 % val.read+1 ℃)
	Humidity (humidity sensor B-530)	$0 \leq HR \leq 100\%$	±(0.1% val.read+0.5)
KD2-PRO	Thermal conductivity	$0 \leq T \leq 150°C$	±(0.5% from 0.2 to 2)$W/(mK)$

2.2. Methods

This study focuses on the thermal behavior of buildings made of compressed and stabilized earth bricks (CSEB) in Burkina Faso, specifically on the influence of their orientation on indoor thermal comfort. An experimental study was conducted on a CSEB building in the city of Ouagadougou, Burkina Faso, located in the Sudanese-Sahelian climatic zone of the country. The objective was to determine the main parameters influencing thermal comfort such as temperatures (indoor and on the building surface), relative humidity, and air velocity in order to evaluate the level of comfort for occupants.

Firstly, an experimental measurement campaign was carried out using specialized equipment to collect in-situ data, allowing for the evaluation of the building's thermal comfort using the Givoni diagram. Subsequently, a dynamic thermal simulation (DTS) of the building's thermal behavior was conducted using the Pléiade Comfie software to determine comfort hours. A comparison between theoretical and experimental results was made to validate the numerical simulation results. Simulations were performed by gradually changing the building's orientation to identify the best orientation in terms of thermal comfort for this specific climate.

Finally, simulations were conducted for the same type of building in the country's other two climatic zones, allowing for the determination of the optimal orientation to ensure optimal thermal comfort for occupants in each zone as indicated in Figure 2.

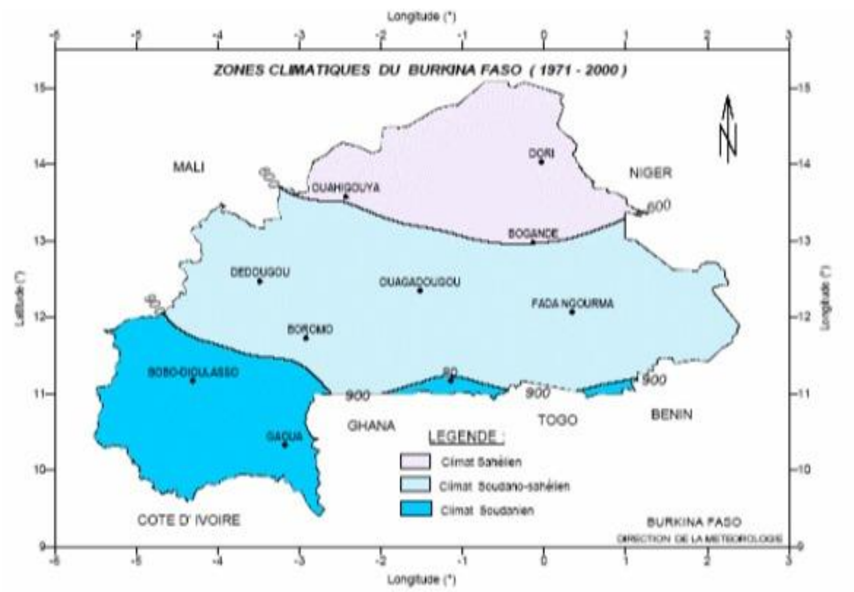

Figure 2. *The three climatic zones of Burkina Faso. Source: National Meteorological Agency of Burkina Faso (NMA-BF)[19].*

2.2.1. Presentation and Modeling of the Building

(i). Presentation of the Building

The office studied is located on the ground floor of a two-storey building for administrative use, consisting of 22 rooms in total. This building is occupied by the staff of the General Directorate for Control of Development and Construction Operations (DGCOCC). The office in question is that of the Director General's secretariat.

It is a polygonal shaped room (Figure 3) with an area of 25.11 m^2, equipped with two windows measuring 120×130 cm^2 (East side) and 120×120 cm^2 (South side), as well as two internal doors measuring 80×220 cm^2 each, oriented towards the West (Figure 3). Four people work there permanently, in addition to occasional visitors. There are also various electrical appliances such as two printers, four computers, a refrigerator, an air conditioner and three lamps. The constituent elements of the office envelope and their thermophysical characteristics are listed in Table 2.

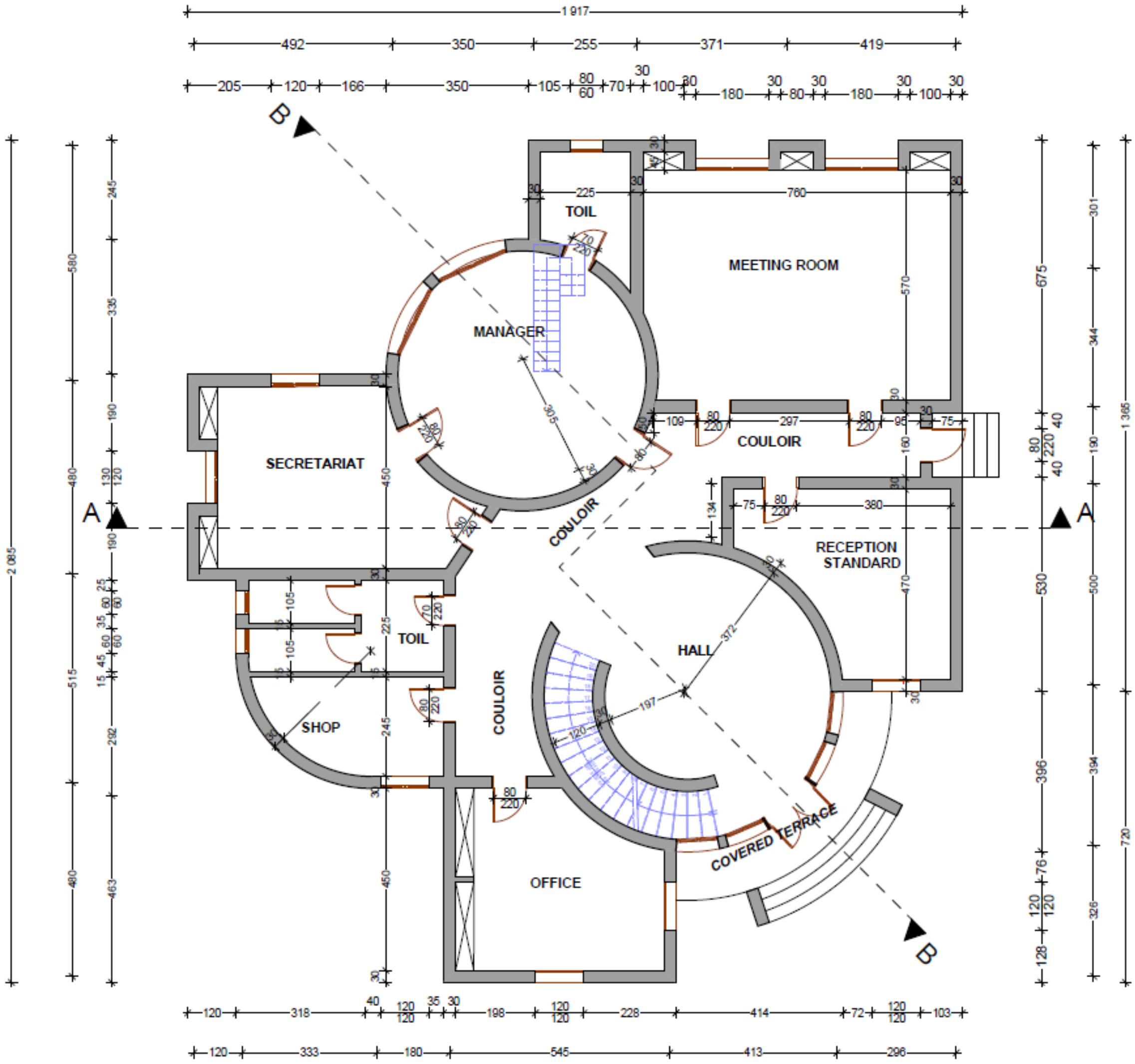

Figure 3. *Ground floor plan of the studied building.*

Figure 4. *Photos of the building studied.*

Table 2. *Thermo-physical properties of the office envelope studied [20, 21].*

Materials Units		Thickness th (cm)	Conductivity thermal $\lambda(W.m^{-1}K^{-1})$	Volumic mass $\rho(kg.m^{-3})$	Thermal diffusivity α $(10^{-6}m^2s^{-1})$	Thermal effusivity $E(J.s^{-\frac{1}{2}}m^{-1}K^{-1})$	Resistance to water vapor diffusion $\mu(m^2.h.P_a.mg^{-1})$
CSE walls		30.000	0.556 ±0.006	1835.450 ±27.532	2.140 ±0.023	1202.291±10.720	15±0.300
Low floor		55.000	0.671 ±0.007	1959.760±28.392	2.360 ±0.034	1398.155±12.873	10±0200
High floor		20.000	1.151±0.002	2500±37.500	1.5±0.021	2.5±0.023	130±2.600
Windows Doors	Glass Window	0.004	1.400±001	2530±37.950	0.5±0.005	0.84±0.007	∞
	Iron frame	2.000	50±0.539	7.500±112.580	12±0.128	0.64±0.005	∞
	Louver	0.100	72±0.776	7.870±118.000	22.8±0.245	0.8±007	∞
Wooden ceiling		0.100	0.15±0.001	565±8.477	1.5±0.021	0.4±004	35±0.700

(ii). Thermal Modeling and Simulation of the Office

The premises studied are the site of various forms of hygrothermal transfers such as exchanges by radiation (solar contributions), conduction (walls), convection (air) and internal contributions due to the energy exchanges of household appliances and the contributions of the occupants. The different energy exchanges between the environment, the premises studied and the occupants are illustrated in Figure 4.

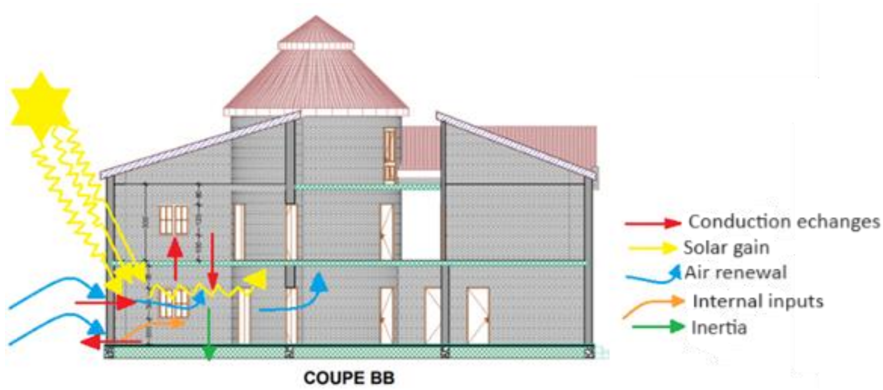

Figure 5. *Representation of the different forms of hygrothermal exchanges in the building studied.*

In order to take into account all heat exchanges in the room, we opted to use the dynamic simulation tool DST Pleiades Comfie which we took care to study. Its calculation engine the equations used by this tool are suitable for the local climate because they take into account different physical phenomena such as: solar input, exchanges through walls, air circulation, thermal inertia, action of occupants, etc. The Pléiades Comfie Thermal Dynamic Simulation (TDS) calculation engine is based on a multi-zone finite difference model reduced by nodal analysis. In fact, the office we are studying is considered a thermal zone delimited by the walls. The thermal zone is finely divided into several homogeneous meshes called systems. It is assumed that the meshes are isothermal, that is, they instantly have uniform temperatures. For each mesh, a thermal balance is established. From the equations obtained for all the meshes, we develop a thermal model for each zone, that is, for the entire premises and its occupants. This local balance is based on the energy received by the mesh through solar radiation; the various internal thermal inputs from the occupants, the electrical cooling and lighting equipment. As the outside temperature varies over time, the assessment is carried out in a variable regime. Starting from the fact that the volume of each mesh is constant, there is no exchange of energy linked to work.

The equations which characterize the evolution of the temperature within each cell are established from the Fourier thermal diffusion equation given by the following equation (1):

$$\rho C_v \frac{\partial T}{\partial t} = \lambda \Delta T + P_v \quad (1)$$

With:

$\frac{\partial T}{\partial t}$: The partial derivative of temperature with respect to time;

ΔT: Temperatures differences compared to Cartesian coordinates;

λ: the thermal conductivity of the wall, ρ: the density of the wall, C_v: the mass volume capacity of the wall;

P_v: the power volume of the internal sources.

For a mesh located in the internal part of a wall, the heat balance is written using the following Eq. (2):

$$C\dot{T} = \frac{A}{\frac{1}{h_{ins}}+\frac{e}{2\lambda}}(T_{zone} - T) + \frac{A}{\frac{e}{2\lambda}+\frac{e'}{2\lambda'}}(T' - T) + \frac{\frac{A}{A_{opaque}}}{1+\frac{1}{h_{ins}}(\frac{e}{2\lambda})} Q'_{ground} \quad (2)$$

For an intermediate mesh, the heat balance is given by the following Eq. (3):

$$C'\dot{T}' = \frac{A}{\frac{e}{2\lambda}+\frac{e'}{2\lambda'}}(T' - T) + \frac{A}{\frac{e'}{2\lambda'}+\frac{e''}{2\lambda''}}(T'' - T') \quad (3)$$

For an outer mesh of the outer wall, the heat balance is given by the following Eq. (4):

$$C''\dot{T}'' = \frac{A}{\frac{e'}{2\lambda'}+\frac{e''}{2\lambda''}}(T' - T'') + \frac{A}{\frac{1}{h_{out}}+\frac{e''}{2\lambda''}}(T_{out} - T') \quad (4)$$

For an outer mesh of the inner wall, the heat balance is given by the following Eq. (5):

$$C''\dot{T}'' = \frac{A}{\frac{e'}{2\lambda'}+\frac{e''}{2\lambda''}}(T' - T'') + \frac{A}{\frac{1}{h_{out}}+\frac{e''}{2\lambda''}}(T_{eq} - T'') \quad (5)$$

For a mesh located in the ambient air of the office, the heat balance is given by the following Eq. (6):

$$C_{total}\dot{T}_{zone} = \Big\{ \sum_{external\ walls}\left[\sum_{Glazing}[UA_w + UA]\right](T_{out} - T_{zone}) + \sum_{Walls} \frac{A}{\frac{1}{h_{ins}}+\frac{e}{2\lambda}}(T_{ground} - T) + \sum_{Walls} \frac{\frac{A}{A_{opaque}}}{1+\frac{1}{h_{ins}}(\frac{e}{2\lambda})} Q'_{ground} + \Psi L(T_{out} - T_{zone}) \quad (6)$$

with:

$$\begin{cases} Q'_{ground} = \frac{1-(1-\alpha_m).A_{transparent}}{A_{opaque}+A_{transparent}} * Q_{ground} \\ U = \frac{1}{\frac{1}{h_{ins}}+\sum_{Layers}\frac{e}{\lambda}+\frac{1}{h_{out}}} \end{cases}$$

In the previous equations, e: thickness of a layer of material (m); ρ: density of a material kgm^{-3}; λ: thermal conductivity of a material (W/m/K); C: specific heat of a material (Wh/kg/K); U: heat transfer coefficient of a wall in W/m ^{2}/K; A: surface area of a wall in $m^{2;}$ A_{opaque}: sum of opaque surfaces of an area; $A_{transparant}$: sum of transparent surfaces of an area; U_{Ag}: transfer coefficient with the ground (W/K); h: surface heat transfer coefficient (including radiative and convective transfers), index ins (resp. out) on the interior (resp. exterior) side; ψ_L: overall transfer coefficient corresponding to thermal bridges between a zone and the outside (W/K); $\dot{m}$: minimum ventilation rate of the zone (kg/s); T: temperature; $\dot{T}$: derivative of a temperature; P: thermal power (positive or negative) supplied to a zone by heating or cooling equipment, ventilation, internal supplies, occupants; C_{total}: thermal capacity of the air and light walls included in a zone (Wh/ K); Q'_{ground}: net solar flux remaining in the zone in W; Q_{ground}: the solar radiation entering through the various glazing units in the area, calculated for the time being, taking into account any masks (distant masks, integrated masks, removable blackouts); T_{eq}: equivalent temperature (output of the system of equations of an adjacent zone); α_m: average absorption factor of the surfaces of a zone and the indices ': intermediate mesh of a wall, ": outermost mesh of a wall; m: medium; out: exterior; ins: interior; T_{ground}: soil temperature at 10 m depth; T_{zone}: temperature of the area considered.

After the heat balances in the different meshes, a zonal model is established in the following matrix form (system of equations in Eq. (7):

$$\begin{cases} C\dot{T} = AT + EU \\ Y = J.T + G.U \end{cases} \quad (7)$$

Where: T is the vector of mesh temperatures; U the vector of external climatic stresses (solar fluxes, temperatures, air speed, etc.); Y the vector of output data (zone temperatures); C the diagonal matrix of specific heat capacities; To the matrix of terms of exchange between the meshes; E the matrix of the terms of exchange between the meshes and the stresses, J: the matrix connecting the outputs to the temperatures of the meshes; G the matrix connecting the outputs to the requests.

After reduction, coupling and arrangement, we obtain the following system (system of equations in Eq. (8):

$$\begin{cases} \dot{X}_g = F_g.X_g + B_g^{\alpha}.\dot{U}_g + B_g^{\beta}.\dot{Y}_g \\ Y_g = H_g.X_g + S_g^{\alpha}.U_g + S_g^{\beta}.Y_g \end{cases} \quad (8)$$

where:

$F = P^{-1}.C^{-1}.A.P;$

$B = P^{-1}.A^{-1}E;\ H = J.P;$
$S = G - J.A^{-1}.E$

$X_g$is the request state vector; Yg of the coupling variables (containing the temperatures equivalent); F is a diagonal matrix whose i th diagonal term is $i -1/\tau$, i τ being the ith time constant of the zone; U_g of external stresses (outside temperature, solar flux, internal power).

We introduce into the system above a time step Δt to obtain time values $(n+1)\,\Delta t$ and system 8 is transformed into the following system of equations (9):

$$\begin{cases} X_g^{n+1} = exp(F_g.\Delta t).X_g^n + W_g^\alpha.(U_g^{n+1} - U_g^n) + W_g^\beta.(Y_g^{n+1} - Y_g^n) \\ Y_g^{n+1} = H_g.X_g^{n+1} + S_g^\alpha.U_g^{n+1} + S_g^\beta.Y_g^{n+1} \end{cases} \quad (9)$$

In this system: $U_g^{n+1}\ et\ U_g^n$are the vectors of the requests at times $(n+1)\cdot\Delta t$ and $n\cdot\Delta t$. The matrices W_g^α and are W_g^βconnected to the matrices B_g^α and B_g^β respectively by the relation: $W_i^j = exp\left(\frac{-\Delta t}{\tau_i}\right).B_i^j$.

The resolution of this system of equations was done using the implicit finite difference method and a simulation program on Matlab software.

2.2.2. Modeling and Thermal Simulation of Office Variants

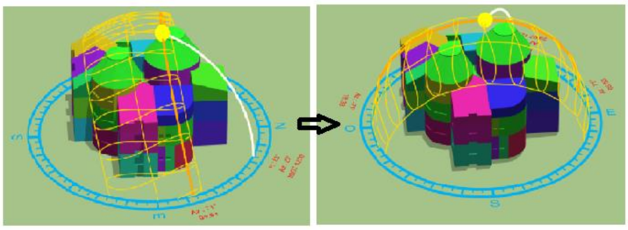

Figure 6. Modeling of the East and South orientations of the office studied.

The basic variant, which is the initial and actual position of the desk (EAST position), has been gradually modified (rotated) to obtain variants 1 to 7, with orientations respectively: SOUTHEAST, SOUTH, SOUTHWEST, WEST, NORTHWEST, NORTH, and NORTHEAST. Modeling and simulations have been carried out on all these variants. Figure 5 provides an illustration of the modeling of variants 1 and 3 (East and South) of the desk. Variant 3 was obtained by rotating the basic variant 90 °clockwise.

3. Results and Discussions

For the data from the experimental measurement campaign, it is first represented in Figures 7 to 11, the evolution of the external and internal temperatures for the first weeks of the first 6 months of the year 2024.

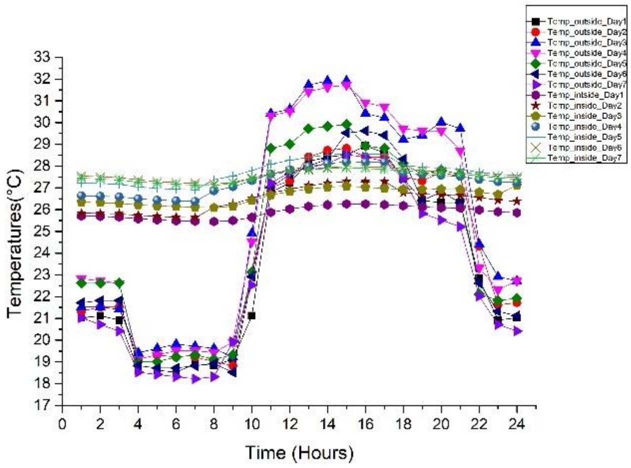

Figure 7. Evolution of external and internal temperatures in the month of January.

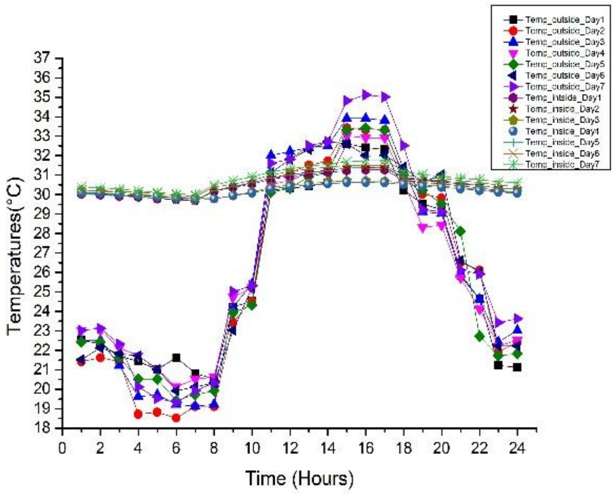

Figure 8. Evolution of external and internal temperatures in the month of February.

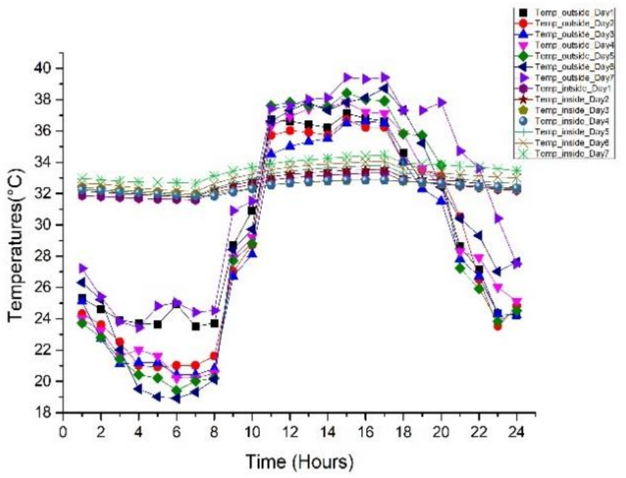

Figure 9. *Evolution of external and internal temperatures in the month of March.*

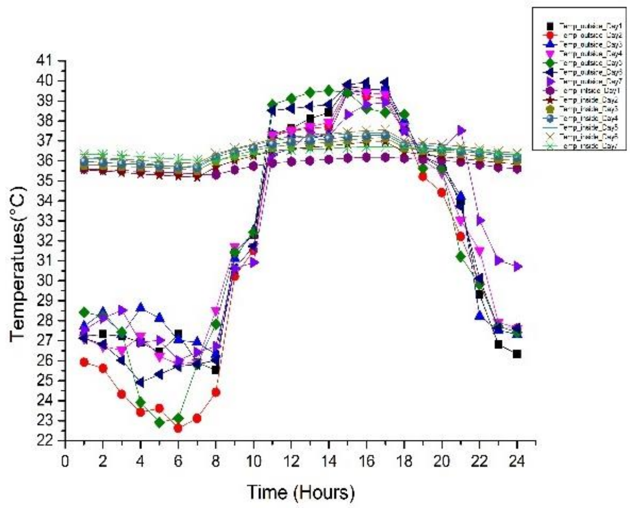

Figure 10. *Evolution of external and internal temperatures in the month of April.*

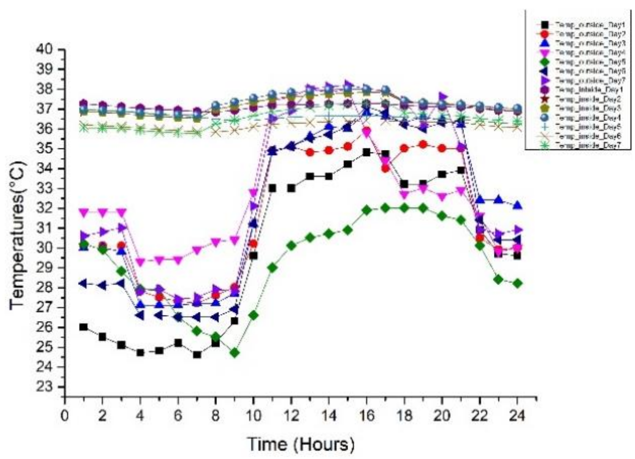

Figure 11. *Evolution of external and internal temperatures for the month of May.*

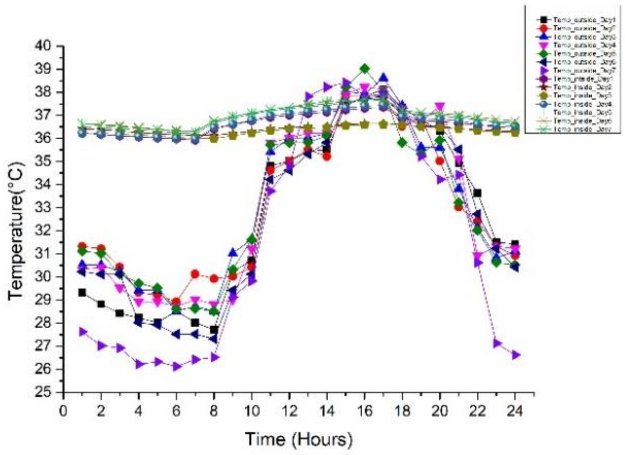

Figure 12. *Evolution of external and internal temperatures for the month of June.*

The evolutions of these curves show that the indoor temperature of the office is insensitive to variations in outdoor temperature. The average thermal lag is 6 hours between outdoor and indoor temperatures with a maximum difference of 10 ℃ between the outside and inside of the office. This can be explained by the good thermal inertia of the compressed earth blocks. This result is in good agreement with studies conducted on the thermal performance of compressed earth blocks, particularly by Majumder et al. 2021, whose results have shown the good thermal insulation of compressed earth materials [20, 22]. Since thermal comfort is not only related to temperature, the data is reported in the Givoni diagram for the city of Ouagadougou in order to estimate the thermal comfort of office occupants. This has led to the result shown in Figure 12.

Based on the results of this figure, a total of 2176 hours of discomfort were recorded, representing a rate of 50.20%, compared to 2158 hours of discomfort (49.80%) with zero ambient air velocity. This choice was made because the measurements taken mostly showed zero velocities in the office. Despite the good thermal insulation performance of the Building Thermal Comfort (BTC) system, the office experienced more than half of the hours of discomfort with low ambient air velocities. However, when the ambient air velocity is considered at 1.5 m/s, the Givoni diagram shows 68.5% of hours in comfort compared to 31.50% in discomfort. These results are consistent with the dynamic thermal simulation results using the Pleiades Comfie software. The Givoni diagram in Figure 12 provides the proportions of comfort and discomfort rates throughout the year based on air velocities.

When comparing the experimental results to the numerical simulation results, it is noted that they are approximately identical. Any discrepancies observed are likely due to the software mesh being coarse for computational time reduction purposes and potential uncertainties in equipment measurements.

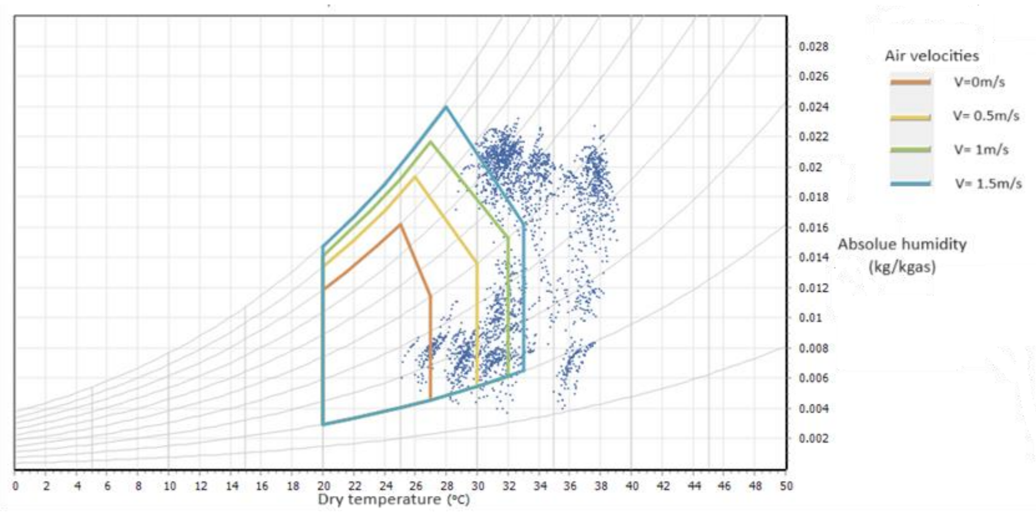

Figure 13. *Distribution of simulation data on the Givioni diagram.*

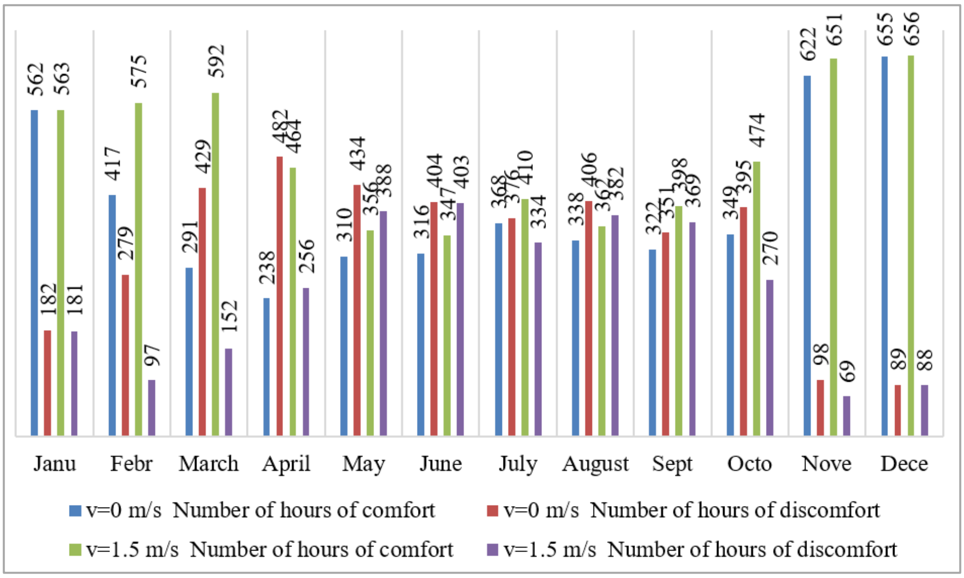

Figure 14. *Annual analysis of hours of comfort and discomfort with the Givoni diagram.*

It is therefore possible to deduce that the uncomfortable situation of the office is partly due to an inappropriate orientation of the building in general, and in particular that of the studied office, especially its openings (doors and windows). These openings do not promote air renewal within it. These results are consistent with previous research on this subject, such as that of Ouedraogo et al. (2015), which shows that a roof orientation favorable to ventilation can reduce the thermal loads of the habitat; [22, 23], whose research results led him to conclude that natural ventilation is a simple and important technique that can imp rove indoor air quality, protect health, provide thermal comfort, and reduce the electrical energy consumption used in air conditioning systems [23]. The thermal simulations of the six variants yielded results that are recorded in Table 3.

Table 3. *Summary of thermal simulation results for all variants.*

Variants-orientations	Total comfort hours	IHT	Average air speed (m/s)	Discomfort percentage (%)	Annual cooling requirement (kWh)
0-EST	4788	1.6	0.22	54.65	753.35

Variants-orientations	Total comfort hours	IHT	Average air speed (m/s)	Discomfort percentage (%)	Annual cooling requirement (kWh)
1-SOUTH-EAST	3870	0.8	0.15	44.18	1062.45
2-SOUTH	3788	1.4	0.3	43.24	1024.2
3-SOUTH-WEST	4288	1.9	0.12	52.37	818.15
4-WEST	4097	1.5	0.11	46.76	979.29
5-NORTHWEST	3104	1.9	0.08	35.43	1757.7
6-NORTH	3094	1.6	0.4	37.31	1054.62
7-NORTH-EAST	6833	0.5	1.25	78.1	523.78

Based on the results of Table 3, it can be deduced that the orientation that allows for maximum comfort in the secretariat office is the NORTHEAST orientation. With this orientation, the windows are not only sheltered from solar heat gain, but also in the optimal direction for ventilation. This allows for continual air renewal in the office. Additionally, the hygro-thermal index (HTI) is low, therefore the hours of discomfort are not too severe since the data does not deviate too far from the comfort range.

The most unfavorable orientation in terms of thermal comfort for the office is the variant 5, which is the NORTHWEST orientation. This orientation exposes the windows to afternoon solar heat gain and is also unfavorable for air circulation in the space. This leads to continuous overheating of the office, as the annual cost for cooling is very high for this variant.

Furthermore, it can be said that given the low cooling requirements (ventilation or air conditioning), the use of photovoltaic energy to improve comfort in the office during periods of discomfort is possible.

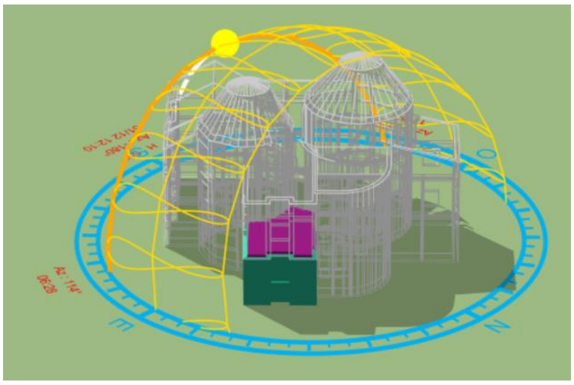

Figure 15. Image of the modeling of the optimal orientation for the office studied.

Simulations of the same space were carried out in several cities in the three climatic zones of Burkina Faso, taking into account the specific climatic conditions of these zones. The results obtained highlight that the optimal orientation for thermal comfort in Ouagadougou is not suitable for other cities in the country, such as Dori, Kaya, Banfora, Ouahigouya, and Bobo Dioulasso. The results obtained for the three climatic zones have led to general recommendations for each climatic zone. Indeed, we have divided Burkina into three regions for building orientation according to the sun's trajectory in order to achieve optimal thermal comfort for occupants. These regions include:

1) The Sahelian region, in the north of the country, characterized by a dry and hot climate with high temperatures and low precipitation. In this region, it is advisable to orient buildings in a way that minimizes sun exposure and promotes natural ventilation to reduce heat inside homes.
2) The Sudanese-Sahelian region, in the center of the country, with a semi-arid climate and dry and wet seasons. In this region, it is important to consider the direction of prevailing winds and orient buildings to take advantage of cool breezes and avoid overheating during the monsoon season.
3) The Sudanese region, in the south of the country, characterized by a humid tropical climate with high temperatures and abundant precipitation. In this region, it is advisable to orient buildings in a way that minimizes sun exposure and promotes natural ventilation to reduce heat inside homes.

4. Conclusion

This study on the thermal behavior of buildings made of compressed earth bricks stabilized in Burkina Faso highlighted the importance of building orientation to ensure optimal thermal comfort for occupants. The results of simulations and experimental measurements showed that the northeast orientation is the most favorable for the studied office, providing a good balance between indoor temperature, natural ventilation, and sunlight. Furthermore, recommendations were made to adapt building orientation to the different climatic zones of the country. These results could be useful for the design of sustainable and energy-efficient buildings in the region.

The main constraint in this study is the lack of detailed data on the psychological factors influencing occupants' thermal preferences in order to propose a reliable model of occupants' behavior. Additionally, the study was conducted on a single building, which does not allow for generalization of the results. However, it is important to note that every building construction project is unique, and there is no standard orientation guaranteeing comfort for all sites.

In order to maximize thermal comfort optimization in bio-chemical buildings, we plan to further investigate the influence of occupants' behavior on the thermal comfort of buildings made of compressed and stabilized earth bricks (CSEB).

Abbreviations

BTC	Building Thermal Comfort
CSEB	Compressed and Stabilized Earth Bricks
NMA-BF	National Meteorological Agency of Burkina Faso
DST	The Dynamic Simulation Tool
GDCDCO	General Directorate for Control of Development and Construction Operations
HIT	Hygrothermal Index

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Conflicts of Interest

The authors declare no conflicts of interest.

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