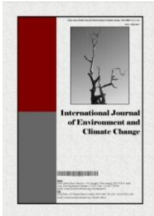

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Study of Local Construction and Technique: Adequacy of an Existing Nubian Vaulted Building with the "Bioclimatic" Concept Including the Performance of Its Envelope in Sahelian Climate of Ouagadougou

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Authors' contributions

This work was carried out in collaboration among all authors. Authors FZ, DYKT and BJK designed the study and wrote the protocol. Authors FZ, DYKT, BJK and EO performed the statistical analysis and wrote the first draft of the manuscript. Authors FZ and BJK managed the literature searches and the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

This study permitted to evaluate the adequacy of an existing Nubian vaulted building with the "bioclimatic" concept including the performance of its envelope. In that purpose, we needed to analyze its architectural concept and to measure parameters such as the temperature of the

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internal and external surfaces of all the façades (walls, roof and floor) of the study building. The measurement campaign took place over three (03) days in the month of January 2018 with a one-hour step for temperatures. Out of eleven (11) bioclimatic principles identified, six (06) were respected in the design of the building. In addition, we obtained thermal amplitudes of the interior surfaces lower than 1.5°C for the walls and 5°C for the roof, a decrement factor lower than 12% for the walls and 17% for the roof and a thermal time lag of 6 to 8 hours on in average for the walls and 4 to 6 hours in average for the roof. Finally, after evaluation of the thermal loads, with the Nubian vault building a reduction of a bit more than one third (1/3) of the thermal loads is achieved comparatively to a building of the same size made of cinder blocks for the walls and aluminum roofing sheet. However, this comfort offered by the Nubian vault can be improved with more bioclimatic provisions which we have recommended.

Keywords: Nubian vault; bioclimatic principles; envelop performance; thermal time lag; thermal decrement factor; thermal amplitude.

1. INTRODUCTION

The building is the place of several stakes in particular in the fields of economics, environment, energetic and for hygrothermal comfort. Indeed, in the context of galloping urbanization in sub-Saharan Africa [1], a part of the population lives in slums or precarious housing. According to UN-Habitat in its 2013 census [2], estimates show that around 50% of the population living in cities lives in slums. Yet one of the objectives of sustainable development (SDO) is precisely to provide decent housing.

Moreover, the construction sector is responsible for 18.4% of greenhouse gas emissions [3]. Practices in the construction sector consume a lot of conventional primary energy. IAE estimates show that its consumption can be as high as 42% of total energy consumption.

The comfort issue is not negligible. According to the investigations of Urs wyss [4], within the framework of a market study [5] in which potential customers for new housing were questioned about the criteria for choosing a roof for their home, it emerged that thermal and climatic aspects come second as the main criterion or reason for choosing the type of roof, after the aspects of durability and resistance. Building climate-adapted habitats is then something most of people are aware of. Therefore, the need to adhere to the bioclimatic building concept is obvious.

Among all the possibilities available for us to face the above-mentioned stakes, there is the valorization of natural (building) materials, endogenous (local) materials adapted to the local context and with a low negative environmental impact.

Several approaches, both scientific and empirical, have already been initiated.

In Burkina Faso an institution, in the 1990s, LOCOMAT (agency for the promotion of local materials), took the initiative to promote the use of local products such as compressed earth bricks (BTC), cut laterite blocks (BLT), through structures for the promotion of housing and technical support for the implementation of those materials.

On the empirical level, a way is the argumentation based on example. Thus, we have increasingly witnessed the spread in Africa, precisely in Burkina Faso and Niger, of earthen constructions, constructions which in addition to "proposing an economic response" (training of the workforce in new techniques, direct benefit for the local economy, more affordable constructions), propose a construction solution adapted to the local context close to traditional techniques [4]. This is the example of the CSB (timberless construction), the Nubian vault (VN). These are constructions without steel, without wood. The majority of cases exist in rural areas in Burkina and Niger. However, in the Magreb, thanks to the architect Hassan Fathy and the "New Gourna village" he designed, earthen constructions and vaulted roofs have flourished.

On the scientific level, few investigations are being carried out. We have the WYSS investigations on earthen construction described in the works "La construction en " matériaux locaux ", Etat d'un secteur à potentiel multiple" [4], "dissémination de techniques de construction de toiture économique et non consommatrices de bois au Burkina Faso" [6]. His works show the relevance of this type of construction in the socio-economic context of Sahelian countries as well as the techniques and limitations. Indeed, constructions made of local materials can present some limitations. This concerns the maintenance of the envelope and more precisely of the roof by the users. In addition to this, there is the acceptability because earthen construction is still considered as a symbol of poverty and non modernity. At the institutional level, we note the absence of regulations on earth construction techniques and standards for most local materials.

To address this situation, ABNORM, the Burkinabé agency for standardization, metrology and quality, has established the NBF 02 - 003: 2009 standard, dealing with the mechanical, physical and hydric characteristics of cement-stabilized BTC as construction materials in building. A project to establish a standard for BLTs is also underway. Another approach is to study existing buildings made of local materials. This is the case of LAWANE et al. [7], who conducted temperature and relative humidity measurements according to climatic influence (rainy day and a dry day during 2012) to analyze the hygrothermal comfort of an on a pilot building made of a corrugated steel roof and walls composed of BLT. The results shows that in comparison to outside temperatures, the walls act in the direction of smoothing inside temperature: The differences between extremes temperatures (maximum versus minimum) are for inside approximately 5°C for dry season and 4°C during rainy season while they are for outside the building 8.3°C for dry season and 5°C during rainy season. As for the relative humidity, the differences between extreme (maximum versus minimum) follow the same trend: approximately 15% for dry season and 5% during rainy season for internal and approximately 23% for dry season and 12% during rainy season external.

Another study is that of Malbila et al. [8] that compared the hygrothermal behaviour of two existing buildings, one made of cement block and the other of BLT, the criteria being the orientation and material of the building walls. They came to the result that the houses in BLT and cement blocks (cinder blocks) have each different behaviors concerning their influence on the interior ambience but the use of eco materials such as BLT makes it possible to reduce energy consumption in the building.

For our study, we conducted our investigations on 3 points:

- an evaluation of the adequacy of an existing Nubian vaulted (VN) construction based on bioclimatic principles by analyzing its architectural structure
- an evaluation of the thermal performance of its envelope
- a simplified comparative energy balance study of the VN construction and a conventional building with cinder blocks walls and a roof covered with aluminum roofing sheet and whose ground plan would be the same as the VN building.

Our approach is in line with the logic of providing scientific elements on the advantages of the VN construction envelope in order to participate in making this type of construction credible and to promote the establishment of regulations that will frame this type of construction. In other words, we want to contribute to the promotion of local materials and a fortiori architectural designs based on materials with low environmental impact and adapted for comfort in hot and dry climates.

This work is therefore intended to be a decision-making aid for the construction of Nubian vaults on the basis of an existing case.

2. METHODOLOGY

2.1 Presentation of the Study Building

The study building is an unoccupied Nubian vaulted dwelling in a large family courtyard located in the district 2 of the city of Ouagadougou, in the Hamdalaye district (12°22'18.6"N 1°33'10.8"W) (Fig. 1).

In this study, the Nubian Vault (VN) building consists of a living room and two bedrooms, with a total floor area of 42.65 m2 (see Fig. 2 (a) and 2 (b)).

As for the roof, it is consisted of two vaults and built in adobe at 3.10m sub-floor height (Fig. 3). From the inside to the outside, a layer of adobe bricks 4 X 12 X 24 cm, a plastic sheet, a layer of earth for the loading of the vault are laid and finally the elevation of the acroteria.

Fig. 1(a). Aerial view of the study building

Fig. 1(b). Image of the East and West facades of the study building

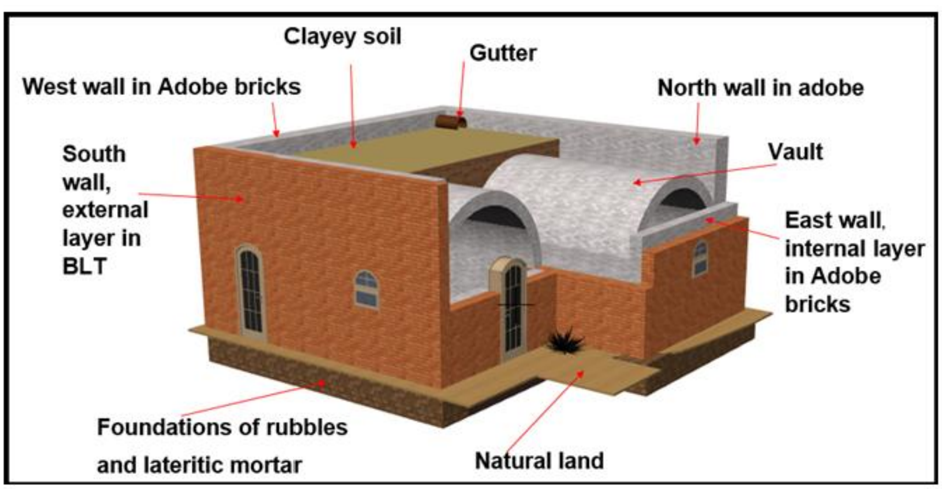


Fig. 1(c). Design 3D of the study house emphasizing the vaults and the walls layers

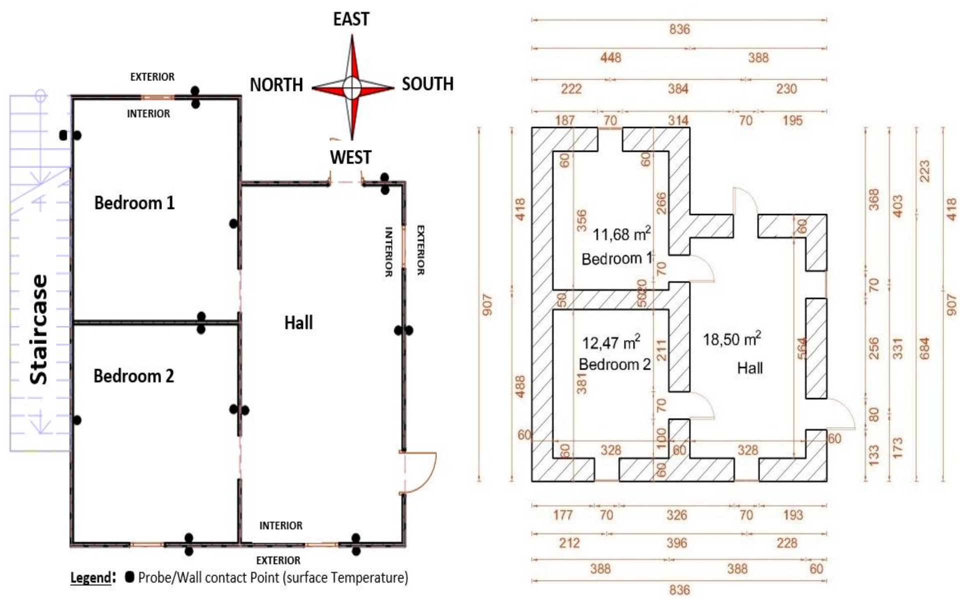
The walls, 60 cm thick (2 cm plaster), are made of adobe bricks 10 X 20 X 40 cm except for the walls facing East and South which are made, from the inside to the outside, of a layer of adobe next to a layer of BLT. Fig. 4 (a) and 4 (b) show the brick arrangements; it can be seen that the crossing of the bricks is alternated in each row to systematically cancel out any overlapping of the joints. The openings (doors and windows) are made of metal louvers.

Finally, the foundations are made of wild stones with a digging depth of 70 cm.

Note: For the study building, on the outside, a layer of cement plaster was applied to the visible part of the joints for more protection.

2.2 The Main Principles of Bioclimatic Design

One of the aims of this study is to evaluate or verify the bioclimatic aspect of the Nubian vault by analyzing its architectural design and its implantation in the environment.



(a) (b)

Fig. 2. Plan of the Nubian vault. (a) Layout of the rooms and orientation of the VN building. (b) Level plan of the VN building

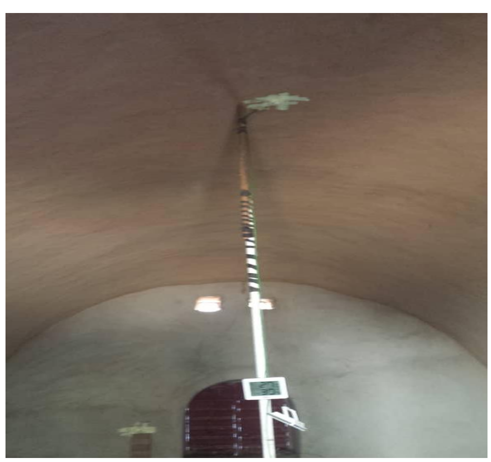


Fig. 3. The vault of the living room seen from the inside

(a) (b)

Fig. 4. (a) Image illustrating the mixed structure of the walls on the East and South sides; (b) Image illustrating a wall bearing a Nubian vault made of adobe [9]

The bioclimatic design of a building consists in adapting the building to the specific weather conditions and in obtaining the greatest comfort with a minimum of auxiliary energy sources. In order to achieve this, some principles must be implemented or deserve special attention.

Therefore it is a matter of noting that the following criteria (non exhaustive) established for the "bioclimatic" concept have been taken into account:

The siting of the building on the land - the surrounding environment - solar protection: The study of the site and the climate enables the best possible use to be made of the potential for renewable energy (geothermal, solar, etc.), cooling (natural ventilation to promote Venturi effects, thermosiphon, etc.) and protection or sun protection (existing vegetation on the ground and on the walls, sun screens such as trees, buildings along the shoreline, etc.).

Orientation and internal organization of the house: This is a key criterion in architectural design. The course of the sun as well as the latitude of the site is the elements to be taken into account. In tropical zones, preferably the "buffer" spaces, i.e. the less inhabited spaces (garage, shop, kitchen, etc.) will be located on the sides most exposed to the sun rays (East or West), i.e. on the East side [10]. As for the shape of the house, the elongated rectangles with the large facades facing North or South constitute a good compromise [11].

Remark: There are also interior elements such as curtains but since our habitat was not occupied at the time of the study, this point will not be considered.

Building materials: The choice of material should take into account the following criteria: environmental impact, maintenance of performance over time, thermal inertia, durability, contribution to comfort and health and cost. Local materials, particularly earth materials, are to be recommended in the context of bioclimatic design, especially those with good thermal but also mechanical properties.

The thermal characteristics of the materials used in this study are presented in Table 1.

Some bioclimatic principles [15] on which we will base our appreciation (through observation) of the bioclimatic aspects of the study building are summarized in Table 2.

2.3 Measuring the Temperatures of the Surfaces of the Study Building Envelope

We want to assess the thermal behavior of the envelope by taking the temperature of the internal and external surfaces of the façades (walls, floor, roof) of the habitat. These temperature values will allow us to find the thermal time lag in hours ([h] formula (1) [16]), the decrement factors of the interior surfaces temperatures in percent (Am [%] formula (2) [16]) and the thermal amplitudes in degrees Celsius (ΔT [°C]) which are decisive for the evaluation of the thermal performance of the envelope of a house.

Fig. 5 illustrates these parameters.

$$\Psi = t_{T_{int,max}} - t_{T_{ext,max}} \quad [h] \tag{1}$$

$$Am = 100 \times \frac{\Delta T_{int}}{\Delta T_{ext}} \; [\%] \tag{2}$$

So we carried out a three-day series of measurements from 03/01/2018 to 06/01/2018.

For this purpose, thermocouples (probes) of types "k" and "J", attached to data loggers (optimum temperature measurement accuracy of ±0.05%) (Fig. 6), were placed on the interior and exterior surfaces of the façades. The time step adopted for the temperature measurements was one hour (1h). Fig. 2 (a) shows the location of the thermocouples.

Table 1. Thermal properties of the few materials used in the study

	Cinder block [12]	Adobe [13]	Compressed earth bricks (BTC) (improved by 3% to 6% cement) [14]	BLT [7]
Thermal conductivity λ [W/m.k]	0.67	0.814± 0.173	0.6	0.51 ± 0.08
Specific heat capacity (ρ.C) [kJ/m3.K]	1100	1985.9 ±0.539	3570	2633.54 ±185.5

Table 2. Bioclimatic parameters to be verified

Verification parameters	Bioclimatic principles
Orientation of the main North-South façade	North-South
Internal organization	Living area not exposed (North-South)
House shape	Rectangular
Glazing of openings	Simple glazing/Double Glazing
Protection of windows	Protection of openings against solar radiation
Vegetation	Presence of vegetation against the sun's rays
Solar protection of walls	Protection of walls against solar rays
Local materials with good thermal inertia for wall construction	Local materials with high thermal inertia
Roof	Insulating roof
Semi-passive cooling system	Passive or semi-passive air renewal
Energy source	No fossil energy

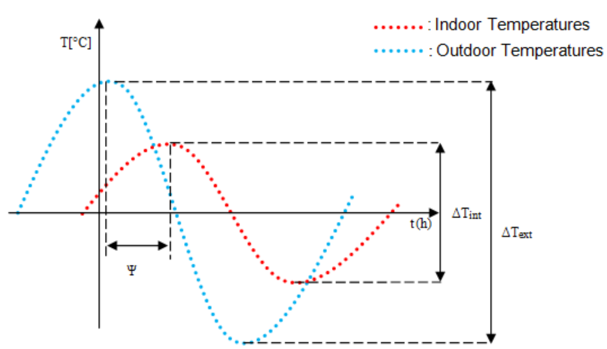


Fig. 5. Illustration of thermal time lag Ψ, decrement factor and thermal amplitudes ΔT

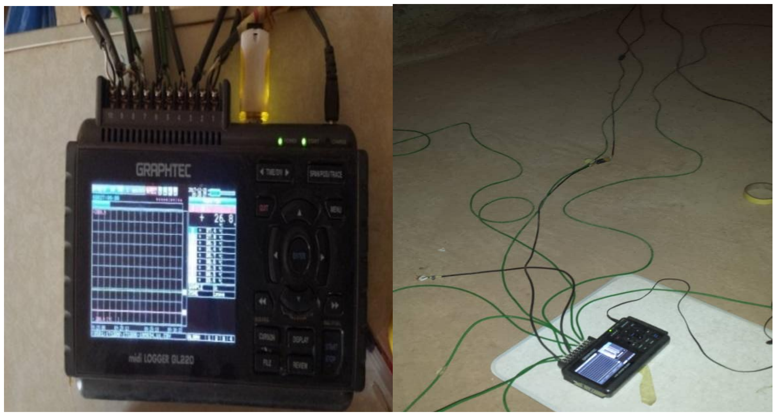


Fig. 6. Image of midi data logger LOGGER GL220 used in this study

NB: In order to minimize the parasitic effects, some precautions have been taken:

- we applied thermal grease on the surfaces (Fig. 7 (a)), at the points of contact between the probes (thermocouples) and the walls in order to empty the air voids and reduce as much as possible the contact resistance between the wall surface and the probe.
- The ends of the thermocouples were insulated from the ambient air with pieces of polystyrene and then reinforced with adhesive paper to maintain contact (see Figs. 8 (a), 8 (b)).
- The thermocouples were positioned so that the ends point to the wall surfaces.
- In order to secure the thermocouples to the outside walls, 6 mm clips were used (see Figs. 7 (b) and 9.

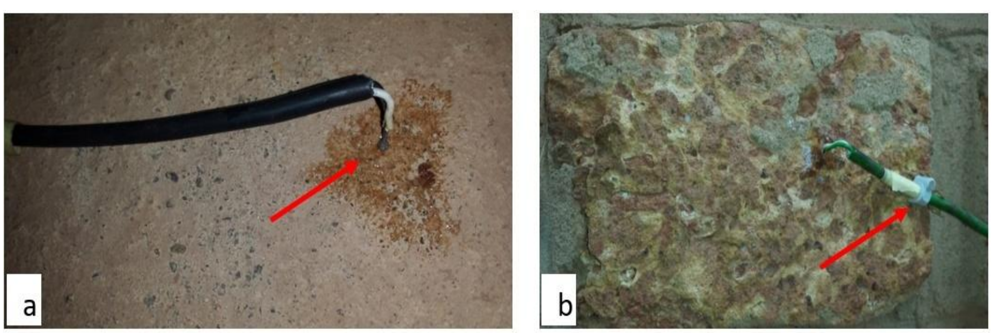
2.4 Energy Performance: Simplified Heat Balance

To complete the assessment of the thermal performance of the Nubian vault house, it is necessary to know the energy performance of the study building. We therefore compared it to that of a non existing cinder block building with the same plan (Fig. 10) and dimensions. The difference is that the walls are made of 15 cm thick hollow blocks, and the roof is made of aluminum roofing sheet.

The simplified heat balance method has been used as it is more realistic in the assessment of air-conditioning heat loads for tropical countries [12].

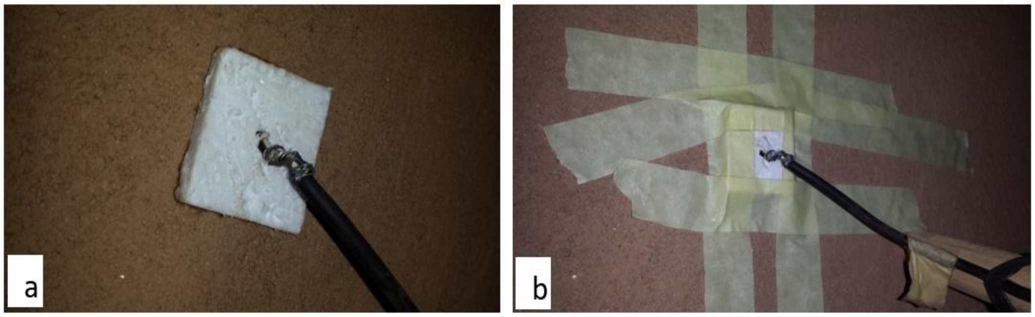
The evaluation of the heat balance thus consisted in calculating the thermal loads QST [W] according to the formula (3) for the hottest day of the year 2018 in Ouagadougou, on April 29, 2018 and according to the following basic conditions:

- Basic external conditions: θ_{eb} = 40°C; HR_{eb} = 20%; ω_e= 9.3 [g/kgas]
- Indoor baseline conditions: θ_{ib} = 26°C; HR_{ib}= 51%; ω_i= 14.7 [g/kgas]



(a) (b)

Fig. 7. (a) Thermocouple placed with the use of thermal grease; (b) Thermocouple immobilized with a clip



(a) **(b)**

Fig. 8. (a). Thermocouple image placed and insulated with polystyrene; (b) Thermocouple image placed and insulated with polystyrene and reinforced with sticky paper

Fig. 9. Images of thermocouples immobilized with wooden and metal tube supports

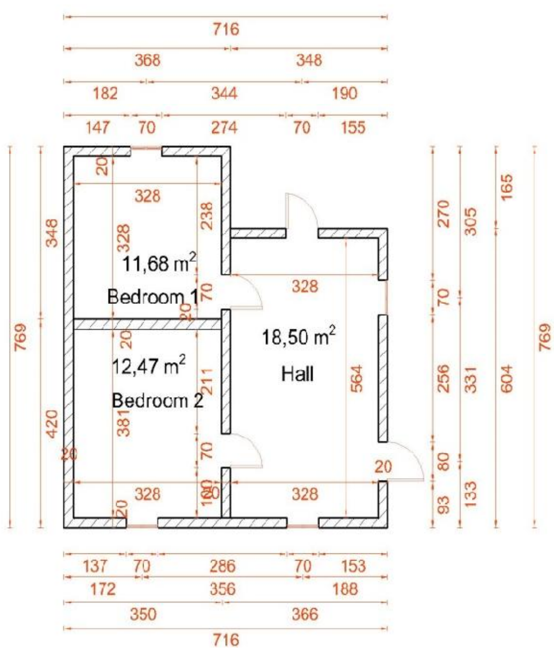


Fig. 10. Plan of the cinder block building

$$Q_{St} = Q_{Str} + Q_{SRm} + Q_{SRv} + Q_{Sr} + Q_{Lr} + Q_{SOc} + Q_{SLoc} + Q_{ecl} + Q_{Sequip} \quad (3)$$

With

$$Q_{Str} = S \times K \times (\theta_{eb} - \theta_{ib}) \quad (4)$$

$$Q_{SRm} = S \times \alpha \times f \times R_m \quad (5)$$

$$Q_{SRv} = 0 \text{ : No glazing} \quad (6)$$

$$Q_{Sr} = q_v \times (\theta_{eb} - \theta_{ib}) \times 0{,}33 \quad (7)$$

$$Q_{Lr} = q_v \times (\omega_e - \omega_i) \times 0{,}84 \quad (8)$$

$$Q_{SOc} = n \times C_{SOc} \quad (9)$$

$$Q_{LOc} = n \times C_{LOc} \quad (10)$$

$$Q_{ecl} = 1{,}25 \times P \quad (11)$$

Q_{Str} [W] Heat input transmitted by conduction and convection through walls; Q_{SRm} [W] Heat input transmitted by radiation through the walls; Q_{SRv} [W] Heat input transmitted by radiation through the glazing; Q_{Sr} [W] Sensitive gains through air exchange; Q_{Lr} [W] Latent Gains through Air Exchange; Q_{SOC} [W] Significant gains for occupants; QLOC [W] Latent gains for occupants; Q_{secl} [W] Heat input through lighting; $Q_{Sequipment}$ [W] Heat input by equipment; q_v [m^3/h]external air flow rate: one volume per hour; K [W/m.°C] the overall transmission coefficient; S [m^2] exchange surface; θ_{eb} [°C] outdoor temperature of the hottest day of the year 2018; θ_{ib} [°C] basic indoor air temperature; H_{reb} [%] relative humidity corresponding to the hottest day of the year 2018; H_{rib} [%] basic relative humidity inside the building; α absorption coefficient ; *f* solar radiation factor; R_m [W /m²] intensity of solar radiation on the walls; ω_e [g/kgas] Moisture content of outdoor air on the warmest day of the year 2018; ω_i [g/kgas] basic water content of indoor air; n number of persons; C_{Soc} [W] the sensible heat of the occupants; C_{Loc} [W] is the latent heat of the occupants; P [W] = 8 x S: Lamp power flux.

Let us state that, despite the fact that the study building was unoccupied at the time of our measurements, we considered making assumptions about occupancy (see Appendices 7 to 9).

3. RESULTS AND DISCUSSION

3.1 Verification of Bioclimatic Criteria

The results of the verification of bioclimatic criteria are summarized in Table 3.

Based on Table 3, we can conclude that six (06) bioclimatic principles out of eleven (11) are respected in the design.

3.2 Analysis of the Temperatures of the Interior and Exterior Surfaces of the Building Envelope

In this part, our analyses will focus on temperature variations of the interior and exterior surfaces of the walls, the roof (of all rooms). Thus, Tables 4 to 6 present the mean values of the thermal time lag, the decrement factor of the interior temperature and the thermal amplitudes of the different walls exposed to solar radiation of the study building. Since the partition walls as well as the floor are not exposed to the sun, it is therefore not interesting to calculate their thermal time lag and thermal decrement factors, especially since doors separating the different rooms have not been installed.

Table 3. Verification of building bioclimatic parameters

Verification parameters	Bioclimatic principles	Observation in relation to the study building	Principle respected?
Orientation of the main facade	North-South	Large façades oriented North-South	Yes
Internal organization	Living area not exposed (North-South)	Living area located on the West and East side	No
House shape	Extended	Rectangular	Yes
Glazing of openings	Glazing/Double Glazing	Absence of glazing	No
Protection of windows	Protection of openings against sunlight	No protection	No
Vegetation	Presence of vegetation against solar rays	Presence of vegetation	Yes
Solar protection of walls	Protection of walls against solar rays	No protection	No
Local materials for wall construction	Local and high thermal inertia materials	Adobe and BLT	Yes
Roof	Insulating roof	Local materials with high thermal inertia	Yes
Semi-passive cooling system	Passive or semi-passive air renewal	Absent	No
Energy source	Absence of fossil energy (SONABEL*)	Absent	Yes

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Table 4. Mean values of amplitudes, decrement factors, thermal time lag for the 3 days of measurement_HALL

Parameters	East Wall	West Wall	North Wall / Partition Wall	South Wall	Roof	Floor
Temperature amplitude of internal surfaces [°C] ± 0.05 %	1.23	0.97	0.53	0.60	3.40	0.67
Temperature amplitude of external surfaces [°C] ±0.05 %	13.13	25.33	0.63	26.53	31.17	-----
Thermal time lag [h]	8.33	7.33	-----	8.67	6.33	-----
Decrement factor of temperature of internal surfaces [%]	9.41	3.83	-----	2.26	10.94	-----

Table 5. Mean values of amplitudes, decrement factors, thermal time lag for the 3 days of measurement_BEDROOM 1

Parameters	East Wall	West Wall / Partition Wall	North Wall	South Wall / Partition Wall	Roof	Floor
Temperature amplitude of internal surfaces [°C] ± 0.05 %	1.17	0.50	0.37	0.37	4.13	0.50
Temperature amplitude of external surfaces [°C] ±0.05 %	11.23	0.60	13.20	0.63	31.17	-----
Thermal time lag [h]	8.33	-----	8	-----	4.33	-----
Decrement factor of temperature of internal surfaces [%]	10.39	-----	2.80	-----	13.30	-----

Table 6. Mean values of amplitudes, decrement factors, thermal time lag for the 3 days of measurement_BEDROOM 2

Parameters	East Wall / Partition Wall	West Wall	North Wall	South Wall / Partition Wall	Roof	Floor
Temperature amplitude of internal surfaces [°C] ± 0.05 %	0.60	1.13	0.50	0.53	5.17	0.50
Temperature amplitude of external surfaces [°C] ±0.05 %	0.50	23.93	13.20	0.63	31.17	-----
Thermal time lag [h]	-----	8.67	8	-----	4.67	-----
Decrement factor of temperature of internal surfaces [%]	-----	4.76	3.80	-----	16.61	-----

3.2.1 About the walls

In addition to a substantial wall thickness (60 cm), the eastern face of the building is exposed to the sun, but this exposure is attenuated by vegetation (Fig. 1). Indeed, a tree positioned opposite and covering more the side of bedroom 1, helps to block the sun's rays from the moment it rises until it is at its zenith.

According to the results of Tables. 4 to 6:

- There are low amplitudes of the temperatures of the inner surfaces of the walls. In particular, thermal amplitude lower than 1°C for the wall facing North. For the other walls, we also obtained low thermal amplitudes on the interior surfaces, the maximums, lower than 1.5°C, being observed on the walls facing East and West. In other words, the temperature variation of the inner faces is very small despite the high thermal amplitudes observed on the outer faces (more than 10°C).
- In addition, we obtain mean thermal phase time lag value between 7 hours and 8 hours for all the walls. These results indicate an attenuation of the temperature fluctuations at the interior surfaces in the case of the study building.
- As for the decrement factors, which correspond to the percentage of thermal flux transmitted through the walls, except for the wall facing East for which the decrement factor is 10.39%, the values are less than 5%.

3.2.2 Report on the roof

From 9am to 5pm the temperature of the inside face is lower than the outside face and from 6pm to 8am the temperature of the inside face is higher than the outside face. This is to be expected due to the drop in outside air temperature during the night and the inertia of the building walls.

Another observation is that the internal and external surfaces thermal amplitudes of the roof are the highest of envelope of the study building (see Tables 4 to 6). The roof is the most exposed part of the building and therefore receives a lot more of solar radiation.

At last, despite the high temperatures of the exterior face of the roof, we find decrement factors of 10.94%, 13.33% and 16.61% respectively at the level of the hall, bedroom 1 and bedroom 2 (Tables 4 to 6). The thermal time lag of the roof obtained is in average 6 hours for the hall and 4 hours for the bedrooms.

Compared to the walls, these results are expected because a large part of the heat gains occur at the roof (about 30% to 40% of the heat gains in buildings [17]). In addition, the walls of the bedrooms, apart from the West facing wallof bedroom 1, are the least exposed to the sun. Consequently, their surface temperatures are more influenced by those of the hall and its ambience.

3.3 Evaluation of Thermal Charges Using the Simplified Heat Balance Method

Tables 7 and 8 summarize the heat balance results for the study Nubian vault building and the imaginary building made of cinder blocks.

Table 7. Total thermal loads of the different rooms of the he study Nubian vault building

Rooms	External loads [w]				Internal loads [w]				Q_{ST}
	Q_{Str}	Q_{SRm}	Q_{Sr}	Q_{Lr}	Q_{SOC}	Q_{LOC}	$Q_{sélec}$	$Q_{séquip}$	
Hal	1405.69	2353.72	254.10	249.48	252	236	148	1050	5948.99
Bedroom 1	877.79	1559.87	161.70	158.76	126	118	93.44	250	3345.57
Bedroom 2	935.86	1449.65	161.70	158.76	126	118	99.68	250	3299.65
Total q_{st}	3219.34	5363.25	577.50	567	504	472	341.12	1550	12594.21
	9727.09				2867.12				
	12594.21								

Table 8. Total thermal loads of the different rooms of the building made of cinder blocks

Rooms	External loads [w]				Internal loads [w]				Q_{ST}
	Q_{Str}	Q_{SRm}	Q_{Sr}	Q_{Lr}	Q_{SOC}	Q_{LOC}	$Q_{sélec}$	$Q_{séquip}$	
Hal	3143.06	2353.72	254.1	249.48	252	236	148	1050	7686.36
Bedroom 1	2174.59	1559.87	161.7	158.76	126	118	93.44	250	4642.37
Bedroom 2	2162.75	1449.65	161.7	158.76	126	118	99.68	250	4526.55
Total q_{st}	7480.41	5363.25	577.5	567	504	472	341.12	1550	16855.27
	13988.15				2867.12				
	16855.27								

For the same internal charges, the heat balance that we carried out shows that the Nubian vaulted building envelope reduces by a little more than one third (1/3) the thermal loads of a cinder block building covered with aluminum roofing sheet and having the same surface area as the habitat of the study. Consequently, the Nubian vault housing envelope is more energy efficient in tropical climates than conventional cinder block housing and can therefore be an energy-saving solution. This is also significant for the environment.

4. CONCLUSION

The results allowed us to conclude that our Nubian vaulted study building does not meet all the bioclimatic criteria, in particular, the internal organization of the rooms, the protection of the openings and the south wall exposed to the sun's rays and the presence of a semi-passive cooling system for the renewal of indoor air. In addition, with thermal amplitudes below 1.5°C for the walls and 5°C for the roof, a decrement factor below 12% for the walls and 17% for the roof and a thermal time lag of 6 to 8 hours in average for the walls and 4 to 6 hours in average for the roof, the Nubian vaulted building envelope has considerable assets for thermal comfort due to its interesting thermal inertia. Finally, the evaluation of the heat balance of the Nubian vault building revealed a reduction of a little more than one third (1/3) of the thermal loads compared to that of a conventional cinder block building. Therefore, the Nubian vault building envelope is indeed a solution for energy savings and more environmentally friendly practices. As a recommendation, a photovoltaic installation could be used as an energy supply, especially given the climatic advantages of the Sahelian zones. We also recommend a plant plantation on the south side and/or solar protection for the openings on the same side. Finally, to limit the action of erosion on the walls of the Nubian vault building while using local materials that are more environmentally friendly, we recommend adding a layer of lime plaster on the outer envelope.

As a perspective, it would be interesting to analyze the envelope performance through a whole year.

This work is an advocacy for the spreading of local adapted construction as Nubian Vault construction and techniques.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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