Current Journal of Applied Science and Technology

39(29): 110-123, 2020; Article no.CJAST.61284
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Valorization of Local Construction and Technique: Hygrothermal Behavior, Thermal and Visual Comfort of a Nubian Vaulted Construction in Sahelian Climate of Ouagadougou

Fati Zoma[1,2*], David Y. K. Toguyeni[1,3], Barkwendé Jude Kiemtoré[4] and Emmanuel Ouedraogo[4,5]

[1]Laboratory of Physics and Chemistry of Environment, University Joseph KI-Zerbo, Ouagadougou, Burkina Faso.
[2]University of Fada N'Gourma, P.O. 54, Fada N'Gourma, Burkina Faso.
[3]Polytechnic School of Ouagadougou, Ouagadougou, Burkina Faso.
[4]Laboratory of Thermal and Renewable Energies, University Joseph KI-Zerbo, Ouagadougou, Burkina Faso.
[5]University of Ouahigouya, P.O. 346, Ouahigouya, Burkina Faso.

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.

Article Information

DOI: 10.9734/CJAST/2020/v39i2930963
Editor(s):
(1) Dr. Jakub Kostecki, University of Zielona Góra, Poland.
Reviewers:
(1) Marco César Prado Soares, University of Campinas, Brazil.
(2) Sridhar Mandava, Gokaraju Rangaraju Institute of Engineering and Technology, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/61284

Original Research Article

Received 10 July 2020
Accepted 15 September 2020
Published 29 September 2020

ABSTRACT

This study allowed appreciating hygrothermal behavior, thermal comfort and the visual comfort of an existing Nubian vaulted building in the city of Ouagadougou. To achieve that purpose, we measured parameters such as the temperature and relative humidity of the indoor and outdoor environments as well as illumination by daylight inside the studied building. The measurement campaign consisted of two (02) series of three (03) days in January 2018: one series with insulation of the louvered openings by polystyrene and the other series without the insulation. We carried out the

Corresponding author: E-mail: fatesmir@yahoo.fr;

measurements of relative humidity and illumination at 7, 10, 12, 15, 17, 20 and 22 o'clock and adopted a one-hour measurement time step for temperatures. The analysis of these parameters showed that the level of natural lighting in the building was insufficient. In addition, for the indoor ambiance, we have obtained indoor thermal amplitude less than 1.5°C, a decrement factor of less than 6%, a time lag of 6 to 8 hours. As for operative temperatures, they are within the thermal comfort zone of the Givonni diagram. As for the couple (Temperature, Relative Humidity), the thermal comfort zone proposed by Givonni is reached when the louver openings are insulated.

Keywords: Nubian vault; hygrothermal analysis; thermal comfort; thermal time lag; thermal decrement factor; thermal amplitude.

1. INTRODUCTION

In recent years, earthen constructions have proved to be an answer to the problems of thermal (comfort) in buildings, energy demand and the negative impact of the construction sector on the environment.

Indeed, with conventional constructions in concrete and metal sheet for the roof, the indoor environment experiences almost the same thermal evolution as the outside [1]. In such cases, a problem of thermal comfort arises due to the harshness of the Sahelian climate, which is hot and dry. Yet conventional constructions are common in urban areas where access to electricity, mainly of thermal origin, is more evident. One thing leading to another, we are witnessing a significant demand (consumption) of energy to compensate for the situation of discomfort. In regions with a tropical climate, estimates indicate that between 40% and 80% of total electricity consumption in buildings is used for air-conditioning [2]. Overall, from the manufacture of construction materials to the operation of the building, the environment is affected: 46.9% of total greenhouse gas emissions worldwide [3]: Hence the renewed interest in earthen constructions. To this can be added the political will of WAEMU to integrate energy efficiency requirements into the building code throughout its jurisdiction [4].

Thus, in the same dynamic, the thermal monitoring of earthen constructions is necessary to know the efficiency of the materials and techniques used in the real case.

We can count the work of Bernouali et al. [5] on two (02) buildings with compressed mud brick walls and flat insulated roofs.

In Burkina Faso, LAWANE et al. carried out an experimental study by following the hygrothermal behaviour of a cut laterite brick (BLT) construction [6]. More recently, MALBILA et al. looked at two social houses in Bassinko in the city of Ouagadougou and compared them. One was made of BLT and the other of cinder block, both houses having sheet metal for roofs [7].

For our study, we were interested in houses built with the technique of Nubian vault (NV) construction.

In the 2000s, WYSS and SAURET carried out a similar study [8], during the rainy season in the region of Banfora (South-West of Burkina Faso), on a 2nd generation Nubian Vaulted housing with walls entirely made of adobe; they showed that the studied earthen construction, that is made without wood or steel, offers a better adaptation to the Sahelian climate compared to a housing made of sheet metal and cinder blocks. However, the technique has evolved since 2007 to adapt to local realities, with increasingly refined comfort indicators.

In this paper, our study focuses on an existing Nubian Vaulted building, but this time, built in adobe and cut laterite bricks (BLT), in the urban area of Ouagadougou. More specifically, we carried out measurements during Harmattan season in order to analyzing hygrothermal behavior, thermal and visual comfort that can occur in the Nubian vaulted building.

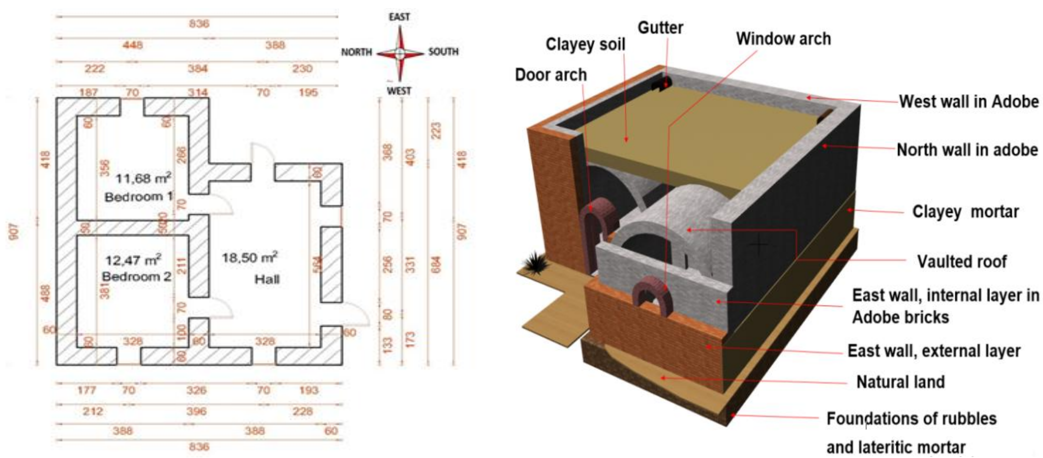
Our goal through this study is the promotion of local constructions and techniques. It is also an advocacy for the implementation of thermal regulations based on local techniques and know-how.

2. METHODOLOGY

2.1 Presentation of the Studied Building

The studied building (Fig. 1) 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. Image of the East and West facades of the studied building



(a) (b)

Fig. 2. (a) Level plan of the studied Nubian vault building. (b) 3D sketch of the studied building

In this study, the Nubian Vault (NV) building consists of a living room and two bedrooms, with a total floor area of 42.65 m^2 (Fig. 2 (a)). Fig. 2 (b) displays a sketch of the layers in the studied habitat.

The roof, a terrace type, is made of two vaults of different lengths, 9.06 m and 8.36 m and built with adobe at 3.10 m 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 . The construction of the vaults does not require shuttering or any other kind of support [9].

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. Figs. 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 rubble stones and lateritic mortar filling a dig of 70 cm deep and 80 cm wide. Here, a plastic sheet is also used before elevation of load-bearing walls in order to prevent from capillary upwelling of water.

In sum up, the study Nubian vault building is without steel, without wood, without concrete.

Besides, the walls, entirely made of locally made materials with low negative impact on environment, are thicker: 60 cm instead of 25 cm which is widely encounter in cinder blocks buildings. As for the roof, apart from the presence of plastic sheet for water tightness, it is also made of locally made materials instead of aluminum roofing sheet encounter in cinder blocks buildings.

Let us state that, for the studied building, on the outside, a layer of cement coating was applied to the visible part of the joints for more protection; likewise interior surfaces where cement coating was applied for finishes.

General steps and technique of Nubian Vault construction are described in reference [9,10].

2.2 Comfort-Related Parameters

We intend to appreciate thermal and visual comfort.

According to Yves Jannot et al. the thermal comfort of a building depends mainly on the following parameters [11]:

- the air temperature
- air humidity
- wind speed inside the building
- the radiant temperature of the surrounding walls
- metabolism of the occupants
- the thermal resistance of the garment

In this study, given that the building is unoccupied, data collection was mainly based on measurements of the following parameters:

- temperatures of the building's internal and external environments.
- relative humidity inside and outside the building.
- illumination by daylight in the different rooms of the building.

The measurement campaign took place in the period from 03/01/2018 to 10/01/2018.

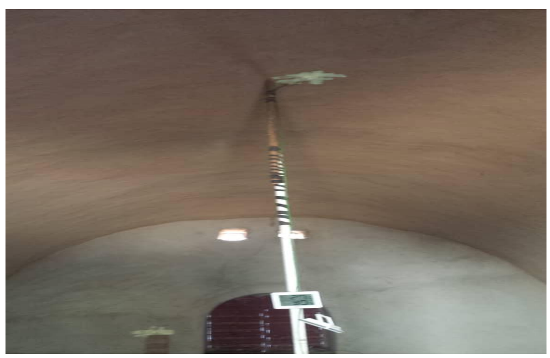


Fig. 3. The vault of the living room seen from the inside

(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]

2.2.1 Measuring ambient temperatures in different rooms

We performed two (02) series of measurements of three days each: a first series without insulating the window and door louvers with polystyrene and a second series with insulation to observe the impact of the insulation on the air infiltration (Fig. 5 (a), 5 (b)). To do this, thermocouples (probes) of types "k" and "J", attached to data loggers (with optimal temperature measurement accuracy of ± 0.05%), were placed on the internal and external faces of the walls. For the acquisition of the temperatures of the indoor environment, the thermocouple was suspended 1.5 m from the floor.

The measurement time step adopted for the temperatures is one hour (1h).

Fig. 6. shows the location of the thermocouples.

Let us state that, in order to minimize the parasitic effects and thermal resistance, 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 end points to the wall surfaces.
- In order to secure the thermocouples to the outside walls, 6mm clips were used (see Figs. 7 (b) and 9).

(a) (b)

Fig. 5. Image showing (a) window insulated with polystyrene; (b) Insulation of door with polystyrene.

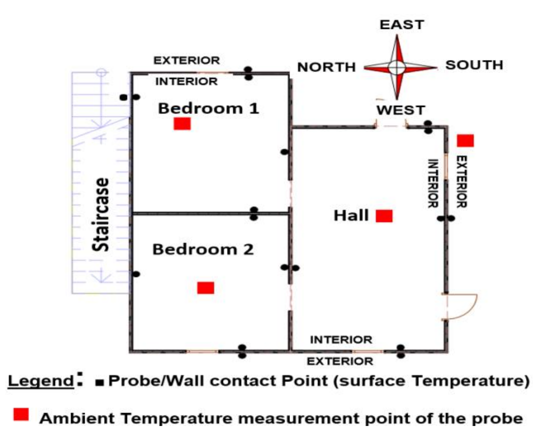
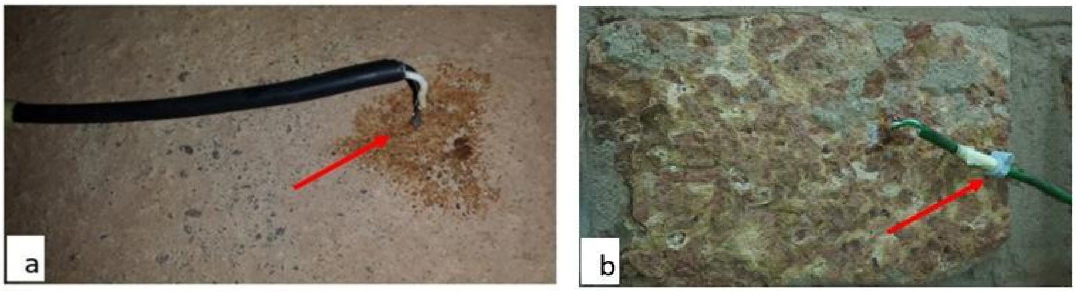
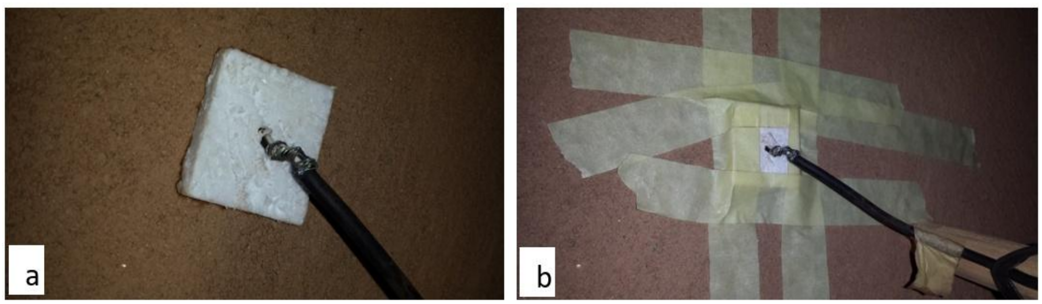


Fig. 6. Plan of the studied Nubian vault with location of the thermocouples (probes)



(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

2.2.1.1 Evaluation of operative temperatures: Indicators of the comfort of the environment surrounding the user

The ISO 7730 standard recommends limiting to 3°C the difference between the air temperature at 0.1 m and 1.1 m from the floor to prevent from the vertical temperature gradient heterogeneity [12] and a fortiori the discomfort. Indeed, the internal surface temperature of the walls influences the feeling of comfort of individuals. Hence the concept of the operative temperature as an indicator of comfort. In fact, the operative temperature is also known as the perceived temperature. It is then related to the temperature of the air in contact with the user. Whereas the modes of heat transfer between a solid and a fluid are convection and radiation. Thus the operative temperature depends on the average radiant temperature that is the temperature related to the feeling of the surrounding surfaces: walls, ceilings, floors and windows [13].

According to standard NF EN ISO 7726 of 2002, the operative temperature Top is determined according to the formula (1):

$$T_{op} = \frac{h_c * T_{air} + h_r * T_{mr}}{h_c + h_r} \quad (1)$$

T_{op}: operative temperature; T_{air}: room temperature; T_{mr}: mean radiative temperature; h_c and h_r: thermal coefficients for convection and radiation respectively.

In this study, we have chosen to keep the proposal of TRNSYS 16, which is inspired by formula (1), to calculate the operative temperatures of the different rooms of the building on the basis of the following expression:

$$T_{op} = A_{op} * T_{air} + (1 - A_{op}) * T_{surf} \quad (2)$$

With:

$$A_{op} = \frac{h_c}{h_c + h_r} \quad (3)$$

$$T_{surf} = \frac{\sum_j h_{ci_{wall}} \times T_{W_j} + h_{ci_{ceiling}} \times T_{C_i} + h_{ci_{floor}} \times T_F}{4 \times h_{ci_{wall}} + h_{ci_{ceiling}} + h_{ci_{floor}}} \quad (4)$$

$$h_r = 4 \times \varepsilon \times \sigma \times T_a^3 \quad (5)$$

T_{air}: indoor room temperature; T_{surf}: weighted average value of wall temperatures; T_{wj}: interior surface temperature of wall j; T_{Ci}: interior surface temperature of ceiling; T_F: interior surface temperature of the floor; h_c: convection heat transfer coefficient; h_r: radiation heat transfer coefficient; $h_{ci,wall}$: convective heat transfer coefficient of the internal surface of the wall (Appendix 1); $h_{ci,ceiling}$: convective heat transfer coefficient of the ceiling ; $h_{ci,floor}$: convective heat transfer coefficient of the internal surface of the soil.

Fig.10. illustrates the heat transfer in the building, between wall and the indoor air.

2.2.1.2 Thermal time lag, decrement factor for indoor temperatures

To evaluate the thermal comfort of the study dwelling, we also determined dynamic parameters such as thermal time lag in hours ([h] formula (6) [14]), decrement factors of the indoor temperature in percent (Am [%] formula (7) [14]) and the thermal amplitudes in degrees Celsius (ΔT [°C]).

While thermal time lag of a building informs on the delay taken by heat flux to pass through the wall, decrement factor evaluates the mitigation of heat flux through the wall. As for thermal amplitude, it provides information on the range of temperature fluctuation.

Thus, for indoor thermal comfort, a large thermal time lag, a low decrement factor and small amplitude of the indoor temperature is required. Fig. 11. illustrates these parameters.

$$\Psi = t_{T_{int,max}} - t_{T_{ext,max}} \quad [h] \quad (6)$$

$$Am = 100 \times \frac{\Delta T_{int}}{\Delta T_{ext}} \quad [\%] \quad (7)$$

2.2.2 Relative humidity

The relative humidity (HR) of humid air, expressed as a percentage, compares the water vapour content of air to the saturation water vapour content at the same temperature. In a building, it is a determining factor for the thermal comfort of the occupants, hence the need to measure its variation over the course of the day.

An Otio type hygrometer, with a sensitivity for values greater than or equal to 20%, was hung in the middle of the rooms at a height of 1.70 m from the low floor to collect the different relative humidity values in percentage (%) at the following hours: 7, 10, 12, 15, 17, 20 and 22 o'clock; at the same time, the relative humidity of the environment outside the building was collected.

2.2.3 Daylight Illumination (illumination by daylight)

Illuminance is the quotient of the luminous flux received to a surface element; its unit in the International System [SI] is lux. Solar daylighting is ideally sought after in a building to save energy consumption.

For good daytime illuminance inside the building, certain bioclimatic architectural provisions must be respected. The purpose of these measures is to see whether the building meets visual standards.

In general, the proportion of daylighting is not defined by the regulations precisely because it

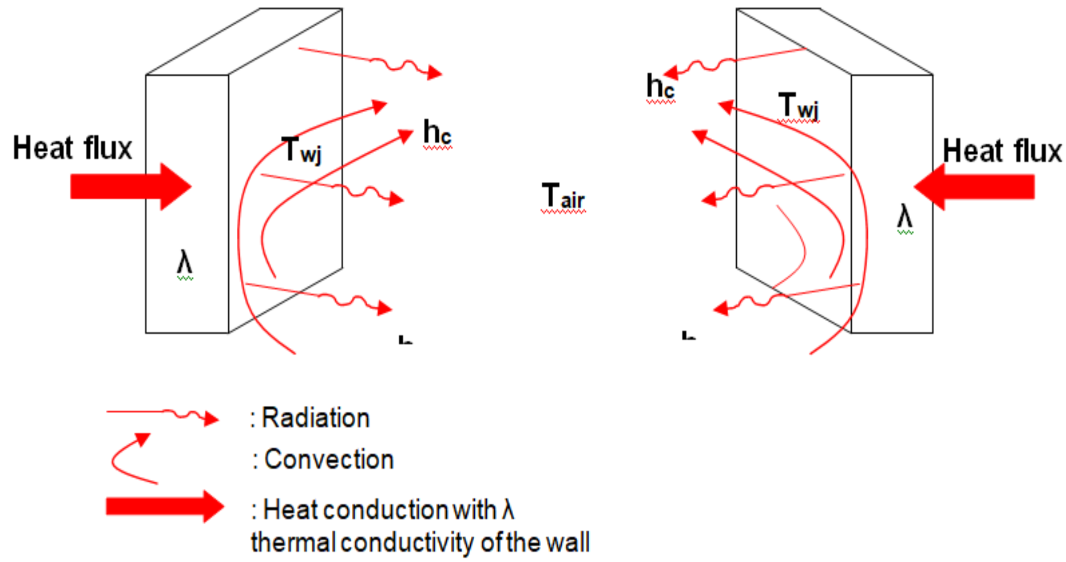


Fig. 10. Illustration of heat transfer between wall and the indoor air

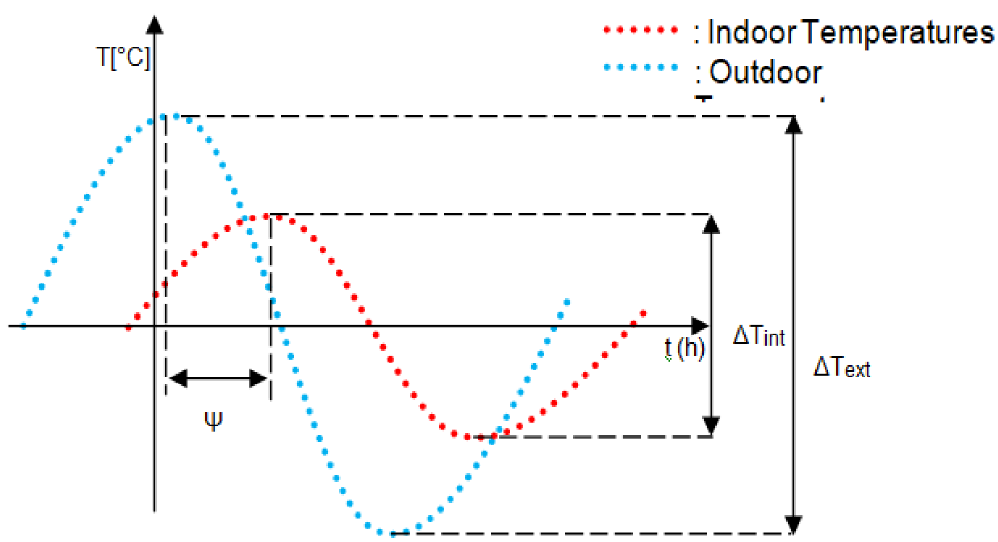


Fig. 11. Illustration of thermal time lag Ψ, decrement factor and thermal amplitudes ΔT

depends on the architecture, the time of year and the time of day. According to the prescriptions of the NF EN 12464-1 standard for restaurants, hotels, reception, cash desks and concierges, the average illuminance should be maintained in 300 lux [15].

For the measurements of the illuminance inside the building, we used a LT lutron LX-107 type luxmeter with an accuracy of ± 5% (+2 digits) for the measurement. The information was collected at the following hours of the day: 7, 10, 12, 15, 17, 20 and 22 o'clock.

3. RESULTS AND DISCUSSION

3.1 Analysis of Ambient Temperatures

When we compare the average maximum and minimum temperatures of the indoor environment of the series where the louvered openings were covered with polystyrene with the temperatures of the indoor environment of the series without the insulation, for each of the rooms, we find a temperature difference of less than 1°C and 1.5°C, respectively, for the maximum and minimum temperatures (Table 1). Therefore, the polystyrene insulation of the louvers did not have a major impact on the indoor temperatures of the NV building environment.

In this section, our analyses will be focused on ambient temperature variations of, only, the series of measurements without insulation (of all rooms).

Table 2 shows the mean values of the thermal time lag, decrement factor of the indoor temperature and the thermal amplitudes of the indoor-outdoor environment of the studied building.

We make the following observations and analyses:

- From 8:00 pm to 7:00 am the temperature of the outdoor environment is lower than the indoor one and from 8:00 am to 7:00 pm the trend is reversed (Appendix 1). This is attributable to the drop in temperature of the outside air during the night and vice versa during the day, but also to the effect of the inertia of the building envelope.

- If we look at the graph of Fig. 12, which shows how the temperatures of the environments (indoor and outdoor) evolve during the time, we can see that the curves of the indoor environment of the rooms remain almost constant. This is corroborated by the small amplitudes of the indoor temperatures: 1.27°C, 0.73°C and 0.90°C, respectively, for the living room, bedroom 1 and bedroom 2 (Table 2). A similar work on a building with 30 cm thick walls consisted of BLT and a corrugated roof with a false ceiling 1.5 m below the level of the sheet metal [6], showed an indoor thermal amplitude of 5°C during dry season in Ouagadougou which includes January. Therefore, with 60 cm walls and a roof made of local materials, interior temperature amplitudes of less than 2°C, decrement factors of less than 6% and thermal time lag of at least 6 hours, the studied Nubian vault building indicates an interesting thermal inertia.
- Table 3 presents the mean radiant temperatures taken equal to the weighted average values of the wall temperatures (see formula (4)) and the operative temperatures for each room and for the three (03) days of measurements.

We note that the operative temperatures are close to the mean radiant wall temperatures. Moreover, the operative temperatures are within the thermal comfort zone of the Givonni diagram, which corresponds to the temperature range [20°C; 27°C].

Overall, these different observations could be explained by the thickness of the walls and the type of materials of which the Nubian vault construction is made. Indeed, the increase in wall thickness leads to a greater specific heat capacity and therefore significantly reduces the temperature fluctuation of the inner surface of the wall. Moreover, the small fluctuation in the temperature of the indoor air is also due to the roof built in raw earth with a significant thickness. A study carried out by TOGUYENI and al [16] has shown actually the importance of insulating the roof with local materials to reduce air conditioning loads, air conditioning being needed to avoid temperature fluctuations which cause discomfort.

Table 1. Average minimum and maximum indoor air temperatures

		Non-insulated louvers [°C] ±0.05 %	Louvers insulated with polystyrene [°C] ±0.05 %	Difference [°C] ±0.05 %
Hall	min	25.73	24.50	1.23
	MAX	27	27.47	0.47
Bedroom 1	min	26.30	25.03	1.27
	MAX	27.03	26.80	0.23
Bedroom 2	min	25.93	24.70	1.23
	MAX	26.83	26.73	0.10

Table 2. Mean values of the thermal amplitudes, thermal time lag, and decrement factors of the indoor/outdoor environment for the 3 days of measurement without insulation

Parameters	Hall	Bedroom 1	Bedroom 2
Amplitude of indoor temperatures [°C] ±0.05 %	1.27	0.73	0.90
Amplitude of outdoor temperatures [°C] ±0.05 %	22.10	22.10	22.10
Thermal time lag [h]	7	8	6
Decrement factor [%]	5.73	3.32	4.08

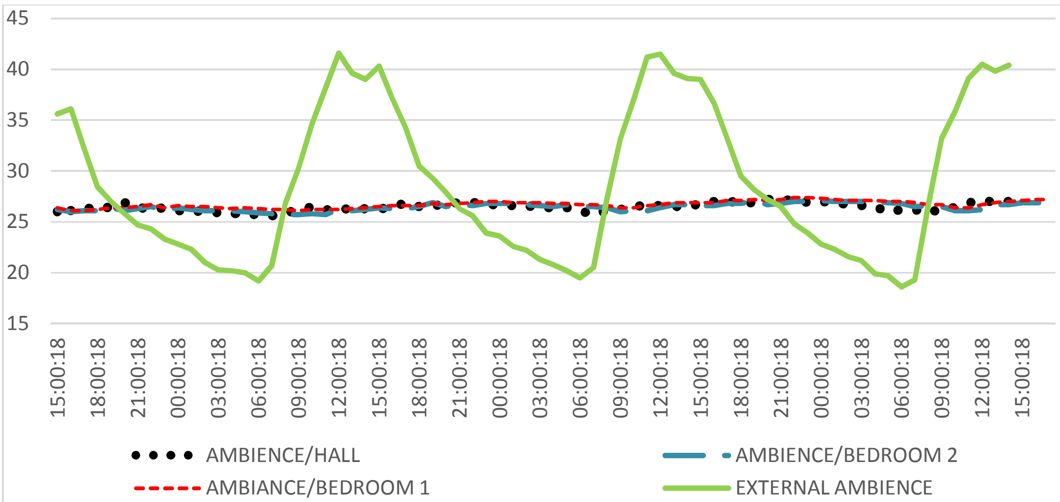


Fig. 12. Evolution of indoor and outdoor temperatures of room for the three days of measurement

Table 3. Mean operative temperatures Top and radiant temperatures T_{surf} of the rooms and for each series of measurements

HALL			
Series of measures	T_{surf} [°C] ± 0.05 %	A_{op} (formula (4))	T_{op} [°C] ±0.05 %
Measures of day 1	26.61	0.999382	26.25
Measures of day 2	27.07	0.999378	26.30
Measures of day 3	27.13	0.999360	26.55
Bedroom 1			
Series of measures	T_{surf} [°C] ± 0.05 %	A_{op} (formula (4))	T_{op} [°C] ±0.05 %
Measures of day 1	26.42	0.999371	26.40
Measures of day 2	27.11	0.999349	26.70
Measures of day 3	26.93	0.999335	26.90
Bedroom 2			
Series of measures	T_{surf} [°C] ± 0.05 %	A_{op} (formula (4))	T_{op} [°C] ±0.05 %
Measures of day 1	26.31	0.999392	26.10
Measures of day 2	26.98	0.999367	26.45
Measures of day 3	26.80	0.999357	26.60

3.2 Analysis of Hygrothermal Data

Firstly, looking at Table 4, in daytime, the relative humidity (HR) of the air outside the building is less than 20%. This is also the case in the different rooms of the building from sunrise to sunset for measurements made without louver insulation, and it is around 8 p.m. that the humidity level starts to reach values between 21% and 22%. On the other hand, when the louvered doors and windows are insulated with polystyrene (Fig. 5), we find that the relative humidity in the rooms of the studied building is between 25% and 40% from 7 a.m. to 10 p.m. (Table 4).

Table 4. Relative humidity in the rooms

Time	Exterior air relative humidity HR [%]		Hall relative humidity HR [%]		Chamber 1 relative humidity HR [%]		Chamber 2 relative humidity HR [%]	
	with no insulation	with insulation	with no insulation	with insulation	with no insulation	with insulation	with no insulation	with insulation
7	0*	0	24	27	0	29	0	28
10	0	0	0	29	0	30	0	30
12	0	0	0	35	0	37	0	36
15	0	40	0	36	0	39	0	37
17	0	22	0	36	0	38	0	38
20	0	0	21	33	21	35	22	35
22	0	0	21	34	21	36	21	35
7	0	0	0	32	0	37	0	35
10	0	28	0	36	0	36	0	34
12	0	27	0	39	0	40	0	40
15	0	0	0	39	0	41	0	40
17	0	0	0	33	0	37	0	36
20	0	0	0	33	0	34	0	36
22	0	0	0	31	20	33	0	34
7	0	0	0	30	0	30	0	32
10	0	0	0	30	0	31	0	32
12	0	0	0	36	0	34	0	37
15	0	0	0	34	0	35	0	37
17	0	0	0	32	0	29	0	34
20	0	0	21	29	20	25	20	28
22	0	0	0	28	20	28	21	24

Table 5. Pair (Temperature and Relative humidity) in the hall

	Relative Humidity		Temperature	
Time [O'clock]	HR [%] without insulation	HR [%] with insulation	T°C [°C] without insulation	T°C [°C] with insulation
15	0	27	26.1	26.5
17	0	29	26.4	26.8
20	21	35	26.9	26.4
22	21	36	26.7	26.2
7	0	36	25.8	24.9
10	0	33	26.4	26.1
12	0	34	26.1	26.8
15	0	32	26.5	26.7

Table 6. Pair (Temperature and Relative humidity) in bedroom 1

	Relative Humidity		Temperature	
Time [O'clock]	HR [%] without insulation	HR [%] with insulation	T°C [°C] without insulation	T°C [°C] with insulation
15	0	29	26.1	26.5
17	0	30	26.4	26.5
20	21	37	26.7	26.5
22	21	39	26.6	26.5
7	0	38	26	25.2
10	0	35	26.2	25.9
12	0	36	26.4	26.2
15	0	37	26.6	26.7

Table 7. Pair (Temperature and Relative humidity) in bedroom 2

	Relative Humidity		Temperature	
Time [O'clock]	**HR [%] without insulation**	**HR [%] with insulation**	**T°C [°C] without insulation**	**T°C [°C] with insulation**
15	0	28	26	26.3
17	0	30	26.3	26.4
20	22	36	26.5	26.2
22	21	37	26.4	26
7	0	38	25.9	24.9
10	0	35	26.2	25.4
12	0	35	26	26
15	0	35	26.3	26.3

The low relative humidity values inside the rooms in the absence of insulation are therefore due to the solar irradiation and the infiltration of outside air through the louvers. In fact, the infiltrations of outside dry air are considerably reduced due to the insulation, resulting in relative humidity values (of all rooms) within the comfort zone of the Givonni diagram ([20% - 80%]).

Secondly, temperature and relative humidity are two related parameters. As the temperature rises, the relative humidity decreases. Tables 5, 6, 7 show the temperature-relative humidity pairs of the different rooms of the building for cases with and without insulation.

We can therefore conclude that the insulation of the louvered doors and windows in the studied building brought the couple (Temperature, Relative Humidity) within the comfort zone of the Givonni diagram: [20°C; 27°C] and [20%; 80%]. This confirms that the insulation of the openings improves thermal comfort by reducing the infiltration (of outside air) which is responsible for the highest thermal gains in the building after the roof [17].

3.3 Illumination Level by Daylight

Table 8 shows the daylight illuminance values measured in the rooms of the building and the outdoor environment.

Table 8. Illuminance values in individual rooms

	Illuminance [Lux] or [lumen/m^2]			
Time [O'clock]	**Exterior (outdoor)**	**Hall**	**Bedroom 1**	**Bedroom 2**
7	530	13	2	0
10	535	40	5	4
12	550	40	11	5
15	1260	15	6	2
17	530	8	3	0
20	0	0	0	0
22	0	0	0	0
7	512	11	3	1
10	570	66	8	5
12	640	58	9	3
15	585	41	10	3
17	425	9	4	0
20	0	0	0	0
22	0	0	0	0
7	505	14	2	0
10	535	65	6	5
12	633	50	13	8
15	424	42	16	4
17	900	4	1	0
20	0	0	0	0
22	0	0	0	0

We can see that the measured illuminance values for the different rooms range from 0 Lux to 65 Lux, which is lower than the recommended value of 300 Lux. Consequently, the studied building does not have the minimum recommended illuminance at times of high sunlight. In conclusion, the building does not meet the comfort criteria with regard to illuminance: lack of visual comfort.

4. CONCLUSION

The results allowed us to conclude that our study Nubian vault building offers insufficient lighting inside and therefore visual comfort is not reached. However, from the point of view of the thermal comfort of the studied building, the calculated operative temperatures are within the thermal comfort zone of the Givonni diagram, but the relative humidity in the rooms only becomes adequate for thermal comfort when the louvered openings are insulated to limit the infiltration of solar rays and outside air. Furthermore, with thermal amplitudes of the indoor air below 1.5°C, a damping factor of less than 6% and a thermal phase shift of 6-8 hours on average, the Nubian vault construction has an interesting thermal inertia, which is in accordance with the thermal comfort noted. As a recommendation, for lighting, a photovoltaic installation could be used to increase the illumination during the day, especially in rooms where the light is very low. Having also noticed the impact of the insulation of the louvers, we recommend double glazing or glazing insulated with solar film for all openings. In perspective, it is important to do the same measurements during rainy and hot season and appreciate the hygrothermal behavior. Moreover, it would be interesting to evaluate the specific energy consumption factor of such a building, which is a key indicator established by thermal regulations for new constructions.

ACKNOWLEDGEMENTS

Our gratitude goes to Mr. Boureima OUEDRAOGO who graciously granted access to his Nubian vaulted house for the needs of this study.We would also like to thank the IRSAT (Institute for Research in Applied Sciences and Technologies) in Burkina Faso for making the luxmeter available to us.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Wyss Urs, Sauret Hugues. Comfort project in the Nubian vault technique. ENERSOL-A. French; 2007.
2. Kemajou A. Ventilation and Air Conditioning Systems, Usually Observed Problems and Technical Solutions, Case Studies. Editor. IEPF (Quebec) G1K4A1 Canada. French; 2002.
3. International Panel on Climate Change (IPCC). Climate Change 2007: Synthesis Report, Summary for Policymakers; 2016. Available:http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.
4. West African Economic and Monetary Union (WAEMU). WAEMU draft of regional code of energy efficiency for new buildings . Draft document. French; 2014.
5. Bernouali H, Brara A, Mahdad M, Mokhtari, F. Thermophysical characterization and thermal monitoring of two buildings made of compressed earth blocks. Annales du bâtiment et des travaux publics. French. 201 1;86(16):8–14.
6. Abdou LAWANE GANA. Characterization of indurated lateritic materials for better use for habitat in Africa. Thesis. University Le Havre (ULH) and International Institute of Water and Environmental Engineering (2iE); Ouagadougou. French ; 2014.
7. Etienne Malbila, David YK, Toguyeni D. Joseph Bathiebo, Jean Koulidiati. Hygrothermal behavior of two buildings constructed in cement bricks and cut laterite blocks. International conference on Energy, Environment and Economics proceedings; 2017.
8. Wyss U, Sauret H. Indicators of comfort in the Nubian vault technique. EPFL - interim report, Association La Voûte Nubienne (AVN). France; 2007.
9. ASSOCIATION LA VOUTE NUBIENNE. Basic technical rules: Nubian vault technical concept (VN). French ; 2014. Available: www.lavoutenubienne.org
10. ASSOCIATION LA VOUTE NUBIENNE. The Nubian Vault, a technical solution for adapted bioclimatic constructions in Africa. French; 2020. Available:https://www.lavoutenubienne.org/IMG/pdf/20-01_concept-tech-vn_usages_technique-construction.pdf
11. Y Jannot, T Djiako. Energy saving and thermal comfort in homes in tropical areas.

Inter-State School of Engineering. Reviewed. Int. Cold. French. 1994;17(3): 166-173.
12. Bassam MOUJALLED. Dynamic modeling of thermal comfort in naturally ventilated buildings. Sciences Institut of Lyon. France; 2017.
13. Abdoulaye COMPAORE. Study of the thermal performance of a typical habitat in Burkina Faso. Application: contribution to the implementation of thermal regulations. Thesis. University of Ouagadougou, Burkina Faso. French; 2017.
14. Layal Chahwane. Valorization of thermal inertia for the energy performance of buildings. Thesis. University of GRENOBLE. French; 2011.
15. Interior lighting Technical guide; 2020. Available:https://www.aitf.fr/system/files/files/egt_nrj_aitf-edf_guide_ecclairage.pdf.
16. David Toguyeni, Ousmane Coulibaly, Abdoulaye Ouedrago, Jean Koulidiati, Yvan Dutil, Daniel Rousse. Study of the influence of local insulating roofing materials on the air conditioning loads of a clay-straw detached house. International Francophone Colloquium of Energy and Mechanics. Ouagadougou, Burkina faso, French; 2012.
17. Ousmane COULIBALY. Contribution to the development of thermal and energy regulations for buildings in Burkina Faso: Basic multiparametric baseline data and thermo-aeraulic modeling CoDyBa and TRNSYS. Thesis, University of Ouagadougou. French. 2011;1-207.

APPENDIX

Appendix 1. Maximum (MAX) and minimum (min) indoor ambient temperatures (indoor air) for each room with corresponding hours / Case without insulation

			Hall		Bedroom 1		Bedroom 2	
			Temperature [°C] ±0.05 %	Time	Temperature [°C] ±0.05 %	Time	Temperature [°C] ±0.05 %	Time
Measures of day 1	Indoor	min	25.6	7	26.1	7	25.7	7
		MAX	26.9	20	26.7	20	26.5	20
	Outside	min	19.2	6	19.2	6	19.2	6
		MAX	41.6	12	41.6	12	41.6	12
Measures of day 2	Indoor	min	25.7	7	26.4	8	26	7
		MAX	26.9	17	27	21	26.9	17
	Outside	min	19.5	6	19.5	6	19.5	6
		MAX	41.5	12	41.5	12	41.5	12
Measures of day 3	Indoor	min	25.9	8	26.4	8	26.1	8
		MAX	27.2	20	27.4	20	27.1	17
	Outside	min	18.6	6	18.6	6	18.6	6
		MAX	40.5	12	40.5	12	40.5	12

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/61284