Journal of Building Construction and Planning Research, 2023, 11, 69-85
https://www.scirp.org/journal/jbcpr
ISSN Online: 2328-4897
ISSN Print: 2328-4889

Study of Construction Techniques and Hygro-Thermal Behavior of a Vernacular Earth Building in a Humid Tropical Climate

Mouhamadou Nabi Kane[1*], Mapathe Ndiaye[2], Emilie Pinard[3]

[1]University College of Architecture Dakar (CUAD), University of Thies, Thies, Senegal
[2]Laboratory of Mechanics and Modeling, University of Thies, Thies, Senegal
[3]McEwen School of Architecture, Laurentian University, Sudbury, Canada
Email: *mnabi.kane@univ-thies.sn

How to cite this paper: Kane, M.N., Ndiaye, M. and Pinard, E. (2023) Study of Construction Techniques and Hygro-Thermal Behavior of a Vernacular Earth Building in a Humid Tropical Climate. *Journal of Building Construction and Planning Research*, **11**, 69-85.
https://doi.org/10.4236/jbcpr.2023.113005

Received: May 17, 2023
Accepted: August 28, 2023
Published: August 31, 2023

Abstract

This study analyzes the know-how of local communities, to draw on techniques that make contemporary buildings more energy efficient. The impluvium hut in the locality of Enampore, Casamance, Southern Senegal, served as the object of study. The hut, including several rooms, is entirely built with earthen walls, earthen floor, earthen ceiling, covered by a double straw roof and its central courtyard. A room noted (L) and a semi-opened living space were chosen as spaces for hygro-thermal experimentation. The hottest average temperature obtained respectively in the room (L) and in the living space is 25.5˚C and 27˚C when outside is about 34˚C. The thermal amplitude inside room (L) is 0.88˚C, in semi-opened living space, is 2.6˚C and outside is 9.5˚C. With these results we can say that room (L) undergoes very low temperature variations and that there is no need to air-condition in the enclosure. The thermal amplitude makes it possible to see the influence of the earthen walls on the interior temperature and its regularity compared to the fluctuation of the external temperature. The thermal inertia of the building walls was characterized using also the time lag and the decrement factor. They was respectively 7.0 H and 0.093 for the room (L). With this result we can say that this material has a high thermal inertia. For humidity, it is high around 78.5% in the room (L), 66.0% at the semi-open living room, when it is 59.0% outside. Through this study, it is possible that the revalorization of vernacular architecture can be an alternative to reduce the energy consumption of buildings.

Keywords

Time Lag, Decrement Factor, Thermal Inertia, Double Skin, Impluvium

1. Introduction

In the context of the current climate crisis, the search for alternative solutions to significantly reduce the consumption of fossil fuels remains a key for the future of our planet and for next generations. Residential and construction sectors consume more than 35% of produced primary energy, mainly for human comfort purposes, as a result, these sectors produce nearly 38% of greenhouse gas emissions [1]. In Africa, the building stock consumes 60% of energy and produces 32% of CO_2 emissions [2]. This is all the more urgent for sub-Saharan Africa, which has the highest urbanization rates, with 42% of the population living in cities [3], and the highest population growth in the World. The rural exodus to urban centers continues, due to climate change and the impoverishment of the countryside. Cities are expanding disproportionately due to housing problems. Urban centers are without limits or apparent contours, even encroaching on natural areas and forests, which aggravates soil mineralization and flooding phenomena. The pressure on the public authorities is aggravated by the strong demand for decent housing but above all on the need for basic services such as the supply of energy.

As for Senegal, the urbanization rate is 46% and a population growth rate is 2.5% [4]. 2.6 million People live in slums [5] and 23.3% are lodgers [6]. Senegal has an urgent constraint to find solutions to house its urban population. This necessarily involves the construction of buildings with a good level of comfort and with low fossil energy consumption. Building with local materials, therefore, remains an economic and social issue.

The control of energy demand and the energy efficiency of buildings is a key issue to tackle global warming. Solutions could be found by taking advantage of existing local architectural design know-how [7] that uses locally available materials and technics for the construction of energy efficient buildings like studying in sub-mountainnous areas of Guilan, Iran. In fact, architectural design adapted to the climate can reduce energy consumption [8]. Unfortunately, apart from Europe and Asia, there have been less than 2 scientific publications per year on vernacular architecture between 1998 and 2018, even if African architecture presents significant potential for bioclimatic methodologies and strategies to regulate climate differences *in situ* [9].

Most of the previous studies on vernacular architecture in sub-Saharan Africa concern anthropological and sociological aspects, the used materials and their behavior [10] [11] and [12], or the comparison of the mechanical performance [13]. They do not generally investigate building-environment relationships, nor the solutions of form, geometry, ventilation system, materials, double envelope or solar protection.

Like the impluvium hut, many vernacular constructions are characterized by a high thermal inertia [14]. The materials used for walls are generally stones, earth or bricks that allow a high time lag for the diurnal heat transfer.

In the field of vernacular architecture, [15] analyzed the effectiveness of passive strategies in the thermal performance of a rammed earth building located in Southern Portugal. [16] has explored a mixed-method adaptive comfort approach for understanding thermal comfort in vernacular dwellings in Mediterranean climate in Alentejo, Portugal. In the same way, [17] has studied, the thermal comfort of vernacular earth-sheltered buildings in Meymand, Iran. For all these studies on vernacular architecture, it has been concluded that these vernacular constructions have real thermal comfort during hot periods. The obtained results demonstrate that, in various geographical areas and with different materials and construction techniques, vernacular architecture provides a solution for the thermal comfort [18].

As to [19], they went further by comparing the comfort of the inhabitants in both semi-open and indoor environments in different vernacular constructions in arid areas in China. The fairly similar levels of comfort in the old buildings, allow residents to move around and occupy the different spaces according to their daily activities, as for the impluvium hut. In the same way, [20] studied the relationship between architectural form and human comfort in semi-open space in a Mediterranean island, in Cyprus. The interest of semi-open spaces in the constructions of Cyprus, in addition to the advantages of comfort adapts to the way of life, the customs and the needs of the occupants. These architectural design, including an inner courtyard guarantying the socio-cultural and psychological security, intimacy and relationship for occupiers, environmental and aesthetic considerations, are found in the studied impluvium hut.

Even if the materials, the climate, and types of construction in the case studies presented above may differ from those of the impluvium hut, they provide precious information on the performance of local knowledge to reduce fossil energy consumption in the building cooling or heating.

Vernacular buildings are characterized by walls built with significant wall thicknesses to take advantage of their thermal inertia [14]. Thus to evaluate the thermal inertia of a material, three parameters can be used: the thermal amplitude, the time lag and the decrement factor.

For that, Toure *et al.* [21] have investigated the thermal properties of a building envelope, with walls made of stabilized earth bricks in tropical climate. Their study shows that the stabilized earth bricks envelope improves the time lag up to 6 hours. Nevertheless, the South-facing walls receive more solar radiation. Therefore, even if the shift in the time lag is significant, it does not guarantee comfort for the night during hot periods. Also, the size of the cell model, with a volume of 1 m^3 may influence the heat exchange compared to a real condition.

Also, the determination of the time lag and decrement factor for several walls with light or dark color has been done by [22]. This study shows that several parameters such as the orientation, the azimuth, the solar absorption, the color and the temperature of the walls and the floors, can influence the time lag and the decrement factor. This study also provides excellent guidance in the building design process even if it is done with a digital simulation, they show also the limits of simplified calculation methods that do not take into account those parameters.

As to [23] studied the future of clay-based construction materials using a wide variety of clays to produce different building materials. They also used several techniques to improve the clay mixing by stabilization with alkaline activation and microwave drying. But the limit of their experimentation, resides in the clay mixing with industrial products and in the use of energy-consuming drying methods that leads to certain environmental problems. In the same way, [24] investigated the climatic comfort of several earth made buildings, stabilized earth bricks, compressed earth bricks or concrete in urban space in Senegal. However, even if the thermal performance of earthen buildings is verified in an urban environment, the study was not carried out on buildings entirely in earth. In fact, the buildings were made with mixed materials, with a main structure in reinforced concrete and the filling walls made of different earth-based materials. The study did not take into account the dense urban environment, the influence of the surrounding buildings and the orientations.

The originality of this work is based on the hygro-thermal study of a vernacular earthen building in a humid tropical climate in West Africa. Most of these time lag and decrement factor studies have been based on scaled-down [21], or digital models [22]. Also, many studies on the hygrothermal behavior of vernacular architecture are carried out in Europe [15] [16] and [20] or Asia [17] and [19]. This building is also remarkable for its architectural form, its construction system with its double protection, its courtyard and its strategies for adapting to its environment.

The objectives of this study consist of identifying endogenous technical constructions that can help achieve thermal comfort. Our approach consisted also in analyzing the building techniques in relation with the energy performance, level of climatic comfort, hygrothermal performance, energy efficiency and bioclimatic advantages provided by this local construction. First, we will present the geographical context and the environment of the catchment area of Enampore. We will then approach the functional analysis and the composition of the impluvium hut and detail its materials and construction techniques. Further, we analyze its natural ventilation system and finally, the data obtained in the three spaces of the impluvium hut.

2. Presentation of the Impluvium Hut

2.1. Location

The studied impluvium hut is located in Enampore, in the district of Ziguinchor, in the natural forest region of Casamance, Southern Senegal (**Figure 1**). Casamance is the wettest region of Senegal, with an average cumulated annual precipitation of 1200 mm [4]. The rainy season in Casamance goes from June to October, and the dry season from November to May. It consists of dense and wooded forest which are mainly located in the Southern part. The fluvio-maritime zone is occupied by Mangrove. Some tall trees populate its forest, including kapok

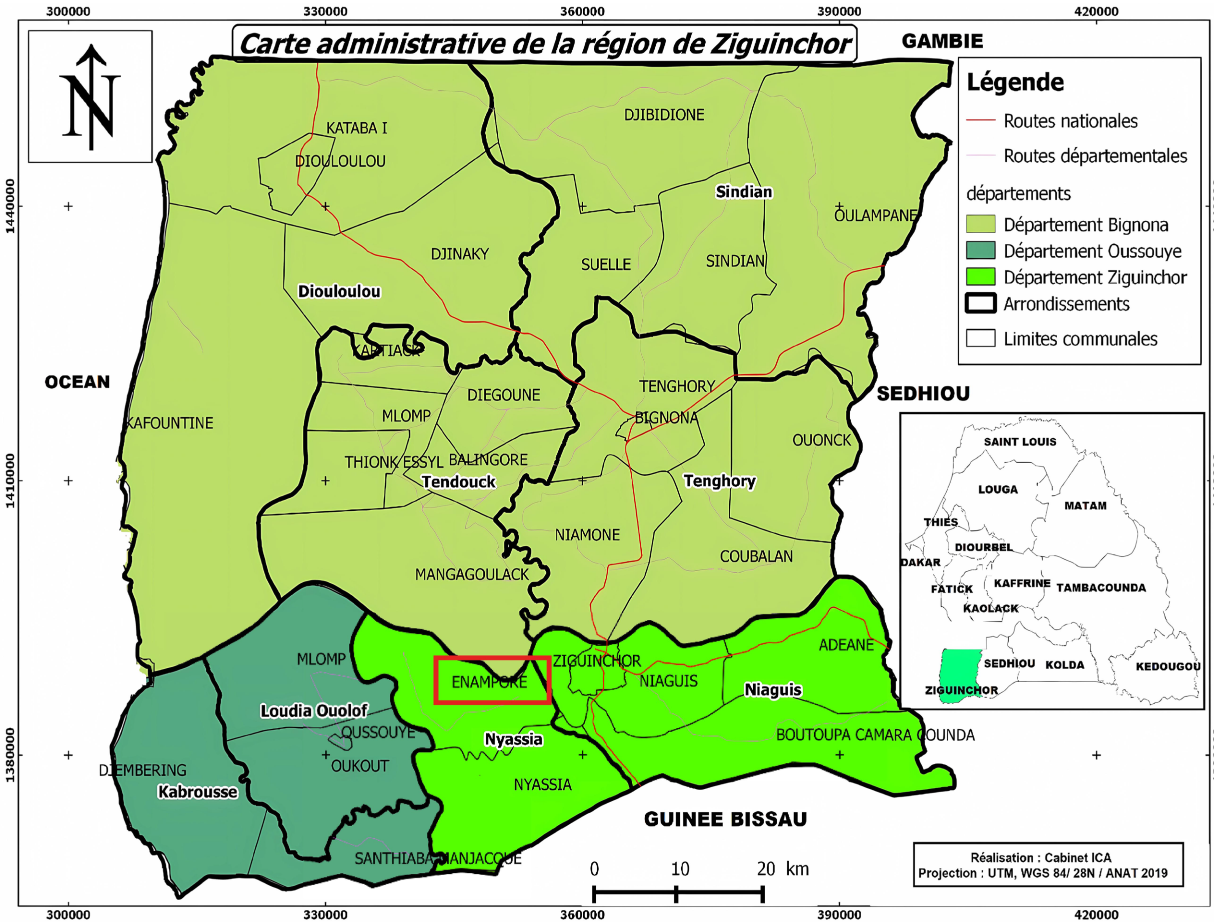

Figure 1. Geographic situation of Casamance. The location of the studied impluvium hut is shown by the red square (Source ANAT, 2019 modified).

trees, baobabs, caïlcédrats, and palmyra palms. They can reach 30 to 35 meters in height.

The hydrographic network of the region is mainly formed by the Casamance River which divides the territory, depending to its floods and makes the land saturated with salt (**Figure 2(A)** and **Figure 2(B)**). Temperatures can vary from 20˚C to 43˚C. The warm season in Casamance lasts for 2.9 months, from February to May, with an average daily high temperature above 36˚C.

2.2. Technical Construction

The Casamance impluvium hut is one of the most emblematic and most important traditional constructions of Senegal (**Figure 3**).

The hut provides shelter to several families of the same lineage. It is a space for socialization for the family, accentuated by its concentric shape, which isolates the occupants from the outside. Its construction involves the whole community and its maintenance is carried out through several generations. The studied specimen is about 120 years old, and remains among the oldest vernacular construction still intact in the locality. It has been, for this reason, classified as an historic monument by the [25].

(A)

(B)

Figure 2. Aerial photography of Hydrography (A) and forest (B) around the locality of Enampore. The location of the impluvium hut is represented by the red circle (Source Google Earth, 2022 modified).

Figure 3. View of the impluvium hut in its natural environment.

The available specimen extends over an area of approximately 1100 m^2 and is composed of 13 rooms acting as bedrooms and attics, and forming a concentric open space around an interior veranda (**Figure 4** and **Figure 5**). This veranda is enlightened by an inner courtyard in the center which is also used to evacuate rainwater.

Around this courtyard, clay columns rise and support the framework of the roof. The bedrooms and attics are protected from the outside by a concentric space made up of service rooms. Several entrances give access to the heart of the house even if there is a main entrance. The other doors allow occupants to enter, exit and to access to service rooms. Nevertheless, it is important to notice that the doors do not offer a view of the interior from the outside. The hut is surrounded by tall trees which provide a lot of shadow on the ground and on the hut all day long (**Figure 3**). The different spaces are used according to daily activities (services, rest, and living space). This is also conditioned by the ambient temperature and the light of the places (**Figures 4(A)-(F)**).

Mix of earth and water using the "kadiandoumagne" tool (A). Clay wall built by stratum using cob technique (B). Kapok wood door (C). Two columns marking the main entrance and supporting the framework (D). Mangrove wood in ceiling and the palmyra palm beams (E). Wooden posts holding the ridge purlins (F). Rafters and fastening systems and straw roof (G). The palmyra palm posts supporting the framework (H).

(A) Kitchen (outdoor) **(B)** Services (semi-open) **(C)** Room (indoor)

(D) Living space (semi-open) **(E)** Living space (semi-open) **(F)** Courtyard (outdoor)

Figure 4. Views of the exterior and interior of the impluvium hut.

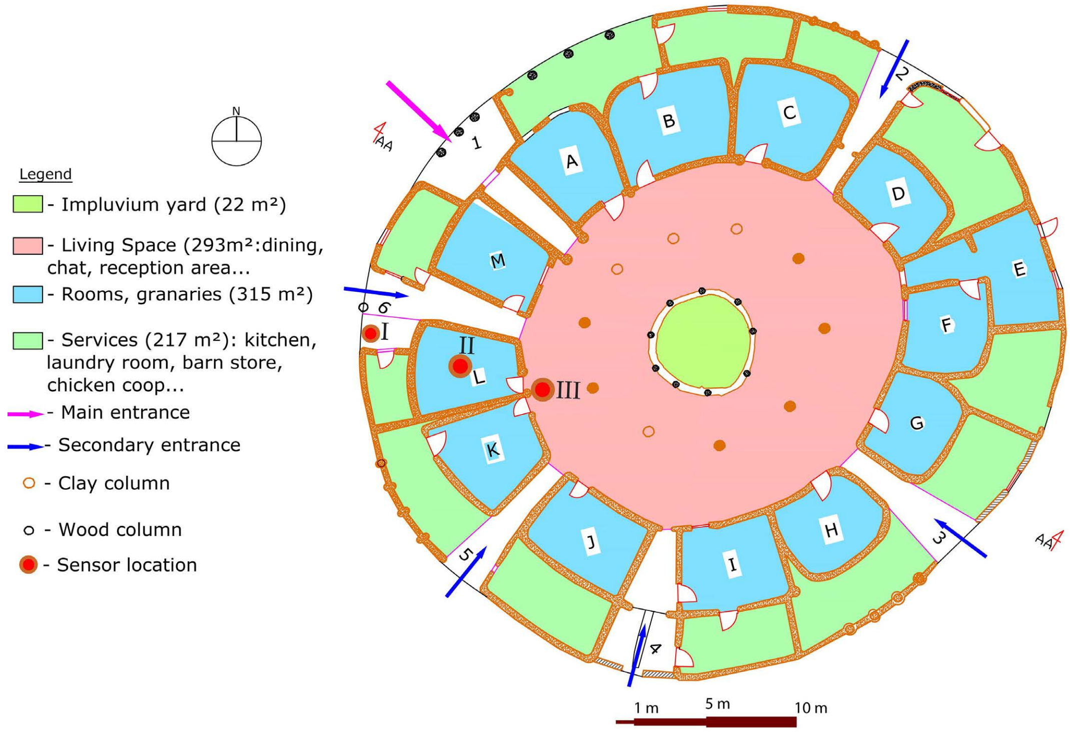

Figure 5. Spatial organization of the impluvium hut showing the location of measuring devices.

The hut is built using a tamped and compacted clay, which also covers the floor. The walls are made of 40 cm thick clay built using the cob technique (**Figure 7(A)** and **Figure 7(B)**). The walls are raised in strata of 50 cm height (**Figure 6**). The clay is extracted on site, wetted and kneaded by trampling for hours. Then, the earth is covered with palmyra palm leaves to protect it from the sun and evaporation, and left to rest until the next day. Then balls, in plastic state, are formed and stacked to form the walls. The balls forming the wall are then cut to have a smooth finish thanks to a traditional tool, the "kadiandoumagne" (**Figure 7(A)**), also used to work the land of culture: Clay columns, built in the same way as the walls, support the roof and the frameworks (**Figure 7(D)**). The walls of the night rooms have an interior height of 3.55 m. These rooms are first covered by a ceiling in decorative mangrove wood, supported by palmyra palm wood beams (**Figure 7(E)**). Above this wood mangrove ceiling, a 20 cm thick clay layer serves as a floor. This clay floor is accessible. The access doors to the rooms are short with a lintel height of 1.50 m. The floors of the rooms are at a height of 3.75 m. The hut is covered with a large thatch roof that overflows on the exterior walls of the rooms. The ridge of the framework is at a height of 6.75 m. The space between the bedroom floor and the straw roof is accessible and also serves as storage space. The height of the straw roof of courtyard level is 1.70 m (**Figure 7(F)**). The doors of the rooms are made of wood from the roots of kapok tree (*Ceiba pentandra*) (**Figure 7(C)**). All the spaces, rooms and veranda, are surmounted by a high frame which trusses, purlins and rafters are made of different size palmyra palm wood (**Figure 7(H)**). The structural elements are connected

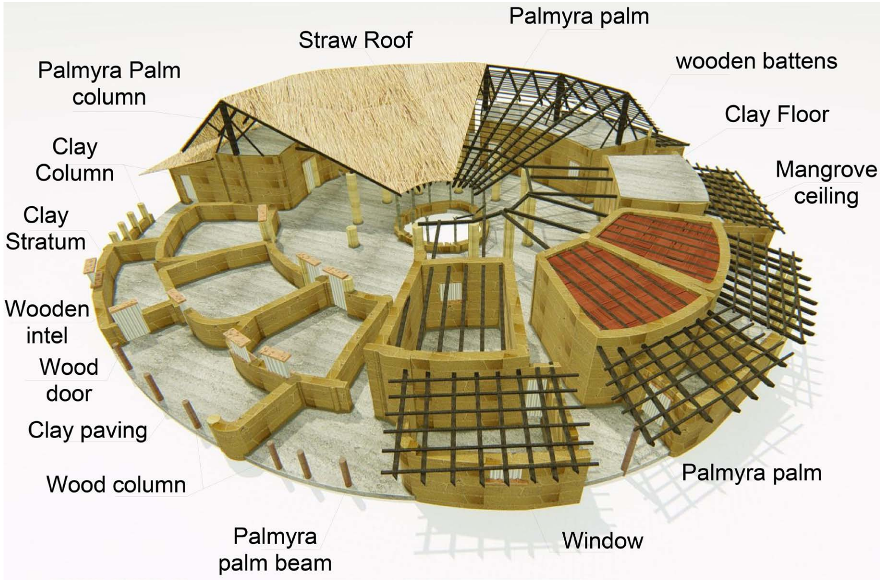

Figure 6. Constructive device and materials.

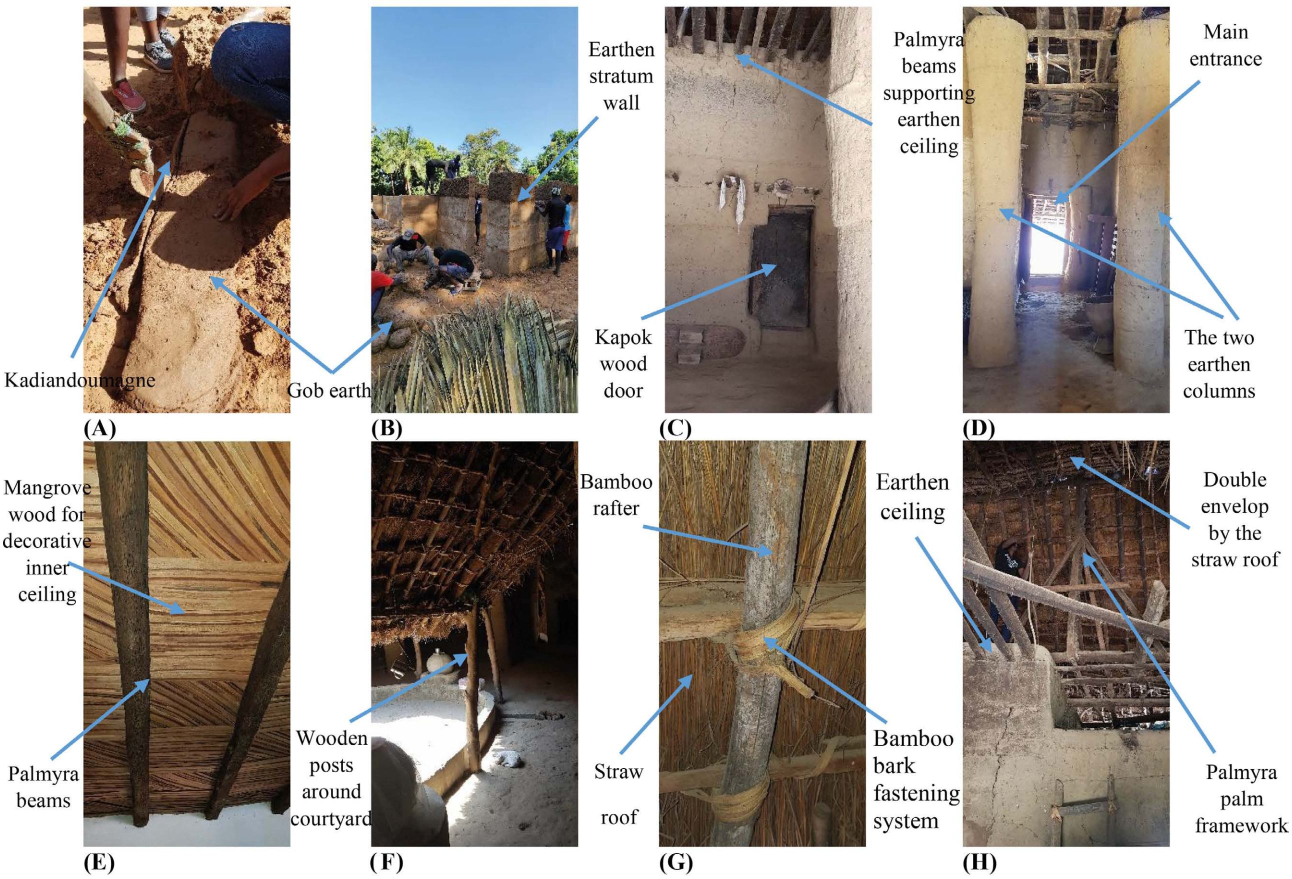

Figure 7. Technical construction.

using bamboo barks (Figure 7(G)). The framework is covered by a straw roof. The service spaces have trusses of the same type but are only covered with thatch (Figure 6). The impluvium hut was built with geo-sourced and bio-sourced renewable materials. The work and living areas are covered by a straw roof and those for rest by a double roof: an earthen floor and a straw roof (**Figure 6**). The construction of the impluvium box is a community work. The elders knead the earth and make it into balls. Some young people carry them to the work site, others do the elevations (**Figure 7(B)**).

2.3. Ventilation Systems

The conception of the impluvium hut allows for it to be naturally well ventilated (**Figure 8** and **Figure 9**). Ventilation is facilitated by the 6 inlets (**Figure 8**) which open in several directions. This allows the air to circulate everywhere in the building all the day, whatever the seasons and the direction of the winds. The air enters through one door and can exit through the opposite ones. The ventilation of the double roof (**Figure 9**) also promotes the evacuation of heat and especially humidity from the floor and stored agricultural products. The inner courtyard also plays an important role for air circulation.

3. Building Monitoring

3.1. Presentation of the Experimental Cell

Our approach for hygrothermal comfort study consisted in using an identified room, noted room (L) (**Figure 5**), in the impluvium hut as an experimentation

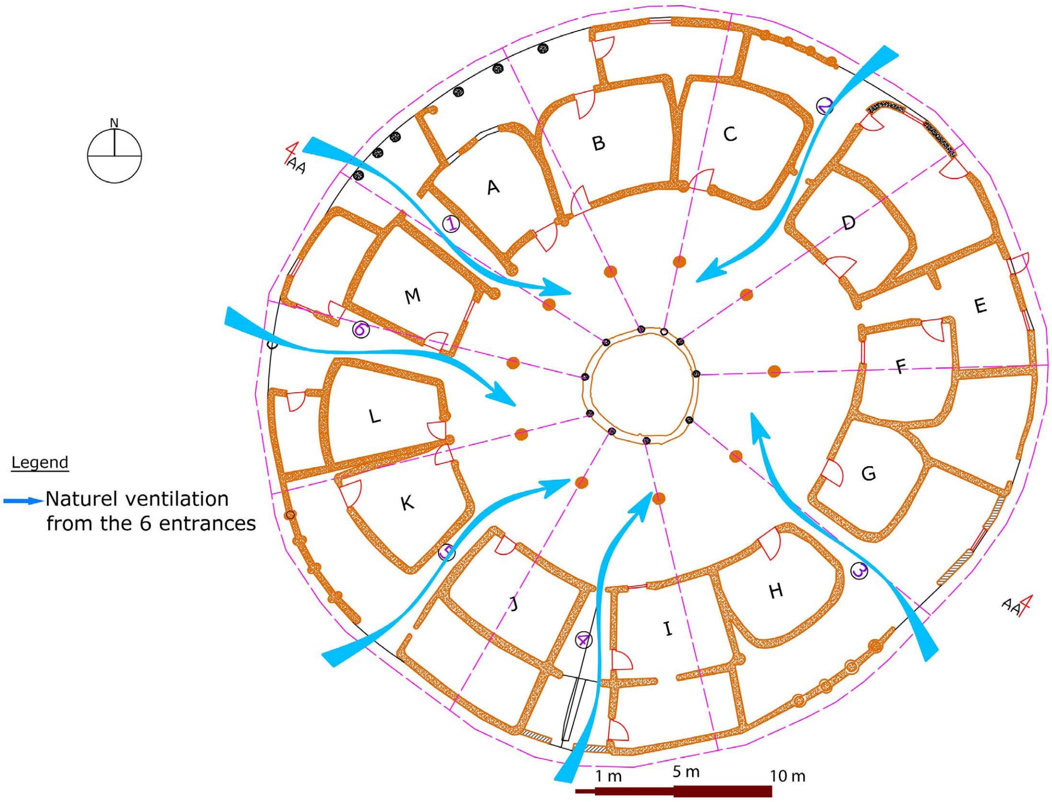

Figure 8. Horizontal section of the impluvium hut showing natural ventilation system. The rooms are indiquated by alphabetic letters allowing to locate the room (L).

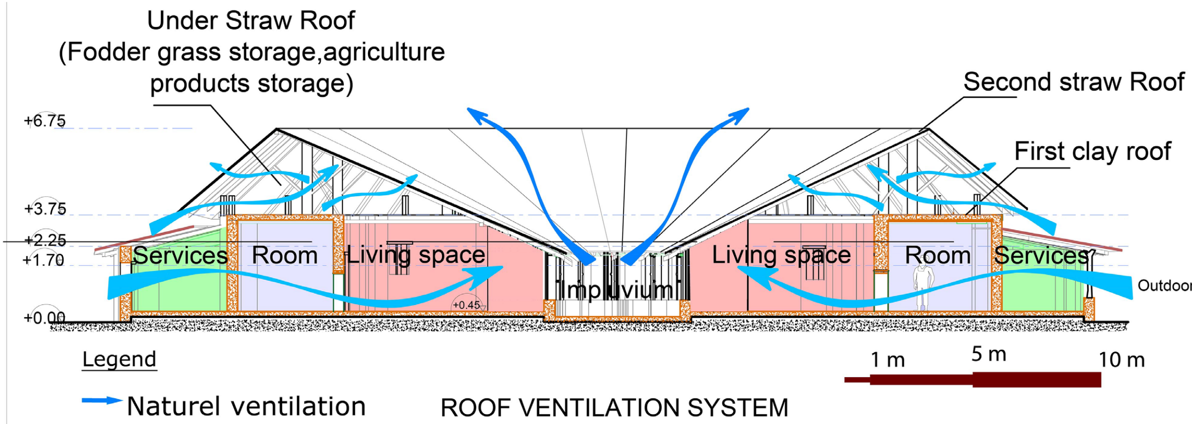

Figure 9. Vertical section of the impluvium hut showing the role of the main roof in the natural ventilation system.

space. It is of trapezoidal geometric form (2.50 m × 5.00 m × 5.70 m). It is positioned inside the hut and is surrounded by four different spaces: a service space, a bedroom, an entrance hallway and the semi-opened living room is positioned inside the hut and is surrounded by four different spaces: a service space, a bedroom, an entrance hallway and the semi-opened living room. These four spaces protect it from the outside. Temperature and hygrometry measurements were taken in the life-size hut, *in situ*. The results of the various temperature and hygrometry data will be presented at the level of the spaces concerned by the experiment.

3.2. Instrumentation

We used three "DATA LOGGER" recorder devices to measure the temperature and the humidity of the three spaces. The three "DATA LOGGER" were placed at a height of 1.50 m from the ground outside the hut, inside the room (L) and in the interior veranda (**Figure 5**). The "DATA LOGGER" (**Figure 10**) are dedicated to measuring ambient temperature and relative humidity.

For temperature and relative humidity, the measurements were carried out from November, 30th to December 16th, 2021. The precision of the measurements are ±3% for relative humidity and ±1˚C for temperature.

4. Results and discussions

The measured temperature and relative humidity from November, 30th to December 16th, 2021 are presented on **Figure 11** and **Figure 13**.

Inside the room (L), the fluctuations of the temperature are less important, 0.88˚C, than those of the semi-opened living room and outside (**Figure 11**). The interior of the room (L) undergoes slight temperature variations due to the thermal inertia of the 40 cm thick earthen walls (**Figure 7(B)**). The temperature of the semi-opened living room fluctuates because it is in contact with the outside. So, the service areas, then the interior veranda and also the straw roof provide triple protection for the room (L) against variations of the outside temperature.

Figure 10. Data logger.

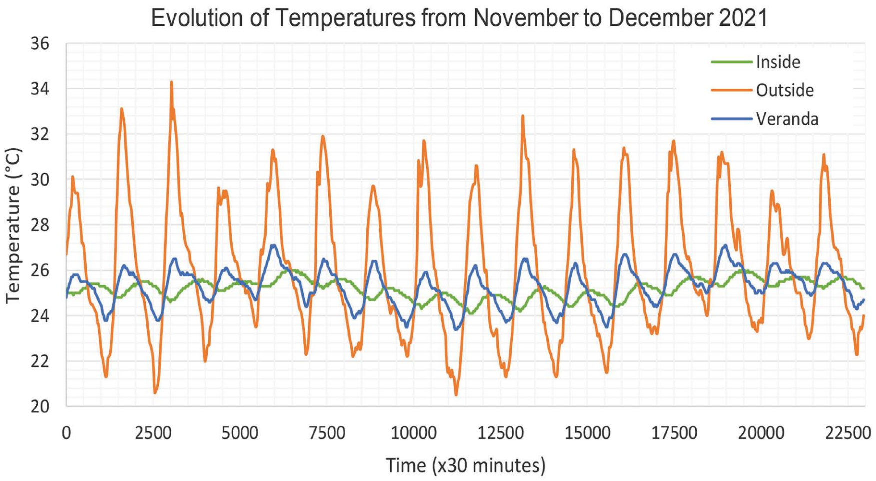

Figure 11. Evolution of temperature on site November-December 2021.

The three sets also protect living spaces against direct solar radiation (**Figure 12**). The impluvium hut is in a forested area and the trees intercept 60% to 90% of solar radiation, preventing the solar radiation according to [26]. This results in a decrease in the temperature of the ground which also influences the temperature around the hut. The experimental results show that we have an average temperature around 25.5˚C in the room (L). With this average temperature, there is no need for air conditioning. This temperature obtained is due to architectural aspects, materials, ventilation, solar protection and the surrounding environment. The double roof, as well as the spaces surrounding the night areas, plays an important role in protecting the catchment area against direct radiation and hot winds during the summer. This brings a level of comfort, thanks to this additional envelope as evidenced by a study by [27] who have experimented with several hypotheses for the use of double skin on several faces in a housing prototype to improve interior thermal comfort, taking climatic conditions close to the equator in Santiago de Cali, Colombia.

For the humidity, it remains practically stable around 78.5% in the room (L). The humidity remains quite high (**Figure 13**) due to the rainy season which ends at the end of October in the southern region. The air and the ground are waterlogged. The mangroves and the river have overflowed their beds.

The veranda undergoes variations like the exterior, this is due to its semi-open character (**Figure 13**). It is more influenced by the outside.

The measured data from the impluvium hut are used to assess the thermal amplitude of the room (L) and the semi-opened living room as well as their reaction to the temperature variations of outside.

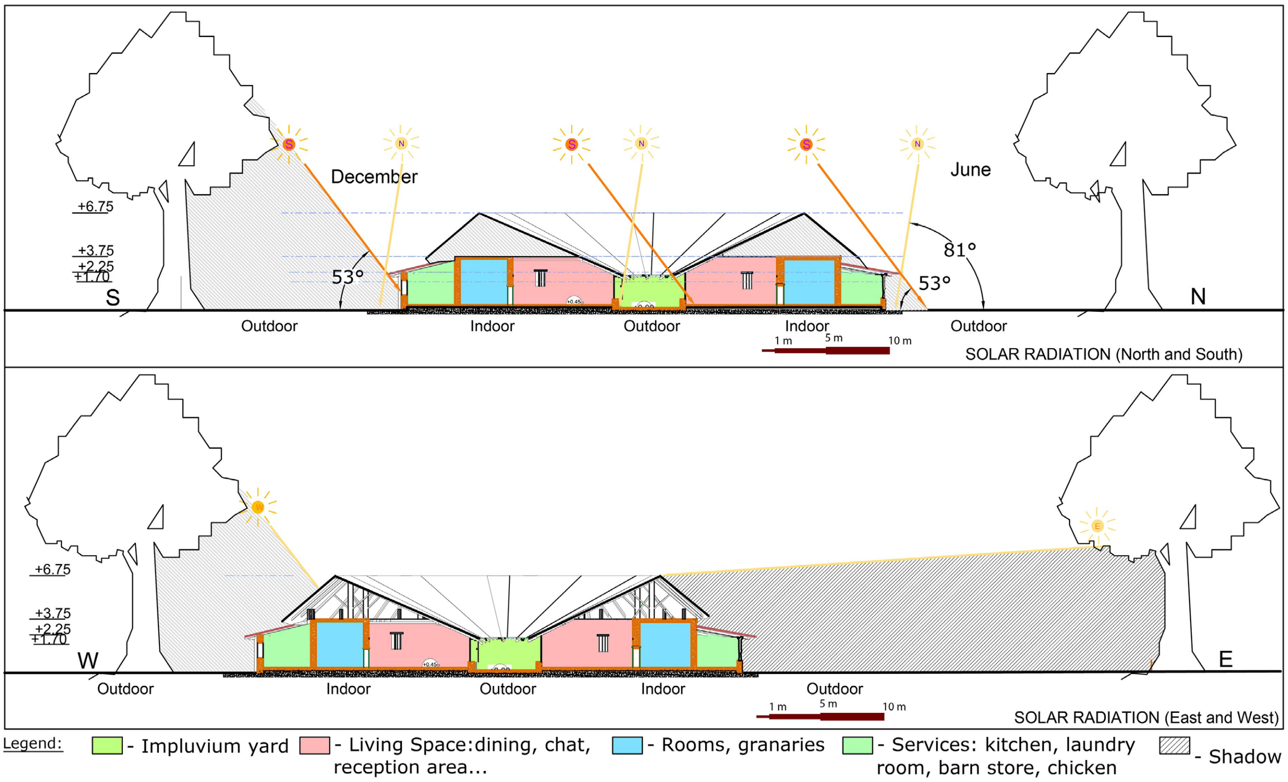

Figure 12. Study of sunshine on the impluvium hut.

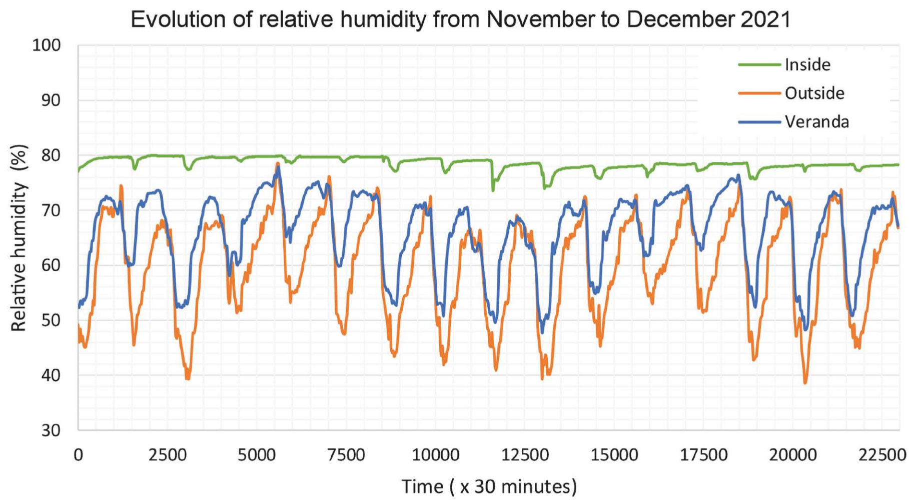

Figure 13. Evolution of relative humidity on site for November to December 2021.

The thermal amplitude A (˚C) is given by the relation:

$$A = T_{\max} - T_{\min} \tag{1}$$

where $T_{\max}$ and $T_{\min}$ are respectively the maximum ambient temperature and minimum ambient temperature.

The results of thermal amplitudes show that, the room (L) is practically not subject to variations in external temperatures (Table 1).

To quantify the inertia, we calculate the time lag and the decrement factor.

The time lag is given by the following relation:

$$\varphi = t_{Ti_{\max}} - t_{Te_{\max}} \tag{2}$$

where $t_{Ti_{\max}}$ and $t_{Te_{\max}}$ are respectively the time when the ambient-air temperature inside the test room (L) is maximum, and the time when the outdoor average equivalent temperature is maximum.

The decrement factor f is given by the following relation:

$$f = \frac{Ti_{\max} - Ti_{\min}}{Te_{\max} - Te_{\min}} \tag{3}$$

where $Ti_{\max}$ is the maximum ambient-air temperature inside the test room (L), $Ti_{\min}$ is the minimum ambient-air temperature inside the test room (L), $Te_{\max}$ is the maximum outdoor average equivalent temperature and $Te_{\min}$ is the minimum outdoor average equivalent temperature.

The results obtained are summarized in the **Table 2**.

The results show a time lag inside the room (L) around 7.0 h and a decrement factor around 0.093 (**Table 2**) This shows the strong thermal inertia of gob wall. Through these results we can say that the variations in temperature and humidity outside are not felt inside.

Compared to the study of [21], we can say the gob wall has more inertia than the BTC, because they found in their study a time lag of 6 h and a decrement factor of 0.4 during 4 days. These values are explained by the thermal inertia of the earthen envelope of the chamber and the spaces and peripheral protection layers (services, veranda and second straw roof) which results in thermal comfort of the impluvium hut. Neither heat nor solar radiation are in direct contact with the room walls, and also the building is exposed to air movement and air speed with the 6 entrances and the double roof (**Figure 8** and **Figure 9**). Also, the temperature of the ground around the building which was to increase the temperatures of the walls because of the solar radiation are decreased by the tall trees around the construction (**Figure 2(B)**, **Figure 3** and **Figure 12**).

Table 1. Thermal amplitudes in different locations from December 8 to 15th, 2021.

Day	1	2	3	4	5	6	7
Inside Room L	0.9	0.9	1.0	0.9	1.0	0.8	0.7
Veranda	2.4	2.8	2.8	2.6	3.2	2.3	2.1
Outdoor (ambient temperature)	9.5	10.1	11.5	10.0	9.9	8.5	7.2

Table 2. Time lag and decrement factor from December 8 to 15th, 2021 of the room (L) in the impluvium hut.

Day	1	2	3	4	5	6	7
Time lag (hr)	7.00	7.00	7.50	7.00	7.00	7.00	7.00
Decrement factor	0.094	0.089	0.087	0.090	0.101	0.094	0.097

5. Conclusions

The objective of this study was to know the technical construction and the hygro-thermal behavior of a traditional building. Therefore a detailed study of the building was made as well as the monitoring. The results give an average temperature and an average humidity, inside the room (L) respectively around 25.5˚C and 78.5%. The quantification of the thermal inertia pushed us to calculate the time lag and the decrement factor. The time lag (7 h) and decrement factor (0.093) obtained in the room (L) show that the temperature and humidity variations are not noticeable in the room, which shows that its gob wall a high thermal inertia. For hygrometric aspects, we can say that the gob material has a good ability to regulate humidity.

The permanent circulation of air around the building is facilitated by the 6 entrances, the impluvium courtyard and the double roof. This impluvium hut maintains an almost stable temperature throughout the measurement period and can be considered as a "passive building" and an energy efficient building for local people.

The design of the impluvium hut is adapted to the tropical humid climate and respects its environment. These results show also the impact of good design on indoor comfort conditions. The thermal inertia of the earthen walls of impluvium hut, its ventilation system, the strategy of stratification and hierarchy of spaces, its double roof, its shape, its inner courtyard and the trees around as an essential, economical, ecological method to design a comfortable habitat during hot periods.

Through this study, we can say that the revalorization of technical construction of vernacular buildings and the know-how of local populations can therefore be a guarantee of energy-efficient construction and reduction of energy consumption in buildings.

Acknowledgements

Thanks to the occupants of the impluvium box for having authorized and facilitated the work of inventory surveys and the various measures and in particular to the head of the family, Mr. Arona Manga.

Thanks to the students of License 3 of the University College of Architecture of Dakar Promotion 2020-2021for their participation in the inventory of fixtures of the catchment area.

Thanks to Professors Vincent Sambou and Pape Moussa Touré of the Ecole Supérieure Polytechnique, Energy Department of the Cheikh Anta Diop University of Dakar for their advice on scientific orientations

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] United Nations Environment Program (2020) 2020 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector. https://wedocs.unep.org/handle/20.500.11822/34572;jsessionid=3B7EA328512E1A23AB640EDCFB7F99DB

[2] United Nations Environment Program (2020) Regional Roadmap for Buildings and Construction in Africa 2020-2025: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector. https://globalabc.org/sites/default/files/inline-files/Africa_Buildings%20Roadmap_FINAL_1.pdf

[3] The World Bank (2018) Urban Population (% of Total Population)—Sub-Saharan Africa. The World Bank, Washington DC. https://data.worldbank.org/indicator/SP.URB.TOTL?locations=ZG

[4] Agence Nationale de La Statistique et de la Démographie ANSD (2020) Situation économique du Sénégal de 2017 à 2018. https://www.ansd.sn/sites/default/files/2022-11/1-SES-2017-2018_Etat-structure-population_0.pdf

[5] De Andrés, E.Á., Cabrera, C. and Smith, H. (2019) Resistance as Resilience: A Comparative Analysis of State-Community Conflicts around Self-Built Housing in Spain, Senegal and Argentina. *Habitat International*, **86**, 116-125. https://doi.org/10.1016/j.habitatint.2019.03.003

[6] Agence Nationale de la Statistique et de la Démographie ANSD (2020) Conditions d'habitat des ménages: Eléments d'éclairage en période de pandémie de Covid 19.

[7] Zohari, S. and Azemati, S. (2022) Comparison of Vernacular and New Construction Materials and Methods in Sub-Mountainnous Areas of Guilan in Terms of Energy Saving. *International Journal of Architectural Engineering & Urban Planning*, **32**, 1-15. http://ijaup.iust.ac.ir/article-1-624-en.html

[8] Ochedi, E.T. and Taki, A. (2022) A Framework Approach to the Design of Energy Efficient Residential Buildings in Nigeria. *Energy and Built Environment*, **3**, 384-397. https://doi.org/10.1016/j.enbenv.2021.07.001

[9] Nguyen, A.T., Truong N.S.H., Rockwood D. and Tran L.A.D. (2021) Studies on Sustainable Features of Vernacular Architecture in Different Regions across the World: A Comprehensive Synthesis and Evaluation. *Frontiers of Architectural Research*, **10**, 222-223.

[10] Brasseur, G. (1979) Famille africaine et habitat. ORSTOM, Paris, 17-20.

[11] Dujarick, P. (1986) Maisons sénégalaises: Habitat rural. Centre Africain pour l'Architecture UNESCO, Dakar.

[12] Elamé, J.E. and Landry, T.T.N. (2022) The Bamiléké family estate as an instance of endogenous architecture in Cameroon. The Canadian Geographer, 1-12. https://onlinelibrary.wiley.com/doi/10.1111/cag.12804

[13] Widera, B. (2021) Comparative Analysis of User Comfort and Thermal Performance of Six Types of Vernacular Dwellings as the First Step Towards Climate Resilient, Sustainable and Bioclimatic Architecture in Western Sub-Saharan Africa. *Renewable and Sustainable Energy Reviews*, **140**, Article ID: 110736. https://doi.org/10.1016/j.rser.2021.110736

[14] Talenti, S. and Teodosio, A. (2022) At the Roots of Sustainability: Mediterranean Vernacular Architecture. *HERITAGE* 2022 *International Conference on Vernacular

Heritage: *Culture*, *People and Sustainability*, Valencia, 15-17 September 2022. https://doi.org/10.4995/HERITAGE2022.2022.15621

[15] Fernandes, J., Silva, S.M., Mateus, R. and Teixeira, E.R. (2020) Analysis of the Thermal Performance and Comfort Conditions of Vernacular Rammed Earth Architecture From Southern Portugal. *Encyclopedia of Renewable and Sustainable Materials*, **4**, 1-10. https://doi.org/10.1016/B978-0-12-803581-8.11460-2

[16] Costa-Carrapiçoa, I., Sanchez-Guevarra, C. and Redondas Marreroc, D. (2022). Understanding Thermal Comfort in Vernacular Dwellings in Alentejo, Portugal: A Mixed-Methods Adaptive Comfort Approach. *Building and Environment*, **217**, Article ID: 109084. https://doi.org/10.1016/j.buildenv.2022.109084

[17] Khaksar, A., Tabadkani, A., Shemirani, S.M.M., Hajirasouli, A., Banihashemi, S. and Attia, S. (2022) Thermal Comfort Analysis of Earth-Sheltered Buildings: The Case of Meymand Village, Iran. *Frontiers of Architectural Research*, **11**, 1214-1238. https://doi.org/10.1016/j.foar.2022.04.008

[18] Al-Habaibeh, A. (2019) Architectural Lessons for the Future, via the Past. *The UNESCO Courrier*, **2019**, 28-33. https://doi.org/10.18356/7be73260-en

[19] Chang, S., He, W., Yan, H., Yang, L. and Song, C. (2021) Influences of Vernacular Building Spaces on Human Thermal Comfort in China's Arid Climate Areas. *Energy and Buildings*, **244**, Article ID: 110978. https://doi.org/10.1016/j.enbuild.2021.110978

[20] Philokyprou, M., Michael, A. and Malaktou, E. (2021) A Typological, Environmental and Socio-Cultural Study of Semi-Open Spaces in the Eastern Mediterranean Vernacular Architecture: The Case of Cyprus. *Frontiers of Architectural Research*, **10**, 483-501. https://doi.org/10.1016/j.foar.2021.03.001

[21] Toure, P.M., Dieye, Y., Gueye, P.M., Sambou, V., Bodian, S. and Tiguampo, S. (2019) Experimental Determination of Time Lag and Decrement Factor. *Case Studies in Construction Materials*, **11**, e00298. https://doi.org/10.1016/j.cscm.2019.e00298

[22] Ruivo, C.R., Ferreira, P.M. and Vaz, D.C. (2013) On the Error of Calculation of Heat Gains through Walls by Methods Using Constant Decrement Factor and Time Lag Values. *Energy and Buildings*, **60**, 252-261. https://doi.org/10.1016/j.enbuild.2013.02.001

[23] Shubbar, A.A., Sadique, M., Kot, P. and Athertonc, W. (2019) Future of Clay-Based Construction Materials—A Review. *Construction and Building Material*, **210**, 172-187. https://doi.org/10.1016/j.conbuildmat.2019.03.206

[24] Soumare, E.M. (2019) L'intérêt de construire des bâtiments bioclimatiques à usage d'habitation en milieu tropical à partir de matériaux locaux. Harmattan, Dakar.

[25] Ministry of Culture and Leisure (2006) Order Publishing the List Listed Historical sites and Monuments. Republic of Senegal, Dakar.

[26] Liebard, A. and De Herde, A. (2005) Traité d'architecture et d'urbanisme bioclimatique: Concevoir, édifier et aménager avec le développement durable. Observ'ER, Paris.

[27] Lopez-Escamilla, A., Herrera-Limones, R. and Leon-Rodríguez, A.L. (2022) Evaluation of Environmental Comfort in a Social Housing Prototype with Bioclimatic Double-Skin in a Tropical Climate. *Building and Environment*, **218**, Article ID: 109119. https://doi.org/10.1016/j.buildenv.2022.109119