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Study of a Bioclimatic Building in Wet Tropical Zone: Application of the Study of the Thermal Behavior of a Building in Cote D'ivoire

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Abstract: With population growth, the demand for housing continues to grow. Also, the energy crisis has shown the need for an energy efficiency policy in the building sector. Estimating the thermal behavior of a building is important in the energy efficiency approach. We present in this article the results concerning the climatic comfort in a building of the city of Abidjan. In this work, we study the thermal behavior of a building of architectural typology validated by the presidential construction program of 60,000 social housing units; our choice is also justified by the habit of Ivorians to live. This architectural model is implemented, with regard to the envelope, with a local material, available, offering the natural comfort: the clay brick. Today, earth material is gaining interest among architects and scientists because of its excellent thermal properties and abundant availability. Our experiments show, on the one hand, that in Côte d'Ivoire, to perform a simulation based on single-zone modelling or multizone modeling, from a low clay brick house, provides similar results; on the other hand, clay brick, when subjected to solar radiation, enhances overheating of the air in the building.

Keywords: Clay Brick, Walls, Thermal, Building

1. Introduction

Africa is the continent where population growth is fastest. It will by the way in the late 21th century, the second most populous continent after Asia according to the UN median scenario [1]. This demographic growth is intensifying the demand for housing. In Côte d'Ivoire, in this case, the housing deficit in urban areas is estimated at 600 000 units; and half of this deficit is concentrated in Abidjan [2].

Indeed, most developing countries are undergoing an import of urban and architectural models [3]. New architectures integrating artificial climate control techniques at the expense of local models, based on careful and judicious choice of site and orientation, taking into account the sun, wind and humidity, better adapted to geoclimatic data specific to these regions [4].

Compressed clay brick is a material that reduces building consumption when seeking thermal comfort acceptable to its occupants [5, 6]. This remarkable material plasticity and availability satisfying expectations as diverse as the response of the physical, environmental or financial, but also the aspirations of human nature, social and cultural [6].

2. Materials and Methods

Presentation of the study building

The geometry of the building is modelled in 3D using the Google Sketch Up software of the Google editor. This software is coupled with Open Studio to make it possible for Energy plus to read data (architectural and energy). We carried out a numerical study of the thermal behaviour of the building modelled in mono zone and multi zones. As for the single zone model, we consider the room’s doors are opens.

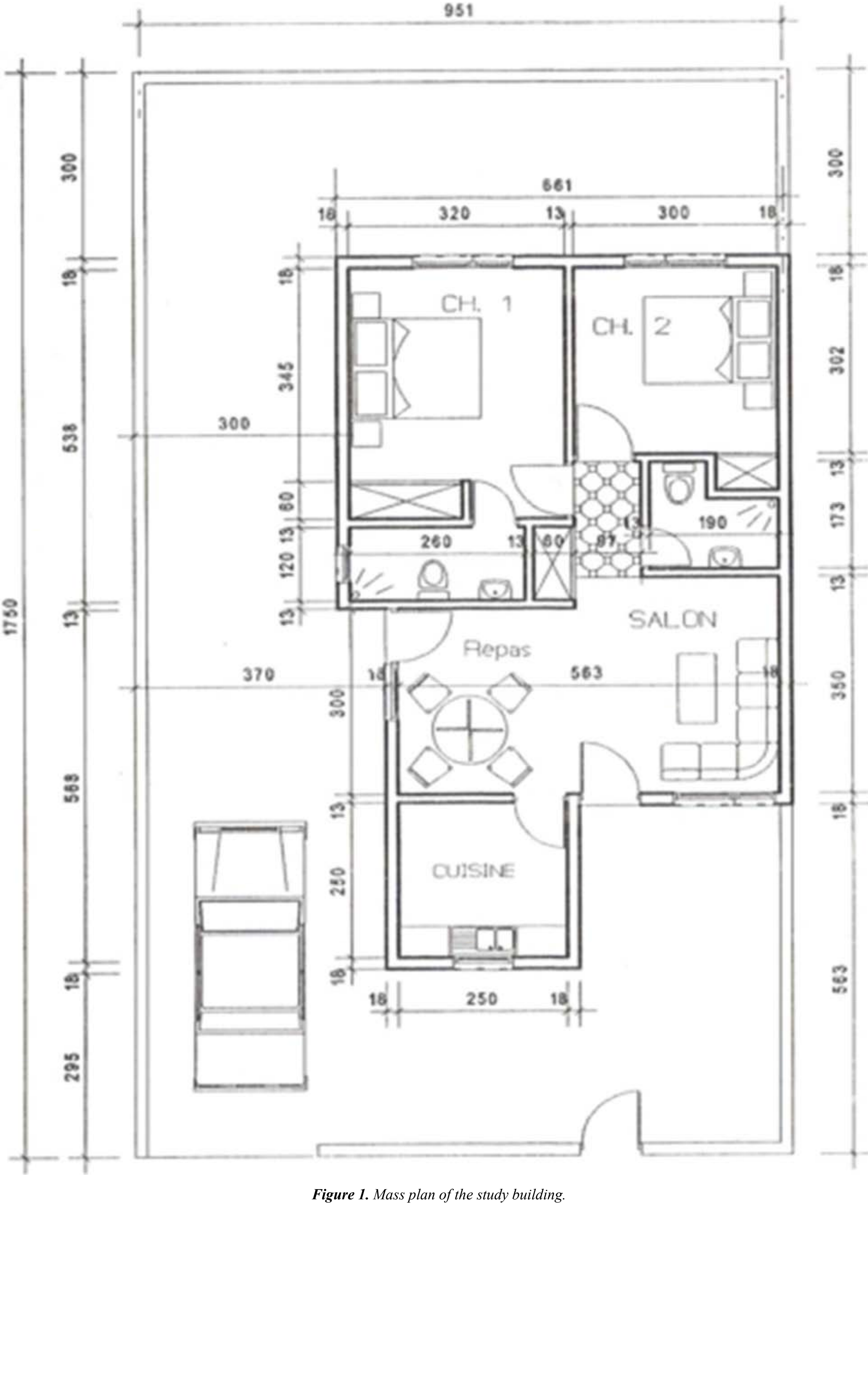

Figure 1. *Mass plan of the study building.*

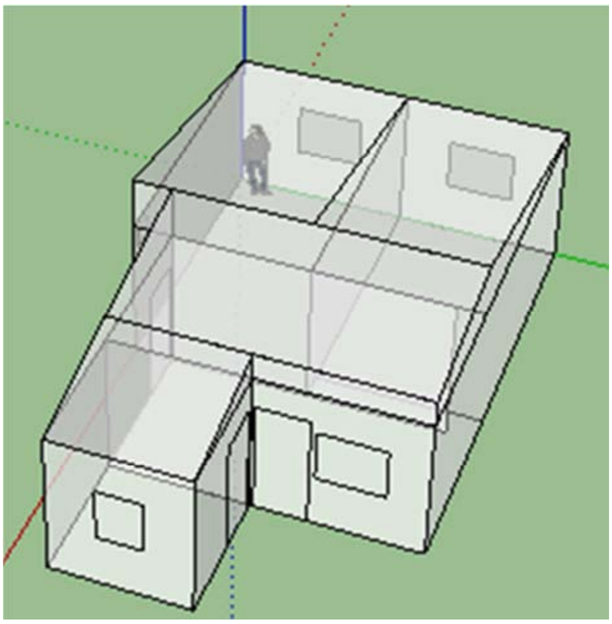

Figure 2. *Sketch Up modelling of the study building.*

Table 1. *Constituent material envelope and their thermal characteristics [7].*

	Materials	conductivity (W / m°C)	thickness (m)	specific heat (J / kg°C)	density (kg / m3)
INTERIOR FLOOR	Concrete	1.4	0.1	1700	2200
	interior coating	0.833	0,015	1000	1000
	exterior coating	0.833	0,015	1000	1000
OUTER WALLS	outside clay brick	0.9	0.15	3200	1000
	interior coating	0.833	0,015	1000	1000
	interior coating	0.833	0,015	1000	1000
INNER WALLS	interior clay brick	0.9	0.1	3200	1000
	interior coating	0.833	0,015	1000	1000
	red lacquer	50	0,002	450	7800
ROOF	steel galva	50	0,002	450	7800
	sheet steel	50	0.01	450	7800
CEILING	wood	0.09	0.0127	1170	592
DOOR	25mm wood	0.0254	0.15	1630	608

From the architectural point of view, it is a typical residential building in Cote d'Ivoire. The construction model is based on architectures validated by the government as part of the construction of 60000 social housing units.

Table 2. *Thermo physical Properties of Materials (Reagan and al., 1979).*

Materials	Conductivity (W / m°C)	Specific heat (J / kg°C)	Density (kg / m^3)
Galvanized steel sheet	50	450	7800
coating	1,150	1000	1700
Concrete	1.4	1000	2200

Table 3. *Surface Properties of Materials (Kultulr and al., 2012).*

	Infrared emissivity	Solar absorptivity
Exterior plaster	0.9	0.6
Red lacquered roof	0.8	0.6
Galvanized steel	0.2	0.6
White interior plaster	0.9	0.2

Our building is built in clay brick with 0% cement content. The thermal characteristics of the model's building materials are indicated by the thermo-physical properties and surface properties (Table 2 and 3) as stated in literature [8]. The albedo of the surrounding soil is 0.2 [9].

The main entrance of the building is oriented North. The walls are made of clay brick 0.15 m thick and 0.10 m thick respectively for the exterior and interior and are covered on the outside and inside with a thickness of cement coating. 0.015 m. The partitions have the same composition as the wall. The floor consists of a layer of laterite surmounted by a layer of concrete as a screed with a smooth finish. The vaulted double slope roof is made of galvanized sheet steel with filler. The roof is not ventilated. The outer face is pre-lacquered with a colour between red and orange. The total area of the walls is estimated at 115.05 m^2, of which 26.56 m^2 are facing north, 35.57 m^2 are oriented full east, 17.36 m^2 are facing south and 35.57 m^2 are facing west. The total areas of windows are 4.56 m 2 of which 2 m^2 on the north side i.e.

7.53% of the surface of this wall; 0.16 m^2 On the east face of which 0.45% of the surface of this wall and 2.4 m^2 on the south face is 13.82% of the surface of this wall. The building has an interior volume of 297.3 $m^{3.}$

2.1. Meteorological Data

The study is carried out for the climate of the Ivory Coast and meteorological data are derived from the meteonorm database [10] and in the TRY format with an epw extension. They are provided with .ddy files (day year) which regroup the statistical analysis of the hourly data and contains the typical days of each seasons. These design days are calculated according to ASHRAE HOF design condition tables.

The coordinates of the registration station of Abidjan-Airport are as follows:

Latitude [deg]	5.25
Longitude [deg]	-3.9
Elevation [m]	8.00

2.2. The Tropical Humid zone: Presentation and Delimitation

This zone is defined as the part of the Earth's surface that receives the Sun's rays twice a year and it is perpendicular at noon when the sun passes to the zenith. It extends in total to 46 ° 55 'of latitude, symmetrically on both sides of the equator. The air temperature varies between 27 and 32°C during the day and between 21 and 27°C at night. Relative humidity is around 75% all year round. Solar radiation is important, although it is partially mitigated by cloud cover; the wind is weak; precipitation is important [11]. Also, precipitation and winds are the main determinant of the seasons [12]. Seasonal zonal balancing means that a large part of the tropical regions are alternately subjected to arid and rainy season of months. This vast area actually embraces quite diverse natural environments that share only their high temperature throughout the year (see Figure 2).

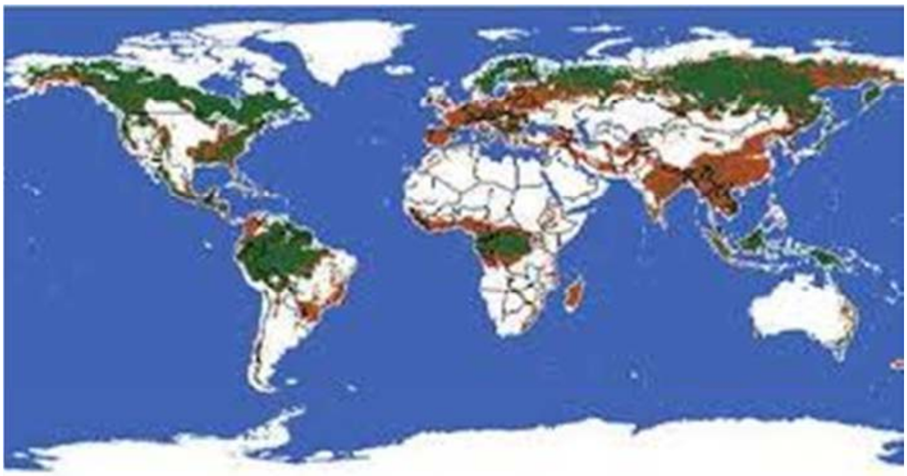

Figure 3. *World map with tropical wetland represented in green and orange according to the abundance of vegetation (by François catzetflis).*

The limits of comfort or thermal discomfort are difficult to define in a precise way. However, comfort limits in the form of diagrams and thermal indices were determined in controllable laboratory environments, to facilitate their use by the researcher (table 4).

A relatively high air temperature can thus be made bearable by increasing the air velocity, while conversely the effect of a high air velocity can be compensated in a zone limited by a temperature rise.

Table 4. *Summer comfort threshold temperature values, in degrees Celsius [13].*

1 / Choice of the temperature threshold (V_{air} = 0 m / s) according to the external humidity								
T_e / HR	<45%	45% -60%	> 60%	* - for the hottest month Te - average outdoor temperature of the maximum HR- the average outdoor relative humidity of the minimum				
> 30°C	29°C	27°C	27°C					
30°C > T_e > 28°C	-	27	27°C					
<28°C	-	26°C	26°C					
2 / Correction of previous thresholds according to the expected air speed :								
Comfort threshold temperature ($T_{thresholdconf}$)								
0	0.06	0.13	0.50	0.80	1.00	1.50	2.00	3.00
26	26	27	29	30	30	31	31	32
27	27	28	30	31	31	32	32	33
28	28	29	31	32	32	33	33	34
29	29	30	32	33	33	34	34	35

2.3. Presentation of Study Tools: Software

Google Sketch Up: Google Sketch Up is a particularly effective software for geometric modelling in 3 dimensions of buildings. It is made freely available by the Google publisher. It allows the plug in Open Studio to provide the architectural model with thermal properties.

Open Studio: Thanks to Open Studio, Energy plus can read geometric data, created from Google Sketch Up, in order to perform thermal calculations selected in the Run Manager section. This allows the user to access the model, run simulation tests, and examine the data. It currently supports Energy Plus simulations.

Energy plus: Thermal simulation in the sense of Energy plus is the interaction of an architectural building model, a climate model and a building use model. This last model will not be taken into account because we consider our building in free evolution that is without energy system. Therefore, the main assumptions concern the building envelope, the aeraulic, and the numerical model of resolution. Also, the method of transfer functions "CTFs" was used for the resolution of heat transfer equations in the walls and at the level of the roof. For convective exchange, we considered the ASHRAE proposed Thermal Analysis Research Program (TARP) correlation for interior surfaces and the DOE-2 correlation for exterior surfaces. Moreover, the model of the sky is based on the empirical model described by Perez [14].

2.4. Calculation Method of Heat Transfer Through the Envelope: CONDUCTION - CTF

The most basic solution is the equation that links the heat flux passing through a surface to the temperature variation on both sides of a surface element as shown in equation:

$$q_{ko}^{n}(t) = \sum_{j=0}^{\infty} X_j T_{o,t-j\delta} \sum_{j=0}^{\infty} Y_j T_{i,t-j\delta} \quad (1)$$

Where « q_{ko}^{n} » is the heat flux, « T » is the temperature, « i » is the inside of the building element, « o » is the outside of the building element, « t » is the current time step, and « X » and « Y » are the answer factors.

The solution contains elements called conduction transfer functions (CTFs). The basic form of a conduction transfer function solution is represented by the following equation:

$$q''_{ki}(t) = -Z_o T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_o T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \theta_j q_{ki,t-j\delta}^{n} \quad (2)$$

$$q''_{ko}(t) = -Y_o T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + Y_o T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \theta_j q_{ko,t-j\delta}^{n} \quad (3)$$

For the external heat flux ($q'' = q / A$)
Where
X_j External CTF coefficient, j = 0,1, ... nz.
Y_J CTF coefficient across the wall, j = 0,1, ... nz.
Z_J Internal CTF coefficient, j = 0,1, ... nz.
θ_φ CTF flux coefficient, j = 1.2, ... nq.
T_i Temperature of the inside face
T_o Temperature of the outside face
q_{ko}^{n} Heat flow by conduction on the outer face
q^{n} Heat flow by conduction on the inside

2.5. Convection Calculation Method: TARP

Walton has developed a mathematical model to take into account convection. This model is called TARP, or Thermal Analysis Research Program [15]. In this model, the Outer convection is divided into forced and natural components [16] and the total convection coefficient is the sum of these two components:

$$h_c = h_f + h_n \quad (4)$$

The forced convection component is based on the correlation of Sparrow, Ramsey and Mass [17] (Sparrow et al., 1979).

$$h_f = 2.537 W_f R_f \left(\frac{PV_z}{A}\right)^{1/2} \quad (5)$$

Where $W_f = 1.0$ For surface exposed to the wind
Where $W_f = 0.5$ For non-windy surface
The surface roughness coefficient R_f is based on the ASHRAE graph of surface conductance [18] (ASHRAE, 1981).

3. Results and Discussion

An annual average hourly temperature analysis indicates that 51% of the readings is between 21°C and 27°C and 48% between 27°C and 38°C

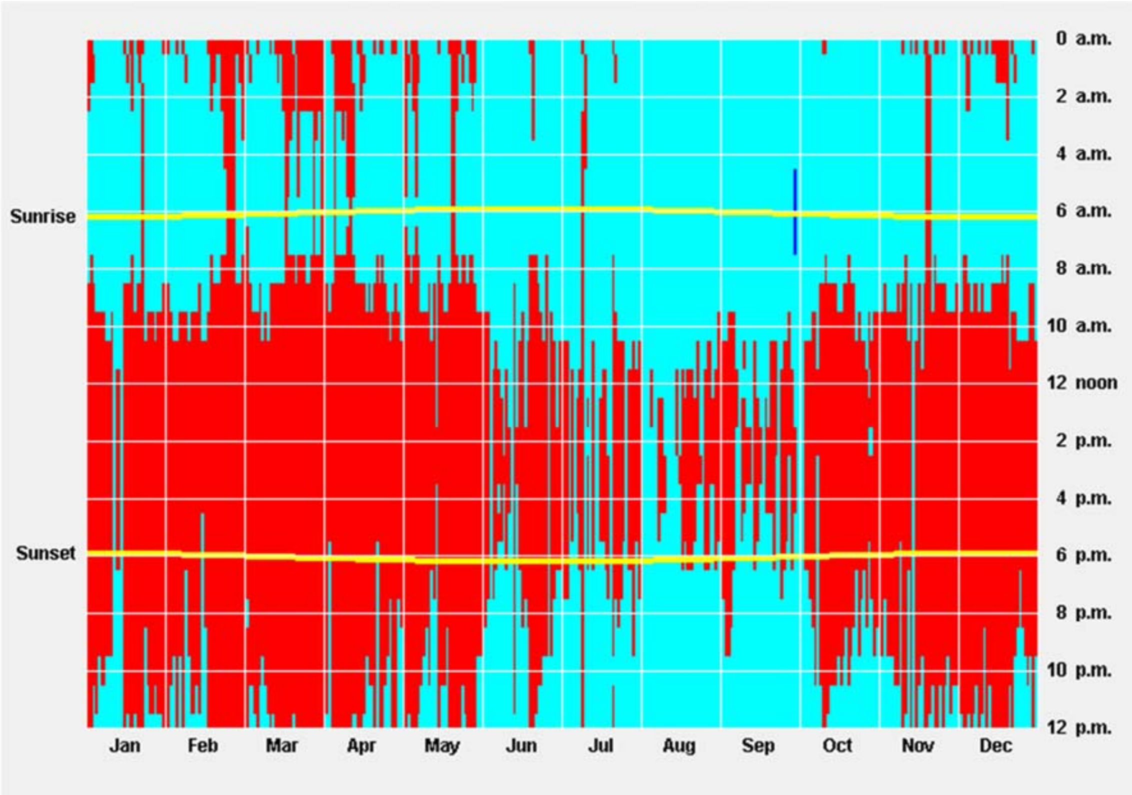

Figure 4. *Hourly distribution of annual moisture (climate consultant).*

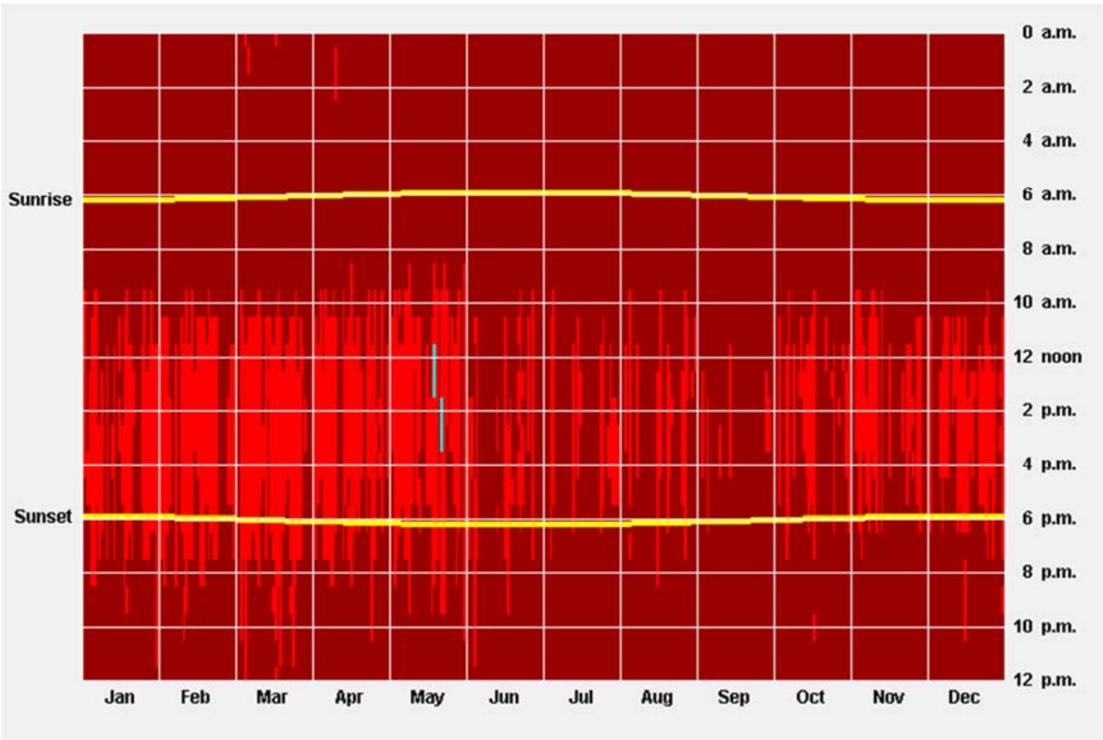

Figure 5. *Hourly distribution of annual temperature (climate consultant).*

An annual average hourly humidity analysis indicates that we have 18% of readings that are between 60% RH and 80% RH and 82% above 80% RH

Orientation and the winds

We represent the wind rose that defines for each direction:

(1) In yellow the proportion of hours of the year according to each direction.

(2) in blue and red respectively temperatures between 21°C and 27°C and between 27°C and 38°C

(3) -in green, we have relative humidity

(4) In orange colour (for the different gradients) the intensity of the winds

a the light orange represents the minimum intensity,

b Orange represents the average of the wind intensities

c Dark orange represents maximum intensity

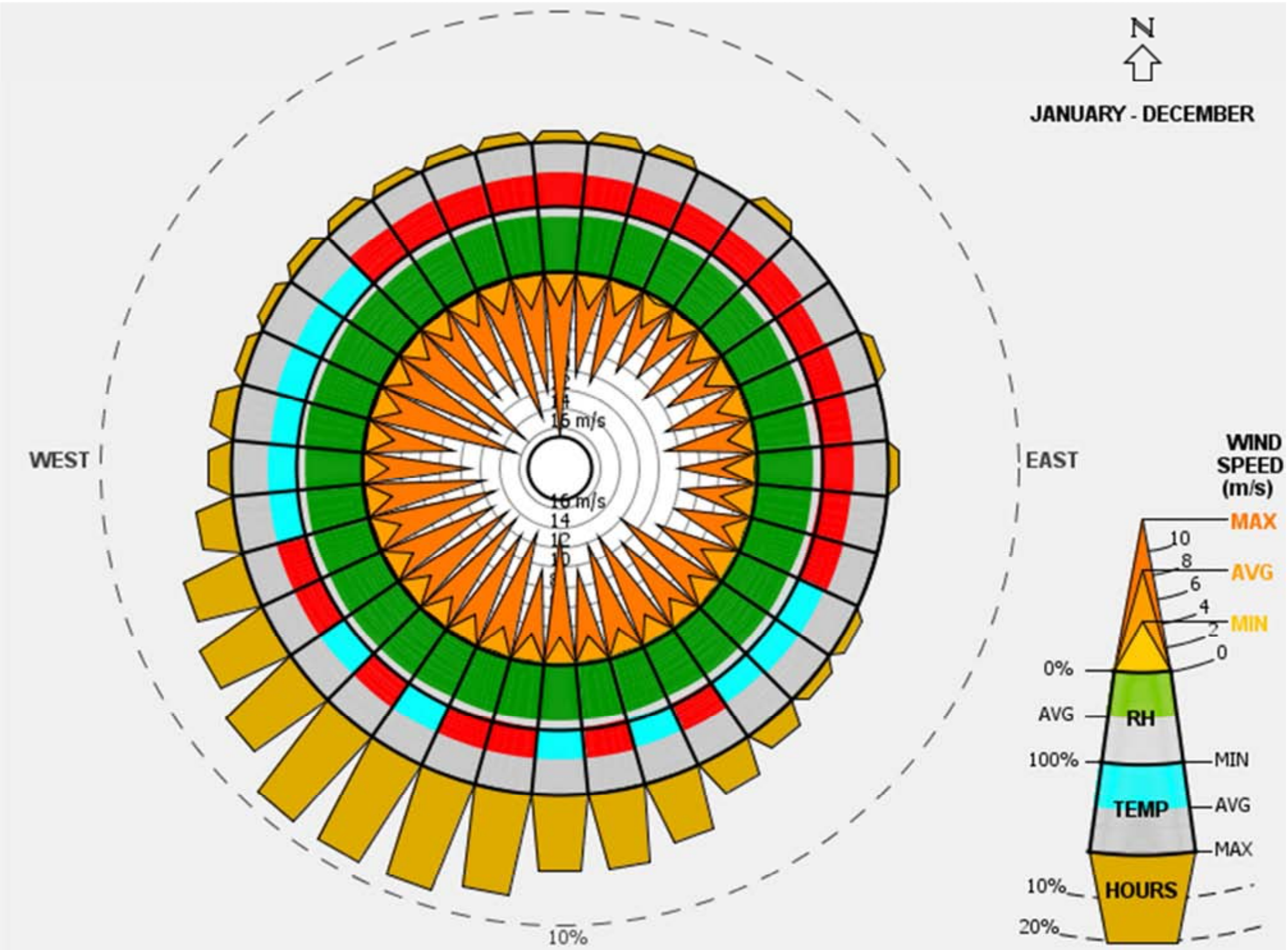

Figure 6. *Annual wind (climate consultant).*

We observe that:

(1) The direction of the prevailing winds is south -west
(2) The average wind intensity is 2m / s for all directions
(3) Southeast, south, southwest, and northwest directions record the highest wind intensities ranging from 12 m / s to 16 m / s
(4) South-west temperatures are colder than temperatures, north and northeast

According to Figure 5, 28% of the winds has a speed lower than 2 m / s, 20% has a speed between 2 and 3m / s, 33% of the winds has a of speed between 3 and 5 m / s, 18% of the winds has a speed between 5 and 9 m / s and 2 % a speed greater than 9 m / s.

Thus 70% of the winds do not exceed the speed of 5 m / s and the monthly average of 2.2m / s. In another study, Arens concluded that the comfort zone can be expanded to 31°C with an air velocity of 1m / s or more [19]. The analysis of the monthly distribution of temperature and relative humidity of the city of Abidjan indicates that most of the year is outside the comfort zone.

Our work aims to characterize the sensation of thermal comfort that an occupant will feel in our building. The operating air temperature of the building, as a bioclimatic index, is used to thermally characterize comfort. To take into account the seasonal variability, we carried out our study over a period of one year thanks to the Energy plus calculation program.

Recall that the standard minimum and maximum comfort temperatures are respectively 24.2°C and 27°C respectively. Also, the soil temperature that was not provided by the meteorological file, we took a recommendation according to ASHRAE specification of the soil's temperature equal to 24.77°C.

Figure 6 shows the annual changes in the operational indoor temperature of the building for single-zone and multi-zone configurations in order to analyse the impact of the choice of one or the other of these two configurations.

In addition, the thermal comfort threshold temperatures of a building in a tropical humid zone are shown in order to have a basis for analysis.

In the multi zone configuration, the roof has a high temperature of more than 2°C compared to other areas that are, by the way, very similar.

Also, the results for a mono zone dynamic thermal simulation gives a difference in building and exterior temperatures ranging from 2°C to 5°C. The work done by Kabore [20], for the city of Ouagadougou in Burkina Faso, shows that for a building of different architecture but with the same materials as our case study of temperature differences of the order of 2°C to 5°C for the period from 14 to 23 February 2014.

However, comfort is reached only 11 days in the year while outdoor weather conditions give 191 days. The envelope of our clay brick building is, therefore, a source of overheating of the air : it promotes a greenhouse effect.

These 11 days of comfort during all the time of the year, which are :

(1) 1 day in the period of very high temperature that is January 15
(2) 10 days in the relatively low temperature period i.e. July 12, 04, 06, 07, 11, 12, 13.14 August, 08 and 17 September.

Finally, the presence of sun is a source of discomfort in tropical areas. This can also be seen in the work of Givoni, Ahmed khan, Sako, and Assimakopoulou [21, 22, 23].

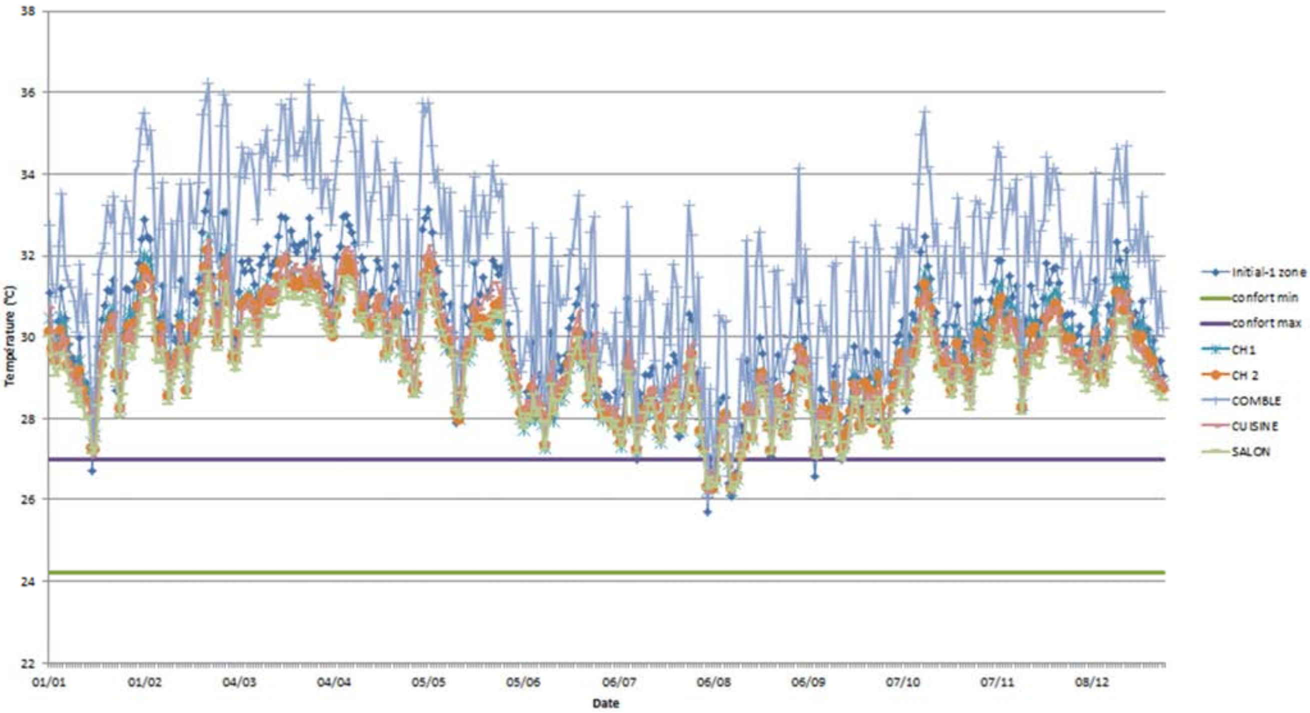

Figure 7. *Annual evolution of the operating temperature of the indoor air of the building for single-zone and multi-zone configurations.*

4. Conclusion

Our research was on a residential building of an architectural typology largely widespread and adopted by the Ivorian government within the framework of the presidential project for the construction of 60 000 social housing. The implementation of the walls was done in clay brick, in our work of numerical study of the thermal behaviour. In addition, these simulations have been done with the Google Sketch UP, Open studio and Energy plus software. We retain that for a low house in Ivory Coast, mono zone model as multi zone model can be used to characterize thermal behaviour for bulding. Also, clay brick, although better at cinderblock can help to create overheating of the building air at the expense of comfort. New energy and environmental concerns regarding thermal comfort in buildings require precise knowledge of temperatures and heat transfer through the walls. In Ivory Coast, solar radiation contributes to overheating for buildings. Thus the design of the walls of a bioclimatic building requires protection.

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