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THERMAL COMFORT IN A BUILDING CONSTRUCTED OF FOAM CONCRETE MADE IN BURKINA FASO

Adélaïde Lareba Ouédraogo[1*], Germain Wend-Pouiré Ouédraogo [1,2], Kossi Bouto Imbga[1,3], Boureima Kaboré[1,3], Gilbert Nana[1], Karim Toussakoe[1], Bruno Korgo[1], Sié Kam[1], Dieudonné Joseph Bathiebo[1], Florent Pèlèga Kiéno[1], Philippe Blanchart[4]

[1] *Laboratory of Thermal and Renewable Energies (LETRE), Department of physics, University Joseph KI-ZERBO, 03 P.O.Box 7021, Ouagadougou, Burkina Faso;*
[2] *University of Fada N'Gourma, Department of physics, PO Box 54 Fada, Burkina Faso;*
[3] *Norbert Zongo University of Koudougou, Department of physics, BP 376, Burkina Faso;*
[4] *Institute for Research on Ceramics (IRCER), European Center for Ceramics, 12 Rue Atlantis, 87068 Limoges –France*
Corresponding author e-mail: adeo62@yahoo.fr

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ABSTRACT

Thermal comfort is a feeling of well-being in a given environment. In the context of sustainable development, new regulations on thermal insulation in the building sector are leading researchers to design new materials for energy-saving systems and ensuring comfort in the habitat. We highlight the effects induced by the use of Pr. Blanchard's foamed concrete (FC) in construction in order to reduce energy consumption and ensure hygrothermal comfort in the home. This article numerically studies the thermal comfort for buildings constructed with materials such as foamed concrete, cinder block, compressed earth brick (CEB), adobe and cut laterite block (CLB). The comparison of the hygrothermal behavior (temperature and relative humidity) of premises made of different materials was carried out with three typical climates (January: dry and cold period, April: dry and hot period and August: humid period and mild temperature) under climatic conditions of Ouagadougou in Burkina Faso. The results showed that for the months of January, April and August the temperatures of the foamed concrete room (FC-930, thickness: th=17.5 cm) having respectively values of 296 K, 304 K, and 298 K is always lower to other materials. The relative humidity of the foamed concrete cell (FC-930, th=17.5 cm) in the months of January, April and August has values of 19%, 31 % and 63.7 % respectively which are also higher than those of the cells built with several local materials. Thus, a building constructed with foamed concrete has better thermal comfort than those made of concrete block, CEB, adobe and CLB.

RESUME

Le confort thermique est une sensation de bien-être dans un environnement donné. Dans le cadre du développement durable, les nouvelles règlementations en matière d'isolation thermique dans le secteur du bâtiment, conduisent les chercheurs à concevoir de nouveaux matériaux pour des systèmes économes en énergie et assurant le confort dans l'habitat. Nous mettons en évidence les effets induits par l'utilisation du béton moussé (BM) du Pr. Blanchard, dans la construction afin de réduire les consommations énergétiques et d'assurer un confort hygrothermique dans l'habitat. Cet article étudie numériquement le confort thermique pour des bâtiments construits avec des matériaux tels que du béton moussé, de parpaing, de brique de terre comprimée (BTC), d'adobe et bloc latérite taillée (BLT). La comparaison du comportement hygrothermique (température et l'humidité relative) des locaux en différents matériaux a été effectuée avec trois climats typiques (Janvier: période sèche et froide, Avril: période sèche et chaude et Août: période humide et température douce) sous des conditions climatiques de Ouagadougou au Burkina Faso. Les résultats ont montré que pour les mois de Janvier, Avril et Août les températures du local en béton moussé (BM-930, e=17,5 cm) ayant respectivement des valeurs de 296 K, 304 K, et 298 K est toujours inférieure aux autres matériaux. L'humidité relative de la cellule en béton moussé (BM-930, e=17,5 cm) du mois de Janvier, Avril et Août a respectivement des valeurs de 19 %, 31 % et 63,7 % qui sont également supérieures à celles des cellules construites avec plusieurs matériaux locaux. Ainsi, un bâtiment construit avec du béton moussé présente un meilleur confort thermique que ceux en parpaing, BTC, adobe et BLT.

I. INTRODUCTION

The primary function of a building is to adapt to the ambient climate and to provide a comfortable and conducive indoor environment for the occupants. However, due to climate change, ensuring the comfort of the occupants of a building is quite complex. Thermal comfort is said to be achieved when the occupants can carry out, in a satisfactory thermal environment, the activities for which the building is intended. The envelope of a building is the interface between the interior atmosphere and the exterior environment. It is the seat of heat, humidity and air transfers which determine the internal climate of the building. Current environmental concerns encourage the construction of efficient buildings from an energy point of view. The walls of the envelope are generally the seat of hygro-thermal transfer. Hygrometric transfers remain negligible most of the year in the Sahelian zone. They impact the energy performance of the walls and are permanent for existing buildings. They are in balance with the external and internal environment (Nadarajan M. and Kirubakaran V., 2016, Zheng P. and al., 2022, Zoure A. N. and Genovese P. V., 2022, Zhang J. and al., 2022). Thermal comfort expresses the satisfaction of well-being with respect to the thermal environment (Padfield T., 1998, ASHRAE, 2004, Mouss H. S. and al., 2019, Zhang Y. and Liu C., 2021). Thermal comfort is linked to six parameters such as ambient air temperature, average wall temperature, metabolism, relative air humidity or hygrometry, air speed and clothing. But it includes three basic parameters such as air temperature, relative humidity and air velocity. Humidity is one of the indoor environmental factors that can affect thermal comfort inside a building (Liping W. and Wong N. H., 2007, Akande O. K. and Adebamowo M. A., 2010, Zhao Q. and al., 2020, Nouadje M. B. A. and Kapen P. T., 2022, Woloszyn M. and al., 2009, Djamila H. and al., 2014). In addition, the external thermal comfort of buildings influences the quality of the environment and human behavior in urban neighborhoods (Zhang Y. and Liu C., 2021). Thermal comfort is an essential issue for housing occupants. One of the main elements to consider in this sense is the humidity level. However, too high humidity will promote the development of mold or fungi as well as the peeling of the paint if the temperature is hot. We study the hygrothermal comfort inside a foamed concrete building, which we compare to that created in buildings constructed using materials such as cement blocks, CEB, adobe and the CLB, under climatic conditions of Ouagadougou. This makes it possible to confirm that the foamed concrete building greatly reduces the thermal loads to be overcome to achieve thermal comfort, thus leading to a rational use of the energy necessary for air conditioning.

Burkina Faso has three typical climates such as the month of January which is a cold, dry and non-rainy period. The month of April is also a dry period with high temperatures (heat period) and the month of August which is a rainy, humid period with mild temperatures.

II. MATERIAL AND METHODS

II.1 Thermo-physical properties of foamed concrete

The thermo-physical properties of the studied material are summarized in Table 1.

Table 1. Thermo-physical properties of the foamed concrete studied (Ouedraogo L. A. and al., 2021, Ouedraogo L. A. and al., 2022)

Samples	FC1	FC2	FC3	FC4
Density (kg/m^3)	650	730	830	930
Thermal conducti-vity (W/m.K)	0.05	0 .09	0.16	0.2
Thermal diffusivity (m^2/s)	$2.53.10^{-8}$	$5.4.10^{-8}$	$1.16.10^{-7}$	$1.23.10^{-7}$
Thermal effusivity ($J/m^2Ks^{1/2}$)	291	387	455.75	579.75
Specific heat capacity (J/kg.K)	2819.46	2289.3	1619.38	1780.09

II.2 Building model

The geometry of the room for the simulation is a parallelepiped having the following dimensions: Length (L= 4 m), width (l = 4 m) and a height of (h = 3 m). The construction is located on an area of 16 m^2 (Ouédraogo L. A. and al., 2022). The walls and the slab roof are constructed with foamed concrete. The main face of the building, where the door is located, faces north. This facade transmits less heat, because it receives a relatively weak irradiation compared to those received on the other walls.

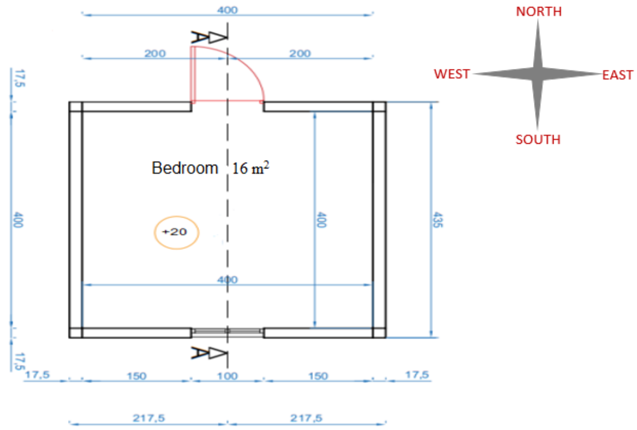

Fig.1. Geometry of the habitable cell studied

The geometry of the model was implemented in COMSOL Multiphysics 5.3a software in 3 dimensions. A calculation program was designed using Matlab software to determine the global solar radiation flux arriving on the East, West, South and North faces of a building under the latitude of Ouagadougou. The equations P_{wi} , translating the global radiation fluxes per m², are expressed using Fourier series (Ouedraogo L. A. and al., 2022). They are incorporated into the COMSOL software for simulation.

$$P_{wface}(t) = a_{0,face} + \sum_{i=1}^{n} a_{i,face} \cos(iw_{face}t) + \sum_{i=1}^{n} b_{i,face} \sin(iw_{face}t) \quad (1)$$

For the energy analysis of the building, we use COMSOL and MATLAB software.

II.3 Modeling of thermal and hygrothermal transfers in the building

Heat transfer in the modeled room is described by conduction in the walls and by convection and radiation in the indoor air. While conduction describes the passage of heat through the wall and partially the transfer of heat into the indoor air, convection describes the transfer of heat into the indoor air of the room. Thus, the sum of these three processes gives the general heat equation.

a. Heat transfer equations

The general heat transfer equation is as follows (Gerlich V., 2011, Nikishkov G. P., 2009, Charvátová H. and al., 2018):

$$(\rho C_p)\frac{\partial T}{\partial t} + \rho C_p \mathrm{u}.(\nabla \mathrm{T}) = -\nabla.(q) + \mathrm{Q} \quad (2)$$

$$\mathrm{q} = -\lambda(\nabla \mathrm{T}) \quad (3)$$

With ρ : Density of the fluid (kg/m³), C_p : Specific heat capacity at constant pressure of the fluid (J/kg.K), ρC_p : Specific heat capacity at constant pressure (J/m³.K), T : Ambient temperature (K), λ : Equivalent thermal conductivity of the medium, u : Fluid velocity field (m/s), Q : Possible heat source (W/m³), q : Heat flux (W/m³).

For the simulation of heat transfers in the walls, the heat conduction equation used is:

$$(\rho C_p)\frac{\partial T}{\partial t} = \nabla.(\lambda \nabla T) + Q \quad (4)$$

$$(\rho C_P)\frac{\partial T}{\partial t} - \lambda \nabla^2 T = Q \quad (5)$$

Assuming that the internal air volume is at a homogeneous temperature at each calculation step in the entire occupied space, we make at each instant the heat balance of this air volume by taking into account all the heat fluxes transmitted to it by convection and radiation (Ouedraogo L. A. and al., 2022, Gerlich V., 2011, Charvátová H. and al., 2018).

$$m_{air}\rho_{air}C_P\frac{dT}{dt} + \int_S (n.q)\,dS = Q_v \quad (6)$$

With m_{air} : Mass of the air, ρ_{air} : Density of the air, $\frac{dT}{dt}$: Total derivative, Q_v : Sources of specific heat.

Conditions to the limits

The different heat fluxes, convection and radiation, on the inner and outer boundaries in equations (7), (8), (9) and (10) have been considered. There is no internal heat production in our study model (Ouedraogo L. A. and al., 2022, Gerlich V., 2011, Nikishkov G. P., 2009, Charvátová H. and al., 2018, Oumarou F. A. and al., 2021).

$$q = h_i\left(T_P - T_{\mathrm{int}}\right) \text{ on } \partial\Omega_{\mathrm{int}} \quad (7)$$

$$q = \varepsilon\sigma\left(T_{p,\mathrm{int}}^4 - T_{\mathrm{int}}^4\right) \text{ on } \partial\Omega_{\mathrm{int}} \quad (8)$$

$$q = h_e\left(T_e - T_p\right) \text{ on } \partial\Omega_{ext} \quad (9)$$

$$q = \varepsilon\sigma\left(T_p^4 - T_{amb}^4\right) \text{ on } \partial\Omega_{ext} \quad (10)$$

With q : Heat flux, h : Heat transfer coefficient, T_p: Wall temperature, T_{int} : Internal temperature, T_e: External temperature, ε : Emissivity, σ : Stefan Boltzmann constant, T_{amb}: Ambient temperature

b. Equations for determining relative humidity

To analyze the hygrometric behavior of the building through absolute humidity or relative humidity, the classic Bertrand formula or that of Antoine can be used to determine the saturation vapor pressure.

- **Bertrand formula**

$$P_{vsat}(T) = 101325 \times 10^{(17{,}443 - 2795/T(K) - 3{,}868 \times \log_{10}(T(K)))} \quad (11)$$

Avec P_{vsat}: Saturating vapor pressure in (Pa)
T: Temperature in (K)

- **Formula of Antoine**

Antoine's equation gives the saturation vapor pressure of a substance at a given temperature. The coefficients of the equation are only valid for a temperature interval.

$$T = \frac{B}{A - \log_{10}\left(\frac{P_{vs}}{P_0}\right)} - C \quad (12)$$

$$P_{vs} = P_0 \times 10^{\left(A - \frac{B}{T+C}\right)} \quad (13)$$

With: P_{sat} : saturation vapor pressure (Pa), P_0 : standard pressure (Pa), A, B, C: Antoine's constants

For $273 \leq T(K) \leq 303$ with A=5,40221 B=1838.675 C=-31.737
For $304 \leq T(K) \leq 333$ with A=5,20389 B=1733.926 C=-39,485
The general relationship of the thermodynamics of moist air is given by the following relationship:

$$RH = \frac{P.H_{ab}}{P_{vsat}.(H_{ab} + 0{,}622)} \quad (14)$$

With P: Atmospheric air pressure equal to 101325 Pa

Table 2. Climate data for Ouagadougou (data from 1991-2021)

Month	Average minimum tempera-ture (°C)	Average maximum tempera-ture (°C)	Average tempera-ture (°C)	RH (%)
January	17.7	32.9	25.1	16
April	26.4	39.6	33.1	27
August	22.8	30.2	26.1	79

Table 2 represents the average temperature and relative humidity from 1991 to 2021 for the months of January, April and August. The average temperature obtained with a value of 33.1°C makes April the hottest month of the year and that of 25.1°C makes January the coldest month of the year.

Study hypotheses:

- In this simplified model, considering the very low air speeds within the building we do not introduce a momentum equation;
- Small openings at the door and window lead to a low air change of about 0.1V/h; The medium considered is isotropic;
- Heat transfer by conduction is unidirectional in the walls;
- The temperature is uniform in a wall;
- The air used is homogeneous and transparent to radiation;
- The materials are assimilated to gray bodies;
- The thermo-physical properties of the materials are constant;
- It is assumed that at 0h, beginning of the simulation, all the walls of the envelope are at the same temperature of 303K;
- It is assumed that the volume of internal air is at homogeneous temperature at each step of time, throughout the occupied space; we make at each moment, the thermal balance of this volume of air taking into account all the heat fluxes that are transmitted to it by convection, radiation and infiltration.

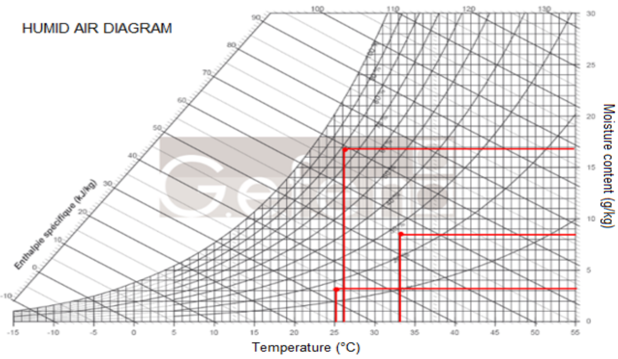

Fig.2. Diagram of humid air (Source: Jacques Besse)

In our study, we chose respectively for the months of January, April and August an average daily temperature of 25.1°C; 33.1°C; 26.1°C with relative humidity of 16%, 27% and 79%. We determined the average absolute humidity on the diagram of humid air, we obtain, respectively, with values of 0.00325; 0.0085; 0.0169 kg of water/kg of dry air for the months of January, April and August.

- **Thermal comfort diagram**

In the psychrometric chart, the thermal comfort zone is determined by Givoni.

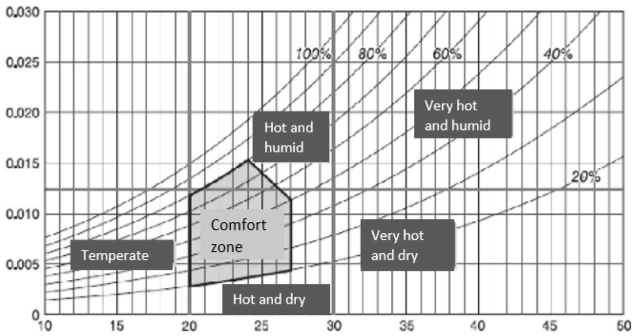

Fig.3. Thermal comfort zone (Givoni) (BOT BILL V., 2014)

The proposed comfort temperature is in the range; (20°C $< T <$ 27°C) for relative humidity in the range (20 % $< RH <$ 80 %).
Thermal comfort is not only linked to a fixed temperature. Everyone's feelings, the "operative" temperature in a space, the humidity of the ambient air, the air speed, also play a role in the feeling of comfort (ISO 7730 standard). According to this standard, we can adopt the comfort zone having 0.5m/s for the Sudano-Sahelian zone.

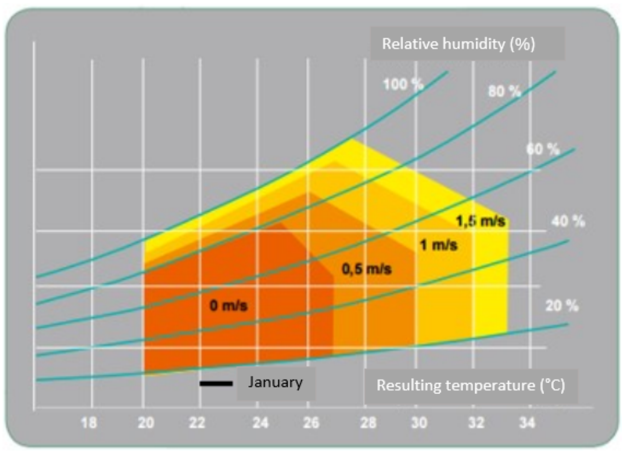

Fig.4: Thermal comfort according to ISO 7730)

III. Results and discussion

III.1 Hygrothermal behavior of different buildings

The results obtained below are those of the evolutions of the temperature and relative humidity of the internal air of buildings made of different materials for the months of January, April and August. We notice in this study that the relative humidity evolves in the opposite direction of the temperature.

a. Evolution of temperatures and relative hygrometry in the building

Figures 5, 6, 8, 9, 11 and 12 show the evolution of the average internal and external temperatures and of the internal and external relative hygrometry of the building constructed with foamed concrete of different thicknesses as well as that of other materials for the months of January, April and August.

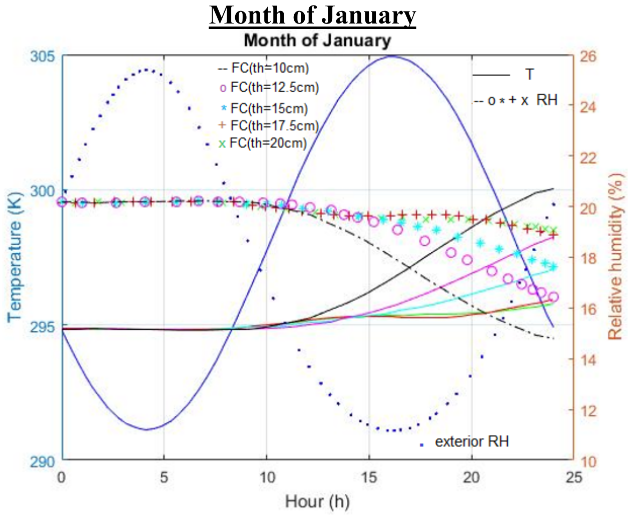

Fig.5. Evolution of the temperature and relative humidity of the external air and the internal air of a building (foamed concrete) of different thicknesses for the month of January.

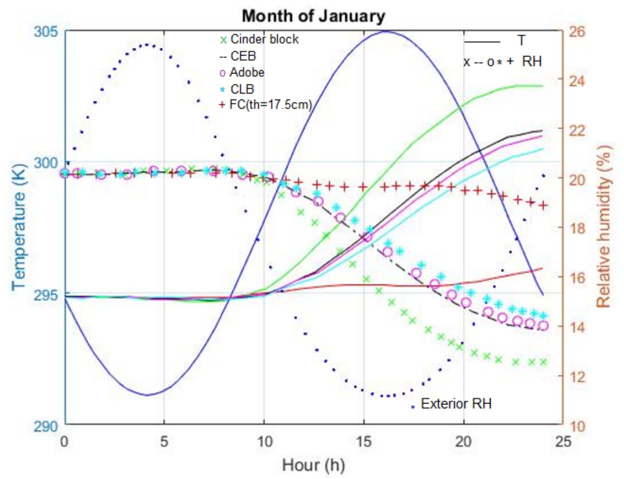

Fig.6. *Evolution of the temperature and relative humidity of the external air and the internal air of a building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of January*.

We find that for the month of January the relative humidity of the internal air of the foamed concrete building of different thicknesses (**Fig.5**) varies between 14.5 % and 20.2 % when the temperature varies from 294.85 K to 300 K. We remain outside the comfort zone, due to too low a relative humidity. You just have to slightly humidify the interior atmosphere to find yourself in the comfort zone.
The evolutions of temperature and relative hygrometry for the same model of building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of January, are illustrated in **fig.6**. The cell of foamed concrete (e=17.5cm) leads to a maximum temperature T_{max} =296 K for a minimum relative

humidity HR_{min} =19%. One obtains respectively, for the cells in concrete block, CEB, adobe, CLB (T_{max}=303K; HR_{min}=12.5%); (T_{max}=301.5; HR_{min}=13.9%); (T_{max}=301K; HR_{min}=14%); (T_{max}=300.4; HR_{min}=14.2%).

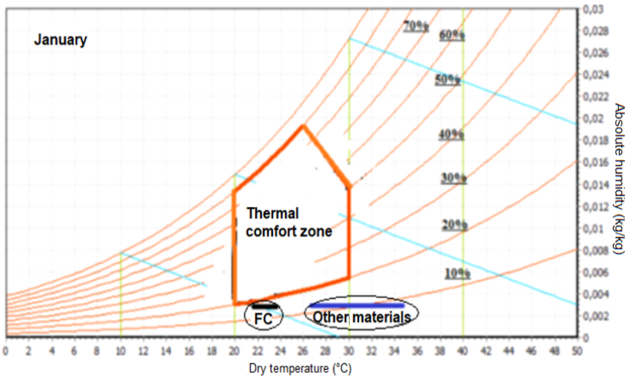

Fig.7. Locations of the different atmospheres (monthly average) in the Givoni diagram (January)

It then appears clearly that in this scenario, there are no thermal loads to overcome with a FC cubicle, it suffices to slightly humidify the room to reach the thermal comfort zone; which is not the case for other materials.

Similar simulations are made for the months of April and August; the figures (8, 9, 11 and 12) below summarize the results obtained. month of April

Month of April

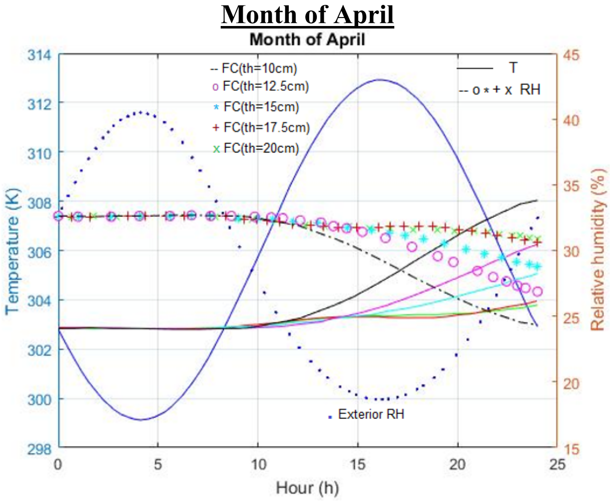

Fig.8. Evolution of the temperature and relative humidity of the external air and the internal air of a building (foamed concrete) of different thicknesses for the month of April

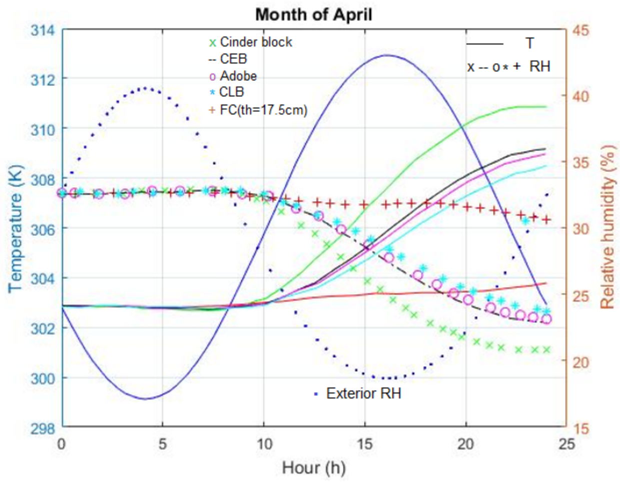

Fig.9: Evolution of the temperature and relative humidity of the external air and the internal air of a building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of April.

We note that for the month of April the minimum relative humidity of the internal air of the foamed concrete building of different thicknesses (**fig.8**) varies between 24% and 32.6% when the maximum temperature varies from 302.9 K to 308 K.

The evolutions of temperature and relative hygrometry for the same model of building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of April, are illustrated in **fig.9**. The cell of foamed concrete (e=17.5cm) leads to a maximum temperature T_{max}=304 K for a relative humidity HR_{min}=31%. For the block cells, CEB, adobe, CLB are obtained respectively (T_{max}=311K; HR_{min}=20.85%); (T_{max}=309.2; HR_{min}=22.9%); (T_{max}=309K; HR_{min}=23.2%); (T_{max}=308.5; HR_{min}=23.8%).

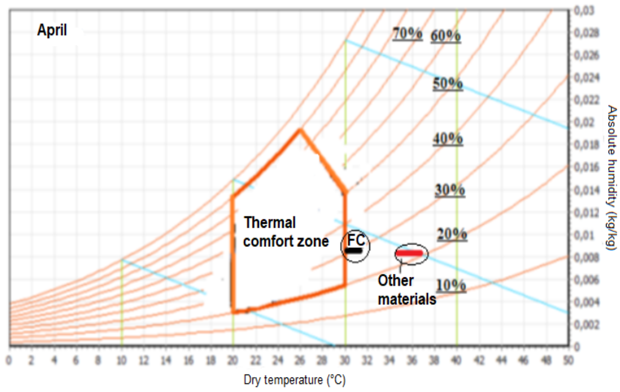

Fig.10: Locations of the different atmospheres (monthly average) in the Givoni diagram (April)

In April, **fig.10** above indicates a thermal load of two (2) degrees, to be overcome, in order to achieve thermal comfort. We note that with the other materials, we find ourselves in the most favorable case, with a thermal load greater than four (4) degrees.

Month of August

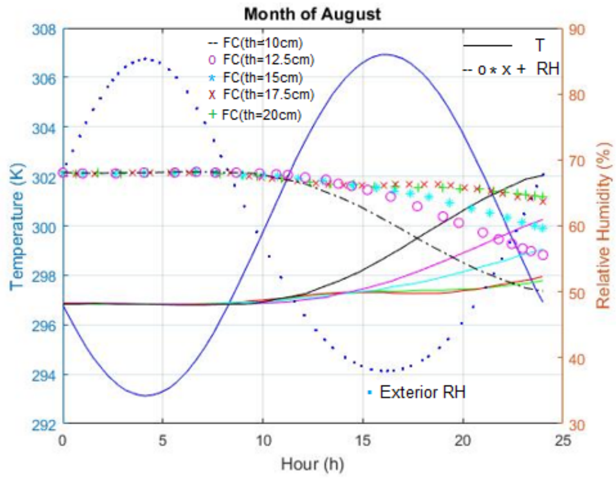

Fig.11: Evolution of the temperature and relative humidity of the external air and the internal air of a building (foamed concrete) of different thicknesses for the month of August

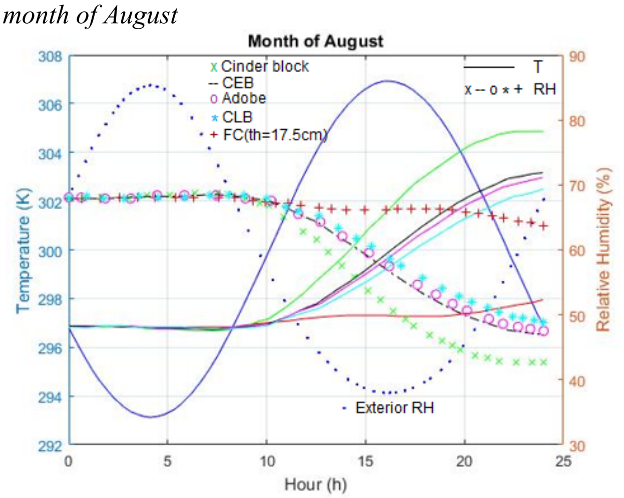

Fig. 12: Evolution of the temperature and relative humidity of the external air and the internal air of a building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of August.

For the month of August, the minimum relative humidity of the internal air of the foamed concrete building of different thicknesses (**fig.11**) varies between 50% and 68% when the maximum temperature varies from 296.99 K to 302 K.

The evolutions of temperature and relative hygrometry for the same model of building constructed using different materials (FC, CLB, Adobe, CEB, Cinder block) for the month of August, are illustrated in **fig.12**. The cell of foamed concrete (e=17.5cm) leads to a maximum temperature T_{max}=298 K for a relative humidity HR_{min}=63.7%. For the concrete block cells, CEB, adobe, CLB are obtained respectively (T_{max}=305K; HR_{min}=42.6%); (T_{max}=303.2; HR_{min}=46.96%); (T_{max}=302.9K; HR_{min}=47.5%); (T_{max}=302.5; HR_{min}=48.8%).

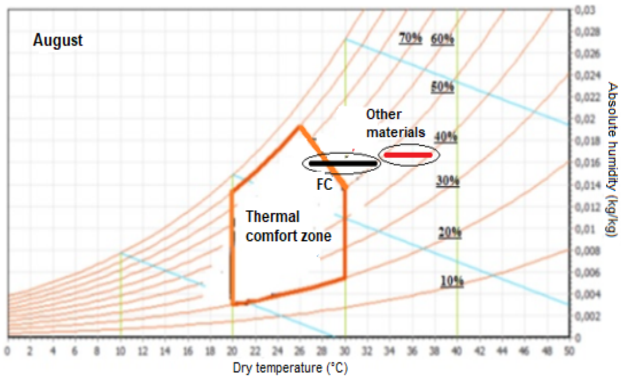

Fig.13: Locations of the different atmospheres (on a monthly average) in the Givoni diagram (August)

In August, **fig.13** above indicates that with a thickness of FC brick greater than 12.5 cm, we are in the thermal comfort zone. However, with other materials, it is necessary to overcome a thermal load greater than four (4) degrees, to achieve thermal comfort.

In the month of January, the relative humidity of foamed concrete FC-930, th=17.5cm, being less than 30%, is due to the fact that this period is dry, characterized by the presence of harmattan. It also has low absolute humidity. On the other hand, in the months of April and August, the relative humidity of the internal air of the foamed concrete building FC-930, th=17.5cm presents values which are in the comfort zone, as well as the month of 'August. This allows us to say that the building of the internal air of foamed concrete FC-930, th=17.5cm, in the month of January, April and August is more comfortable than those of cinder block, BTC, Adobe, BLT.

In general, the foamed concrete building has internal environments of lower temperatures than those of other materials, for relative humidities which belong to the thermal comfort zone. In August we even reach the comfort zone and in January with 1 or 2 % of relative humidity, we would still find ourselves in the comfort zone. With other materials, thermal loads of more than four (4) degrees must be overcome.

CONCLUSION

In this article, the indoor thermal comfort of buildings was simulated by considering buildings constructed with well-known materials and that of poorly known foamed concrete in Burkina Faso. The simulations were carried out for the periods of January, April and August. The variation in temperature and relative humidity inside houses depends on the climatic seasons and the geographical location. The climatic data used for the simulation of the buildings are those of Ouagadougou. The simulation of the model with Comsol Multiphysics 5.3a and MATLAB software allowed us to obtain results on the temperature and the relative hygrometry of the internal and external air of the building. These results showed that for the months of January, April and August the temperature of the foamed concrete FC-930, th = 17.5 cm having respectively values of 296 K, 304 K, and 298

K is always lower than the other materials. The relative humidity of the foamed concrete FC-930, th = 17.5 cm in the months of January, April and August has values of 19%, 31% and 63.7% respectively which are also higher than that of the cells made of local materials. Thus, foamed concrete FC-930, th = 17.5 cm has relatively low temperatures and high relative humidity compared to cinder block, CEB, adobe and CLB. Note however that this range of relative humidity is found in the thermal comfort zone, only the average internal temperatures deviate from it. Thus, a building constructed with foamed concrete has better thermal comfort compared to other materials. In the Sahelian zones, with the temperature plays an important role on the thermal comfort of the habitats.

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REFERENCES

Akande O. K. and Adebamowo M. A., 2010"Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria," in *Proceedings of Conference: Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk*, 2010, no. October, p. 11.

ASHRAE, 2004 "ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy. ANSI/ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.".

BOT BILL V., 2014 "Etude et réhabilitaton du système de climatisation en vue du refroidissement du LATE de l'ENSET de Douala," Université de DOUALA - DIPET.

Charvátová H., Procházka A., and Zálešák M., 2018 "Computer Simulation of Temperature Distribution during Cooling of the Thermally Insulated Room," *MDPI*, pp. 1–16.

Djamila H., Chu C., and Kumaresan S., 2014 "Effect of Humidity on Thermal Comfort in the Humid Tropics," *Sci. Res. J. Build. Constr. Plan. Res.*, no. 2, pp. 109–117.

Gerlich V., 2011 "Modelling of heat transfer in buildings," *Fac. Appl. Informatics ,Tomas Bata Univ. Zlín Nám. T.G. Masaryk. 5555, Zlín 760 01, Czech Repub.*, pp. 1–5.

Liping W. and Wong N. H., 2007 "The impacts of ventilation strategies and facade on indoor thermal environment for naturally ventilated residential buildings in Singapore," *Build. Environ.*, vol. 42, no. 12, pp. 4006–4015.

Moussa H. S., Nshimiyimana P., Hema C., and Zoungrana O., 2019 "Comparative Study of Thermal Comfort Induced from Masonry Made of Stabilized Compressed Earth Block vs Conventional Cementitious Material," *Sci. Res. Publ. J. Miner. Mater. Charact. Eng.*, vol. 7, no. 385–403, pp. 385–403.

Nadarajan M. and Kirubakaran V., 2016 "Simulation Studies on Indoor Relative Humidity Maintenance in Rural Residential Buildings Using Sustainable Building Materials," *J. Mech. Civ. Eng.*, vol. 13, no. 4, pp. 51–57.

Nikishkov G. P., 2009 "Introduction to the finite element method," University of Aizu, Aizu-Wakamatsu 965-8580, Japan, P.85.

Nouadje M. B. A. and Kapen P. T., "Three-dimensional numerical simulation of indoor thermal comfort for sleeping environments: A case study of residential buildings in the city of Bandjoun, Cameroon," *ELSEVIER Sol. Energy*, vol. 242, pp. 56–69, 2022.

Ouedraogo L. A., Messan A., Malbila E., Ouedraogo E., Bathiebo D. J., Kieno F. P., and Blanchart P., 2021 "Thermo-Physical , Mechanical and Hygro-Thermal Properties of Newly Produced Aerated Concrete," *J. Mater. Sci. Surf. Eng.*, vol. 8, no. 2, pp. 1021–1028.

Ouédraogo L. A., Kabré S., Malbila E., Compaoré A., Saré R., Ilboudo P., Kam S., Korgo B., Bathiebo D. J., Kieno F. P., and Blanchard P., 2022 "Comparative Study of the Thermal and Mechanical Properties of Foamed Concrete with Local Materials," *Sci. Res. Publ. World J. Eng. Technol.*, pp. 550–564.

Ouédraogo L. A., Malbila E., Dabilgou D., Amadou F. O., Ouédraogo S., Ouédraogo S., Messan A., Kam S., Bathiebo D. J., Kiéno F. P., and Blanchart P., 2022 "Evolution of the Average Temperature of the Interior Atmosphere of a Habitable Cell Made of Foamed Concrete in Burkina Faso," *Phys. Sci. Int. J.*, vol. 26, no. 2, pp. 11–24.

Oumarou F. A., Ouedraogo A., Ky S. M. T., Bhandari R., Konfe A., Konate R., Adamou R., Bathiebo D. J., and Kam S., 2021 "Effect of the Orientation on the Comfort of a Building Made with Compressed Earth Block," *Sci. Res. Publ. Smart Grid Renew. Energy*, vol. 12, no. January, pp. 99–112.

Padfield T., "THE ROLE OF ABSORBENT BUILDING MATERIALS IN MODERATING CHANGES OF RELATIVE HUMIDITY," The Technical University of Denmark, Department of Structural Engineering and Materials, Ph.D. thesis, 1998.

Woloszyn M., Kalamees T., Abadie M. O., Steeman M., and Kalagasidis A. S., 2009 "The effect of combining a relative-humidity-sensitive ventilation system with the moisture-buffering capacity of materials on indoor climate and energy efficiency of buildings," *Build. Environ.*, vol. 44, no. 3, pp. 515–524.

Zhang J., Li P., and Ma M., 2022 "Thermal Environment and Thermal Comfort in University Classrooms during the Heating Season," *Build. Artic. MDPI*, pp. 1–20.

Zhang Y. and Liu C., 2021 "Digital Simulation for Buildings ' Outdoor Thermal Comfort in Urban Neighborhoods," *Build. Artic.*, vol. 11, no. 541, pp. 1–10.

Zhao Q., Lian Z., and Lai D., 2020 "Thermal Comfort models and their developments: A review," *Energy Built Environ. J. Pre-proof*, pp. 1–36.

Zheng P., Wu H., Ding Y., Liu Y., and Yang L., 2022 "Thermal comfort in temporary buildings: A review," *Build. Environ. Artic. 109262*, vol. 221, no. ISSN 0360-1323.

Zoure A. N. and Genovese P. V., 2022 "Development of Bioclimatic Passive Designs for Office Building in Burkina Faso," *Sustain. , MDPI*, pp. 1–23.

