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Evaluating Thermal Performance and Environmental Impact of Compressed Earth Blocks with Cocos and Canarium Aggregates: A Study in Douala, Cameroon

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Abstract. A novel low-cost earthen construction system integrating biosourced aggregates is proposed for houses' erection of low-income households. This study is based on in-situ measurements on two representative test cells constructed in Douala, with a typical hot and humid climate. One of these buildings is made with a hollow cement block as a reference, and the other with biosourced earth bricks modified with Cocos nucifera and Canarium schweinfurthii aggregates. Dynamic thermal simulations of the two test cells were performed using the EnergyPlus building performance simulation program. The results are based on measuring air temperature and humidity, and the simulation leads to defining the discomfort hours and the annual energy consumption. The adaptive ASHRAE 55 thermal comfort model was used to evaluate the comfort conditions. The results show that air conditioning systems provide the best comfort systems with minimums of about 95% for plastered and unplastered wall construction systems. Biosourced compressed earth brick constructions offered the best thermal performance with comfort ranges of around 96% and 44% for air conditioning and natural ventilation, respectively. In terms of energy consumed, there was a gain of about 100 kWh over the year. Energy consumption is lower in the biosourced compressed earth brick building than in the hollowed cement block building: this one offered the lowest comfort range of about 40% in natural ventilation. The construction provisions were considered for the life cycle assessment, and two scenarios describing the origin of the cement raw materials were considered. It can be seen that cement accounts for more than 95% of the impacts for both construction systems, as well as for the scenarios of its origin. In all situations, the hollowed cement block construction presented the highest impact on the global warming potential: 66 $KgCO_2eq$ and 89 $KgCO_2eq$, respectively, without plaster and with plaster. It can also be seen that the plastered layer had a carbon footprint (in terms of Green House Gas Emissions (GHG emissions)) of almost 40% on the overall functional unit. Canarium Schweinfurthii and Cocos Nucifera materials accounted for only 1% of the overall impact.

Introduction

In its fifth report on climate change mitigation policies, the Intergovernmental Panel on Climate Change (IPCC) estimated that buildings account for 32% of global energy demand, 24% of which is in the domestic sector alone and 51% of electricity demand [1]. The sector is estimated to consume more than 3 billion tonnes of raw materials and 12% of drinking water annually. Within the meantime, construction, renovation, and demolition generate more than 40% of solid waste in developed countries. Greenhouse gas (GHG) emissions from the building sector were estimated in 2010 to be 9.18 GtCO2eq [1], about one-fifth of the global total for all sectors. Under the combined effect of population growth and massive urbanization, these emissions could double or even triple by 2050. The world's population would then be around 9 billions, with the urban population rising from 53% today to over 80% [2]. This reflects a significant carbon footprint and contribution to anthropogenic climate change. This population growth problem creates a glaring housing problem for rich and less developed nations. It is therefore not surprising that the UN, in its 17 Sustainable Development Goals (SDGs), anticipates in its 11th SDG to think about sustainable cities that will experience an exodus of more than half the population by 2030. This rapid urbanization will pressure water supply and waste disposal systems, the living environment and public health [3].

Like in other African countries, Cameroon has been confronted to housing problems since 1980 [4], and the current situation is increasingly precarious [5]. At this point, the development of ecological construction materials and secondary resources would make it possible to solve the dual problem of the availability of 'sustainable' construction and respect of the environment. Indeed, these ecological materials - raw earth, wood, biological aggregates and natural reinforcing fibers - are available and offer better insulation than conventional materials - cement, concrete, steel, glass, plastics and synthetic materials derived from oil [6, 7].

However, cement-based materials are the most used materials for wall construction in urban areas in Cameroon. Raw earth bricks are rarely used in urban areas but are more present in rural areas. These materials are mainly used in urban areas as exterior-facing bricks. The literature, conversely, indicates that cement-based materials have a lower energy efficiency than earthen materials [8, 9]. Furthermore, the production process of cement-based materials is very polluting and quite expensive [10].

The earth material can be firstly processed by increasing the compaction pressure to improve the characteristics of raw earth [11, 12], which leads to an increase in density and compressive strength, but, conversely, an optimization in hydrophilic and insulating potential. Secondly, performances may be improved through chemical stabilization, i.e., cement or lime [13, 14]. Finally, reinforcement is also achieved by adding plant by-products [14 - 16], such as fibers from sugar cane bagasse, plantain stem, and cork aggregates. Biosourced aggregates from hard shells and cores can also be substituted for sand particles. Due to their low density and conductivity coefficient, the latter leads to lighter constructions with low thermal inertia.

Therefore, rational energy management in buildings is becoming a major issue that should concern all actors in the development process - households, construction companies, and production companies. Therefore, it is important to assess the energy performance of buildings by adopting bioclimatic design practices. These strategies and architectural techniques seek to take maximum advantage of the sun in the dry season and protect against it in the wet season. It will therefore be necessary to take into account the orientation of the building, the thickness of the walls, the efficient choice of building materials, the management of solar gain, the construction system of the roof, the ventilation system and use scenarios for thermal comfort analysis [19, 20].

In his research on efficient construction practices, Mahar tested eight possible orientations for a residential building in a dry, semi-arid climate in Quetta, Pakistan [21]. He found that by orienting the front facade to the south, he obtained more hours of comfort throughout the year.

In this same study, Mahar [21] defined several construction strategies for thermal comfort optimization. He defined 6 construction strategies: (1) action on the thermal inertia of the wall by increasing its thickness; (2) action on the constitution of the wall by increasing the layers of insulation, (3) action on the type of glazing (double or triple), (4) action on the roof constitution with capping, (5) combined action on the constitution of the wall and the roof, (6) combined action on the type of glazing, the constitution of the roof and wall. The best performance was obtained by insulating the roof with capping (10.7% improvement), but also by combining the constitution of multilayer walls with roof insulation (13.2% improvement) and, finally, the combination of triple glazing with multilayer wall and roof insulation with capping (14.6%).

Several other works show that the constitution of the wall with that of the glazing influence more than 60% in the thermal comfort. Then, Nematchoua et al. specified in 2017 the obligation of polystyrene insulation (0.08 m thickness) of the walls in cinder block in Douala for an energy gain of approximately 51.69 $/m^2 [22]. This sandwich wall construction system could allow energy savings evaluated between 58% and 77% for ventilation by air conditioning over the year [23, 24].
Ventilation systems aim to regulate indoor air quality: temperature, distribution, air renewal rate, and pollutant concentration [20, 25]. Ventilation is a strategy to achieve correct air quality and to bring fresh air from the outside into the indoor space. Different methods can achieve this process: mechanical ventilation using a fan or an extractor; natural ventilation, which is the result of temperature and pressure variation between the outside and the inside generating an air current; or hybrid ventilation (mechanical-natural), used to compensate the weaknesses of natural ventilation when conditions are not favorable. In a comparative analysis, natural ventilation has a lower energy consumption and climate impact than mechanical solutions [25]. Costanzo et al. [26] show that natural ventilation can have limitations and reduce efficiency when operating temperatures are above 25°C with internal heat gains above 40 W/m^2. Grigoropoulos et al. [27] stated that natural ventilation can reduce energy consumption by up to 20% per month, without depending exclusively on comfort needs, compared to air-conditioning systems. It also influences the perception of safety, daylight conditions or acoustic comfort. On the other hand, it can also cause discomfort due to the high speed of the indoor air.
The materials chosen will affect the environment because wall construction strategies influence thermal comfort.
For buildings, seven functional requirements are defined by the construction products regulation [28]: mechanical resistance; safety in the event of fire; hygiene, health, and the environment; safety in use and accessibility; protection against noise; energy saving and thermal insulation; and sustainable use of natural resources. A large research study has determined the best composition of compressed earth bricks modified with fibers [12]. Energy-saving and thermal insulation mandatories need now to verify how the use of modified compressed earth bricks may influence global thermal performance and the environmental impact of buildings.
The method used is to simulate the annual thermal performance and the life cycle environmental impact of two buildings: the first with biosourced compressed earth brick (BCEB) modified by Cocos nucifera (CN) and Canarium schweinfurthii (CS) aggregates and the other with the hollow concrete block (HCB). This comparison uses an energy simulation model with the EnergyPlus code integrated into the DesignBuilder software and the environmental footprint. Thermal comfort was assessed during the simulations on the model buildings using the adapted ASHRAE comfort model.
As described earlier, urbanization is expected to increase GHG emissions associated with building materials production in the Global South. Therefore, it is important to understand the impact of earth construction on thermal comfort and increasing GHG emissions risks of the construction sector. This paper introduces a new BCEB composition to improve indoor thermal comfort and reduce the embodied GHG emissions of wall constructions. New reinforcement materials of Cocos nucifera (CN) and Canarium schweinfurthii (CS) aggregates are introduced to biosourced compressed earth blocks and assessed using advanced building thermal modeling and life cycle assessment best practices based on ISO 14040 [29].

Materials and Methods

Construction of the two tests cells

Two calibrated test cells were built on the site of the University of Douala (4°03'20.7 'N 9°44'35.9 ‘E). The two buildings are identical in interior dimensions of 3 × 3 m^2 for a height of 3m. One is built with Hollow Cement Blocks (HCB), and the other with Biosourced Compressed Earth Bricks (BCEB) modified with Cocos Nucifera and Canarium Schweinfurthii aggregates (CNCS). This name is adopted to designate a combination of 2/4 grade CN and CS aggregates (proportion 50/50). The BCEB was stabilized with 8% of ordinary Portland cement (OPC) and modified with 5% CNCS [16].

The architectural sections (Fig. 1) show constructions with isolated footings and continuous stringers. The posts are chained at 3 m in height. The roof has 4 symmetrical slopes with a 1.5 m pitch and a 1 m overhang. The slab is unsmoothed with a mortar formulation of 300 $Kg.m^{-3}$. The ceiling is made of $50/10^{th}$ mm plywood.

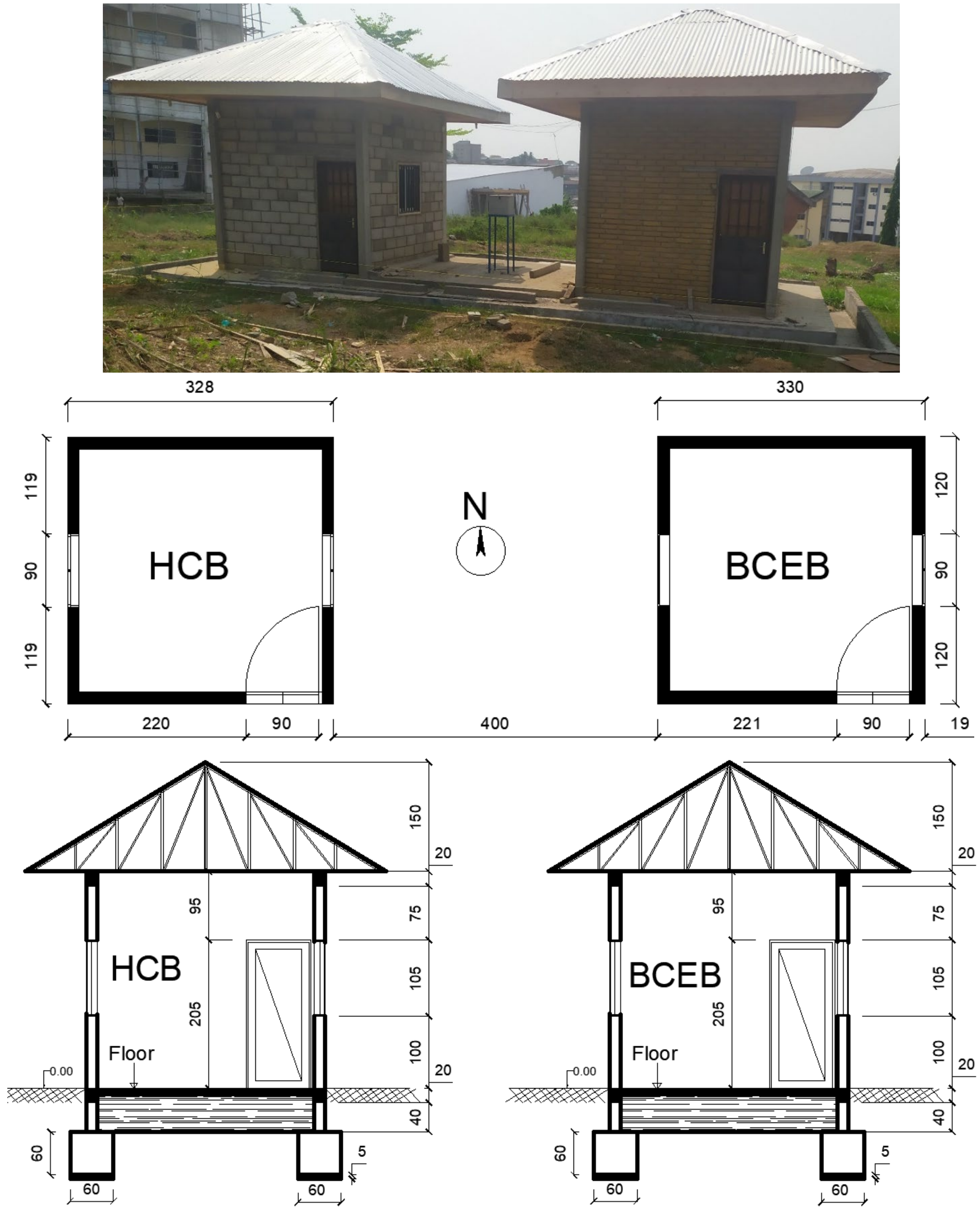


Fig. 1. Architectural details of the pilot buildings (dimensions in m)

Each building has 2 opposed single-glazed windows of 0.90 × 0.90 m each in the east-west direction, which is the main wind direction on the site. They also have a 0.90 × 2.10 m wooden door on the northern façade. Each building has specific parameters (Tab. 1): type of wall, roof, ceiling, and paving.

Table 1. Construction parameters of the different buildings

Type of building	Area	Roof	Ceiling	Wall	Floor
HCB	$9m^2$	Aluminum sheet	Plywood	Mono wall	Concrete
BCEB	$9m^2$	Aluminum sheet	Plywood	Mono wall	Concrete

Dynamic thermal simulation method

The overall simulation methodology (Fig. 2) was based on four steps: (1) the collection of climatic data of the study area, (2) the development of the numerical simulation model, (3) the definition of the validation criteria, and (4) the analysis of the concept of comfort according to the simulated model.

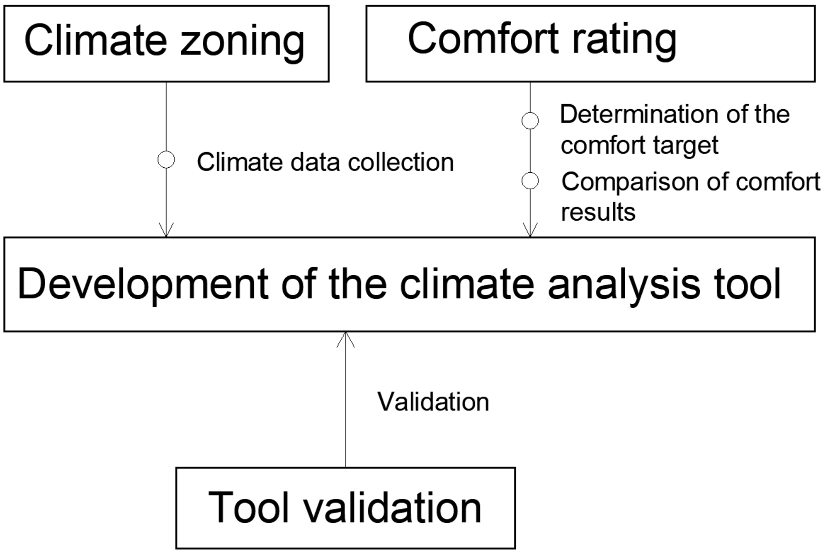


Fig. 2. General conceptual framework of the simulation

During the modeling stage in the DesignBuilder v7.0.1 software, the properties of the different building elements (Tab. 2) are introduced while constructing the numerical model. The dynamic calculation code EnergyPlus v.9.6.0 was used for the thermal simulation. DesignBuilder is a comprehensive and user-friendly Graphical User Interface (GUI) for the EnergyPlus simulation engine. EnergyPlus implements detailed building physics for air, moisture, and heat transfer, including treating radiative and convective heat transfer separately to support radiant system modeling and calculating thermal comfort metrics. The software simulates sub-hourly time steps to handle climate dynamics and interfacing with thermal comfort analyses. EnergyPlus is tested according to ASHRAE Standard 140 methodology [30].

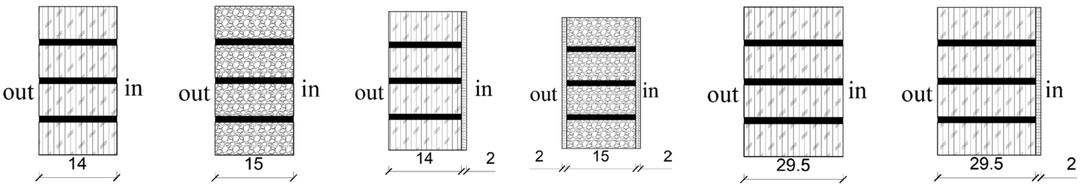
The infiltration rate was set at 0.5 $m^3.h^{-1}$, and the average air velocity was at 0.3 $m.s^{-1}$ outside the building. To round off the thermophysical properties of conventional materials already indicated in Table 2, the composition of each building wall is given in Table 3 according to each scenario. The simulation scenarios considered the stretcher and grid walls (Fig. 3).

Table 2. Properties of building construction elements

		Material	Thickness (cm)	Density ($kg.m^{-3}$)	Thermal conductivity ($W.m^{-2}C^{-1}$)	Thermal capacity ($J.kg^{-1}C^{-1}$)
wall	HCB	concrete	15	1400	0.9	1260
wall	BCEB (panneresse)	BCEB_CNCS	15	1200	0.38	1000
wall	BCEB (header)	BCEB_CNCS	29.5	1200	0.38	1000
plaster		concrete	2	1600	0.72	840
roofing		aluminum	0.006	2700	230	2511
ceiling		plywood	0.05	400	0.12	960
paving		concrete	10	1950	1.150	1650
doors		wood	4	450	0.14	1700
windows		glass	0.6		0.9	

The situations were that of air renewal by air conditioning and secondly by natural ventilation. The walls were either plastered facades for both buildings, interior plastered walls for the BCEB, and interior and exterior plastered walls for the HCB.

Table 3. Wall construction data according to each scenario

Scenario	A	B	C	D	E	F
Number of layers	1	1	2	3	1	2
Thickness (m)	0.14	0.15	0.16	0.19	0.295	0.315
UV (W/m^2K)	1.85	2.97	1.76	2.55	1.057	1.041
Wall system						

The ASHRAE Adaptive model was used to evaluate the comfort in the two buildings for 2020, with the sensors recording at hourly intervals. According to the seasonal parameters, this model is adapted for hot and humid climates like Douala.

The EnergyPlus simulation file was compiled from data collected at the site by a weather station available at the university.

The weighting method in which the exponential value (α) has been set to 0.8 in this method.

The exponential mean temperature prediction equation (Eq. 1) was used according to ASHRAE 55 [31].

$$\overline{t_{pma(out)}} = (1-\alpha)\left[t_{e(d-1)} + \alpha t_{e(d-2)} + \alpha^2 t_{e(d-3)} + \ldots\right] \quad [1]$$

The acceptability limits were determined [21] by considering the upper and lower acceptability limits of 80% (Eq. 2 and 3).

- The upper limit of acceptability of 80% (°C) : $0.31\overline{t_{pma(out)}} + 21.3$ [2]
- The lower limit of acceptability of 80% (°C) : $0.31\overline{t_{pma(out)}} + 14.3$ [3]

The number of exceeded hours (EH) represents those during which the environmental conditions are outside the comfort zone requirements for the adaptive model during the occupied hours of the analysis period. For this purpose, the EH was calculated (Eq. 4) from the standard [21].

$$EH = \sum (H_{>upper} + H_{<lower}) \quad [4]$$

With $H_{>upper} = 1$ if otherwise 0; and $T_{op} > t_{upper}$

$H_{<upper} = 1$ if otherwise 0; and $T_{op} < t_{lower}$

Similarly, for the air conditioning ventilation model, the comfort criterion set by ISO 17772-1 [23] is defined in equation 5.

$$T_o > t_{\max=28°C} \quad [5]$$

Calibration of the numerical model

In any simulation and data projection study, calibration is considered one of the most important steps for data validation.

The simulated data were calibrated against the measured (indoor operative temperature) to create the most appropriate conditions for the real measurements. The calibration method used consisted of several steps based on ASHRAE 140 [30] and in line with previously published studies [32, 33].

There are several guidelines for calibrating a new model. In this study, two recommendations mentioned in ASHRAE guideline 140 [30] were applied: Coefficient of Variation or Square Root Error (CVRMSE) (Eq. 6) and Mean Bias Error (MBE) (Eq. 7).

$$CVRMSE(\%) = \frac{1}{m}\sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n}} \quad [6]$$

$$MBE(\%) = \frac{\sum_{i=1}^{n}(m_i - s_i)}{\sum_{i=1}^{n} m_i} \quad [7]$$

With si and mi representing, respectively, the simulated and measured data of **indoor operative temperature** over a given interval. The 'n' is the total data in the measurement interval. It is recommended that a simulation model be considered calibrated if the criteria listed in Table 4 are met [30].

Table 4. Calibration criteria

Standard	Monthly criterion		Time criterion	
	MBE	CVRMSE	MBE	CVRMSE
Ashrae 14	5	15	10	30

The model in this analysis was calibrated hourly, using the average air temperatures inside the two buildings as a reference.

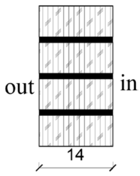
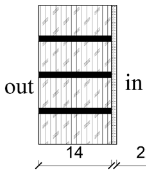
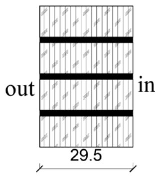
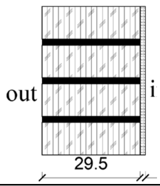
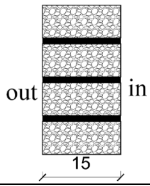
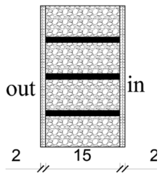
Environmental footprint (GHG emissions Equivalent)

Functional unit boundary

This environmental impact assessment study was limited to the construction phase (A1-A3 and A4-A5) of the constructed pilot buildings according to ISO 14040 [29] and CEN 15804+A2 [34]. The use stage was excluded from measuring the embodied carbon impact. It is a best practice of life cycle assessment to exclude the 'use' modules from the analysis, typically B1-B7. More importantly, limiting the assessment to the construction phase will allow future researchers to compare the biosourced compressed earth block with commercial cinder blocks based on their cradle-to-gate environmental product declarations (EPD).

Moreover, the functional unit will be limited to constructing 1 m^2 of the wall for each building. The input flows were essentially the raw materials (Tab. 5), and the output will be the single criterion impact on climate change defined in $kgCO_2$ equivalent.

Table 5. Raw material quantities for the 2 buildings

Material (Kg)	BCEB				HCB	
	stretcher		grid		stretcher	
	Total without coating	Total with coating	Total without coating	Total with coating	Total without coating	Total with coating
Scenario	A	C	E	F	B	D
Earth	185.04	185.040	395.780	395.780	0	0
Sand	53.56	197.560	129.600	189.600	159.37	447.37
OPC	24.10	74.100	54.162	75.162	27.67	127.67
CS	4.62	4.626	9.895	9.895	0	0
CN	4.626	4.626	9.895	9.895	0	0
Wall system						

Manufacturing stage

Module A3 – Manufacturing: The manufacturing process of BTC includes the following unit processes:

- Raw material reception and drying: auxiliary materials such as cement and CNCS aggregates, pallets and plastic film are received and stored in a shed at the construction site. Soil is unloaded and stored in a weatherproof location for air drying.
- Soil crushing: The soil is crushed to achieve a uniform grain size. The shredder, with a power of 3 kWh, is connected to the public electricity grid supplied by hydroelectric dams. Soil that is 'wasted' in the screening process is fed back into the crushing process or can be used as backfill.
- Mixing: All materials (earth, cement, CNCS aggregates and water) are mixed. A concrete mixer with a maximum payload of 1500 kg (diesel consumption of 3.2 l/h) carries out the mixing. The mixing time for 1200 kg is 15 minutes.
- Pressing: A Terstaram manual press is used for compaction. Defective blocks are returned to the production cycle.
- Drying and storage: the fresh blocks are laid out for curing on wooden pallets under ambient conditions for at least 28 days under the plastic film. No energy input is required at this stage. After curing, the plastic films are removed, and the blocks are ready for construction.

Construction stage

Module A4 – Transport: This module includes transporting the product, auxiliary materials and equipment to the construction site. This stage is minimized because the storage area is on the construction site.

Module A5 – Construction: The construction process of a CEB wall consists of laying the blocks with 250 kg/m^3 cement mortar. The walls remain bare without plaster after assembly.

A visual framework of this process is presented in figure 3.

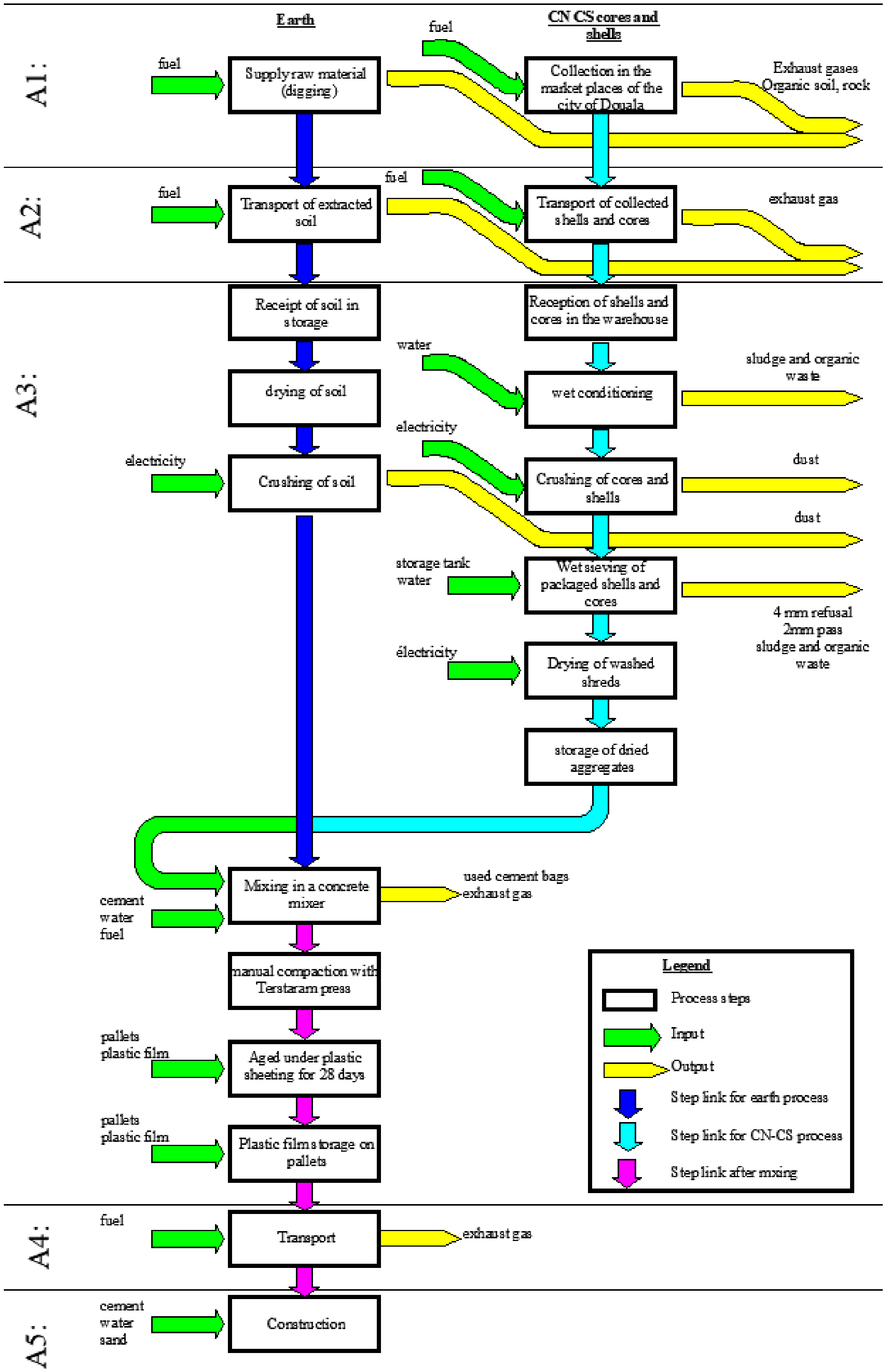


Fig. 3. Flow chart of material processing (A1: Raw material extraction and processing, processing of secondary material input, A2: Transport to the manufacturer, A3: Manufacturing, A4: Transport to the building site, A5: Installation into the building.)

Weighting scenario

Two weighting scenarios were considered (Tab. 6). The first scenario considered the impact factor attributed to the use of OPC as foreseen by the European Union (EU). The second scenario imputed to the previous OPC factor the impact of clinker transport from France to Douala's port - about 4426 km -. This second scenario is because Cameroon's only complete cement plant is in the country's North, and its production is only dedicated to serving the North. For the rest of the country, the cement factories in Douala import clinker mainly from France, thus providing partial line production (2nd combustion). According to the French Ministry of the Environment, quoted by Libération on 19/09/2019 [35], a container ship emits 0.010 and 0.032 $kgCO_2$ per tonne/kilometer. Thus the impact of transport is estimated at 0.14 $kgCO_{2eq}$/kg.

Table 6. Weighting of impacts according to materials [36]

	Scenario 1 (S1): $kgCO_{2eq}$/kg in EU standard	Scenario 2 (S2): $kgCO_{2eq}$/kg including clinker transportation
Earth	0.0230	0.0230
Sand	0.0048	0.0048
OPC	0.9500	1.0900
CS	0.0012	0.0012
CN	0.0012	0.0012

Results of thermal comfort simulation and life cycle assessment (construction phase)

The different values of MBE and RMSE allowed comparing the simulated and measured data. Table 7 shows the different results of the calibration of MBE and RMSE, respectively lower than 10 and 30%, respecting the criteria defined by the guide [38]. The comparison between the different measured and simulated mean indoor temperatures for the periods studied is presented in Figure 8. The simulation model is thus calibrated with hourly data.

Table 7. Calibration data results

HCB		BCEB	
MBE	RMSE	MBE	RMSE
-4.76	7.60	-3.94	14.73

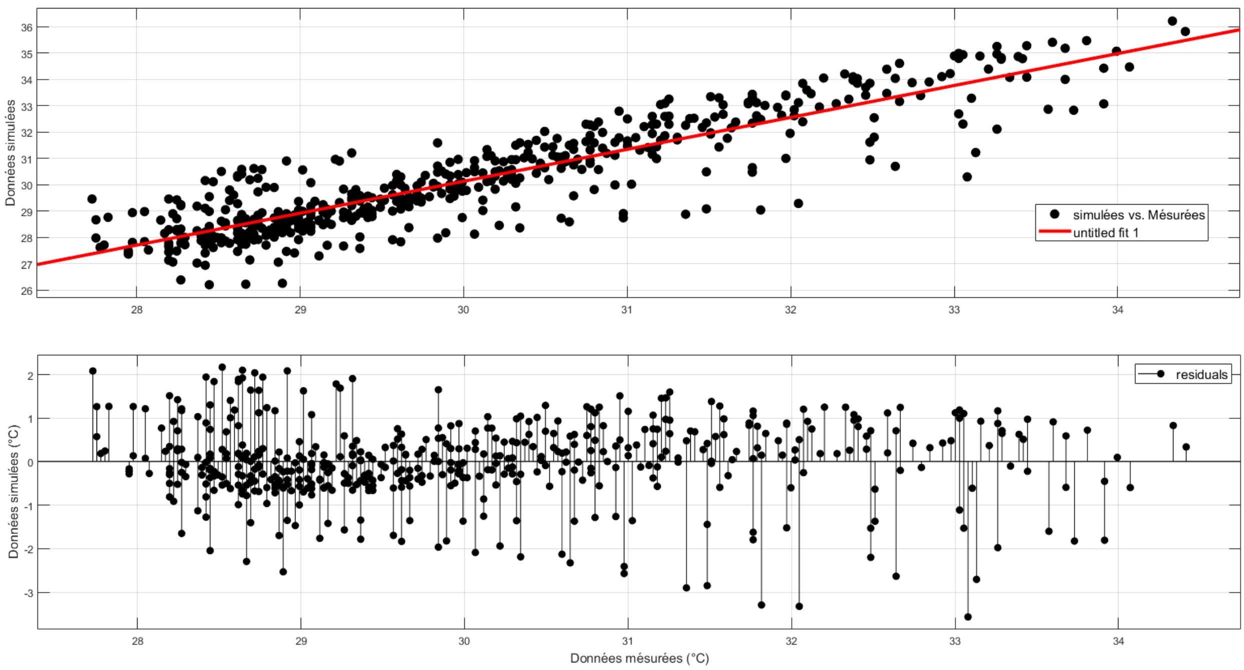


Fig. 4. Calibration curve for hollow concrete block building

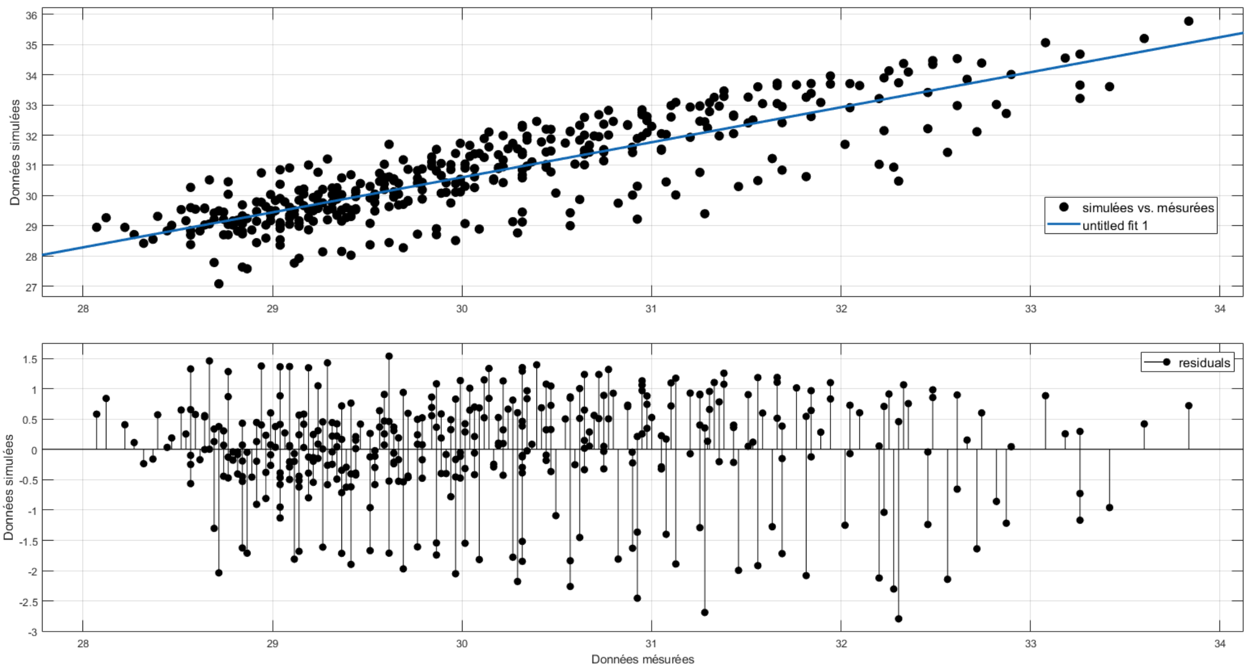


Fig. 5. Building calibration curve in BCEB

The residual analysis shows a correlation between the measured and simulated data of about 85% and 80% (Figs. 4 and 5) for the hollow concrete block and the biobrick buildings, respectively. The simulation model is therefore calibrated with the hourly data.

The average prevailing outdoor air temperature was calculated for all construction scenarios and ventilation modes.

Figure 6 shows the differences between the average air temperatures inside the two buildings. For the building configurations (A and B) (Tab. 3), the BCEB for the specific case of December – a high-temperature month – has daily averages of 0.5°C compared to the HCB. This is because the overall thermal resistance of the HCB wall (0.33 $m^2K.W^{-1}$) is lower than that of the BCEB wall (0.54 $m^2K.W^{-1}$).

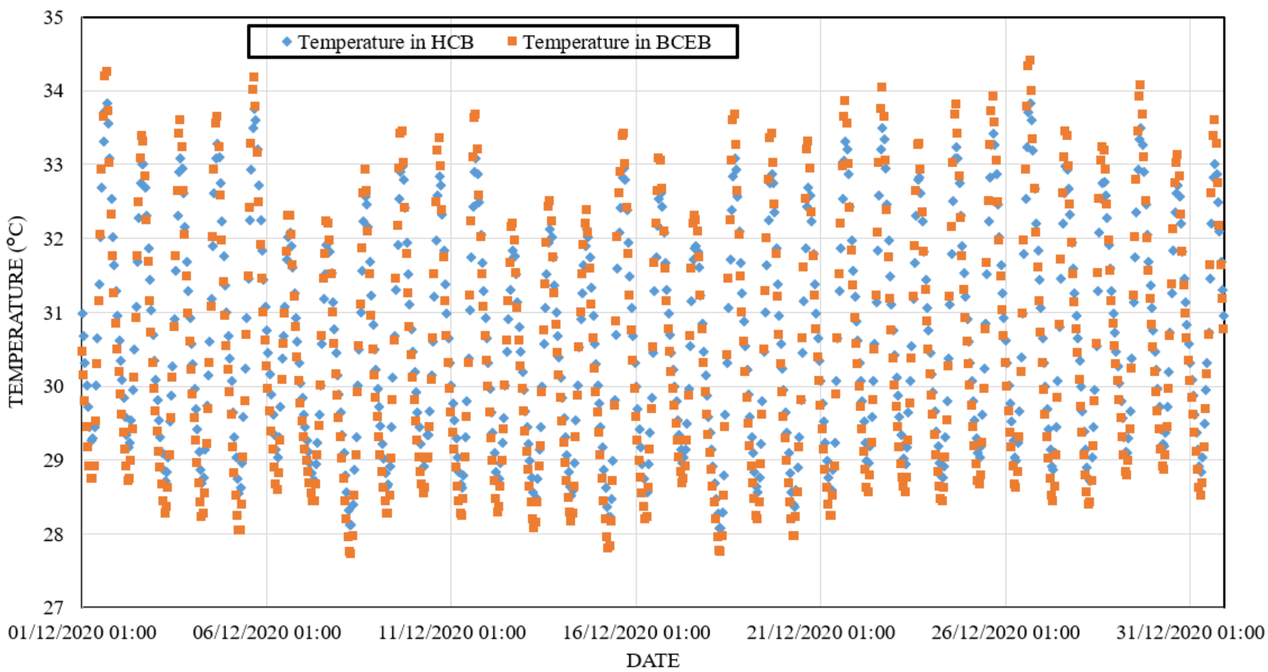


Fig. 6. Comparison of thermal measurement between HCB and BCEB

In the thermal comfort analysis (Fig. 7), for the natural ventilation (NV) and air conditioning (AC) simulations, it is clear that the AC systems offer the best comfort systems with minima around 95% for both with plaster and without plaster for BCEB construction devices. Roughcast constructions offer the best thermal performance, with around 96% and 44% comfort ranges in air conditioning (AC) and natural ventilation (NV). The HCB systems offer the lowest comfort hours (60%) in NV. The studies of Mahar et al. [32] on thermal comfort analysis in the city of Quetta, Pakistan, showed that irrespective of the orientation of the buildings, they obtained comfort ranges of around 43% for an NV analysis. These values are relatively close to those obtained in the present study.
By building in CEB, the thermal gain is around 5%, but in terms of energy consumed, we have a gain of around 100 kWH over the year. The energy expenditure is lower in the BCEB building than in those made of HCB.

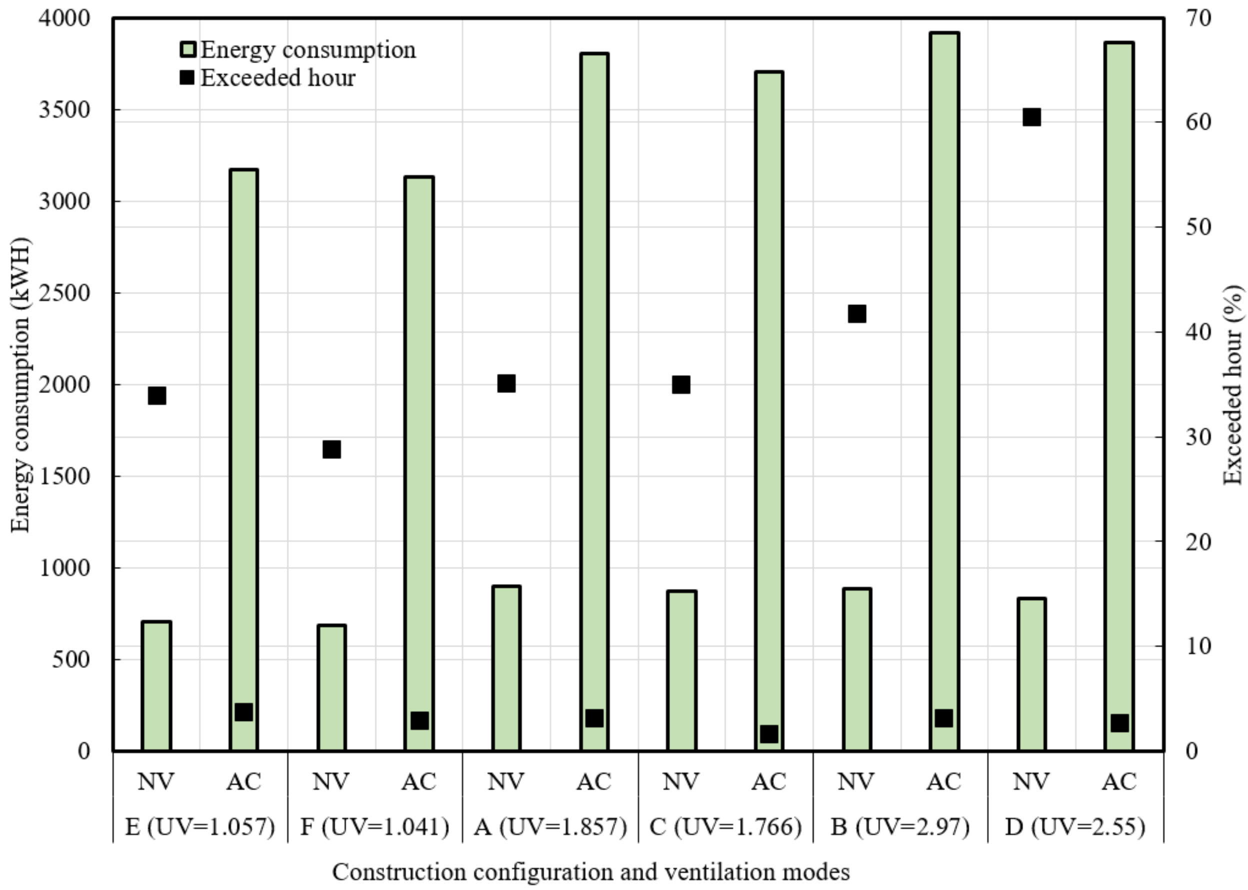


Fig. 7. Heat balance for the different simulation configurations

The adaptive comfort models are strongly related to prevailing outdoor temperatures, as their application directly depends on them. The results (Fig 8) show that discomfort is strongly related to warm conditions rather than cold situations.

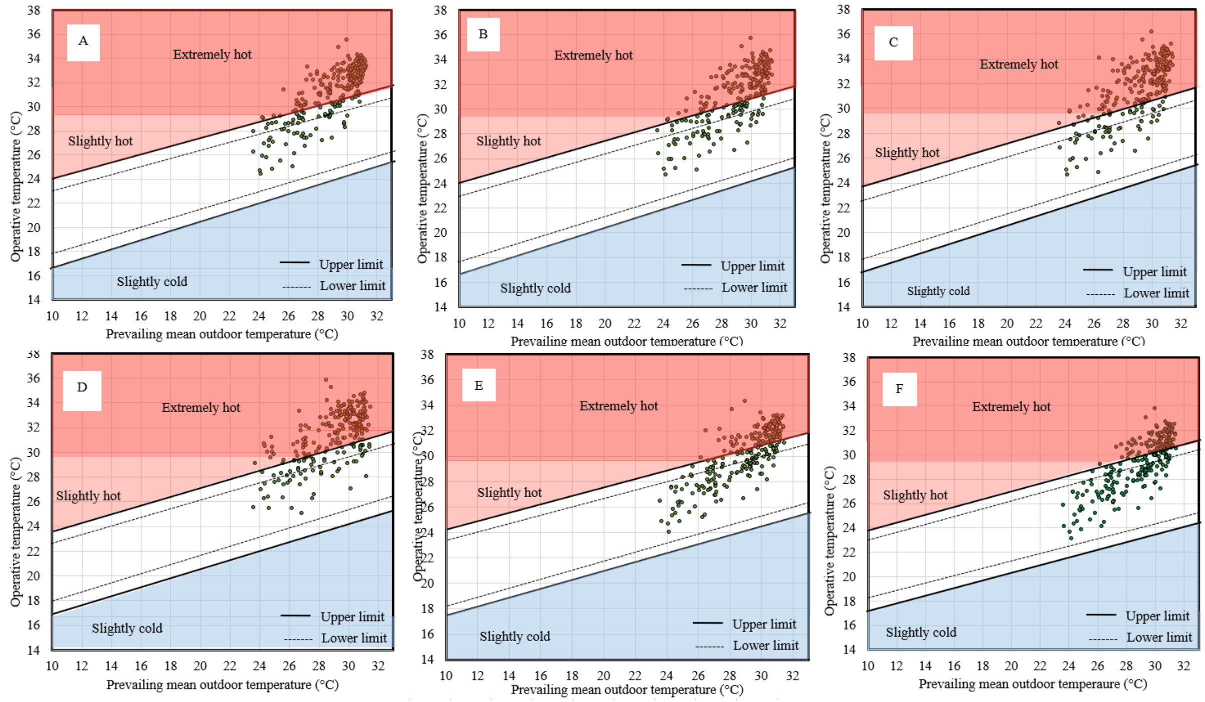


Fig. 8. Thermal comfort graphs according to the adapted model for the simulated scenarios (A, B, C, D, E and F)

Environmental impact assessment

Considering the functional unit to be 1 m^2 of wall, all the materials involved in its construction have been quantified. Each material obtained after a chain of specific operations will have an impact value per $KgCO_{2eq}$.

The construction provisions and two scenarios describing the cement's origin were taken into account.

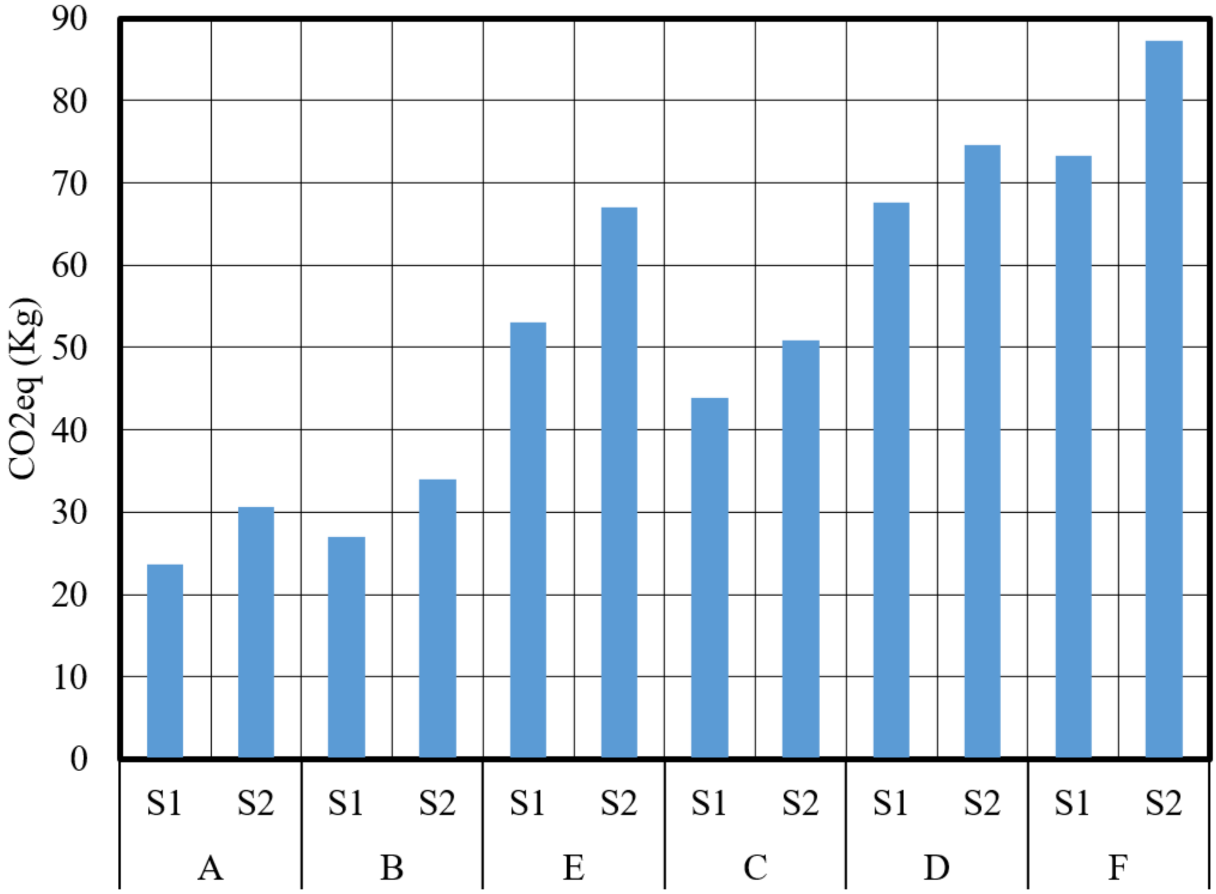


Fig. 9. Assessment of $_{CO2eq}$ according to constructional provisions

It is generally observed (Fig. 9) that cement represents more than 95% of the impacts for all construction provisions and the scenarios of its origin. For all the situations, the construction with plastering presents the greatest impact: 66 $KgCO_{2eq}$ and 89 $KgCO_{2eq}$, respectively, of the considerations without plastering and plastering.
It is also found (Fig. 10) that the rendering layer incurs a carbon footprint of almost 40% of the overall UF value. The CS and CN materials account for less than 1% of the overall impact.

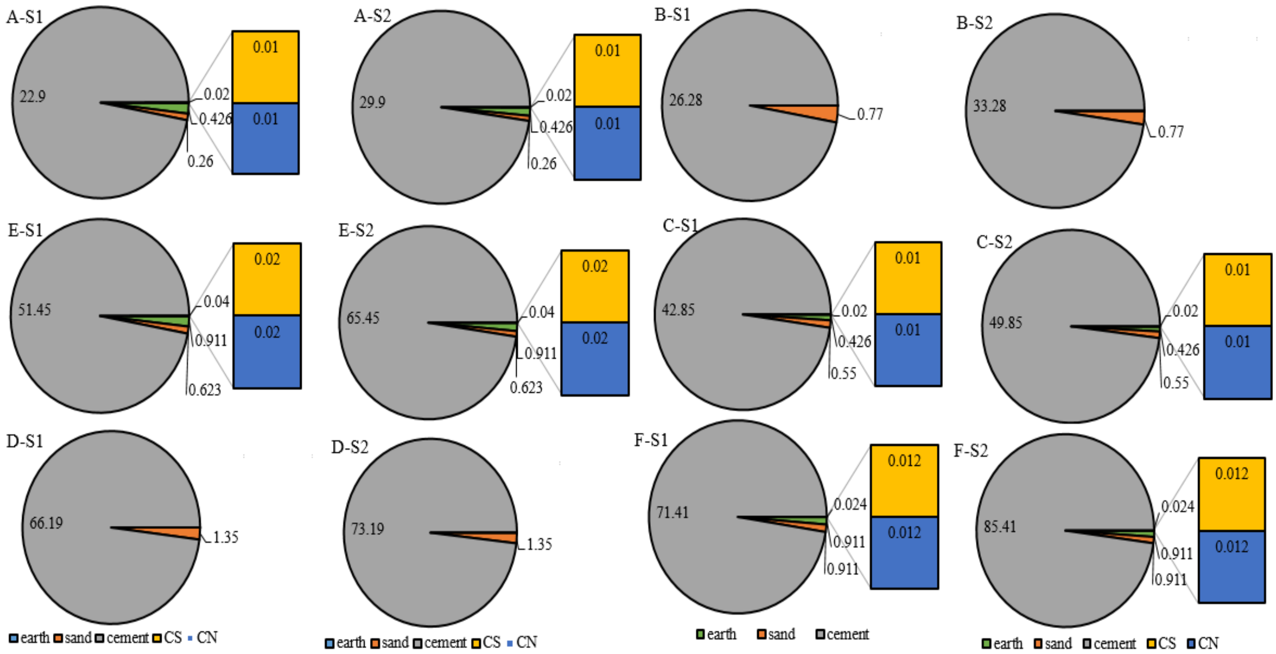


Fig. 10. Distribution of CO_2eq according to constructional provisions

Discussion

It was found that walls with an inner layer of render were better at regulating heat than walls with a single layer. One concern with using insulation materials in an unconditioned building is the risk of increased overheating. This is because the increased thermal resistance of the walls can trap heat from the indoor environment, thus causing high temperatures. However, the results of the current study show that BCEB walls provide better temperature control in both natural ventilation and air conditioning. The thermal comfort analysis, according to the ASHRAE adaptive standard, shows periods of overheating. Studies carried out for buildings in Madagascar [26] – which has a hot and humid climate – or in Burkina Faso [33] – with a hot climate – show that natural ventilation is still adequate to overcome the comfort problem in hot and humid environments. However, the comfort threshold remains enormously low. It could be improved by building scenarios – for walls and floors – in more insulating and lightweight multi-layered materials, improving comfort by about 10% [32]. Shading strategies [27] and using phase change materials [39] would also be very effective, with improvements estimated at around 50%. Finally, combining natural ventilation with air conditioning would offer better comfort than a single ventilation system.
According to the INIES database, for a 50 cm unstabilized adobe wall [40], the global warming impact is estimated at 1.75 $kgCO_{2eq}$. The A-S1 category is the one that comes closest to not taking into account the impact of cement. Without cement, the impact value for A-S1 (14 cm of thickness) would be 0.8 kg CO2eq. In earth-straw construction (~50/50), the INIES database proposes an impact value of -26 kgCO2eq [41]. This justifies bio-additives importance in the construction field for significantly reducing greenhouse gas production.
It would be important to find solutions to increase the content of bio-aggregates, reduce the proportion of cement, or even find palliative solutions to substitute the use of cement.

Conclusions

The objective of this research was to simulate the annual thermal performance and the Life Cycle Assessment of two buildings in the Douala climatic environment: the first with biosourced compressed earth brick (BCEB) modified by Cocos nucifera (CN) and Canarium schweinfurthii (CS) aggregates and the other with the hollow concrete block (HCB). This comparison used an energy simulation model with the EnergyPlus code integrated into the DesignBuilder software and the environmental footprint. Thermal comfort was assessed during the simulations on the model buildings using the adapted ASHRAE comfort model. In thermal comfort analysis, simulations were conducted in natural ventilation (NV) and air conditioning (AC) situations. Based on the results, the following conclusions can be drawn:

- The AC systems offer the best comfort systems, with a minimum of around 95% for plastered and unplastered construction systems.
- The BCEB constructions offered the best thermal performance with comfort ranges around 96% and 44% in AC and NV, respectively. In terms of energy consumed, there was a gain of around 100kWH over the year. The energy consumption is lower in the BCEB building than in the HCB building.
- The HCB construction offered the lowest comfort range, about 40%, in NV.

Regarding the life cycle assessment, the construction provisions and two scenarios describing the origin of the cement raw materials were considered. It can be concluded that:

- Cement accounts for more than 95% of the impacts for both construction systems and the scenarios of its origin.
- The HCB construction presents the highest impact for all simulated situations: 66 Kg CO_2eq and 89 CO_2eq, respectively, without the plastering layer and with plastering.
- The plastered layer incurs a carbon footprint (GHG emissions) of almost 40% on the overall functional unit. The CS and CN materials accounted for only 1% of the overall impact.

Complementary research and further investigations are needed to find solutions to increase bio-aggregate content, reduce the proportion of cement, or even find alternative solutions to partially or substitute cement to reduce the environmental impact of construction with compressed earth blocks. Another way is to consider new thermal simulation scenarios that consider natural ventilation during the night. Integrating humidity-controlled positive ventilation (PCV) or controlled mechanical ventilation (CMV) systems would be another promising solution.

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