# Design Methodology for Sustainable Social Housing with High Environmental Quality in Cameroon

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**Abstract:- In order to absorb the 87% of the cumulative deficit of 2,140,000 social housing units observed in 2021 in Cameroon, it will be necessary to wait a little more than 10 years at an annual construction rate of 200,000 units. In order to avoid that such a project can lead to a social and environmental disaster, it is necessary that it integrates all the concepts of sustainable development from its design phase. In this paper we propose a methodology for designing sustainable High Environmental Quality social housing. This methodology is based on: Life Cycle Analysis of buildings; and High Environmental Quality approach which has been modified and enriched. Modified to take into account Cameroonian specificities in terms of construction standards and where scores have been assigned to all basic targets. Enriched by the introduction of a fifth family reserved solely for social housing. Procedures for assigning scores to the basic targets and determining the performance level of targets were proposed. The criteria that a dwelling must meet in order to be a "sustainable High Environmental Quality social housing" have been defined. This approach has been used to design a High Environmental Quality social housing in Cameroon.**

***Keywords:*** *Social Housing; High Environmental Quality; Life Cycle Analysis.*

## I. INTRODUCTION

According to the DSCE 2010-2020 data (MINEPAT, 2009), Cameroon's social housing deficit situation in 2010 was very worrying. In 2021, this cumulative deficit reached a figure of around 2,140,000 social housing units. By doubling the annual number of social housing units proposed by the National Housing Financing Strategy Document (MINDUH, 2010), it will take about 9.3 years to reduce the 87% of the deficit. The project to build 1,861,000 housing units over a little more than 9 years, at a rate of 200,000 units per year, could lead to both a social and environmental disaster, if it is not carried out in the context of a High Environmental Quality approach. This approach, known as eco-design, which integrates all the concepts of sustainable development, is now used as a guide for the design and construction of works in general and sustainable buildings and housing in particular.

To this end, we note that several eco-design approaches or programs, specifying the procedures and criteria to be met for a building to be green (or HEQ Sustainable), have been established in developed countries. This is for example the case of the programs: Leadership in Energy and Environment Design (LEED) adopted in the United States and Canada around 1998, the Building Research Establishment Environment Assessment Method (BREEAM) set up by Great Britain around the 1990s, the Minergie label used in Switzerland since 1998 and finally the HEQ approach used in France since 2000. The common point of all these programs is the failure to take into account the specificity of social housing.

Starting from the fact that a sustainable HEQ social housing (by extension to sustainable development), would be a housing intended for occupants with modest incomes, capable of preserving: in a sustainable way the environment, the activities of social landlords and the quality of life of the occupants, on a set of criteria and characteristics based on: the financial and environmental performances of the housing, the affordability of the housing, the quality and recyclability of the materials used.

In other words, is it possible to imagine a transition from a sustainable HEQ building to a sustainable HEQ social housing that is both profitable and feasible? Probably yes, provided that the sustainable HEQ is an interesting product both for the occupants with modest incomes and for the social landlords who are the project owners and promoters of the said housing.

In this context, this article proposes an adapted methodology for the design of sustainable HEQ social housing in Cameroon through the integration of specific

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criteria for social housing. The article will be structured in six (06) sections: the proposed methodology (section 2), the synthesis of this methodology (section 3), the material and sources of data used (section 4), a case study using this methodology in the context of a housing construction project (section 5) and the conclusion (section 6).

## II. THE PROPOSED METHODOLOGY

The proposed methodology for the design of sustainable HEQ social housing in Cameroon, lays on two main approaches, namely:

- Implementation of Life Cycle Analysis (LCA) for building;
- Implementation of High Environmental Quality (HEQ) approach enriched by a set of criteria related to social housing in Cameroon.

➢ *Implementation of a Building LCA*

The LCA methodology used here is standardized by the International Organization for Standardization (ISO) in the 1404x series of standards and is based on four interdependent steps: Goal and scope definition (ISO14041), Inventory analysis (ISO14041), Impact assessment (ISO14042), and Interpretation (ISO14043).

- *Goal and Scope*

Defines the field of application of the LCA (LCA: Life Cycle Analysis) by specifying the function(s) of the system, the functional unit associated with it, the boundaries of the system, the life cycle and the type of impact studied.

✓ *Function of the System*

The building studied is intended for the housing of a family. It is assumed that the building will be occupied during its entire life cycle due to moves and installations of old and new tenants.

✓ *System Boundary*

The boundary of the system considered here is the building. But in the evaluation of the impacts, we will take into account: not only the earthworks on the construction site, but also the impacts of the construction materials coming from foreign countries or from localities located outside or inside the said site.

✓ *Lifetime*

Given the economic model of social housing adopted (Ahmadou et al., 2022a) by Cameroon, we note that single-storey housing generally has a minimum lifespan of seventy-five (75) years and multi-storey buildings have a lifespan of between ninety (90) and one hundred (100) years.

- *Inventory Analysis*

It lists and quantifies all the flows of materials and energy entering and leaving the previously defined system. It is essentially based on physical and chemical knowledge. These flows of materials are perfectly known as soon as we have the architectural and execution plans of the building, the schedules for maintenance, exploitation, and replacement of equipment at the end-of-life or obsolete elements of the second work established on all the duration of exploitation of housing.

- *Impacts Assessment*

At this stage, the quantitative and estimated specifications for all the phases of the building's life are known and provide us with information used to calculate the financial and environmental impacts of the housing. For the environmental impacts (Table 1), we will insist on the calculation of impacts related to: resources, risks and human health and finally ecosystems. For the financial impacts (Table 2) we will calculate the Net Present Value, the costs of construction, operation, maintenance and demolition phases.

The objectives of the study, within the framework of the proposed methodology, are to evaluate the financial and environmental impacts of housing in order to obtain quantified impact indicators which allow us to measure financial and environmental performance, and to verify a set of criteria related to social housing.

Table 1 Components of the Environmental Impact Vector, Associated Impacts (Okpwe and Mamba, 2020)

| **Component of impact vector $\overrightarrow{I^{env}}$** | **Associated environmental impact** | **Contributor** | **Unit** |
|---|---|---|---|
| $I^{env}_1$ | Energy consumption | Amount of energy consumed by the product (Energy) | MJ/ product |
| $I^{env}_2$ | Water consumption | Volume of water (in liter) consumed by the product (Water) | L/ product |
| $I^{env}_3$ | Contribution to global warming | Equivalent mass of carbon dioxide generated by the product (GWP) | kg eq-$CO_2$ / product |
| $I^{env}_4$ | Photochemical ozone formation | Equivalent mass of ethylene generated by the product (Smog) | kg eq-$C_2H_4$ / product |
| $I^{env}_5$ | Atmospheric acidification | Equivalent mass of sulfur dioxide generated by the product (Acidification) | kg eq-$SO^2$ / product |
| $I^{env}_6$ | Eutrophication | Equivalent mass of phosphate generated by the product (Eutrophization) | kg eq-$PO_4{}^{3-}$ / product |
| $I^{env}_7$ | Aquatic ecotoxicity | Volume of water polluted by the product (EcotoxAq) | $m^3$ / product |

| | | | |
|---|---|---|---|
| $I^{env}_8$ | Production of Ultimate Waste | Mass of final waste generated by the product (U-waste) | kg/ product |

Table 2 Financial impacts

| No | Financial impact | Contributor | Symbol | Unit |
|---|---|---|---|---|
| 1 | Financial Impact of Construction Work | Construction costs | $C_C$ | CFA francs |
| 2 | Financial Impact of the Use phase | Utilities costs | $C_U$ | CFA francs |
| 3 | Financial Impact of Maintenance | Maintenance costs | $C_M$ | CFA francs |
| 4 | Financial Impact of Deconstruction | Demolition costs | $C_D$ | CFA francs |
| 5 | Financial Impact over the whole life cycle | Life cycle costs | LCC | CFA francs |
| 6 | Net Present Value | Net Present Value | NPV | CFA francs |

- *Interpretation of Results*

Environmental and financial impacts presented in the previous step, allow us to compute corresponding impact indicators, which will be exploited into the evaluation process of specified targets of our proposed modified HEQ approach.

- *Method of Calculating the Replacement Frequency of Object*

The frequency of replacement of the object is essential for establishing maintenance costs and some operation costs. We make use of (1) in order to compute frequency $N_k$ of replacement of an object or equipment no. k, during the lifetime of a building.

$$N_k = E\left[\frac{D_V}{D_{VEk}}\right] - 1 \qquad (1)$$

Where

$E[b]$=integral function of $b$

$D_V$ =Lifetime of the building

$D_{VEk}$ = Lifetime of the object no. k.

➢ *Method of Calculating Financial Impacts*

- *Cost of Price of an Object or Equipment*

For a given object or equipment "$k$" of the building, the cost price is computed making use of (2).

$$C_{CEk} = \sum_i (CP_i \times QP_i) + \sum_j CT_j \qquad (2)$$

Where

$C_{CEk}$ = Cost price of object no. $k$ implemented in the building

$CP_i$ = Cost of one unit of product or raw material no. $i$ used to make object no. $k$

$QP_i$= Number of units of product or raw material no. $i$ within the object no. $k$

$CT_j$ = Cost of task no. j required to implement object no. $k$.

- *Construction Costs of a Building*

Construction costs of a building is computed using (3) applicable for construction project of with public fund in Cameroon (Mamba, 2013a).

$$C_C = \alpha \times \sum_k C_{CEk} = I_0 \qquad (3)$$

Where

$C_C$ = Construction costs of the building

$C_{CEk}$ = Cost price of object no. $k$ implemented in the building

α = Constant value which range from 1.5 to 3.0

$I_0$ = Initial investment of the building.

- *Operation, Maintenance And Demolition Costs*

We compute the operation, maintenance, and demolition costs by using formulas similar to (2) and (3).

- *Break-Even Rent*

According to the economic model of social housing finance (Ahmadou S. et al, 2022a), the level of monthly rents charged to low-income occupants is equal to the annual equilibrium rent divided by 12. we make use of (4) and (5) in order to compute monthly rents.

$$L_m = \frac{L_a}{12} \qquad (4)$$

Where

$L_m$ = House rent per month

$L_a$ = Annual equilibrium rent of a building

And

$$L_a = \left(\frac{1+\alpha_l}{T_{pb}}\right) \times \left(I_0 + (C_M + C_D)\right) \qquad (5)$$

Where

$L_a$ = Annual equilibrium rent of a building

$I_0$ = Initial investment of a building

$C_M$ = Maintenance costs of a building

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$C_D$= Demolition costs of a building

$T_{pb}$ = Payback time (varying from 35 to 40 years)

$\alpha_l$ = Constant value for management fees (= 0.15).

- *Net Present Value*

To compute Net Present Value, we make use of (6) and (7).

$$NPV = -I_0 + \sum_{n=1}^{D_V} \left[\frac{L_a - C_{M\&D}}{(1+i)^n}\right] \quad (6)$$

Where

NPV = Net Present Value

$I_0$ = Initial investment of a building

$D_V$ = Lifetime of the building

$i$ = Discount rate (=3%)

$L_a$ = Annual equilibrium rent of a building

$C_{M\&D}$ = Annual cost related to maintenance and demolition.

And

$$C_{M\&D} = \frac{0.8 \times (C_M + C_D)}{D_V} \quad (7)$$

Where

$C_M$ = Maintenance costs of a building

$C_D$ = Demolition costs of a building

$D_V$ = Lifetime of the building.

- *Indicators for Social Housing*

Two groups of indicators for social housing are considered in our work (Ahmadou et al., 2022b): Indicators of housing affordability for low-income people that depend on a country's level of development; Economic performance indicators for social housing, which are a guarantee of the sustainability of the social landlord's activities and the quality of life of the occupants. Further details can be found in Table 3.

Table 3 Financial Indicators for Social Housing

| **Groups** | **Financial indicator** | **[a] Expression** | **Indicator Unit** |
|---|---|---|---|
| Indicators of housing affordability for low-income people | House rent per month | $L_m$ | CFA franc/ month |
| | House rent per unit floor useful area and per month | $L_m$/FU | CFA franc/ (m$^2$.month) |
| | Payback period | $T_{pb}$ | Year |
| Economic performance indicators for social housing | Construction costs per unit floor useful area | $C_C$/(FU) | CFA franc /m$^2$ |
| | Exploitation costs per unit floor useful area and per lifetime | $C_U$/(FU×$D_V$) | CFA franc /(m$^2$.year) |
| | Maintenance costs per unit floor useful area and per lifetime | $C_M$/(FU×$D_V$) | CFA franc /(m$^2$.year) |
| | Demolition costs per unit floor useful area and per lifetime | $C_D$/(FU×$D_V$) | CFA franc /(m$^2$.year) |
| | Life cycle costs per unit floor useful area and per lifetime | LCC/(FU×$D_V$) | CFA franc /(m$^2$.year) |
| | Net Present Value per unit floor area and per lifetime | NPV/(FU×$D_V$) | CFA franc /(m$^2$.year) |
| | House lifetime | $D_V$ | Year |

FU = Functional Unit, which is the Usable floor area of the house

- *Computation of Environmental Impacts*

- *Environmental Impacts of a Product*

The environmental impact vector of a given product no. $i$ implemented in the building, is computed making use of (8).

$$\overrightarrow{I^{env}_{Ek}} = \sum_i \left(\overrightarrow{I^{env}_{Pi}} \times QP_i\right) + \sum_j \overrightarrow{I^{env}_{Tj}} \quad (8)$$

Where

$\overrightarrow{I^{env}_{Ek}}$= Environmental impact vector of product no. $k$ implemented in the building

$\overrightarrow{I^{env}_{Pi}}$= Environmental impact vector of one unit of raw material no. $i$ integrated into the product no. $i$

$QP_i$= Number of units of raw material no. $i$ integrated into the product no. $i$

$\overrightarrow{I^{env}_{Tj}}$= Environmental impact vector of the required task no. k mobilized in order to make the product no. $j$.

- *Environmental Impacts of a Building*

During construction phase, environmental impact vector of the building is computed using (9).

$$\overrightarrow{I^{env}}_{C} = \sum_k \left(\overrightarrow{I^{env}}_{Ek}\right) \quad (9)$$

Where

$\overrightarrow{I^{env}}_{C}$= Environmental impact vector of the building during the construction phase
$\overrightarrow{I^{env}}_{Ek}$= Environmental impact of product no. $k$ incorporated during the construction phase of the building.

A similar formula is used to calculate the environmental impacts of operation phase, maintenance phase and demolition phase.

- *Environmental Impact of a Building*

Environmental impact vector of a building throughout its whole lifecycle are computed using (10)

$$\overrightarrow{I^{env}}_{LC} = \overrightarrow{I^{env}}_{C} + \overrightarrow{I^{env}}_{U} + \overrightarrow{I^{env}}_{M} + \overrightarrow{I^{env}}_{D} \quad (10)$$

Where

$\overrightarrow{I^{env}}_{LC}$ = Environmental impact vector of the building throughout its whole life cycle

$\overrightarrow{I^{env}}_{C}$ = Environmental impact vector of the building during its construction phase

$\overrightarrow{I^{env}}_{U}$ = Environmental impact vector of the building during its use (or operation) phase

$\overrightarrow{I^{env}}_{M}$ = Environmental impact vector of the building during its maintenance phase

$\overrightarrow{I^{env}}_{D}$ = Environmental impact vector of the building during its demolition phase.

- *Environmental Impact Indicator Vector of a Building*

The environmental impact indicator vector, gives the possibility to compare the environmental performances of a building with different usable area and different lifetimes. The environmental impact indicator vector is computed using (11).

$$\overrightarrow{I^{env}} = \frac{\overrightarrow{I^{env}}_{LC}}{FU \times D_V} \quad (11)$$

Where

$\overrightarrow{I^{env}}$ = Environmental impact indicator vector of the building

$\overrightarrow{I^{env}}_{LC}$ = Environmental impact vector of the building throughout its whole life cycle

FU= Functional Unit (or usable floor area) of the building

$D_V$ = Lifetime of the building.

We will calculate the environmental impact indicator vectors for the construction, operation, maintenance and demolition phases using formulas similar to (11), where $\overrightarrow{I^{env}}$ will be replaced by $\overrightarrow{I^{env}}_{C}, \overrightarrow{I^{env}}_{U}, \overrightarrow{I^{env}}_{M}$ $and$ $\overrightarrow{I^{env}}_{D}$.

➢ *Methodology for the Implementation of the HEQ Approach for Social Housing*

Our approach is inspired by the HEQ one, based on a logic of hierarchy of environmental requirements (ADEME 2005), which aims to limit in the short term and in the long term, the environmental impacts of a construction or rehabilitation operation, while ensuring the occupants healthy and comfortable living conditions. This approach is expressed through fourteen (14) objectives (or targets), which are broken down into sixty-six (66) basic targets.

In this process, the Project owner must establish a list of priorities, choosing from among the fourteen construction targets; at least three that seem the most important and on which a maximum effort will be concentrated. Once treated, they must reach a Very High-Performance level. Then at least four targets will have to benefit from a particular treatment, treated they must reach the Performing level and finally the other targets (at most 7) will be treated at least in accordance with the regulations in force. We note that all of these 14 targets are divided into four (04) Families (or Themes) (ADEME, 2005, 2009).

Taking in account that a social house is affordable to people with low incomes, it is therefore necessary to introduce into the initial HEQ approach, a fifth Family dedicated essentially to social housing. This new family is made up of Target 15 dedicated to the affordability of housing for low-income people and Target 16 reserved for the sustainability of the economic activities of social landlords who promote the said housing. In some basic targets, Cameroonian specificities in terms of construction standards have been integrated. This HEQ approach thus modified is made up of 16 targets or objectives which are broken down into seventy-six (76) basic targets to which scores have been assigned, is the basis of the Adapted Methodology for the Design of Sustainable HEQ Social Housing (MACOLS- HEQ -Sustainable) in Cameroon.

➢ *Synthesis of the Adapted Methodology for the Design, Evaluation of Sustainable Social Housing*

- *Step1*

In this approach, the Project Owner defines his priority targets (or commitments), in the light of his expectations, and decides which ones will be: Highly Performant, Performant or Compliant with the standards and regulations in force.

- *Step2*

Thanks to the Responsible Management System set up by the latter, studies (environmental and geological) of the site are carried out and then validated. A building project adapted to the site and conforming to the Client's requirements is carried out and validated according to well-defined procedures, in order to respond to almost all the client's concerns. At the end of this phase, all the components of the building and the equipment contained in it are defined, the procedures used for the construction and deconstruction at the end of the building's life are known, and the plans for execution, maintenance, replacement of obsolete equipment and maintenance of the accommodation during the period of operation are established.

Quantities and costs estimates of the building at all phases of its life are available and the Life Cycle Analysis of the dwelling can therefore be carried out.

- *Step 3*

On the basis of the information obtained in step 2 (quantities and cost estimates for the different life phases of the building) a Life Cycle Analysis of the housing is carried out. At the end of this analysis, the quantified values of the impacts are calculated for all phases of the building's life. It is from these impact values that the quantitative impact indicators will be calculated and compared to the reference indicators for Cameroonian social housing.

- *Step 4*

With the comparative results between the impact indicators given by the project studied and the reference indicators for Cameroonian social housing, we can then proceed to the rating of the elementary targets, then the targets (in Table 5) of the modified "HEQ" approach that we are proposing and which in its current version has sixteen (16) targets and seventy-six (76) sub-targets.

- *Step 5*

In this step, we will note that for a dwelling to be "sustainable HEQ social housing", it is necessary and sufficient that: targets 15 and 16 dedicated only to social housing, are Highly Performant. In addition, in the first fourteen targets, three targets must be at least Highly Performants, four (04) targets must be at least Performants and at most the other seven (07) targets must comply with current Standards (Table 4).

Table 4 Performance Criteria of a "Sustainable HEQ Social Housing"

| Group of Criteria | Criteria | Targets | Performance Level |
|---|---|---|---|
| HEQ Criteria | HEQ criteria | Three (03) of the top fourteen (14) targets are high performance level | HP |
| | | Four (04) targets out of the first fourteen (14) targets have the Performance level. | P |
| | | No more than seven (07) targets on the first fourteen (14) targets are in Compliance with the Standards. | CS |
| Social Housing Criteria | Affordability for low-income individuals | Target 15 is High Performance level | HP |
| | Economic or financial performance criterion | Target 16 is High Performance level | HP |

- *Rule for Measuring Performance Level of Targets*

In the evaluation of the targets aimed at by the Project Owner, there are three levels of performance: HP (Highly Performant), P (Performant) and CS (for Compliant with current Standards and regulations). Table 5 summarizes the level of performance in relation with the score of a given target.

Table 5 Evaluation of Target Performance

| Target performance | Criterion on the percentage of all scores of the sub-targets constituting the target |
|---|---|
| HP | ≥95% |
| P | [70%; 95% [ |
| CS | <70% |

- *Rule for Scoring Sub-Targets*

The scoring of the sub-targets depends of the indicator's nature, which can be qualitative or quantitative.

- *Sub-Targets using Qualitative Indicators*

These are indicators (relating to compliance: administrative, normative or particular concerns of the Project Owner) that must be answered with a yes or no.

If objective of the sub-target's is achieved (yes), it obtains the maximum score. Otherwise (no) his score is zero (0). In some circumstances, half of the score could be awarded to the sub-target, if the assessor considers that 80% of the requirements for the sub-target examined are compliant.

- *Sub-Targets Using Quantitative Indicators*

In the case of sub-targets using quantitative values (namely, indicators obtained from environmental impacts), we compared obtained values with baseline (or reference values) in context of construction project in Cameroon.

When requirement is not reached, we give a score of "-1", otherwise, we give the maximum score related to the sub-target.

- *Summary Evaluation form of the Proposed Methodology*

Table 6 presents a template to fill by the assessor, in the context of the use of the methodology adapted to the design of sustainable HEQ social housing in Cameroon.

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Table 6 Overview of our Methodology for the Evaluation of Sustainable HEQ Social Housing in Cameroon

| **Themes** | **Targets** | **Activity** | **Design Recommendations (sub-targets)** | **Mark** |
|---|---|---|---|---|
| Green building | Target 1 : Harmonious relationship of buildings with their immediate environment | C01.1 Site analysis | C01.1.1- Conduct a preliminary site survey to identify the type of climate, nuisances and pollution, site risks, local resources of available building materials. | 2 |
| | | | C01.1.2 - Accessibility | 2 |
| | | | C01.1.3 - Services for living together. | 2 |
| | | | C01.1.5 - Consideration of biodiversity. | 1 |
| | | | C01.1.6 - Contribution to the dynamism of the local economy. | 2 |
| | | C01.2 Bioclimatic architecture | C01.2.1 - Favor the south orientation of the facades, and minimize openings to east. | 2 |
| | | | C01.2.2 - Respect of recommended building configuration by climate zone | 2 |
| | | C01.3 Site development | C01.3.1 - Land use coefficient less than 50%. | 2 |
| | | | C01.3.2 - Landscaping of at least 50% of the parcel not occupied by the building. | 2 |
| | | | C01.3.3 - Minimum setback of 1m5 from the boundaries of the plot of land. | 2 |
| | Target 2: Integrated choice of products, systems and construction processes | C02.1 Building materials | C02.1.1 - Use of local materials with low environmental impacts and low indoor pollution | 4 |
| | | | C02.1.2 - Use of recyclable or recycled materials. | 3 |
| | | | C02.1.3- Use of processes using local technology and very energy efficient. | 3 |
| | Target 3: Low nuisance construction site | C03.1 Construction site management | C03.1.1 - Upstream integration of measures allowing the control of construction waste, the reduction of nuisances (noise, dust, sludge). | 1 |
| | | | C03.1.2 - Reduction of energy consumption and air, water and soil pollution during the construction phase (LCA indicators). | 2 |
| | | | C03.1.3 - Environmental impacts during the construction phase. | 3 |
| | | | C03.1.4 - Environmental impacts during the deconstruction phase (LCA indicators). | 3 |
| | Target 4: Energy Management | C04.1 Energy saving during the operational phase | CO4.1.1 - Energy consumption during the operation phase must be lower than the reference value (LCA). | 3 |
| | | | CO4.1.2 - Use of renewable energies to power the building. | 1 |
| | | | C04.1.3 - Limitation of energy consumption by the use of class A equipment and low-consumption lamps of the compact fluorescent or LED type. | 3 |
| | | | CO4.1.4 - Presence of autonomous lighting for paths and outdoor circulations with integrated photovoltaic sensors. | 3 |
| | | | C04.1.5 - The total environmental impact indicators must be lower than the corresponding LCA reference total impacts. | 16 |
| Eco-Mana-gement | Target 5 : Water mana-gement | C05.1 Management of water inflows | C05.1.1 - Installation of a water leak detection system in the internal network. | 1 |
| | | | C05.1.2 - Use of mixer taps and dual-control flushes when supplied by a collective network. | 4 |
| | | | C05.1.3 - Water consumption indicators in the operational phase must be lower than the reference value (LCA). | 4 |
| | | C05.2 Storm water management | C05.2.1 - Use of a rainwater recovery system, for household needs, WC supply, cleaning, watering. | 4 |
| | | C05.3 Waste water management | C05.3.1 - Connection to a collective sanitation network if it exists or to an independent sanitation network. | 2 |
| | Target 6 : Mana-gement of | C06.1 Design of activity waste depots adapted | C06.1.1 - Implementation of a waste sorting procedure. (A trash can with three compartments to be used: one compartment for plastic waste, another for glass waste and a final one for degradable waste. | 1 |
| | | C06.2 Differentiated management of activity waste, adapted to the current collection method. | | 1 |

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|---|---|---|---|---|
| | activity waste | C06.3 $CO_2$ emissions related to energy consumption (LCA indicators) during operation. | | 2 |
| | | C06.4 - Installation of a composter to recycle organic waste. (2 marks) | | 2 |
| | | C06.5 Limitation of the production of activity waste (LCA indicators) during operational phase. | | 1 |
| | | C06.6 Limitation of environmental impact (LCA indicators) on the life cycle of the building. | | 16 |
| | Target 7: Mana-gement of upkeep and maintenance | C07.1 Use of materials and equipment that require less upkeep or maintenance operations. | | 2 |
| | | C07.2 Set up less energy-intensive and less costly upkeep and maintenance procedures | | 2 |
| | | C07.3 Control of environmental impacts (LCA indicators) due to maintenance and upkeep activities or operations. | | 3 |
| | | C07.4 Indicators of maintenance and upkeep operations (LCA indicators). | | 8 |
| Comfort | Target 8: hygrometric comfort | C08.1 building envelope | C08.1.1 Walls : use of materials adapted to the climatic zone of the building requiring few maintenance operations and a long lifespan | 4 |
| | | | C08.1.2 Roof covering: use of materials adapted to the climatic zone of the building with thermal insulation requiring little maintenance and with a long lifespan | 1 |
| | | | C08.1.3 Openings: Favor double glazing for facade windows | 1 |
| | | C08.2 Thermal insulation | C08.2.1 - Thermal insulation (using local materials) of the ceiling, roofing, floors and paving. | 1 |
| | Target 9 : acoustic comfort | C09.1 - Use of acoustic insulation if building near a traffic lane, a factory, etc. | | 2 |
| | | C09.2- Implementation of constructive provisions promoting sound insulation inside the building. | | 2 |
| | | C09.3 - Sheet music with sound reduction, doors of main rooms with solid cores, use of class A coverings. | | 2 |
| | Target 10 : Visual comfort | C10.1 Natural lighting | C10.1.1 - Favor the south facade for the location of large bay windows. Minimize windows on East-West facades. Avoid openings on the north facades. | 2 |
| | | | C10.1.2 - Ration of wall window openings on the South facade, must be compatible with the climatic zone of the building. | 2 |
| | | | C10.1.3 - Direct natural lighting in the circulation corridors and all the stairs serving main rooms. | 2 |
| | | | C10.1.4 - Surface of the bays measured in the table must be less than 1/5 of the usable floor area | 1 |
| | | | C10.1.5 - Appropriate design of shading devices or glazed surfaces (roof overhang, vertical and horizontal shading element, balconies, screens, trees, etc.) | 2 |
| | | | C10.1.6 - Reduction of the risk of glare by the installation of protections. | 2 |
| | | C10.2 Artificial lighting | C10.2.1 Guarantee a level of artificial lighting in compliance with the regulations in force in terms of lighting and visual ergonomics with a low impact on energy consumption. | 2 |
| | Target 11 : olfactory comfortable | C11.1 - Installation of an active ventilation system (VMC or VMR) and/or Installation of a transverse or vertical passive ventilation system by draft effect. | | 3 |
| | | C11.2 - Passive ventilation in WC bathrooms is recommended as a priority in Cameroon to extract odors. | | 3 |
| Health | Target 12: Sanitary quality of spaces | C12.1 - Creation of facilities for disable people: no justification for this criterion having been presented. | | 2 |
| | | C12.2 -Facilitation of access to health care. | | 2 |
| | | C12.3 - Choice of easy-care finishing materials (low demand for water, energy, …). | | 2 |
| | Target 13: Sanitary air quality | C13.1 - Manage the risks of pollution by construction products (target 2). | | 1 |
| | | C13.2 - Manage the risks of pollution by equipment (target 4). | | 1 |
| | | C13.3 - Manage the risks of pollution through upkeep or maintenance (target 7). | | 1 |
| | | C13.4 - Manage the risks of pollution by fresh air (smoke and gas detectors). | | 1 |
| | | C13.5- Limit olfactory nuisance linked to bad smells. | | 1 |
| | | C13.6 - Ensure good ventilation to guarantee air quality (targets 8 and 11). | | 1 |
| | Target 14: Sanitary | C14.1 - Make sure that the water that reaches the tap is drinkable, otherwise take measures fit consumption. | | 2 |
| | | C14.2- Use polyethylene pipes (or equivalent) to avoid the risk of polluting the water consumed. | | 2 |

| | | | |
|---|---|---|---|
| | quality of water | | |
| Social housing | Target 15 : Affordable housing for people with low incomes | C15.1 - Monthly rental cost of rent by type of accommodation. | 8 |
| | | C15.2 - Rental cost per $m^2$ of usable floor area | 2 |
| | | C15.3- Time required for the recovery of the investment | 2 |
| | Target 16: Sustainability of the economic activities of social landlords | C16.1 - Dwelling construction costs | 2 |
| | | C16.2- Maintenance costs | 2 |
| | | C16.3 - Utilities costs | 1 |
| | | C16.4- Demolition costs | 1 |
| | | C16.5 – Life Cycle Costs | 1 |
| | | C16.6- Net Present Value | 2 |
| | | C16.7- Lifetime of the house | 1 |

## III. MATERIALS AND DATA SOURCES USED

The materials used are mainly:

- Data sources of the implementation of LCA;
- The sources of the data related to the implementations of the proposed methodology (MACOLS-HEQ-Sustainable);
- And IT tools.

➢ *Data sources for the implementation of LCA*

The sources for the collection of data on construction products used in the Cameroonian context are mainly from:

- The database established from research work carried out within the Civil and Mechanical Engineering Laboratory of the National Polytechnic School of Yaoundé ( Elime, 2012; Mamba 2013a, 2013b, 2013c; Mamba, 2018; Okpwe, 2021);
- The results of exchanges with professionals in the social housing, building and public works sector (real estate companies, design offices, the ministries of public works, public service and administrative reform, finance, Domains and land affairs, etc.).

For the assessment of the environmental impacts due to the production of energy sources exploited in Cameroon (Table 5), we relied on the work of Mamba (2013c) and Dones et al. (2007).

With regard to the construction project in Cameroon, the work of Elime (2012), Mamba (2013a, 2013b) and Okpwe (2021), provided us with the components of the unit environmental impact vectors, due to energy production, the different ways of transport and some construction products in Cameroon. Tables 7, 8 and 9 provide environmental impacts of some products or process.

Table 7 Environmental Impacts Related to Production of Sources Energy ( Dones Et Al., 2007; Mamba, 2013c)

| | **Fuel** | **Gas** | **Hydro electricity** |
|---|---|---|---|
| Unit | T | $Nm^{3\ a}$ | kWh |
| Energy (MJ/ Unit) | 5.36E+04 | 3.54E-02 | 3.60E-01 |
| Water (L/ Unit) | | | 6.89E-03 |
| U-Waste (kg/ Unit) | | | 1.61 |
| GWP (kg eq-$CO_2$ / Unit) | 4.31E+02 | 1.31E-06 | 3.12E-04 |
| Acidification (kg eq-$SO_2$ / Unit) | 5.75E+00 | 1.31E-06 | 1.41E-06 |
| Eutrophication (kg eq-$PO_4^{3-}$ / Unit) | 2.47E-01 | 1.00E-07 | 2.63E-07 |
| EcotoxAq ($m^3$ / Unit) | | | 1.37E-02 |
| Smog (kg eq-$C_2H_4$ / Unit) | 1.26E-02 | 3.20E-08 | 7.56E-09 |

$1Nm^3 = 1m^3$ of gas under Normal temperature and pressure conditions.

Table 8 Environmental Impacts Related to Transportation in Cameroon (Dones Et Al., 2007 ; Mamba M., 2013c)

| | **Railway** | **river** | **Sea** | **road** |
|---|---|---|---|---|
| Unit | T.km | T.km | T.km | T.km |
| Energy (MJ/ Unit) | 1.13E+00 | 9.15E-01 | 2.41E-01 | 2.22E+00 |
| Water (L/ Unit) | 6.80E-02 | 5.80E-02 | | 1.89E-01 |

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| | | | | |
|---|---|---|---|---|
| U-Waste (kg/ Unit) | 4.89E-04 | 3.35E-05 | | 1.09E-04 |
| GWP (kg eq-$CO_2$ / Unit) | 5.18E-02 | 3.73E-02 | 8.93E-03 | 8.31E-02 |
| Acidification (kg eq-$SO_2$ / Unit) | 4.69E-04 | 3.26E-04 | 2.28E-04 | 5.05E-04 |
| Eutrophication (kg eq-$PO_4^{3-}$ / Unit) | 1.09E-04 | 7.05E-05 | 1.86E-05 | 1.02E-04 |
| EcotoxAq ($m^3$ / Unit) | 1.86E-08 | 2.59E-07 | | 8.43E-07 |
| Smog (kg eq-$C_2H_4$ / Unit) | 7.59E-07 | 1.97E-07 | | 4.68E-07 |

Table 9 Environmental Impacts of Some Processes in Cameroon (Dones Et Al., 2007; Mamba M., 2013c)

| | **Rebars** | **Alumi-nium** | **Cement concreteC20/25** | **Wood (Iroko/ Sapelli)** | **Cement mortar M8/10** |
|---|---|---|---|---|---|
| Unit | T | T | T | T | T |
| Energy (MJ/ Unit) | 5.10E+04 | 2.98E+04 | 6.91E+02 | 8.00E+03 | 7.41E+02 |
| Water (L/ Unit) | 2.21E+04 | 7.66E+02 | 5.76E+02 | 2.00E+01 | 5.89E+02 |
| U-Waste (kg/ Unit) | 7.20E+01 | 8.38E+00 | 4.49E+02 | 0.00E+00 | 3.67E+02 |
| GWP (kg eq-$CO_2$ / Unit) | 4.23E+03 | 3.81E+02 | 1.30E+02 | 6.96E+02 | 1.39E+02 |
| Acidification (kg eq-$SO_2$ / Unit) | 1.74E+01 | 2.04E+00 | 3.27E-01 | 6.32E-01 | 3.49E-01 |
| Eutrophication (kg eq-$PO_4^{3-}$ / Unit) | 1.54E+00 | 1.06E-01 | 4.01E-02 | 1.04E-01 | 4.20E-02 |
| EcotoxAq ($m^3$ / Unit) | 1.27E+02 | 3.47E-03 | 1.79E-03 | 8.00E-03 | 2.00E-03 |
| Smog (kg eq-$C_2H_4$ / Unit) | 2.08E+00 | 1.51E-01 | 1.77E-02 | 1.44E-01 | 1.48E-02 |

- *Sources of Benchmark Indicators for Social Housing*

- *Bioclimatic Architecture*

For bioclimatic architecture, we make use of Mempouo (2015) and Mamadou (2015), which divide Cameroon into 5 climatic zones and for each zone, and propose suitable designs associated with, including constitutive materials.

- *Social Housing Benchmarks*

The reference indicators for Cameroonian social housing are given in Table 10 for the financial reference indicators and in Table 11 for the environmental indicators. They come from the database of the Civil Engineering Lab. of the National Advanced School of Engineering of Yaounde (Mamba, 2018).

Table 10 Financial BENCHMARKS Indicators for Cameroonian Social Housing (Mamba, 2018)

| **Group of indicators** | **Indicator** | **c Indicator unit** | **Reference values for indicator** | **House type** |
|---|---|---|---|---|
| Indicators of housing affordability for low-income people | Maximum rent costs per month | CFA franc/ month | ≤ 27,660 | T1 |
| | | | ≤ 39,900 | T2 |
| | | | ≤ 56,100 | T3 |
| | | | ≤ 80,360 | T4 |
| | | | ≤ 98,805 | T5 |
| | Maximum cost of rent per unit floor area and per month | CFA franc/ ($m^2$.month) | ≤960 | |
| | Payback period | Year | [34;40] | |
| Economic performance indicators for social housing | Construction costs per unit floor area | CFA franc/$m^2$ | <200,000 | |
| | Utilities costs per unit floor area and per lifetime | CFA franc /($m^2$.year) | <2,500 | |
| | Maintenance costs per unit floor area and per lifetime | CFA franc /($m^2$.year) | <2,100 | |
| | Demolition costs per unit floor area and per lifetime | CFA franc /($m^2$.year) | <800 | |
| | Life cycle costs per unit floor area and per lifetime | CFA franc /($m^2$.year) | <8,200 | |
| | House lifetime | Year | [50 ; 100] | |
| | Net Present Value per unit floor area and per lifetime | CFA franc /($m^2$.year) | >0 | |

1.0 CFA franc=0.0017 USD

Table 11 Reference Values of Environmental Impacts for Cameroonian Socials Housing (Mamba, 2018)

| | Construc-tion phase | Exploita-tion ( use) phase | Mainte-nance phase | Demo-lition phase | Life cycle |
|---|---|---|---|---|---|
| Energy (MJ/(m$^2$ year)) | 8.67E+01 | 2.18E+01 | 6.68E+01 | 3.54E+00 | 1.79E+02 |
| Water (L/(m$^2$ year)) | 3.92E+01 | 1.18E+00 | 2.41E+01 | 2.69E-01 | 6.48E+01 |
| U-Waste (kg/(m$^2$ year)) | 1.08E+01 | 4.43E+01 | 4.05E+00 | 1.74E-04 | 5.91E+01 |
| GWP (kgeq-$CO_2$/(m$^2$ year)) | 8.84E+00 | 8.50E-01 | 6.02E+00 | 1.32E-01 | 1.58E+01 |
| Acidification (kgeq-$SO_2$/ (m$^2$ year)) | 2.97E-02 | 4.47E-05 | 2.26E-02 | 8.04E-04 | 5.31E-02 |
| Eutrophication (kg eq-$PO_4^{3-}$/ (m$^2$ year)) | 3.05E-03 | 9.53E-04 | 2.06E-03 | 1.62E-04 | 6.22E-03 |
| EcotoxAq (m$^3$/(m$^2$ year)) | 7.09E-03 | 8.62E+01 | 4.25E-03 | 1.35E-06 | 8.63E+01 |
| Smog (kg eq-$C_2H_4$/ (m$^2$ year)) | 7.65E-03 | 5.39E-04 | 6.75E-03 | 7.49E-07 | 1.49E-02 |

➢ *Software*

We make use of following software:

- Revit 2018 platform, for design and in order to design 6D modeling of the studied dwelling (establishment of the quantitative and estimates costs of construction, maintenance, operation and deconstruction at the end of the building's life as well as the environmental impacts generated);
- Microsoft Excel 2010, for computation of financial and environmental impacts.

## IV. CASE STUDY

The social housing to be designed is located in Yaoundé (Cameroon). The building is a single storey for a family of six (06) people consisting of a couple with four children. The said dwelling will be built on a plot of land of 367.5 m$^2$ which has been put at the disposal of the social landlord free of charge by the public authorities.

➢ *Step 1: Definition of Priority Targets*

The priority targets chosen by the project owner, who is the social landlord, are summarized in Table 12.

Table 12 Hierarchization of Targets by the Contracting Authority or the Social Landlord

| Target | Required Level of performance |
|---|---|
| 1 | HP |
| 2 | P |
| 3 | P |
| 4 | HP |
| 5 | HP |
| 6 | P |
| 7 | CS |
| 8 | CS |
| 9 | CS |
| 10 | CS |
| 11 | CS |
| 12 | CS |
| 13 | CS |
| 14 | P |
| 15 | HP |
| 16 | HP |

➢ *Step 2: Results for the Architectural Design and the Production of the File Execution of Works*

From the client's requirements established in step 1, it appears that the load-bearing structure of the dwelling studied (insulated footings, stringers, beams and lintels) will be made of class C20 reinforced concrete. The 15cm thick non-bearing walls will be made of cement-stabilized earth blocks. The external parts will be coated with a cement-stabilized laterite-based whitewash, while the internal parts will be coated and painted. The wood used for the frame and the doors will be iroko.

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At the end of this phase, all the building components are defined. And the design carried out with Revit 2018 software, shows that the dwelling obtained is a T5, with a usable surface of 86.8m$^2$ and the building's footprint on the plot is 139.6m$^2$, which gives a land occupation coefficient of 38%. Fig. 1, 2, 3 and 4 describe the architecture of the house.

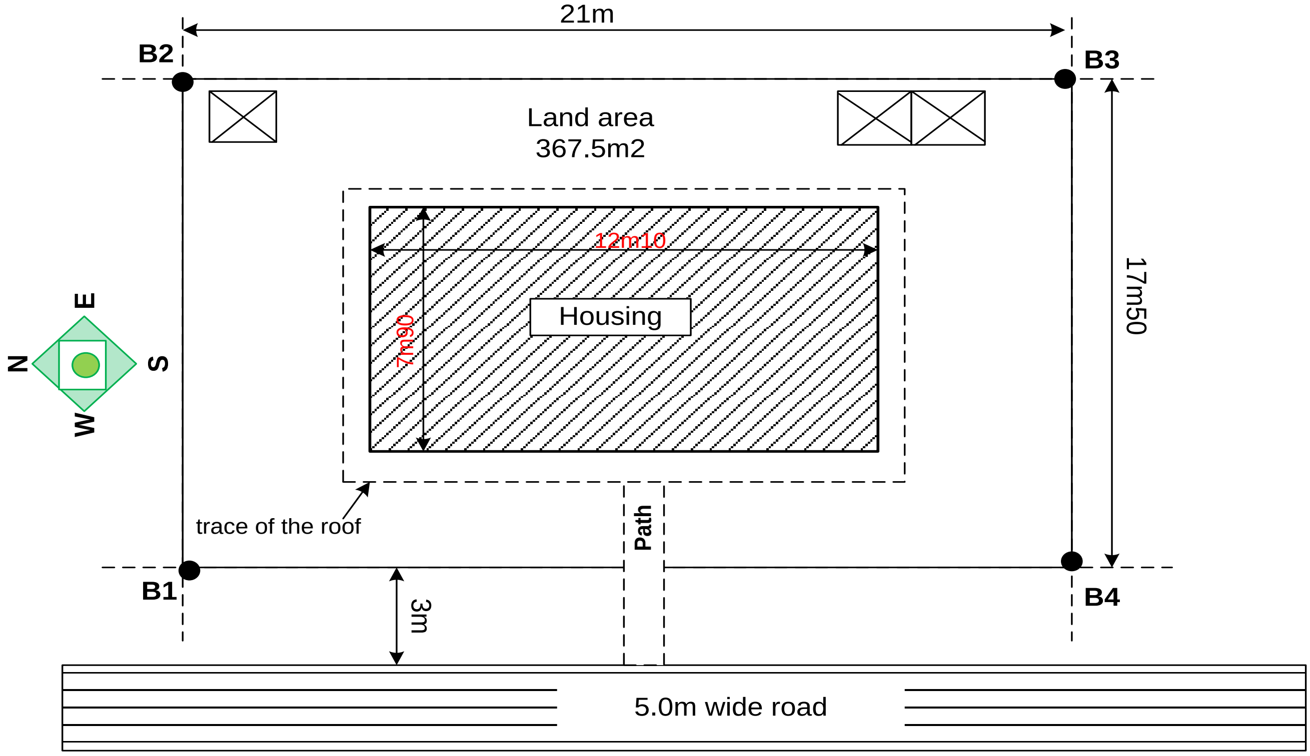


Fig 1 A General View of the House into the Site and Main Access

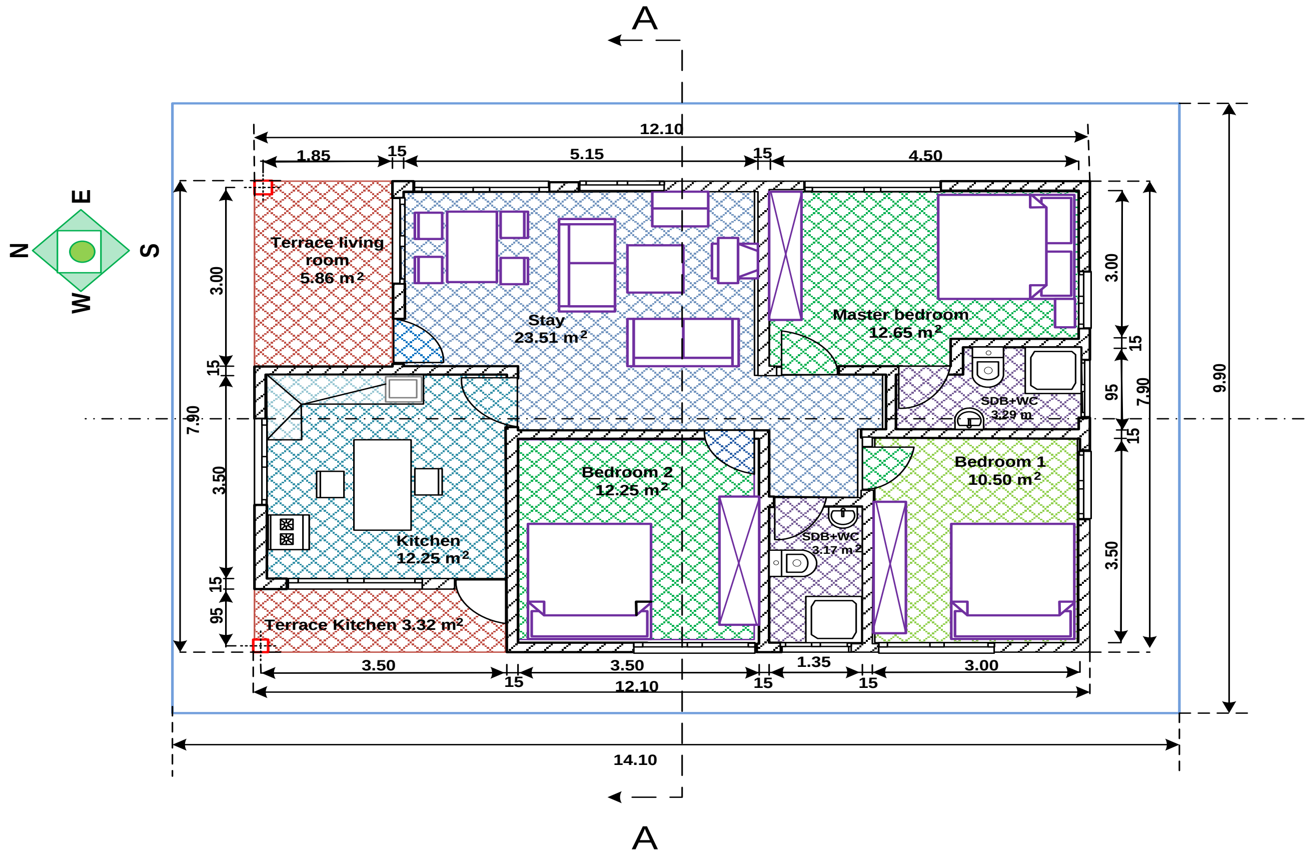


Fig 2 Plan view of the Studied House

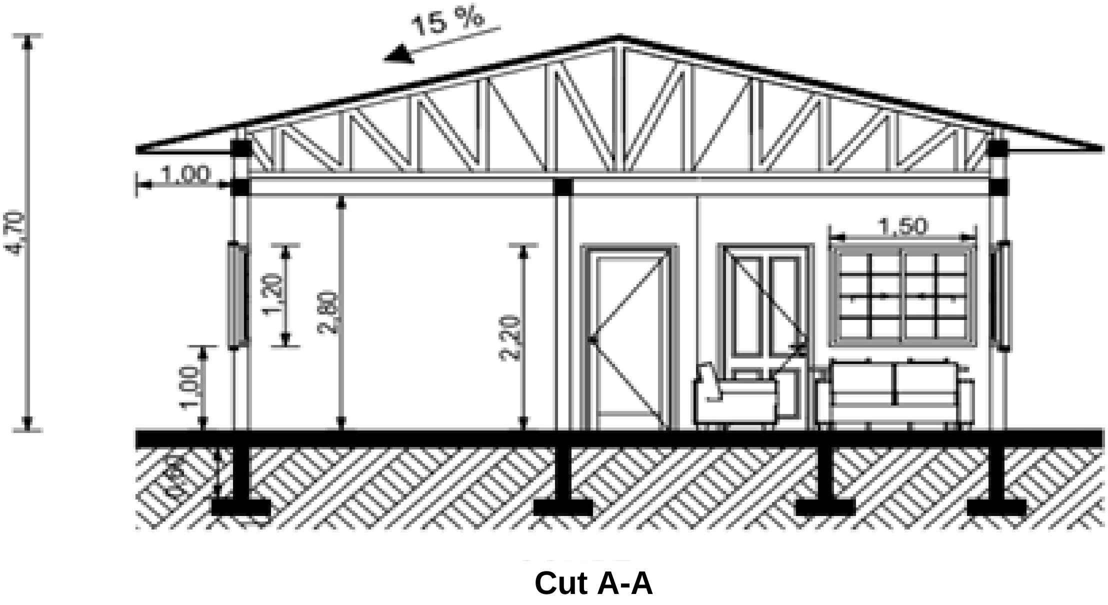


Fig 3 Section A-A of the Studied House

Fig 4 Perspective view of the Studied House

➢ *Step 3: Housing Life Cycle Analysis Results*

Objective of the life cycle analysis is to obtain the environmental and financial impact values that will be used for the calculation:

Financial and environmental impact indicators, in order to check criteria related to the accessibility of housing for people on low incomes and the sustainability of the economic activities of social landlords.

The estimated lifespan of the dwelling is seventy-five years (75 years) and the functional unit of the said dwelling is the usable surface which is $86.8m^2$. The boundary of the system inside which the fluxes are calculated is given by Fig. 5.

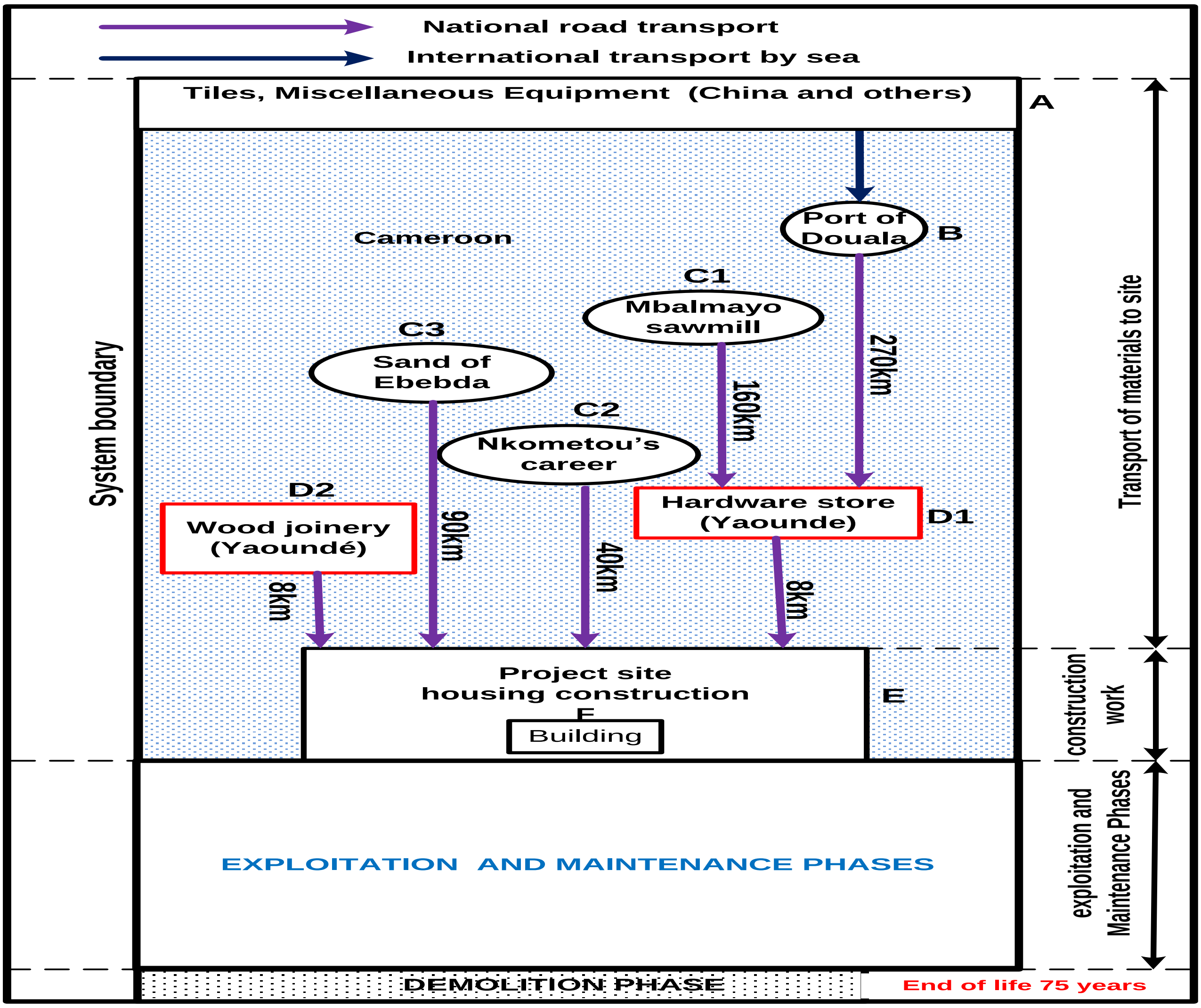


Fig 5 System Boundary used to Study Environmental Performance and Affordability Housing

Computation of environmental and financial impacts follows eight (08) assumptions:

- *H1:* The reference period of this dwelling is 75 years and the year of commissioning is 1st January 2022.
- *H2:* The number of occupants of this dwelling is a couple with four children. And it is assumed that every 15 years a new couple with the same number of children replaces the previous family and consequently the number of occupants of this dwelling will be six (06) persons during the whole life of the dwelling.
- *H3:* The provisional maintenance schedule for the building will take into account the replacement of some equipment at the end of its life by the social landlord, the renewal of coatings and paints, the emptying of the septic tank, the cleaning of the rainwater tank and the maintenance of the garden and access roads. The maintenance costs are entirely borne by the social landlord.
- *H4:* Utilities costs are related to water, electricity, and domestic gas consumption, the replacement of household appliances (television, iron, fridge) and the replacement of light bulbs. These costs are the borne by the occupier.
- *H5:* The demolition of the building will be carried out using a mechanical excavator which may be equipped with a jackhammer for the destruction of the concrete. The demolition materials will be taken to sorting centres for recycling and reuse. The demolition costs will be borne by the social landlord.
- *H6:* The construction cost of the dwelling was obtained from the quantity and estimate of the construction. This cost is entirely borne by the social landlord.
- *H7:* The calculation of the environmental impacts at all phases of the housing life cycle was done by multiplying the unit impact vectors extracted from the ENSP database (some of which are given in Tables 5, 6 and 7 ) by the elements of the quantitative estimates for the construction, maintenance, operation and demolition works.
- *H8:* For reasons of simplicity, the evaluation of construction, demolition, use and maintenance costs during the reference period will be done at constant FCFA.

✓ *Environmental and Financial Impact Values*

- *Financial Impact Values*

Obtained results, which are summarized in Fig. 6, 7 and Table 13, show that: the Life Cycle Cost of the studied house is 49,280,442 FCFA. The percentages of construction, maintenance, utilities and demolition costs are: 35%, 27%, 31% and 7% of the Life Cycle Cost.

Net Present Value of the case study is 7,544,471 FCFA and Payback period of 36 years (Fig. 7). Computation lead to a house rent of 81,775 FCFA.

Table 13 Financial Costs of the Studied House

| No. | Life cycle phases | Financial costs (FCFA) | Bearer of the costs |
|---|---|---|---|
| 1 | Construction phase | 17,072,815 | Social landlord |
| 2 | Exploitation phase | 15,385,049 | Occupant |
| 3 | Maintenance phase | 13,338,000 | Social landlord |
| 4 | Demolition phase | 3,488,578 | Social landlord |
| | Life cycle | 49,284,442 | - |

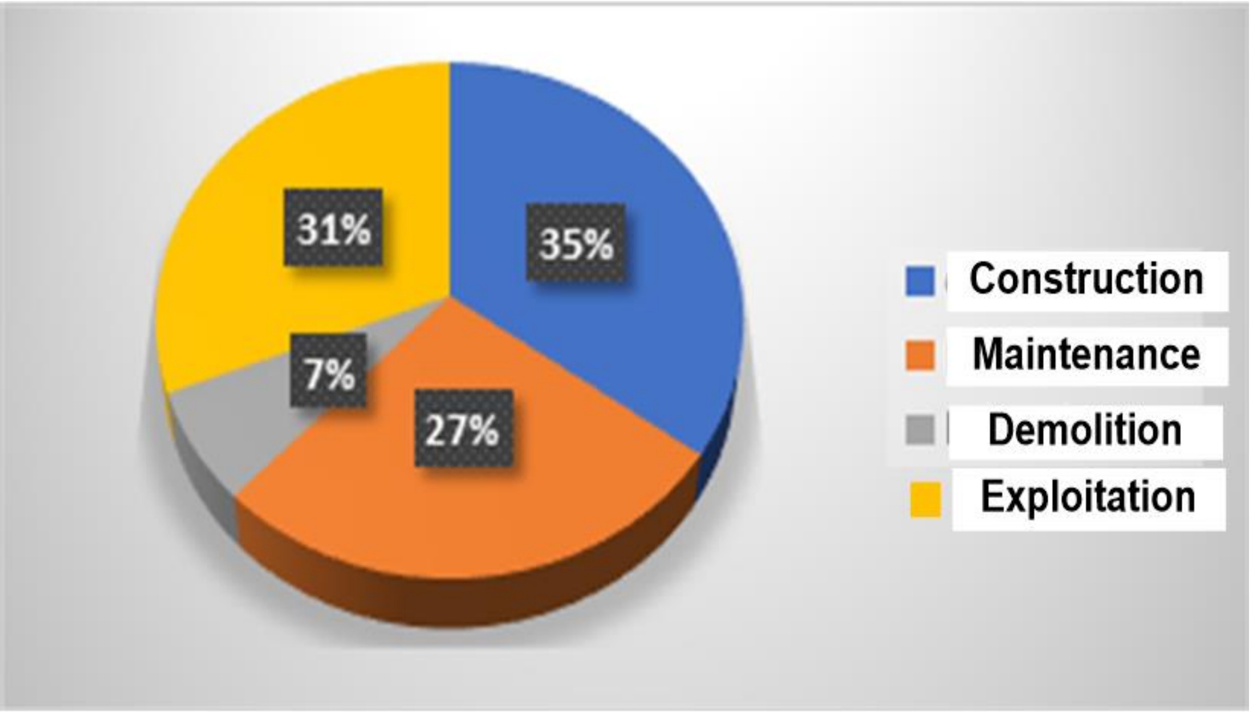


Fig 6 Percentage of Construction, Maintenance, use on and Demolition Costs of the House Studied

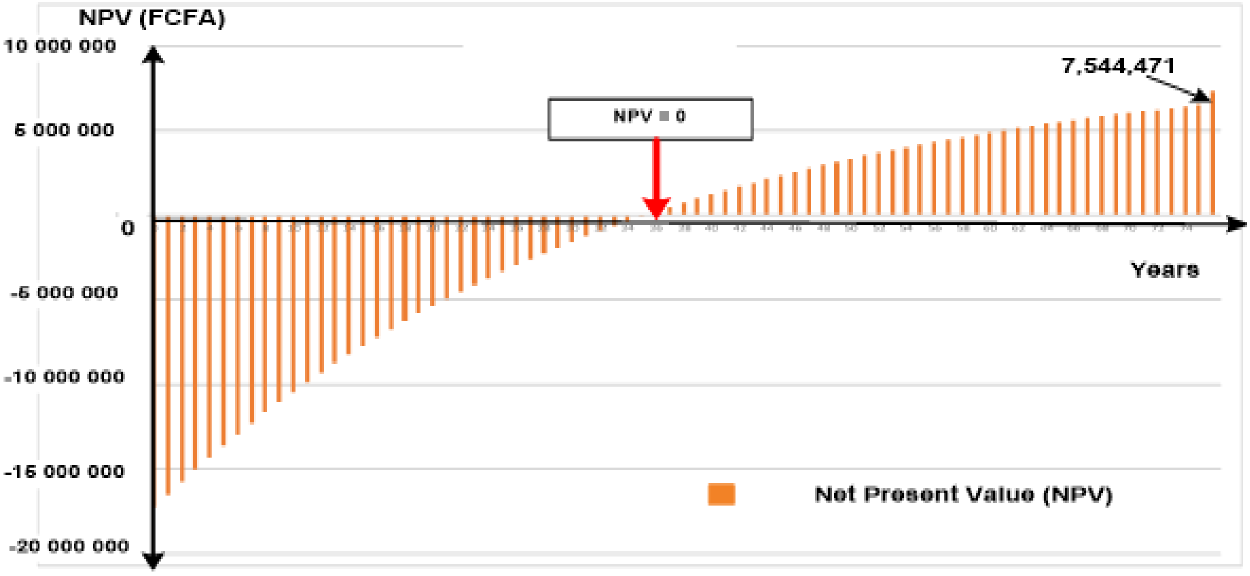


Fig 7 Evolution of Net Present Value During the Lifetime of the Studied House

- *Social Housing Indicators Values*
  Financial impact indicators, summarized in Table 14, show that they meet all the specific criteria for social housing.

Table 14 Values of the Indicators Financial Impacts of the Housing Studied Compared to the Reference Values

| Group of indicators | Indicator | Indicator units | Indicator values of the case study | Reference values for each indicator |
|---|---|---|---|---|
| Indicators of Housing Affordability by Low-Income Individuals | House rent per month (for a T5) | FCFA | 81,775 | <98,805 |
| | House rent per unit floor area and per month | FCFA /m$^2$ | 942 | <960 |
| | Payback period | Year | 36 | [34 ; 40] |
| Indicators of economic sustainability of the social donor | Construction costs per unit floor area | FCFA /m$^2$ | 196,691 | <200,000 |
| | Utilities costs per unit floor area and per lifetime | FCFA) /(m$^2$.year) | 2,363 | <2,500 |
| | Maintenance costs per unit floor area and per lifetime | FCFA /(m$^2$.year) | 2,049 | <2,100 |
| | Demolition costs per unit floor area and per lifetime | FCFA /m $^2$ | 536 | <800 |
| | Life cycle costs per unit floor area and per lifetime | FCFA/(m$^2$.year) | 7,571 | <8,200 |
| | Net Present Value per unit floor area and per lifetime | FCFA/(m$^2$.year) | 1,159 | >0 |
| | House lifetime | Year | 75 | [50 ; 100] |

- *Values of the Components of the Environmental Impact Vector of the Studied Dwelling*
  Results obtained, which are summarized in Tables 15 and 16 and Fig. 8 and 9, show that:

- ✓ Construction and maintenance phases represent 85.8% of energy consumption.
- ✓ Operation phase correspond to 74.5% of ultimate waste and 100% of aquatic ecotoxicity.

Table 15 Environmental Impacts of the different Life Phases of Studied House

| No. | Life cycle phases | Energy (MJ) | Water (L) | U-Waste ( kg) | GWP (kg eq-$CO_2$) | Acidification (kg eq-$SO_2$) | Eutrophication (kg eq-$PO_4^{3-}$) | EcotoxAq (m$^3$) | Smog (kg eq-$C_2H_4$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Construction phase | 4.34E+05 | 1.96E+05 | 5.41E+04 | 4.43E+04 | 1.49E+02 | 1.53E+01 | 3.55E+01 | 3.83E+01 |
| 2 | Exploitation phase | 1.09E+05 | 5.89E+03 | 2.22E+05 | 4.26E+03 | 2.24E-01 | 4.77E+00 | 4.32E+05 | 2.70E+00 |
| 3 | Maintenance phase | 3.34E+05 | 1.21E+05 | 2.03E+04 | 3.01E+04 | 1.13E+02 | 1.03E+01 | 2.13E+01 | 3.38E+01 |
| 4 | Demolition phase | 1.77E+04 | 1.35E+03 | 8.72E-01 | 6.64E+02 | 4.03E+00 | 8.12E-01 | 6.74E-03 | 3.75E-03 |
| | Life cycle | 8.96E+05 | 3.24E+05 | 2.96E+05 | 7.93E+04 | 2.66E+02 | 3.12E+01 | 4.32E+05 | 7.48E+01 |

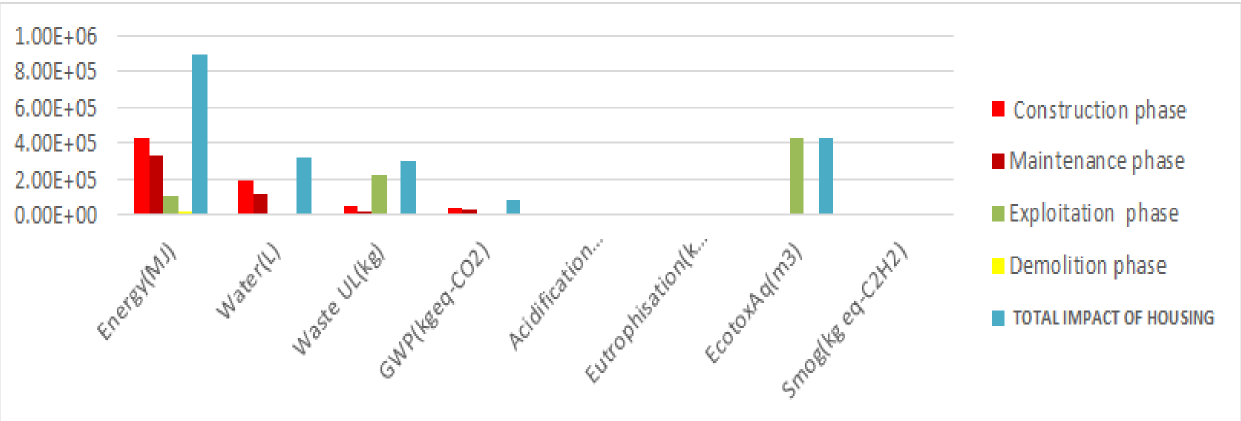


Fig 8 Environmental Impacts of Phases of the Studied House

Table 16 Weight of the Components of Impacts at the different Stages of Life of the Studied Housing

| No. | Life cycle phases | Energy (MJ) | Water (L) | U-Waste ( kg) | GWP (kg eq-$CO_2$) | Acidification (kg eq-$SO_2$) | Eutrophication (kg eq-$PO_4^{3-}$) | EcotoxAq ($m^3$) | Smog (kg eq-$C_2H_4$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Construction phase | 48.5% | 60.5% | 18.3% | 55.8% | 55.9% | 49.0% | 0.0% | 51.2% |
| 2 | Use (exploitation) phase | 12.2% | 1.8% | 74.9% | 5.4% | 0.1% | 15.3% | 100% | 3.6% |
| 3 | Maintenance phse | 37.3% | 37.3% | 6.9% | 38.0% | 42.5% | 33.1% | 0.0% | 45.2% |
| 4 | Demolition phase | 2.0% | 0.4% | 0.0% | 0.8% | 1.5% | 2.6% | 0.0% | 0.0% |
| | Life cycle | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

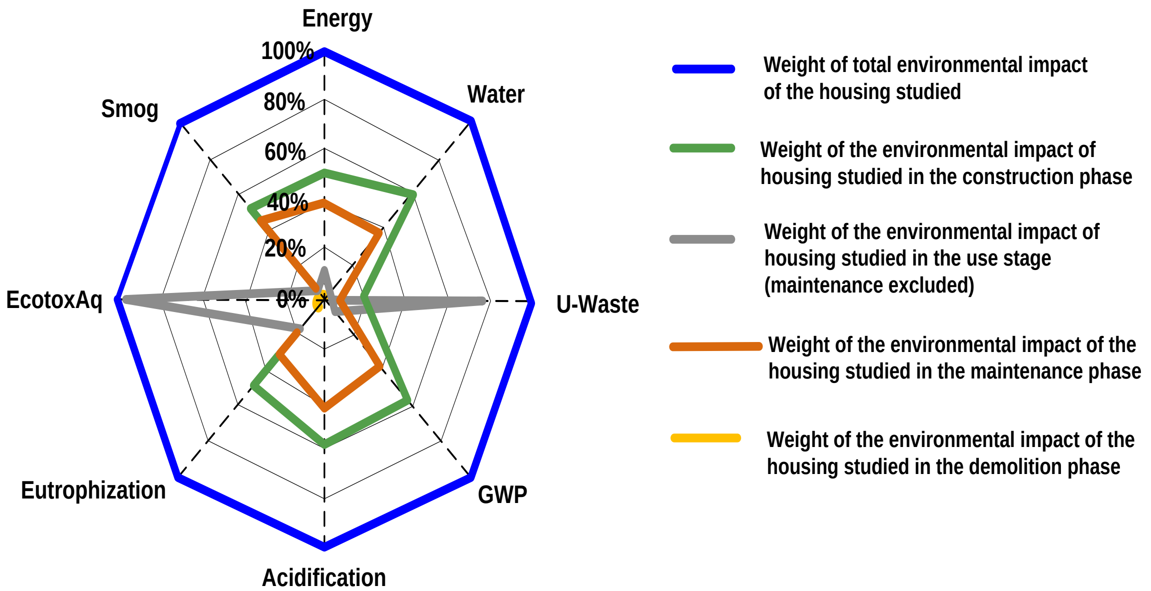


Fig 9 Weight of the Components of Impacts at the different Phases of Life of the Housing Studied in Relation to the total Environmental Impact

- *Environmental Impact Indicator Vector Components Values*

The values of the components of the environmental impact indicators of the studied housing are given in Table 17. Fig.10 which compares the environmental impact indicators: throughout the life cycle of the structure. Obtained results show that all of these indicators are lower than all the values of the components of the corresponding benchmark indicators of the social housing.

Table 17 Indicators of Total Environmental Impacts and the different Life Phases of the Studied Housing

| No. | Life cycle phases | Energy (MJ/ ($m^2$ year)) | Water (L/($m^2$ year)) | U-Waste (kg/($m^2$ year)) | GWP (kg eq-$CO_2$/ ($m^2$ year)) | Acidification (kg eq-$SO_2$/ ($m^2$ year)) | Eutrophication (kg eq-$PO_4^{3-}$ / ($m^2$ year)) | EcotoxAq ($m^3$/ ($m^2$ year)) | Smog (kg eq-$C_2H_4$/ ($m^2$ year)) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Construction phase | 6.67E+01 | 3.02E+01 | 8.31E+00 | 6.80E+00 | 2.28E-02 | 2.35E-03 | 5.46E-03 | 5.89E-03 |
| 2 | Use(exploitation) phase | 1.68E+01 | 9.05E-01 | 3.41E+01 | 6.54E-01 | 3.44E-05 | 7.33E-04 | 6.63E+01 | 4.14E-04 |
| 3 | Maintenance phase | 5.14E+01 | 1.86E+01 | 3.12E+00 | 4.63E+00 | 1.74E-02 | 1.58E-03 | 3.27E-03 | 5.19E-03 |
| 4 | Demolition phasee | 2.72E+00 | 2.07E-01 | 1.34E-04 | 1.02E-01 | 6.18E-04 | 1.25E-04 | 1.03E-06 | 5.76E-07 |
| | Life cycle | 1.38E+02 | 4.98E+01 | 4.55E+01 | 1.22E+01 | 4.09E-02 | 4.79E-03 | 6.64E+01 | 1.15E-02 |

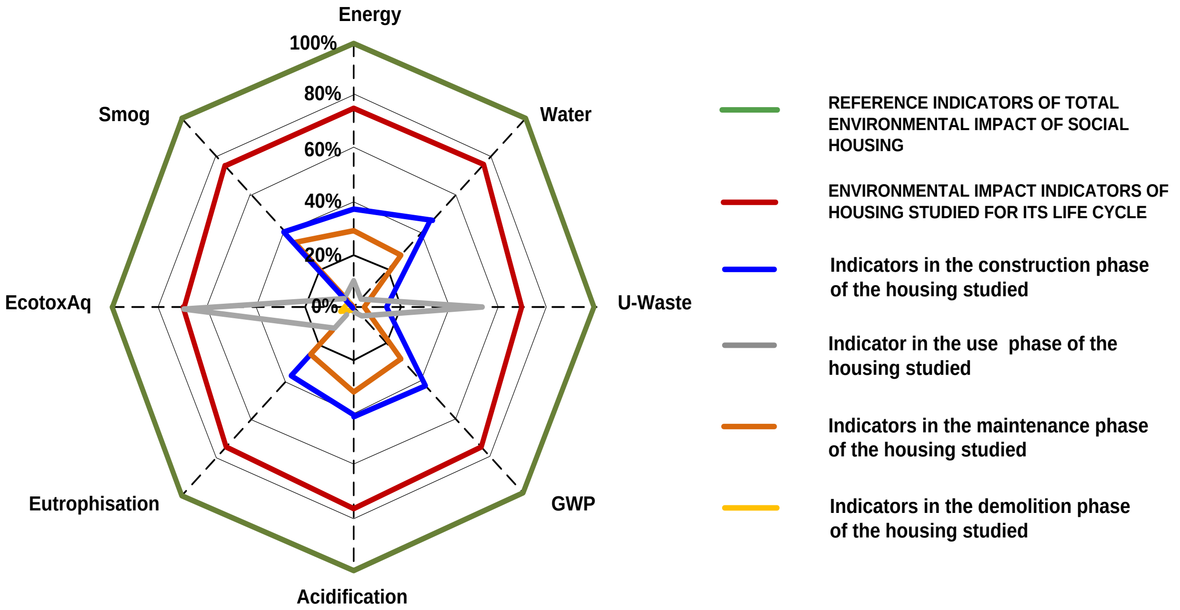


Fig 10 Weight of the Components of the Environmental Impact Indicators: Global and at different Phases of Life of the Housing Studied, in Relation to the Values of the Baseline Impact Indicators Obtained over the Entire Life Cycle of Social Housing

➢ *Step 4: Assigning Scores to Basic Targets*

From the above, we can see that:

- All of the environmental indicators of the studied dwelling are below the values of the environmental impact reference indicators that characterize social housing;
- The financial impact indicators (criteria related to the accessibility of housing for low-incomes people and the sustainability of the social landlord's economic activities) are verified (Table 10).

Based on the information obtained in step 3, we proceeded to score the seventy-six basic targets and the summary of the results obtained is given in Table 18.

➢ *Step 5: Results of the HEQ Approach*

Examination of the scoring results in Table 18, which are summarized in Fig. 11, allows us to draw the following conclusions: all of the Project Owner's concerns have been satisfied. Targets: 1, 4, 5, 15 and 16 are Highly Performing (HP), targets: 2, 3, 6 and 14 are at least Performing (P) and finally targets 7, 8, 9, 10, 11, 12 and 13 are, according to the criteria proposed in the methodology Compliant (CS) with the current construction standards in Cameroon. As the results obtained are identical in every respect to those shown in Table 5, we can therefore say without any hesitation that the studied housing is "Sustainable HEQ social housing".

Table 18 Result of Evaluation of the Housing Construction Project Studied with the HEQ Proposed Approach

| Theme | Target | Activity | Sub-targets | Marks | Answers | Score (Sub-target) | Score (Target) | Score (%) (Target) | Performance level (Target) |
|---|---|---|---|---|---|---|---|---|---|
| Green building | Target 1 : Harmonious relationship of buildings with their immediate environment | C01.1 | C01.1.1 | 2 | Yes | 2 | 23 | 100% | HP |
| | | | C01.1.2 | 2 | Yes | 2 | | | |
| | | | C01.1.3 | 2 | Yes | 2 | | | |
| | | | C01.1.4 | 1 | Yes | 1 | | | |
| | | | C01.1.5 | 1 | Yes | 1 | | | |
| | | | C01.1.6 | 2 | Yes | 2 | | | |
| | | C01.2 | C01.2.1 | 2 | Yes | 2 | | | |
| | | | C01.2.2 | 2 | Yes | 2 | | | |
| | | | C01.2.3 | 3 | Yes | 3 | | | |
| | | C01.3 | C01.3.1 | 2 | Yes | 2 | | | |
| | | | C01.3.2 | 2 | Yes | 2 | | | |
| | | | C01.3.3 | 2 | Yes | 2 | | | |
| | Target 2: Integrated choice of products, systems and construction processes | C02.1 | C02.1.1 | 4 | Yes-but | 2 | 8 | 80% | P |
| | | | C02.1.2 | 3 | Yes | 3 | | | |
| | | | C02.1.3 | 3 | Yes | 3 | | | |
| | Target 3: Low | C03.1 | C03.1.1 | 1 | Yes | 1 | 8 | 89% | P |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | nuisance construction site | | C03.1.2 | 2 | Yes-but | 1 | | | |
| | | | C03.1.3 | 3 | Yes | 3 | | | |
| | | | C03.1.4 | 3 | Yes | 3 | | | |
| | Target 4: Energy Management | C04.1 | CO4.1.1 | 3 | Yes | 3 | **26** | **100%** | **HP** |
| | | | CO4.1.2 | 1 | Yes | 1 | | | |
| | | | C04.1.3 | 3 | Yes | 3 | | | |
| | | | CO4.1.4 | 3 | Yes | 3 | | | |
| | | | C04.1.5 | 16 | Yes | 16 | | | |
| Eco-Mana-gement | Target 5 : Water management | C05.1 | C05.1.1 | 1 | Yes | 1 | **15** | **100%** | **HP** |
| | | | C05.1.2 | 4 | Yes | 4 | | | |
| | | | C05.1.3 | 4 | Yes | 4 | | | |
| | | C05.2 | C05.2.1 | 4 | Yes | 4 | | | |
| | | C05.3 | C05.3.1 | 2 | Yes | 2 | | | |
| | Target 6 : Management of activity waste | C06.1 | C06.1.1 | 1 | Not | 0 | 21 | **91%** | **P** |
| | | C06.2 | C06.2 | 1 | Yes | 1 | | | |
| | | C06.3 | C06.3 | 2 | Yes | 2 | | | |
| | | C06.4 | C06.4 | 2 | Yes | 2 | | | |
| | | C06.5 | C06.5 | 1 | Not | 0 | | | |
| | | C06.6 | C06.6 | 16 | Yes | 16 | | | |
| | Target 7: Management of upkeep and maintenance | C07.1 | C07.1 | 2 | Not | 0 | 8 | 53% | **CS** |
| | | C07.2 | C07.2 | 2 | Not | 0 | | | |
| | | C07.3 | C07.3 | 3 | Not | 0 | | | |
| | | C07.4 | C07.4 | 8 | Yes | 8 | | | |
| Comfort | Target 8: Hygrometric comfort | C08.1 | C08.1.1 | 4 | Yes | 4 | 4 | 57% | **CS** |
| | | | C08.1.2 | 1 | Not | 0 | | | |
| | | | C08.1.3 | 1 | Not | 0 | | | |
| | | C08.2 | C08.2.1 | 1 | Not | 0 | | | |
| | Target 9 : Acoustic comfort | C09.1 | C09.1 | 2 | Not | 0 | 4 | 67% | **CS** |
| | | C09.2 | C09.2 | 2 | Yes | 2 | | | |
| | | C09.3 | C09.3 | 2 | Yes | 2 | | | |
| | Target 10 : Visual comfort | C10.1 | C10.1.1 | 2 | Not | 0 | 7 | 54% | **CS** |
| | | | C10.1.2 | 2 | Not | 0 | | | |
| | | | C10.1.3 | 2 | Yes | 2 | | | |
| | | | C10.1.4 | 1 | Yes | 1 | | | |
| | | | C10.1.5 | 2 | Yes | 2 | | | |
| | | | C10.1.6 | 2 | Yes | 2 | | | |
| | | C10.2 | C10.2.1 | 2 | Not | 0 | | | |
| | Target 11 : Olfactory comfortable | C11.1 | C11.1 | 3 | *Yes-but* | 1.5 | 3 | 50% | **CS** |
| | | C11.2 | C11.2 | 3 | *Yes-but* | 1.5 | | | |
| Health | Target 12: Sanitary quality of spaces | C12.1 | C12.1 | 2 | Not | 0 | 4 | 67% | **CS** |
| | | C12.2 | C12.2 | 2 | Yes | 2 | | | |
| | | C12.3 | C12.3 | 2 | Yes | 2 | | | |
| | Target 13: Sanitary air quality | C13.1 | C13.1 | 1 | Yes | 1 | 3 | 50% | **CS** |
| | | C13.2 | C13.2 | 1 | Not | 0 | | | |
| | | C13.3 | C13.3 | 1 | Not | 0 | | | |
| | | C13.4 | C13.4 | 1 | Not | 0 | | | |
| | | C13.5 | C13.5 | 1 | Yes | 1 | | | |
| | | C13.6 | C13.6 | 1 | Yes | 1 | | | |
| | Target 14: Sanitary quality of water | C14.1 | C14.1 | 2 | Yes-but | 1 | 3 | 75% | **P** |
| | | C14.2 | C14.2 | 2 | Yes | 2 | | | |
| Social housing | Target 15 : Affordable housing for people with modest incomes | C15.1 | C15.1 | 8 | Yes | 8 | 12 | 100% | **HP** |
| | | C15.2 | C15.2 | 2 | Yes | 2 | | | |
| | | C15.3 | C15.3 | 2 | Yes | 2 | | | |
| | Target 16: Sustainability of the economic activities of social landlords | C16.1 | C16.1 | 2 | Yes | 2 | 10 | 100% | **HP** |
| | | C16.2 | C16.2 | 2 | Yes | 2 | | | |
| | | C16.3 | C16.3 | 1 | Yes | 2 | | | |
| | | C16.4 | C16.4 | 1 | Yes | 1 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C16.5 | C16.5 | 1 | Yes | 1 | | | |
| | | C16.6 | C16.6 | 2 | Yes | 2 | | | |
| | | C16.7 | C16.7 | 1 | Yes | 1 | | | |

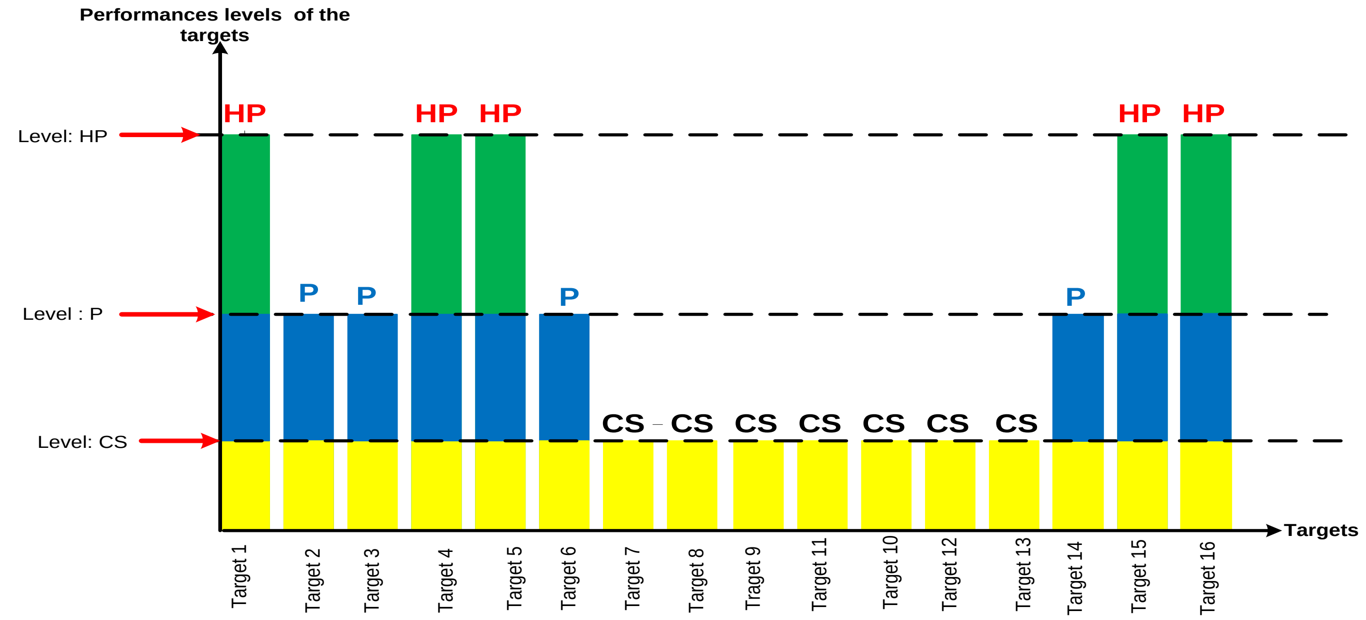


Fig 11 Level of Performance Achieved by the Evaluation of the Sixteen (16) Targets (*CS: Compliance of the Target with Current Standards; P: Performance, Efficient; HP: High performance*).

## V. CONCLUSION

In the end, the proposed methodology for the design of sustainable HEQ social housing is inspired by the HEQ approach, where rating system of sub-target was adopted and then completed by the introduction of a fifth family essentially devoted to the specific criteria to social housing (Target 15 for the affordability of housing for people on modest incomes and Target 16 for the sustainability of the economic activities of social landlords). A procedure for assigning scores to the basic targets and criteria for defining target performance levels has been proposed. The conditions that a dwelling must satisfy to be “sustainable HEQ social housing” have been clearly defined. This new methodology, which does not present any difficulties in its implementation, was used in the context of a project to design a single-storey dwelling to be occupied by a family consisting of a couple and four children. The results obtained indicate that the studied housing is “sustainable HEQ social housing” and that the operating phase contributes for 74% to the production of final waste and for almost 100% to aquatic ecotoxicity.

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