DESIGN METHODOLOGY FOR GREEN POULTRY HOUSES IN THE SAHELIAN ZONE.

Abstract:

The chicken production sector is growing rapidly inSahel. However, this sector suffers many losses due to heat stress in chicken houses. This article presents a methodology for designing a green poultry house to combat heat stress in the Sahelian zone. The methodology adopted is based on the development of a green design process and a multi-criteria evaluation approach. A literature review and surveys were first carried out to determine the ecological design standards. Next, design criteria and sub-criteria are identified. Finally, multi-criteria evaluation methods such as FAHP and TOPSIS were used to determine the weights and performance scores of each criterion and sub-criterion. The results obtained show that the "health and quality of the indoor environment" criterion is the first to be taken into account in the design with a weight of 0.54 and a performance score of 0.651, followed by the "economic factors" criterion with a weight of 0.29 and a performance score of 0.452, then the "technical/cost factors" criterion with a weight of 0.11 and a performance score of 0.435 and finally the "choice of site" criterion with a weight of 0.06 and a performance score of 0.423.

In addition, the orientation of the building, health and safety, climatic conditions and the initial investment cost are the most important sub-criteria to be taken into account, with respective weights of 0.45, 0.49, 0.29 and 0.5.

Key words:-
FAHP, Ecological poultry house, Thermal stress and TOPSIS.

Introduction:-

Chicken production is the fastest growing poultry sector worldwide [1]. Africa has recorded the strongest growth in chicken production at 2.27%, compared with 1.13% in the Americas and 0.91% in Europe [2]. However, climatic conditions in Africa, particularly in the Sahel, are unfavourable to chicken production because of the high temperatures that cause heat stress in poultry houses. Heat stress is a phenomenon that adversely affects the health and production performance of chickens. It leads to a high mortality rate in poultry houses during periods of high heat [3, 4, 5] Heat stress occurs when the temperature and humidity index (THI) exceeds the chickens' comfort zone of 56 to 68. Heat stress is fatal when the THI exceeds 70 in poultry houses [6]. To combat heat stress in chickens, the ecological design of poultry houses may be a good strategy. However, in Senegal, as elsewhere in the Sahelian zone, existing poultry houses are ineffective in combating heat stress because of their poor design. This is due to a lack of information on design standards and strategies. For this purpose, it is important to describe a methodology that serves as a guide for poultry house designers in Sahelian countries. Much research has focused on green buildings. (Gultekin and Alparslan, 2011) [7] conducted a study of green building design criteria. They identified four criteria: energy conservation, water conservation, material conservation and architectural design. (Ardebili and Boussabaine, 2010) [8] analyzed the main factors of green building design. The results indicated that the most determining factor is the design aspect and strategy with a percentage of 27.75%, followed by environmental impacts with 24.64%, then environmental strategies with 11.99%, then social aspects with 8.72%, site analysis with 5.22%, and finally economics with 4.81%. (Vesna Kosoric et al, 2011) [9] presented a design process for integrating a PV module into a green building. The process indicates three phases: site selection, generation and optimization of design alternatives, and the design evaluation process. (Lamrani et al, 2017) [10] investigated the thermal performance of green materials based on peanut shell and gypsum. The results showed that the peanut shell-based composite material strongly contributes to the improvement of thermal comfort in construction. (Mostavi et al; 2017) [11] have developed a building design methodology. The methodology is based on multi-objective optimization with the application of genetic algorithms. The results indicated that this method minimizes the life cycle cost and emissions of the building while maximizing the level of thermal comfort. (Dillon and Colton; 2014) [12] described a methodology for the design of net zero energy (NZE) vaccine warehouses for developing countries. The methodology used a simulation-optimization approach combining two simulation software packages (Energyplus and PV Watts). The results showed that thermal insulation and building materials are important parameters in green building design. In addition, investing in better building materials can reduce annual energy consumption by 50% and contribute to reducing building costs by up to $42,000. (Barea et al., 2022) [13] showed that using green strategies such as daylighting and natural ventilation can reduce energy consumption by 33.82 kWh/m^2 in arid climates. (Montana and Sanseverino., 2018) [14] conducted a comprehensive review of building design methodologies. They observed that environmental aspects are often neglected in design. Moreover, the most decisive aspects are costs and energy consumption. (Isaac et al, 2015) [15] have proposed a graph-based methodology for better design. The methodology uses automated graph tools to represent building information such as occupant comfort needs and component design. They have demonstrated that the method is very effective in optimizing green building design. Most work on building design methodology has focused on residential buildings. To our knowledge, there is as yet no methodology for the design of green poultry houses anywhere in the Sahelian zone.

Consequently, this article describes a methodology for designing green poultry houses in Sahel to help designers with the design process. The methodology is based on the development of a green design process and a multi-criteria evaluation approach using two methods such as the Fuzzy Analytic hierarchy process (FAHP) and the Technique of Order of Preference by Similarity to the Ideal Solution (TOPSIS) in order to determine the weights and performance scores of the criteria and sub-criteria considered.

The paper is structured as follows: Section 2 presents the methodology. Section 3 deals with the case study of a conceptual model of an ecological poultry house. Section 4 discusses the results obtained from the evaluation of the green poultry house design criteria.

A. METHODOLOGY

The methodology proposed in this study comprises a green design process and a multi-criteria evaluation approach. The multi-criteria evaluation approach uses two methods, namely FAHP and TOPSIS.

1) Green poultry house design

The design process is based on a combination of literature reviews on green building design and discussions with poultry industry specialists. The process is divided into four phases:

Phase 1: Site selection.

Phase 2: Design requirements

Phase 3: Health requirements

Phase 4: Detailed design of the poultry hous

- Site selection

This phase assesses the site in terms of its natural potential (sunshine, temperature, humidity and vegetation), the nature of the terrain (flat, low-lying or hilly) and accessibility to infrastructure (roads, and electricity). Hot zones, protected areas and flood-prone zones are considered unfavorable areas for setting up poultry houses. Vegetated and shaded areas are recommended.

- Green poultry design requirements

This phase sets out the strategies for designing an ecological poultry house to suit the climate. The main strategies are the orientation, shape and dimensions of the building, solar protection and ventilation and air-conditioning techniques.

  - Bulding orientation

The aim is to find a compromise between minimizing heat gain from the sun rays and good exposure to the wind. Large façades should be oriented along the north-south axis. This orientation reduces the exposure of the east and west facades to the solar radiation. The prevailing wind directions in Senegal are north, north-west and north-east.

  - Shape and dimensions

The parallelepiped shape is recommended for poultry houses, as it is more energy-efficient. In tropical zones, chicks should be reared on a standard of 7 birds per square meter and the width of poultry houses should be between 9 and 12 m to promote heat evacuation in the house [3]. The ratio of building surface area to volume should be as low as possible in hot, dry climates [16].

  - Sun protection

The In Sahelian zones, the heat in poultry houses is mainly due to solar gain. Solar protection must be designed for each component of the building envelope. High-stemmed vegetation is proposed on the façades and roof to limit solar gain towards the building. Roof overhangs and light colors should also be used on all facades. At openings, awnings are recommended to prevent the sun rays from penetrating the interior of the building.

  - Ventilation

The Ventilation is essential for the health and well-being of your chickens. It evacuates stale air laden with ammonia, carbon dioxide and other harmful gases. Natural ventilation should be favored. Mechanical ventilation is necessary in poultry houses during heatwaves, as it reduces heat stress by increasing the speed to increase cooling by convection. Hybrid ventilation saves energy by running fans only when necessary.

  - Air conductioning

In Sahel, during the hot dry season, the THI exceeds 70, which is the threshold for fatal heat stress in chickens on certain days [6]. These extreme conditions require an air-conditioning system for poultry over three weeks old. In this respect, open-cycle evaporative cooling systems can provide a cost-effective and environmentally friendly solution [17].

- Health requirements

This Cleaning and disinfection are required for every new flock of chicks in a poultry house. For effective cleaning, the walls of the building must be smooth, as porous walls are difficult to clean and germs can embed themselves in the pores. A brush, broom or high-pressure cleaner is used to remove organic matter from the walls. The surfaces of the walls must withstand this treatment. Disinfection of the poultry house is necessary to kill bacteria. The walls and ceiling of the hen house must be absorbent to the disinfectant solution.

- Detailed design of the poultry house

The facades, roof, openings and construction materials, the architectural model and the use of renewable energies are defined during this phase..

  - Facade

Energy is transmitted into the building mainly via the façades. A double-skin wall is proposed to limit external heat gain.

  - Roof

The roof is the component of the building that receives the most sunlight. The metal roof is one of the main causes of heat stress in poultry houses. To avoid solar radiation from reaching the roof, a layer of insulation should be added. A gable roof is recommended to limit heat gain in the building from sunlight.

- Opening

Openings should be located on the large facades to facilitate air circulation during the hot period. The openings should be between 50% and 80% of the height of the side elevations to facilitate ventilation [18]. They should be fitted with insulating curtains to control the flow of air into the building during the cooler periods of the year or during the start-up phase. Doors should be placed on the side elevations, to allow access for service and removal of chickens.

- Building materials

Building materials for green poultry houses should be chosen for their good thermal insulation performance, their suitability for sustainable construction and their low environmental impact. The materials must also be available, less expensive and must not encourage the development of viruses or bacteria. They must be easy to clean and dry, to prevent the building becoming damp and allowing parasites and bacteria to nest. Earth-based bricks for façades are recommended because earth absorbs heat waves better than concrete and has good moisture-regulating properties. Typha reeds are recommended for roof construction because of their excellent thermal performance, durability, excellent environmental record and low cost.

- Renewable energy

The use of renewable energy sources (RES) is a very important aspect of green building design. In fact, the use of renewable energy sources makes it possible to reduce the use of fossil fuels. Photovoltaic solar power is recommended for poultry houses to run electrical appliances such as lights and fans. Thermal collectors can be used for heating and air conditioning.

2) Multi-criteria evaluation method

Two multi-criteria evaluation methods, namely the FAHP method and the TOPSIS method, are used in this study to evaluate the criteria in order to determine their importance in the design.

- FAHP method

The Fuzzy Analytic Hierarchy Process (FAHP) is a multi-criteria decision-making technique that allows a set of criteria to be evaluated simultaneously. It was developed to overcome the hierarchical problems of the Analytic hierarchy process (AHP), such as the fact that the decision-maker's personal judgement is not taken into account in the hierarchical process. In this study, FAHP is used to prioritize design criteria. The FAHP method is based on the use of triangular fuzzy numbers for the pairwise comparison scale (Table 1) and on range analysis for the synthetic values.

Table 1 : Fuzzy Saaty scale for pairwise comparison [19]

AHP scale	Number Blurred	Inverse of number blur	Definition
1	(1, 1 , 1)	(1, 1, 1)	Equal importance
2	(1, 2, 3)	(1/3, 1/2, 1)	Scale between the same slightly larger
3	(2, 3, 4)	(1/4, 1/3, 1/2)	low dominance
4	(3, 4, 5)	(1/5, 1/4, 1/3)	Scale between low and high dominance
5	(4, 5, 6)	(1/6, 1/5, 1/4)	Strong dominance
6	(5, 6, 7)	(1/7, 1/6, 1/5)	Scale between high and very high dominance
7	(6, 7, 8)	(1/8, 1/7, 1/6)	Very high dominance
8	(7, 8, 9)	(1/9, 1/8, 1/7)	Scale between very high dominance and absolute dominance
9	(8, 9, 9)	(1/9, 1/9, 1/8)	Absolute domination

This analysis is based on four steps [20]:

Step 1: Calculation of the fuzzy synthetic range given by equation 1.

It is obtained from equation 1.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \qquad (1)$$

With

$\sum_{j=1}^{m} M_{gi}^{j}$ $(j = 1, 2, 3, \ldots, m)$ the fuzzy addition operation given by the following equation :

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (2)$$

And

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \qquad (3)$$

Consequently, the inverse of $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}$ is given by equation 4

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \qquad (4)$$

Step 2 : Calculation of the degrees of possibility of a fuzzy number M_2 being greater than a fuzzy number M_1.

This step considers two numbers of fuzzy $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ and defines the degrees of possibility $V(M_2 \geq M_1)$ such that :

$$V(M_2 \geq M_1) = \sup\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right] \qquad (5)$$

The degrees of possibility $V(M_2 \geq M_1)$ can also be expressed as follows.

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \qquad (6)$$

$$= \left\{\begin{matrix} 1 & si M_2 \geq M_1 \\ 0 & si l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(M_2 - u_2) - (m_1 - l_1)} & \end{matrix}\right\} \qquad (7)$$

Step 3: Calculation of the possibility for a convex fuzzy number to be greater than K convex fuzzy numbers M_i.

The possibility of a convex fuzzy number being greater than K convex fuzzy numbers M_i is calculated according to equation 8:

$$V(M, M_1, \ldots, M_k) = V[(M \geq M_1) et (M \geq M_2), et \ldots et (M \geq M_k)] \qquad (8)$$

$$= min\, V(M \geq M_i), \quad i = 1, 2, 3, \ldots, k \qquad (9)$$

Step 4: Calculation of normalised weight vectors

This step assumes that $d(A_i) = v(S_i \geq S_K)$for k = 1, 2, 3, ..., k

The weight vector is calculated by equation 10.

$$W = [d'(A_1), d'(A_2), \dots, d'(A_n)]^T \qquad (10)$$

Where are $A_i (i = 1,\ 2, \dots ,\ n)$n elements.

The normalised weight vector is calculated by equation 11.

$$W = [d(A_1), d(A_2), \dots, d(A_n)]^T \qquad (11)$$

Where W is the non-fuzzy number.

- TOPSIS method

The Technique of Preference Ordering by Similarity to the Ideal Solution (TOPSIS) is a pragmatic method for dealing with multi-criteria decision-making problems. It was developed by Hwang and Yoon in 1981 with the aim of helping decision-makers compare and rank a set of criteria [21]. TOPSIS is based on the principle that the chosen alternative must have the shortest geometric distance from the positive ideal solution and the farthest geometric distance from the negative ideal solution. The positive ideal solution is defined as the sum of all the best values that can be obtained for each attribute, while the negative ideal solution comprises all the worst values obtained for each attribute. The TOPSIS process consists of seven steps [22]:

Step 1: Determining the decision matrix (A) and calculating the weights W_j.

This step consists of creating a decision matrix and determining the weights of the criteria. In this step, relative weights must be assigned to each criterion according to their importance.

The decision matrix and the calculation of the weights are given by equations (12) and (13).

$$A = (a_{ij})_{m \times n} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} \end{bmatrix} \qquad (12)$$

$$W_j = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \qquad (13)$$

Step 2: Calculation of the normalised decision matrix P_{ij}

This step consists of normalising each attribute value. The normalised value P_{ij} is calculated using equation (14).

$$P_{ij} = \frac{A_{ij}}{\sqrt{\sum_{i=1}^{m} A_{ij}^2}}, i = 1, 2, \dots, m et j = 1, 2, \dots., n \qquad (14)$$

Step 3: Calculation of the weighted normalised decision matrix V_{ij}

In this step, the weighted normalised value V_{ij} is calculated by multiplying the normalised decision matrix by the normalised criteria weights. The weighted normalised value is given by equation (15).

$$V_{ij} = P_{ij} \times W_j, \qquad i = 1, 2, \ldots, m et j = 1, 2, \ldots., n \qquad (15)$$

Step 4: Determination of the positive ideal solutions A^+ and the negative ideal solutions A^-

In this step, the positive ideal solutions are determined by minimising the non-beneficial criteria and maximising the beneficial criteria. On the other hand, negative or worse ideal solutions are obtained by maximising the non-beneficial criteria and minimising the beneficial criteria. The ideal and worst-case solutions are calculated from equations (16) and (17).

$$A^+ = \{(MaxV_{ij} / \ j \in C_b), (MinV_{ij} / \ j \in C_c)\} = V_j^+ \ / \ j = 1, 2, . m \qquad (16)$$

$$A^- = \{(MinV_{ij} / \ j \in C_b), (MaxV_{ij} / \ j \in C_c)\} = V_{\mathrm{j}}^- \ / \ j = 1, 2, . m \qquad (17)$$

Step 5 : Calculation of separation measures

This step consists of finding the separation measures of each alternative with respect to the positive ideal solution and the negative ideal solution. The separation measures are calculated from equations (18) and (19).

$$S^+ = \sqrt{\sum_{j=1}^{m} (V_{ij} - V^+)^2} \ , j = 1, 2, \ldots., m \qquad (18)$$

$$S^- = \sqrt{\sum_{j=1}^{m} (V_{ij} - V^-)^2} \ , j = 1, 2, \ldots., m \qquad (19)$$

Step 6: Calculating the relative proximity of the ideal solution RC^+

The relative proximity of the alternative A_i to A^+ is calculated by equation (20)

$$RC^+ = \frac{S_i^-}{S_i^+ + S_i^-} \ , i = 1, 2, \ldots, m \qquad (20)$$

Step 7 : Classification of preference order or ranking of alternatives according to relative proximity.

Figure 1 shows a summary diagram of the methodology.

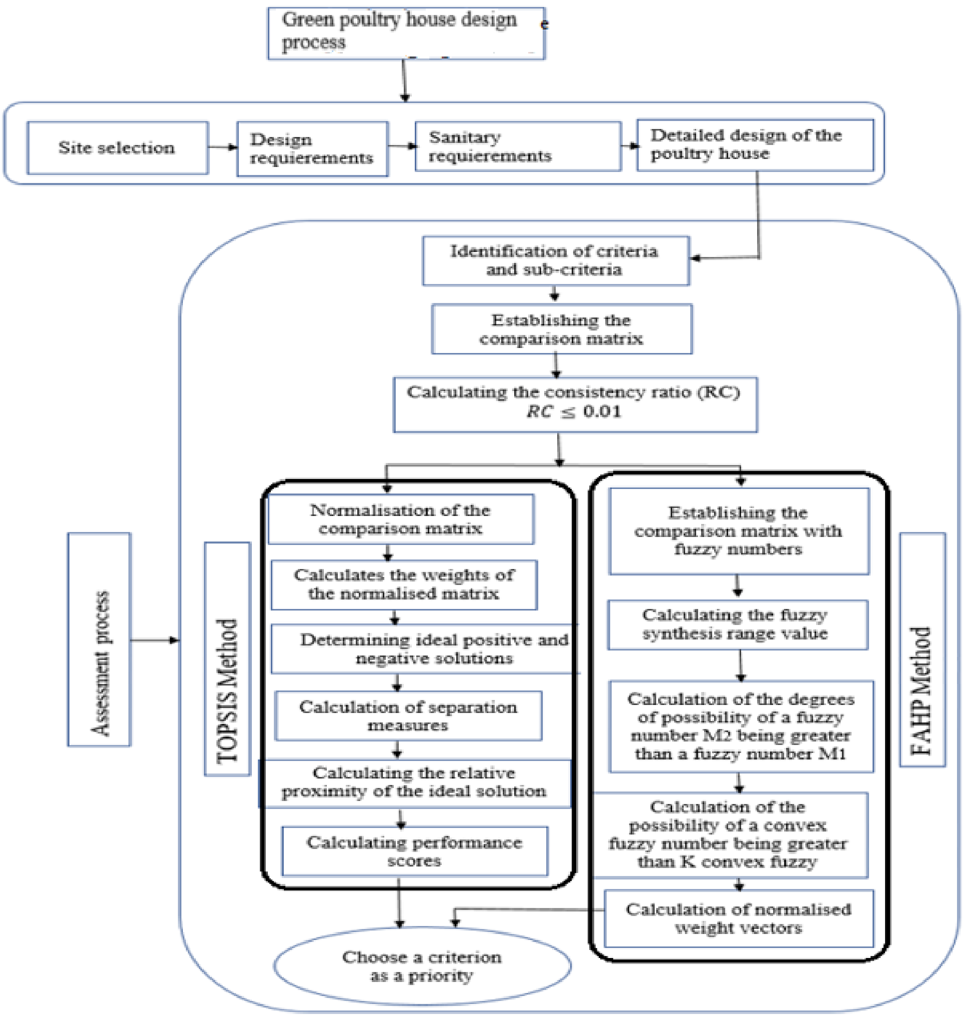

Figure 1:Summary diagram of the green poultry house design methodology

B. CASE STUDY

The building studied is a cross-ventilated poultry house containing 3,000 chickens. The poultry house has 43 m long, 10 m wide and 4.5 m high from the ground to the roof. The double-sloped roof is pitched at 45° and has a 0.6 m overhang on the north façade. The south facade is protected by an elongated roof overhang. The main façades run north-south and have openings covering 70% of the surface area of the façade. The main façades have low walls 0.5 m high. The openings in the facades have an adjustable curtain to control the air speed in the poultry house. The roof has openings to facilitate heat removal by thermal draught. Figure 2 shows the model of the poultry house studied.

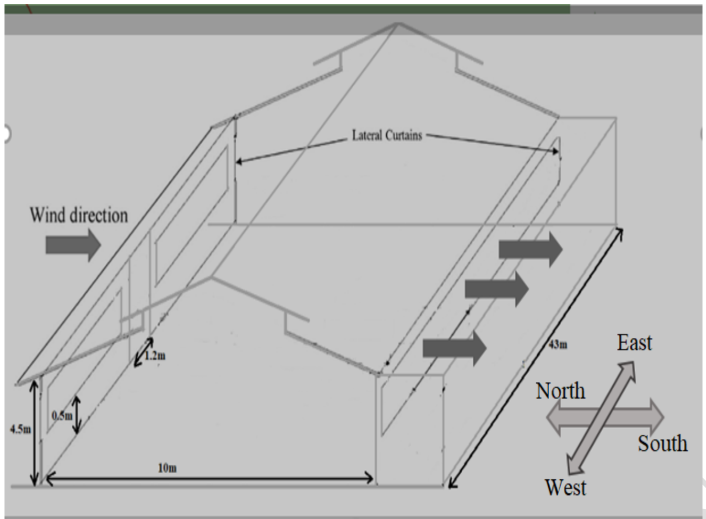

Figure 2 : Poultry house studied

C. DESIGN ASSESSMENT CRITERIA

The various criteria were obtained through a survey of a technical team made up of four poultry technicians, two civil engineers and two farmers. The team was selected on the basis of their knowledge of ecological design and chicken farming. The criteria used to evaluate ecological barn design are site selection (SS), technical factors (FT), health and indoor environmental quality (SE) and economic factors and costs (FC). Each of these criteria is subdivided into sub-criteria, which are listed in full in Table 2. The criteria and sub-criteria are compared in pairs, one by one, to form the comparison matrix. For each matrix, the consistency ratio (CR) is calculated. Matrices with CR values less than or equal to 0.1 were retained, as recommended by SAATY. After checking the consistency, the weights and performance scores for each criterion and sub-criterion were calculated separately in order to prioritize them.

Table 2 : Criteria and sub-criteria assessed

Criteria	Sub-criteria
Site selection (SS)	A_1 : Climatic conditions in the area (sunshine, outside temperature,humidity and wind) A_2 : Nature of the terrain (flat, hilly, high or low-lying) A_3 : Distance from infrastructure (roads, railways, etc.) A_4 : Availability of space (for construction) A_5 : Vegetation (trees, grass, etc.) A_5: Availability of water
Technical factors (FT),	B_1 : Building orientation B_2 : Shape and dimensions B_3 : Building materials (low thermal conductivity)

	B_4 : Maintenance B_5 : Heating and air-conditioning system
Health/indoor Environment quality (SE)	C_1 : Health and safety C_2 : Recyclable materials C_3 : CO_2, CO and NH_3 emissions C_4 : Quantity of disinfectants used C_5 : Waste management
Economic/cost factors (CF)	E_1 : Initial investment costs E_2 : Maintenance costs E_3 : Heating, air conditioning and ventilation costs E_4 : Energy consumption costs E_5 : Water costs

D. RESULTATS AND DISCUTIONS

1) Avaluation of main criteria

Figure 3 shows the results of the evaluation of the main criteria. It can be seen that the criterion "health and quality of the indoor environment" with a weight of 0.54 and a performance score of 0.65 is ranked first, then "economic factors and costs" with a weight of 0.29 and a performance score of 0.45 are ranked second, then "technical factors" with a weight of 0.11 and a performance score of 0.43 are ranked third and "site selection" with a weight of 0.06 and a performance score of 0.42 is ranked last. Consequently, the "health/quality of the indoor environment" criterion is considered to be the most important criterion to be taken into account in the design of ecological poultry houses based on the FAHP method. On the other hand, site selection was not considered a vital design issue. These results were confirmed by the TOPSIS method, which indicates a performance score of 0.65 for the "Health and Indoor Environmental Quality" criterion and 0.42 for the "Site Selection" criterion. These results can be explained by the fact that the health of the chickens and the indoor environment have a major impact on productivity. Initial investment and operating costs are one of the main concerns of farmers in Senegal, as building materials and chick feed are expensive. Technical factors are of lesser importance than health and economic factors, as the operating equipment consists mainly of reusable feeders and drinkers. Site selection is not considered to be an important criterion, as the poultry houses are located in the same geographical area.

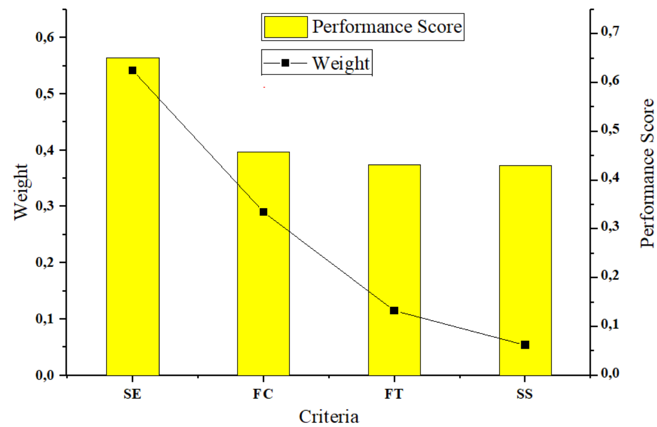

Figure 3: Weights and performance scores for the various criteria

2) Evaluation of sub-criteria

The evaluation of the main criteria alone does not provide a complete assessment of the eco-friendly hen house design. In order to better assess the design of the eco-friendly poultry house, the sub-criteria of each criterion were evaluated to define their order of priority. Considering the main criterion "Health/quality of the indoor environment", five sub-criteria were defined: "Safety and health (C_1)", "Recyclable materials (C_2)", "Emission of CO_2, CO and NH_3 (C_3)" "Quantity of disinfectants used (C4)" and "Waste management (C_5)". The weights and performance scores are shown in Figure 4. The results show that according to the prioritization of the FAHP method, the first three sub-criteria are respectively C_1 with a weight of 0.49, C_3 with a weight of 0.30 and C_4 with a weight of 0.11 and the last two sub-criteria are respectively C_5 and C_2. Similarly, the TOPSIS method evaluated sub-criterion C_1 with a score of 0.73 as first rank, C_3 with a score of 0.59 as second rank, C4 with a score of 0.43 as third rank, C_5 with a score of 0.41 as fourth rank and C_2 with a score of 0.40 as last rank. Safety and health is therefore considered to be the most important factor in the analysis of the "health and environment" criterion. Chicken diseases are greatly feared by producers as they cause considerable economic losses.

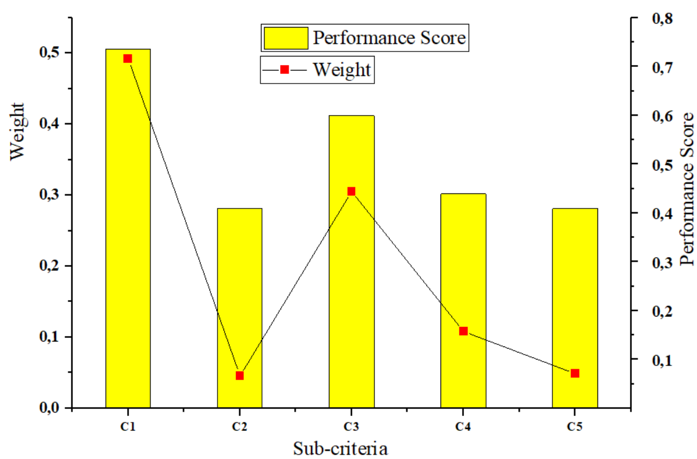

Figure 4: Weights and scores of the sub-criteria for assessing the "health and environment" criteria.

The Technical factors are very important in the design of an ecological poultry house. To assess them, five sub-criteria such as "Building orientation (B_1)", "Shape and dimensions (B_2)", "Construction materials (B3)", "Maintenance (B4)" and "Heating and air-conditioning system (B_5)" were identified. According to the FAHP method, the ranking in order of priority of the sub-criteria for evaluating the "technical factors" are B_1 with a weighting of 0.45, B_2 with a weighting of 0.31, B_3 with a weighting of 0.13, B4 with a weighting of 0.08 and B_5 with a weighting of 0.04 (fig. 5). This ranking was confirmed by TOPSIS with scores of 0.85, 0.46, 0.22, 0.21 and 0.20 respectively for B_1, B_2, B_3, B_4 and B_5. Consequently, the "building orientation" sub-criterion is considered to be the most important parameter for assessing the "technical factors" in the design. Senegal has a lot of sunshine and heat gain is a result of sunshine. On the other hand, the sub-criteria "Maintenance (B_4)" and "Heating and air-conditioning system (B_5)" are not given much consideration because of their extremely low relative weight. Air-conditioning systems are rarely used in poultry houses. The heating systems used are radiant lamps which do not require maintenance.

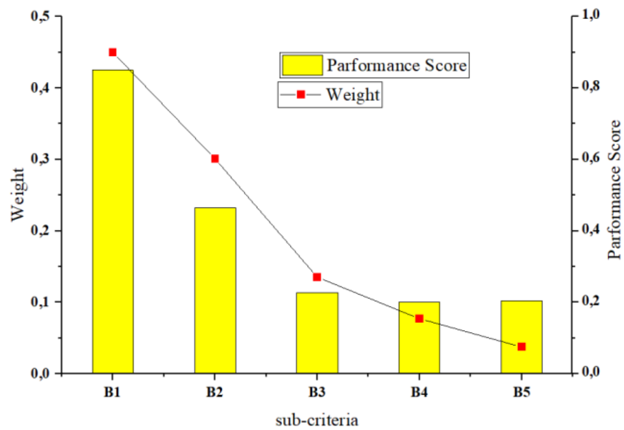

Figure 5 : Weights and scores of the sub-criteria for the evaluation of the "technical factors" criterion

. With regard to the evaluation of the main criterion "site selection", six sub-criteria such as "Climatic conditions of the area (A_1)", "Nature of the terrain (A_2)", "Distance to infrastructure (A_3)", "Availability of space (A_4)", "Vegetation (A_5)" and "Availability of water (A_6)" were evaluated. According to the FAHP method, climatic conditions, availability of space and availability of water are of equal importance, with a weight of 0.29. For the last three criteria, FAHP considered "vegetation" as a priority with a weight of 0.07, then "distance from infrastructure" and "nature of terrain" ranked last (fig. 6). The TOPSIS method, on the other hand, ranked "climatic conditions" first with a score of 0.524, "availability of space" second with a score of 0.522, "availability of water" third with a score of 0.521, "vegetation" fourth with a score of 0.429, "distance from infrastructure" fifth with a score of 0.429, and "nature of terrain" last with a score of 0.058. The TOPSIS method, on the other hand, ranked "climatic conditions" first with a score of 0.524, "availability of space" second with a score of 0.522, "availability of water" third with a score of 0.521, "vegetation" fourth with a score of 0.429, "distance from infrastructure" fifth with a score of 0.429, and "nature of terrain" last with a score of 0.058. As a result, 'climatic conditions' are considered to be the most important parameter for site selection. Climate-related heat waves are a threat to chickens. On the other hand, the "nature of the terrain" was not considered an important parameter for analysing a site because of its extremely low score (0.058). Senegal is a flat country. The FAHP method was unable to classify the sub-criteria climatic conditions, availability of space and availability of water. The TOPSIS method, on the other hand, ranked the sub-criteria in order of priority on the basis of their performance scores.

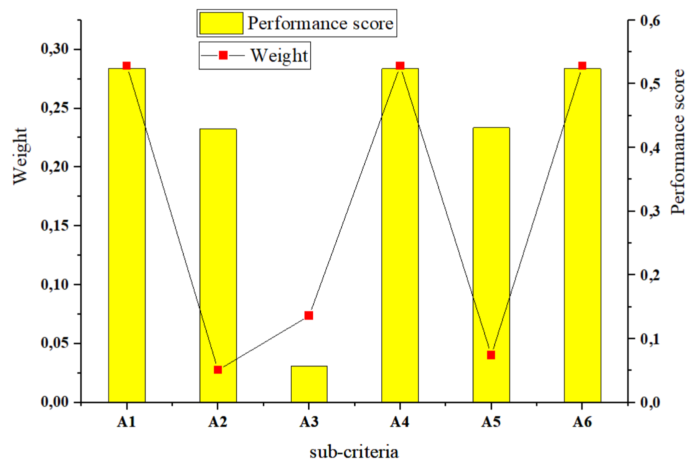

Figure 6 : Weights and scores of the sub-criteria for the evaluation of the "site selection" criterion

In addition to the evaluation criteria, "economic factors and costs" are very important design criteria. To assess these, five sub-criteria are considered: "Initial investment costs (E_1)", "Maintenance costs (E_2)", "Heating, air conditioning and ventilation system costs (E_3)", "Energy consumption costs (E_4)" and "Water costs (E_5)". The FAHP method has prioritized the sub-criteria as follows: "Initial investment costs", "Maintenance costs", "Energy consumption costs", "Heating, cooling and ventilation system costs", and "Water costs". This ranking is based on the representation of weights (Figure 7). Similarly, the TOPSIS method ranked "Initial investment costs" first with a score of 0.748, "Maintenance costs" second with a score of 0.501, "Energy consumption costs" third with a score of 0.431, "Heating, air conditioning and ventilation system costs" with a score of 0.429, and "Water costs" last with a score of 0.412. Consequently, the sub-criterion "Initial investment costs" is considered to be the most important factor in assessing the economic factors. The mobilization of financial resources for investments remains the main concern of producers in Senegal.

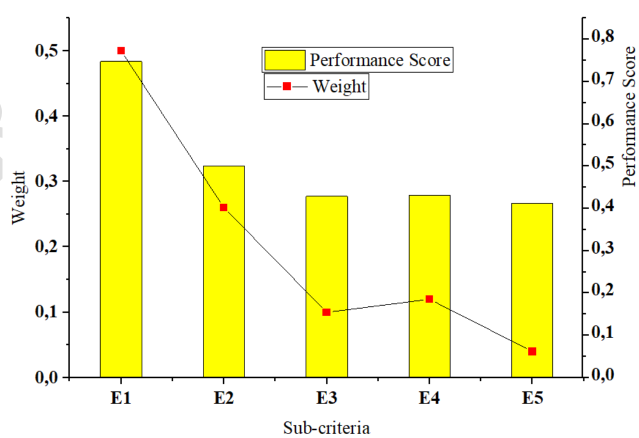

Figure 7: Weights and scores of the sub-criteria for the evaluation of the "economic factors and costs" criterion

E. CONCLUSION

Green poultry houses offer a sustainable solution to the heat stress affecting poultry in the Sahel region. In this study, an ecological poultry house design methodology is developed to assist poultry house designers. The methodology is based on the description of an ecological design process and a multi-criteria evaluation approach. The multi-criteria approach uses two techniques such as FAHP and TOPSIS to determine the weights and performance scores of the criteria and sub-criteria in order to prioritize them in the design. The data used is obtained from a survey of a team specializing in the field. Site selection (SS), technical factors (FT), health and indoor environmental quality (SE) and economic factors (FC) were identified as the main criteria for the design of ecological poultry houses. The FAHP and TOPSIS methods showed that the "health and indoor environment of the poultry house" criterion is the most important factor with a weight of 0.54 and a performance score of 0.651, followed by the "economic factors" criterion with a weight of 0.29. To assess health and the environment, the "health and safety" sub-criterion with a weight of 0.49 and a score of 0.736 is the most important, followed by the "CO2, CO and NH_3 emissions" sub-criterion with a weight of 0.3. To assess the economic factors, "initial cost" is the most important sub-criterion, with a weight of 0.5 and a score of 0.748. Climate is the most important factor in site selection. The FAHP method is very limited for selecting criteria when the weights are equal. The combination of the FAHP and TOPSIS methods makes it possible to objectively select criteria according to their importance. Knowledge of the weights and performance scores of the criteria can help designers in the design process.

Furthermore, future research could improve these results by integrating a optimization technique to determine the cost optimal green poultry house.

F. DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

G. NOMENCLATURE

Symbols

W Weight

S Performance score

1) Abbreviations

FAHP	Fuzzy Analytic Hierarchy Process
TOPSIS	Technique of Preference Ordering by Similarity to the Ideal Solution
SS	Site selection
FT	technical factors
SE	Health/indoor Environment quality
CF	Economic/cost factors

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