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Design and Construction of an Electric and Automatic Incubator for the Incubation of Chicken Eggs at the Higher Institute of Technology of Mamou, Guinea

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Abstract
The objective of this study is to design and build an electric and automatic incubator for the incubation of chicken eggs. The methodology consists of: determining the geometric parameters of the incubator; choose the various electronic and electrical components; build the incubator; program the various commands, make the heat balance; draw the diagram of the whole system and experiment with the incubator. The incubator produced is characterized by the dimensions (80×66×32.5), with three (3) racks with an area of 3600 cm^2 each and the number of cells per rack is six. The total daily thermal balance relating to the device is 2551.744 kJ. The average daily vacuum test temperature and humidity indoors and in the ambient are 37.24°C and 57.68% respectively. During the 21 days of incubation, the average internal temperature varied from 36.10°C (21st day) to 37.65°C (3rd day), with an average of 37.20°C. The relative humidity varied from 53% (7th day) to 74% (20th day), with an average of 59.61%. The device produced made it possible to hatch 470 eggs out of 540 in the incubator, i.e. a hatching rate of 87%.
Keywords: Incubator, Chicken eggs, Design, Electric, Automatic.

1. Introduction
For the needs of survival, human beings are called upon to feed themselves. This diet must be complete to ensure the growth and shape of men. Among the many foods contributing to this balance are proteins. One of the sources of these proteins and not the least is chicken (ANDRIANOELINA Tahina Feno Sitraka, 2010).

Currently in West Africa, the development of the poultry sector such as the production of broiler chickens and laying hens, makes a great contribution to the fight against poverty. This is why the modernization of the design of incubators is the subject of research (Abdou and al., 2021).

The Republic of Guinea is a country with a strong pastoral tradition, with immense natural potential thanks to the diversity of its agro-ecological conditions. Livestock breeding remains the second activity of the rural sector after agriculture. It concerns 283,000 breeders identified in 2000 and their families, whose numbers owned in 2016 are estimated at 6759000 cattle, 2.38 million sheep, 2.85 million goats, 130000 pigs and 30 million poultry. It provides income for 30% of the rural population (Ansoumane S. and al., 2018).

Traditional or modern Guinean poultry farming remains an economic activity widely practiced by the population. It is essentially based on the breeding of laying hens. The chicks are either imported or from local hatcheries. Despite the efforts of local producers, Guinean poultry farmers face enormous constraints related in particular to the lack of funding, the supply of poultry feed and especially competition from chicken meat imports (Rapport Annuaire des Statistiques de l'Elevage 2015-2019, 2020).

Incubation is a phase of multiplication of micro-organisms such as viruses, bacteria, eggs. Egg incubation can be done naturally or artificially. Artificial incubators were invented to complete the development of embryos without the help of their parents (Kasiho Mushagalusa Emmanuel, 2021 and Ramzi B., 2007).

Artificial incubation is the set of operations which, from a quantity of eggs laid, produces the maximum number of viable chicks at the lowest possible cost. This technique uses incubators.

An incubator is a device basically consisting of a closed enclosure, which can be maintained at a constant temperature and humidity through a control system, and eggs are placed in it during incubation. The materials used for the enclosure should be non-porous and easy to maintain for cleaning, PVC, aluminum are ideal for this purpose. They must also be good thermal insulators (RANDRIANAIVO Andriamparany Herizo, 2015).

The natural phenomenon of chick production consists of incubating a hen for a period of 21 days. This artisanal process cannot meet the needs of the population; there then arises a problem of producing a large number of chicks that will be supplied to producers for their activities (King'ori A. M, 2011 and Umar A. B. et al., 2016).

The incubation period varies according to the species, the strain, the physicochemical conditions, the shelf life of the eggs, the age of the breeders and the physical conditions in the incubator. Important parameters affecting incubation are: temperature, humidity, aeration, ventilation, turning and hatching (Una Drakulić and Edin Mujčić, 2021 ; Niranjan L. and al., 2021 ; Kerim Kür ̦sat Çevik and al., 2022).

The need for artificial methods is essential and is based on the artisanal method. The poultry farmer will opt for a massive and usual production. The hens being unable to ensure the ambitions of the latter, he will look into artificial incubators, after making a decision, the poultry farmer will have to choose among the already existing models those adapted to his environment for better performance. We realize that imported incubators cause problems in our industries due to climatic variations. It is in this order of idea that we proposed this research on the design and realization of an electric and automatic incubator for the incubation of chicken eggs.

The overall objective of this work is to design an artificial incubator capable of recreating the ideal conditions for incubating chicken eggs. This includes temperature control, humidity control, some ventilation, but also the inclusion of an egg turning mechanism.

This work aims to answer the following questions:

- What are the parameters to take into account and how to control them?
- How to evaluate the energy needs and the materials necessary to achieve the objectives?
- What are the stages in the design and construction of the incubator?
- How can this research work be continued, improved and adapted to other situations?

2. Materials and Methods

2.1 Materials

2.1.1 Presentation of the study area

This work was carried out in the Electronics Laboratory of the Instrumentation and Physical Measurements Department of the Mamou Higher Institute of Technology. This department is one of the six departments of the said Institute which was created by Ministerial Order No: 2004/9245/MESRS/CAB of August 25, 2004. It is a public institution of a professional, scientific, technical and technological nature, under the Ministry of Higher Education, Scientific Research and Innovation is located in the Télico district, 4 km from downtown Mamou and 270 km from Conakry (Ministère de l'Education Nationale et de la Recherche Scientifique, 2018).

2.1.2 Work equipment

As part of this work, the equipment consists of: work tools, components of the mechanical, electrical and electronic part.

a) Work tools

The work tools are: Phillips screwdriver, drill, test plate, pliers, tin, pair of scissors, adhesive tape, pair of gloves, sandpaper, centimeter, multimeter, glue, saw blade, screwdriver kit, cutter, etc.

b) Components of the mechanical part

The components of the mechanical part are: flat iron with a diameter of 20 mm, angle iron with a diameter of 20 mm, screw-nuts, mesh, frame which frames the turning system, cells, hardboard support with a diameter of 15 mm, plexiglass glass, plywood, formica, etc.

c) Components of the electronic and electrical part

The components of the electronic and electrical part are: Arduino uno board, LCD display, transistors (C1815), temperature and humidity sensor (DHT11), 12v DC relay module, 60 W bulbs, resistors of different values, chemical and dry capacitors, 7812 and 7809 regulators, 1N4007 diodes, electric motor (electric window regulator), light-emitting diodes (LED), 12V DC battery and 220V AC electric fans (Ibrahima TOURE, and al., 2022; Pierre Louis Morpoo Rebeca and al., 2021; Shaymaa A. Hassan; and al., 2022).

2.2 Method

The methodology adopted in this work consists of: programming the controls, choosing the various electronic and electrical components, carrying out the heat balance, developing the flowchart of the program, designing and producing the device, drawing the diagram of the entire system and experiment with the device.

II.2.1 Command programs

The programs and the various codes in the Arduino software that allow the system to work relate to the programming of the commands of the DHT11; digital display via an LCD screen; heat sources and engine.

II.2.2 Heat balance

The thermal balance is made up of external thermal losses, external and internal thermal loads related to the device.

a) External heat losses

The thermal losses (Q_i) due to different walls of the incubator are determined by formula 1 (Andoh P. Y. and al., 2022).

$$Q_i = K_i \times S_i \times \Delta T \qquad (1)$$

Or : Q - heat losses in (W); S - surface of the wall considered in (m²); ΔT - Temperature difference between the two sides of the wall in (°C); K - overall coefficient of thermal transmission of the walls considered expressed in (W/m2°C); i - corresponds to the numbers of the different sides of the incubator, ranging from 1 to 6.

With :

$$K_i = \frac{1}{\frac{1}{h_{ex_i}} + \sum_i^n \frac{e_i}{\lambda_i} + \frac{1}{h_{in_i}}} \qquad (2)$$

Or :

h_{ex}: external convection coefficient in (W/m^2°C); h_{in}: interior convection coefficient in (W/m^2°C); e_i: thickness of the wall considered in (m) of the different materials used which are: plywood and plexiglass; λ_i: coefficient of thermal conductivity of the considered wall in (W/m°C).

Thus, the various external heat losses are calculated as follows:

For side 1 made of Plexiglas (through which we look at the inside of the incubator) and the wooden plywood we have (3):

$$Q_{F1} = Q_{F1CP} + Q_{F1PG} = (K_{1CP} \times S_{1CP} \times \Delta T) + (K_{1PG} \times S_{1PG} \times \Delta T) \qquad (3)$$

$$Q_{F1} = Q_{F1CP} + Q_{F1PG} = -\ 537{,}73 \text{ kJ/jour}$$

For face 2 made of wooden plywood we have (4):

$$Q_{F2} = K_{2CP} \times S_{2CP} \times \Delta T = -\ 906{,}336 \text{ kJ/jour} \qquad (4)$$

For side 3 made of wooden plywood we have (5):

$$Q_{F3} = K_{3CP} \times S_{3CP} \times \Delta T = -\ 1054{,}402 \text{ kJ/jour} \qquad (5)$$

For side 4 made of wooden plywood we have:

$$Q_{F4} = Q_{F3} = 1054{,}402 \text{ kJ/jour}$$

For face 5 made of wooden plywood we have (6):

$$Q_{F5} = K_{5CP} \times S_{5CP} \times \Delta T = -\ 652{,}725 \text{ kJ/jour} \qquad (6)$$

For face 6 made of wood plywood we have (7):

$$Q_{F6} = K_{6CP} \times S_{6CP} \times \Delta T = -\ 569{,}3276 \text{ kJ/jour} \qquad (8)$$

The heat losses through the different walls of the incubator are therefore (9):

$$Q_1 = Q_{F1} + Q_{F2} + Q_{F3} + Q_{F4} + Q_{F5} + Q_{F6} = -\ 4774{,}92 \text{ kJ/jour} \qquad (9)$$

The thermal losses due to the opening of the door (Q2) are calculated as follows (10):

$$Q_2 = n \times \frac{V_u}{V_{S_i}} \times \Delta H \qquad (10)$$

With :

n = $\frac{65}{\sqrt{V_u}}$ = 96,89 : outside air renewal rate ; V_u = L×l×h = 0.450m^3: usable interior volume of the incubator; V_{Si} = V_u/m = 0,163 m^3/kg : interior specific volume and m = 2.755 kg: mass of the incubator; $\Delta H = H_{ex} - H_{in}$ = -

10 kJ/kg: enthalpy difference; H_{ex} = 88 kJ/kg: external enthalpy; H_{in} = 98 kJ/kg: internal enthalpy. Thus we have: Q_2 = - 2674.877 kJ

Egg losses (Q_3) are calculated as follows (11):

$$Q_3 = m \times c \times (T_1 - T_2) = -0{,}795 \text{ kJ/jour} \quad (11)$$

With : m = 50 g: Mass of an egg; c = 3.18 kJ/kg°C: Specific heat; T1 = 32°C and (T2= 37°C) are respectively the temperatures of the ambient medium and those of the surface of the eggs.

b) Internal thermal loads

The various internal thermal loads of the incubator are: the contributions due to the respiration of the eggs and to the fans.

The thermal load losses due to egg respiration (Q_4) are calculated as follows (12):

$$Q_4 = m \times q_{res} = 6102 \text{ kJ} \quad (12)$$

Or : m = 27 kg: total egg mass; qres = 226 kJ/kg: heat of respiration of eggs. Contributions due to fans (13).

$$Q_5 = n \times P \times t = 3801{,}6 \text{ kJ} \quad (13)$$

With : n = 2: number of fans; P = 22 W: power of a fan; t = 24 h: the operating time of the fans.

c) Provisional heat balance

The provisional thermal balance (Q_p) is the sum of various calculated thermal pressure drops (14) (B.Sc Jorge Retamozo and Freddy J. Rojas 2022).

$$Q_p = \sum_1^5 Q_i = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 = 2453{,}01 \text{ kJ} \quad (14)$$

d) Unquantified heat losses

The unquantified heat losses represent 4% of the provisional balance sheet, i.e. (15):

$$Q_6 = 4\% \times Q_P = 98{,}144 \text{ kJ} \quad (15)$$

e) Total heat balance

The total heat balance (Q_t) occurring in the system is obtained as follows (16):

$$Q_t = Q_P + Q_6 = 2551{,}744 \text{ kJ} \quad (16)$$

f) Thermal power of lamps

The thermal power of the lamps is determined by the relation (17):

$$P = \frac{Q_t}{t} = 29{,}53 \text{ W} \quad (17)$$

With : Q_t - total balance in (kJ); t = 86400 s - incubator operating time in seconds. So we can use 30W or 60W lamps.

II.2.4 Choice of components

The different components for the production of the feed are:

a) Choice of regulators

For the correct operation of the device we will need the regulators: 7805 which deliver a continuous voltage of 5V when it receives a voltage higher than the voltage of at least 3V which is the voltage drop across the terminals of the integrated regulator, the 7812 which will deliver a continuous voltage of 12V and a current of 1.5A when the applied voltage is at least greater than the output voltage of 3V for the supply of the relay module, the 78T12 which is a voltage regulator capable to provide a continuous voltage of 12V and a current of 3A when it receives at the input a voltage higher than the voltage of 3V.

b) Choice of filter capacitor

A capacitor charges and discharges at constant current to maintain a constant voltage across its terminals by eliminating noise around a DC voltage. The minimum voltage at the input of the 7812 regulator is (18):

$$U_{cmin} = U_{sortie.rég.} + U_{dif.rég.} = 12V + 3V = 15V \quad (18)$$

The maximum voltage across the capacitor is (2.19):

$$U_{Cmax} = \sqrt{2}U_{2eff} - 2U_{Diodes} = \sqrt{2} \times 15V - 2 \times 0{,}7V = 19, \quad (19)$$

The residual ripple across the capacitor is (2.20):

$$\Delta U = U_{Cmax} - U_{Cmin} = 19.8V - 15V = 4,8V \quad (20)$$

The capacitance of the filter capacitor is determined by the relationship (2.21):

$$C = \frac{I_S}{\Delta U \times F} = 6250\ \mu F \quad (21)$$

Or : IS = 3A - Regulator output current; F = 100Hz -Frequency;

c) Choice of transformer

The price of a power supply depends on the filter capacitor and the transformer, so a compromise will have to be found between the filter capacitor and the transformer. This choice depends on the elements:

- Effective voltage at the primary of the transformer V1;
- Effective secondary voltage V2;
- Apparent power: P = V2× I2, with V2 = 1.2×VS
- Thus: P = 1.2×12V = 14.4V

We will take a secondary rms voltage transformer equal to 15V.

II.2.10 Experimenting with the incubator

a) Incubator empty test

After the incubator was built, we carried out an empty test on May 2, 2022, for twelve (12) hours from 6:00 a.m. to 6:00 p.m., so that the temperature is evenly distributed inside the incubator.

b) Monitoring of the operation of the incubator

The eggs were introduced into the incubator on 05/03/2022 at 6:00 a.m. The evolution of temperature, humidity inside the incubator and in the surrounding environment were monitored and recorded every one hour on the first day, the 10th day, the 17th day and the 20th day. From the 18th day (beginning of hatching) the eggs were placed in the hatcher. During the 21 days of the process (03 to 05/24/2022) the average daily temperatures were recorded.

c) Incubator performance test

The performance test of the incubator is based on the hatching rate of the eggs. This rate is the ratio between the number of hatched eggs (Nécl) over the total number of eggs (NTegg) in the incubator. It is determined by formula 22 (Forson Peprah, and al., 2022; Kifilideen L. Osanyinpeju and al., 2018).

$$T_{Eclo} = \frac{N_{écl}}{N_{Toeuf}} \times 100\% \quad (22).$$

III. Results and Discussion

The results obtained during this work are recorded in the tables and represented by the curves in the figures below.

III.1 Geometric characteristics of the incubator

The geometric characteristics of the incubator, the number of trays, egg cells and the hatching rate are given in Table 1.

Table 1: Geometric characteristics of the incubator

Caractéristiques	**Symbole**	**Valeur**	**Unité**
Height	H	80	cm
Length	L	66	cm
Width	L	32,5	cm
Volume	V	171600	cm^3
Surface of the racks	S_{rac}	3600	cm^2
Number of racks	N_{rac}	3	-
Number of cells per rack	$N_{cells/rac}$	6	-
Number of eggs per cell	$N_{eggs/cell}$	30	-
Total number of eggs	N_{eggs}	540	-
Number of eggs hatched	$N_{eggs\_hatched}$	470	-
Hatching rate	T_{rate}	87	%

The total daily thermal balance relating to the device is 2551.744 kJ. This assessment enabled us to determine the necessary power of the lamps to be installed in the incubator for heating the eggs. Thus, lamps from 30 to 60 W can be used, in this work we used 30W lamps.

III.6 General diagram of the realization circuit

The general circuit diagram of the incubator is given in figure 2.

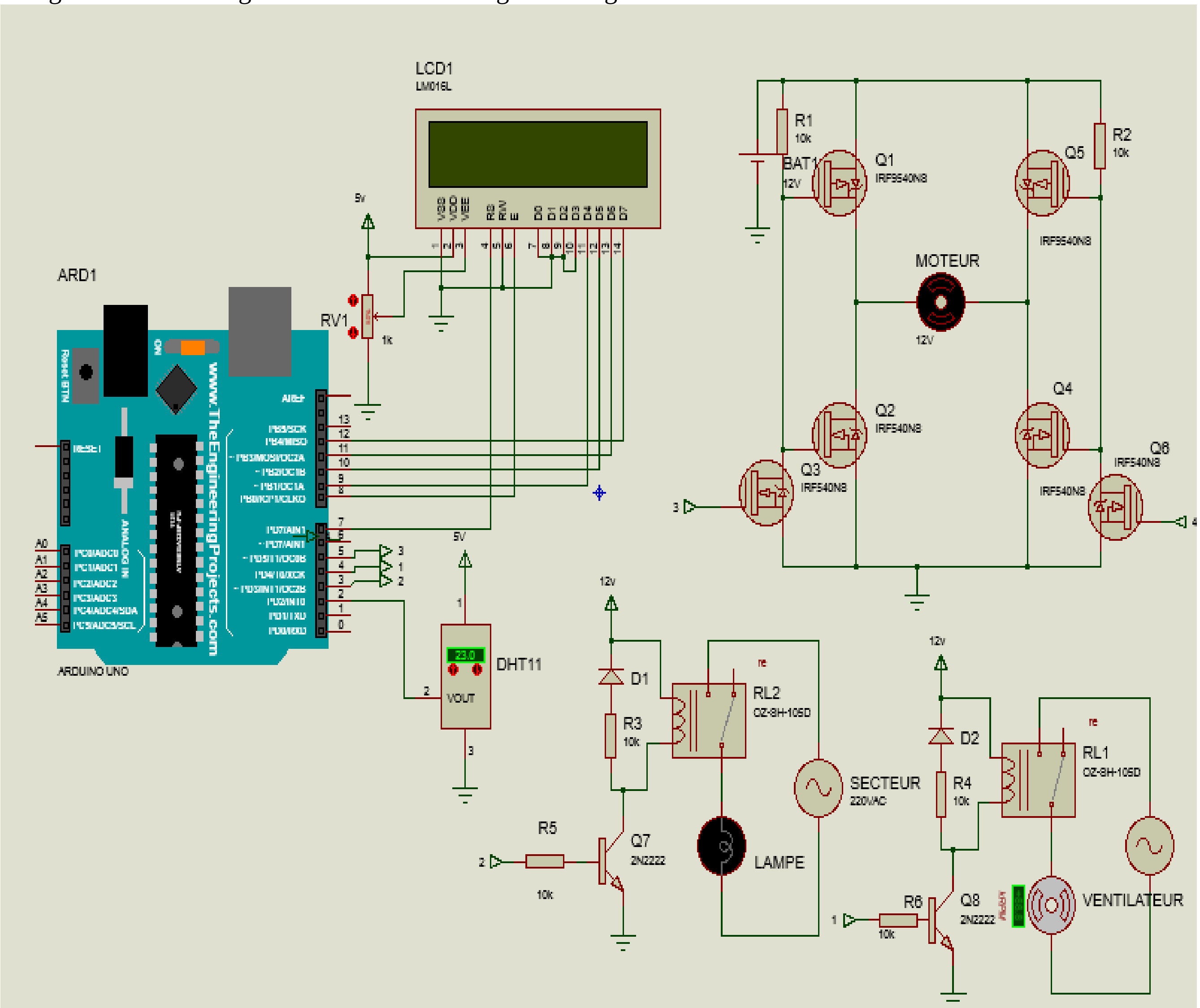

Figure 2: General circuit diagram of the realization

When the power is turned on, the lamps light up at the same time, the fans start up, the temperature and the relative humidity are displayed on the LCD screen, the power indicator of the device s lights up as well as the LED that monitors the temperature range. The data processing unit, which is designed around an Arduino board, controls and displays in the serial monitor the temperature and humidity every five seconds.

The temperature regulation between 37ºC and 38ºC inside the incubator is carried out thanks to a DHT11 type temperature sensor which communicates to the data processing unit (Arduino Uno) the temperature of the enclosure and in turn sends control pulses on the base of the transistor which controls the opening and closing of the relay contacts which turn on or off the lamps which provide heat inside the incubator.
The lamps turn on when the temperature becomes less than or equal to 37ºC and turn off when the temperature exceeds 38ºC. The flipping system is triggered by sending control pulses to the gates of the MOSFETs which drive the motor that turns on the flipping system.

After every eight hours of operation of the device, the motor rotates back and forth to turn the eggs like a natural hen does in order to have a good hatching rate of the eggs.

III.8 Experimentation

III.8.1 Incubator empty test

Before introducing the eggs into the incubator, we switched on the device for twelve hours from 6 a.m. to 6 p.m. so that the temperature was evenly distributed inside the incubator. The values and evolution curves of the temperature and humidity of the incubator empty test are given respectively in table 3 and in figure 4.

Table 3: Evolution of the incubator empty test temperature and humidity

Time	T_{mean_int} (°C)	T_{mean_out} (°C)	H_{mean_int} (%)	H_{mean_out} (%)
6h00	35	23,20	64	70
6h30	35	23,21	64	70
7h00	34	23,30	63	68
7h30	36	23,80	63	68
8h00	36	23,70	61	67
8h30	37	24,50	60	68
9h00	37	24,80	58	67
9h30	37	25,45	57	66
10h00	38	25,80	57	65
10h30	37	25,70	56	64
11h00	38	25,60	56	64
11h30	38	25,70	55	63
12h00	37	26,10	54	62
12h30	38	26,15	55	62
13h00	37	27,20	57	60
13h30	39	28,13	58	60
14h00	38	28,25	57	59
14h30	38	28,30	56	59
15h00	38	28,45	54	61
15h30	38	28,50	55	61
16h00	38	28,60	57	60
16h30	38	28,35	57	59
17h00	38	27,50	57	59
17h30	38	27,10	56	57
18h00	38	27,05	55	57
Mean	**37,24**	**26,1776**	**57,68**	**63,04**

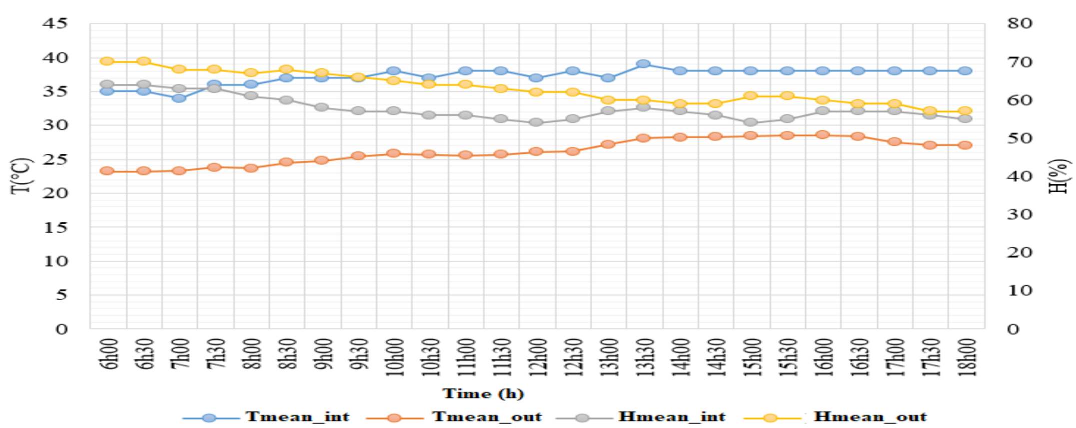

Figure 4: No-load test temperature and humidity curves

The curves in figure 3.4 show the evolution of the test temperature and humidity inside the incubator and in the ambient environment for 12 hours from 6 a.m. to 6 p.m.

The average temperatures inside the incubator varied from 34°C to 39°C with a daily average of 37.24°C, which is relatively equal to the average recommended value (37°C) which certifies the efficiency of an incubator before the introduction of the eggs (Andoh P. Y and al. 2022). The average ambient temperatures varied from 23.20°C to 28.6°C, with a daily average of 26.18°C, which corresponds approximately to the average temperature of the study area.

The curves of variation of the average relative humidity on the secondary axis of figure 3.3 show that the average relative humidity inside the brooder varies from 54% to 64%, with a daily average of 57.68% ; this value is within the relative humidity range (50 to 70%) for the proper functioning of an egg incubator (B.Sc. Jorge Retamozo Ph.D. Freddy J. Rojas, 2022). The relative humidity variation curve inside the incubator is below that of the ambient environment, whose values vary from 57% to 70%, with an average of 63.04%, which is relatively equal to the monthly mean value of the study medium 65%.

III.8.2 Temperature and humidity of the 1st, 10th and 20th day of operation

The evolution of temperature and humidity on the 1st, 10th and 20th day of operation of the incubator is given in Table 3.4.

Table 4: Temperature and humidity of the 1st, 10th and 20th day of operation

Time	03/05/22 (1st day)				12/05/22 (10th day)				22/05/22 (20th day)			
	T_{int} (°C)	T_{out} (°C)	H_{int} (%)	H_{out} (%)	T_{int} (°C)	T_{out} (°C)	H_{int} (%)	H_{out} (%)	T_{int} (°C)	T_{out} (°C)	H_{int} (%)	H_{out} (%)
0h00	37,40	24,50	54	75	37,45	23,80	55	76	37,40	21,90	65	75
1h00	37,45	23,20	55	75	37,46	22,10	56	76	37,45	21,70	65	77
2h00	37,50	23,15	56	76	37,55	22,35	56	77	37,50	22,10	66	77
3h00	37,50	23,10	56	76	37,57	22,30	57	78	37,50	22,15	67	79
4h00	37,44	22,60	55	76	37,58	22,10	56	77	37,44	22,15	68	77
5h00	37,55	22,70	55	77	37,59	22,00	58	77	37,55	22,25	70	77
6h00	37,60	23,54	54	76	37,60	22,15	58	76	37,60	22,25	69	78
7h00	37,55	23,20	56	75	37,58	22,20	57	74	37,55	22,27	72	78
8h00	37,65	24,60	55	74	37,58	22,60	54	74	37,65	22,62	73	77
9h00	37,65	24,70	54	74	37,57	23,65	53	73	37,65	23,30	74	74
10h00	37,70	25,10	54	73	37,60	23,70	54	72	37,70	23,76	75	74
11h00	37,63	25,20	55	72	37,62	24,10	53	72	37,63	24,20	74	71
12h00	37,54	26,80	55	72	37,56	25,20	56	72	37,54	25,10	72	71
13h00	37,55	27,50	56	70	37,54	26,45	56	71	37,55	25,50	70	71
14h00	37,72	28,10	56	70	37,70	27,65	57	71	37,72	26,75	69	70
15h00	37,68	28,15	54	68	37,58	27,75	58	67	37,68	27,20	70	69
16h00	37,47	27,12	56	68	37,57	28,15	57	67	37,47	29,10	72	69
17h00	37,68	25,10	54	67	37,58	27,25	58	66	37,68	26,50	73	68
18h00	37,67	25,00	56	65	37,61	27,10	56	66	37,67	26,45	75	68
19h00	37,72	24,90	55	66	37,64	26,70	57	67	37,72	26,30	75	66
20h00	37,78	24,70	54	65	37,72	25,45	58	68	37,78	25,80	74	66
21h00	37,72	24,65	55	65	37,73	25,60	56	68	37,72	25,70	75	69
22h00	37,50	24,40	56	66	37,59	25,40	57	70	37,50	25,65	76	72
23h00	37,54	24,45	56	68	37,60	25,45	58	72	37,54	25,50	75	73
Mean	**37,59**	**24,85**	**55,08**	**71,21**	**37,59**	**24,63**	**56,29**	**71,96**	**37,59**	**24,43**	**71,42**	**72,75**

The temperature and humidity curves for the 1st, 10th and 20th day of operation of the incubator are given in Figures 5; 6 and 7.

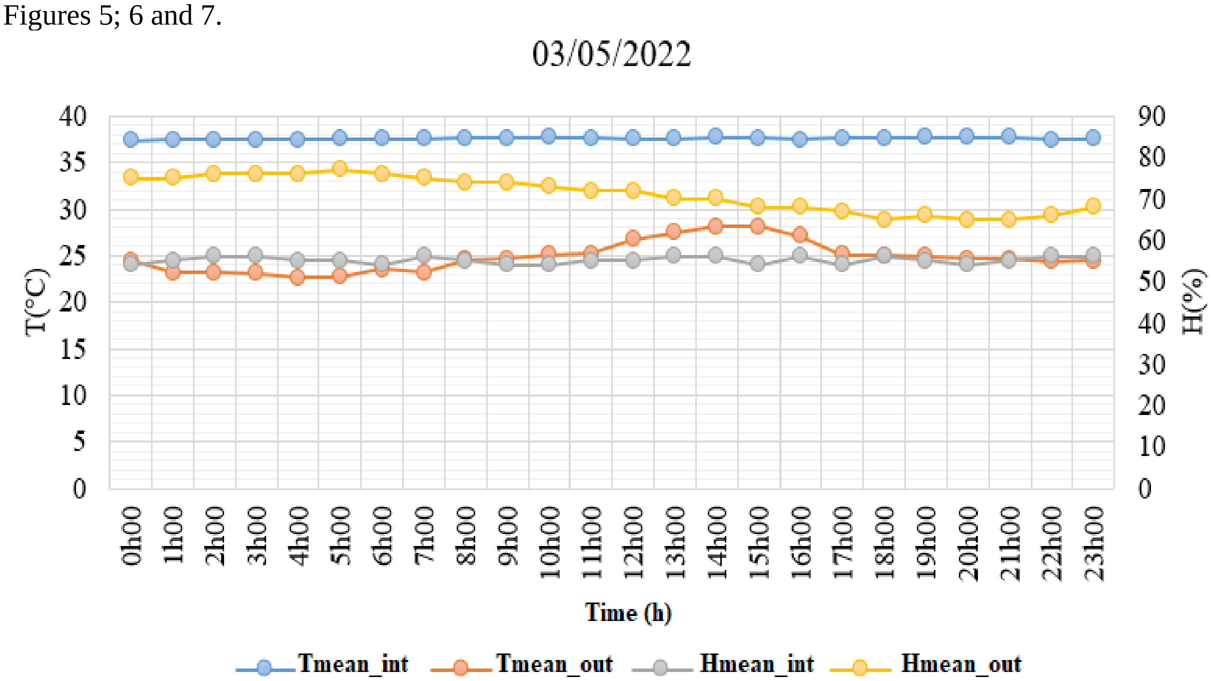

Figure 5: Temperature and humidity curves for the 1st day of operation

The temperature and humidity variation curves for the 1st day (03/05/2023) of operation of the incubator show that the temperature varies from 37.4°C to 37.78°C inside the incubator with an average of 37.60°C, this temperature remains favorable for the proper functioning of the egg incubation process (Frimpong Kyeremeh and Forson Peprah, 2017). The ambient temperature varied from 22.16°C to 28.15°C, with an average of 24.85°C. The relative humidity of incubation and in the ambient environment varied respectively from 54% to 56% and from 70% to 76%, with averages of 55.08% to 71.21%. The variation curve of the relative humidity in the ambient environment remains above that of the incubation, this is justified by the internal heating system of the incubator.

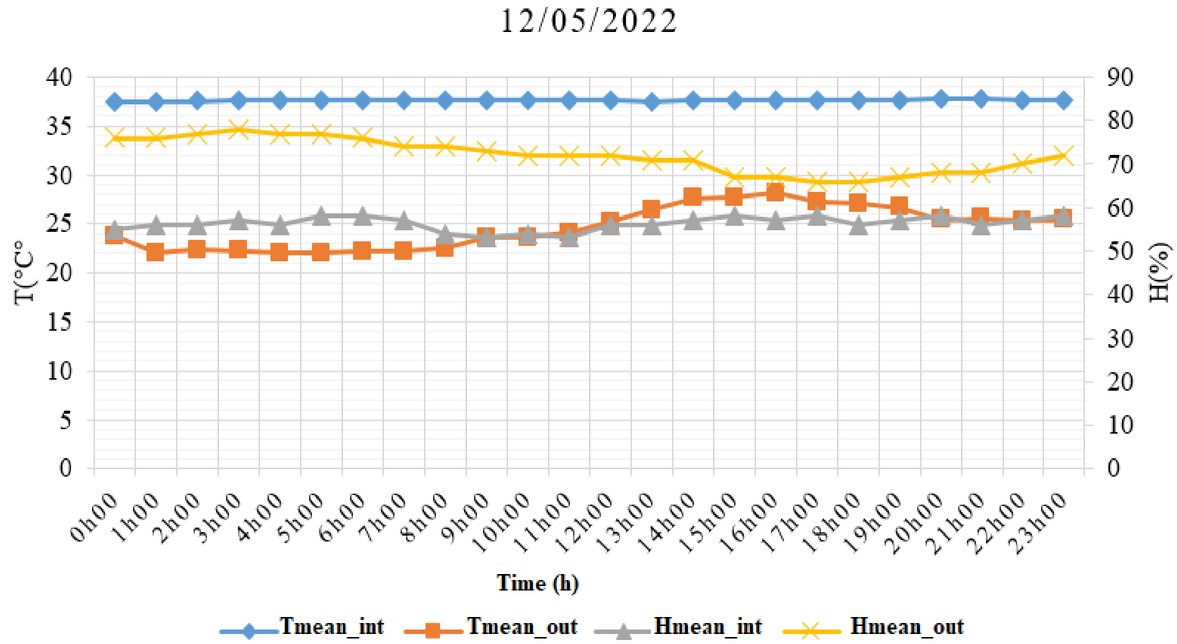

Figure 6: Temperature and humidity curves for the 10th day of operation

The temperature and humidity variation curves for the 10th day (05/12/2023) of incubation are relatively similar to those for the 1st day; the temperature varied from 37.45°C to 37.73°C inside the incubator with an average of 37.59°C. The ambient temperature varied from 22°C to 28.15°C, with an average of 24.63°C these values remain almost the same as the first day. The relative humidity of incubation and in the ambient environment varied respectively from 56% to 57% and from 66 to 78%, with averages of 56.29% to 71.96%.

These values are very close to those of the first day and still remain within the optimal egg incubation range of 37°C to 38°C and 54% to 70% (Frimpong Kyeremeh and Forson Peprah, 2017). This shows a very low disturbance of the temperature and humidity of incubation in the ambient environment.

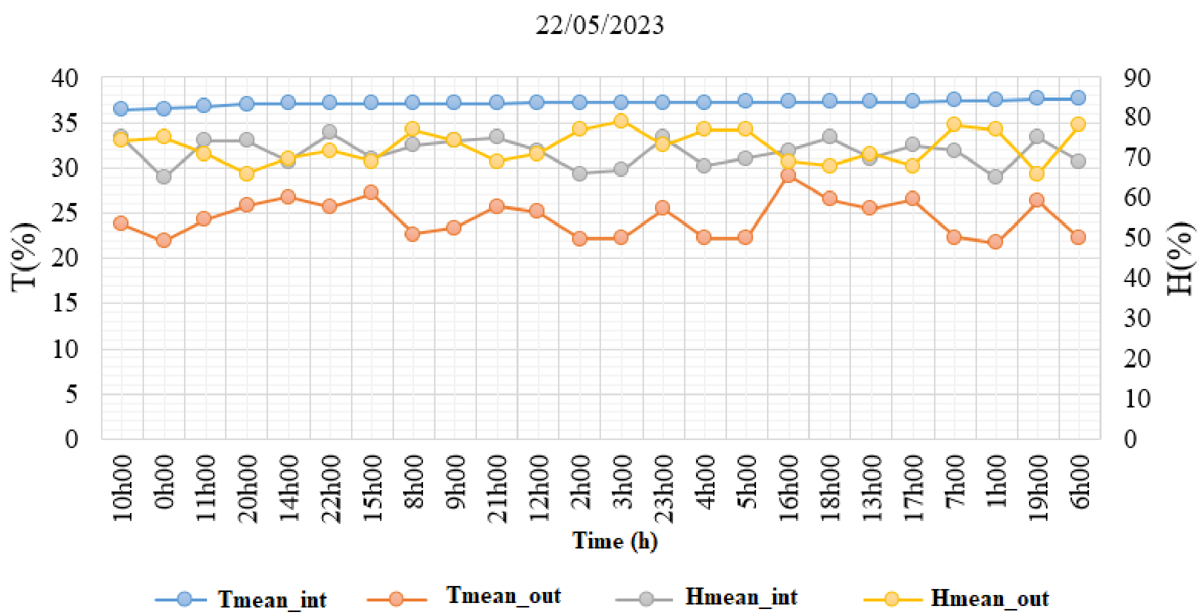

Figure 7: Temperature and humidity curves for the 20th day of operation

The temperature and humidity variation curves of the 20th day (05/22/2023) inside the incubator and in the ambient environment remain uniform to those of the first day and the 10th day of incubation. The average values of temperature and humidity relative to incubation and in the ambient environment are respectively: 37.15°C; 24.43°C; 71.42% and 72.75%. From this 20th day, some eggs hatched, which led to a slight increase in relative humidity and a decrease in temperature in the incubator.

III.8.3 Incubation temperature and relative humidity on the 1st, 10th and 20th day

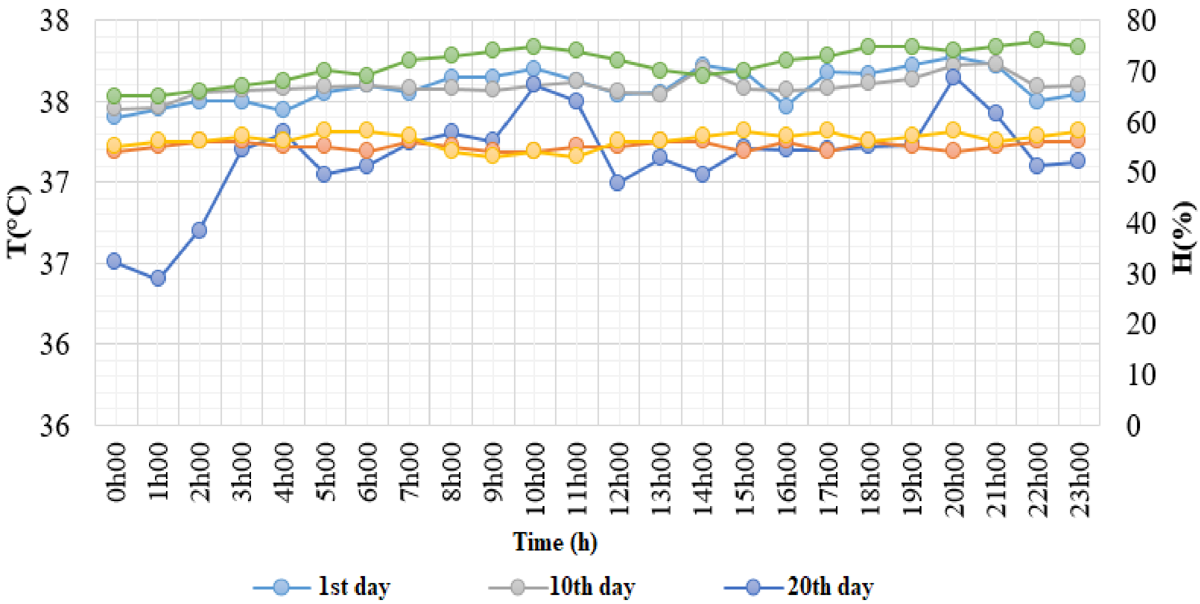

Figure 8: Temperature and relative humidity of incubation on the 1st, 10th and 20th day

The curves in figure 3.8 make a comparison between the evolution of the temperature and the relative humidity of incubation during the 1st, 10th and 20th day. The incubation temperature variation curves of the first day and the 10th day remain very similar and uniform, with the following respective minimum and maximum values: the 1st day (37.40°C and 37.78°C) and the 10th day (37.45°C and 37.73°C). With the same daily average equal to 37.59°C. This shows a relative uniformity of temperature in the brooder during the first two weeks in the brooder. The variation curve for the 20th day shows sudden variations over 24 hours, with a temperature variation of 36.40°C to 37.65°C, for a daily average of 37.15°C. This curve is below the two others of the 1st and 10th day. This is justified by the egg hatching period, from the 18th to the 21st day of incubation. The shape of the incubation relative humidity curves during the three days (1st, 10th and 20th) remain relatively uniform, with the following variations: 1st day from 54% to 56% for an average of 55.08%; 10th day from 53% to 58% for an average of 56.29%; 20th day from 65% to 76% for an average of 71.42%. The relative humidity values of the 20th day remain higher than those of the 1st and 10th day; thus, the curve of the relative humidity variation curve of the 20th day is above those of the 1st and 10th day. This is justified by the hatching period of the eggs.

III.8.4 Average temperature and humidity during the 21 days

During the 21 days of operation, the evolution of the temperature and humidity (internal and external) of the incubator is shown in Table 5.

Table 5: Average daily operating temperature and humidity

Day	T_{mean_in} (°C)	T_{mean_out} (°C)	H_{mean_in} (%)	H_{mean_out} (%)
1	37,60	24,85	55	71
2	37,62	25,30	56	72
3	37,65	24,15	55	71
4	37,60	26,05	54	72
5	37,54	26,20	53	73
6	37,60	24,20	56	70
7	37,54	25,35	53	72
8	37,58	25,40	54	70
9	37,45	25,75	55	68
10	37,59	24,63	56	72
11	37,42	24,30	56	70
12	37,15	25,65	57	69
13	37,15	26,65	57	67
14	37,12	23,50	58	69
15	37,10	24,15	56	72
16	37,10	25,80	60	74
17	37,00	26,70	68	71
18	36,90	26,35	72	69
19	36,20	25,83	73	68
20	36,15	24,43	74	69
21	36,10	24,25	74	70
Mean	**37,20**	**25,21**	**59,62**	**70,43**

The temperature and humidity variation curves (internal and external) of the incubator are shown in Figure 9.

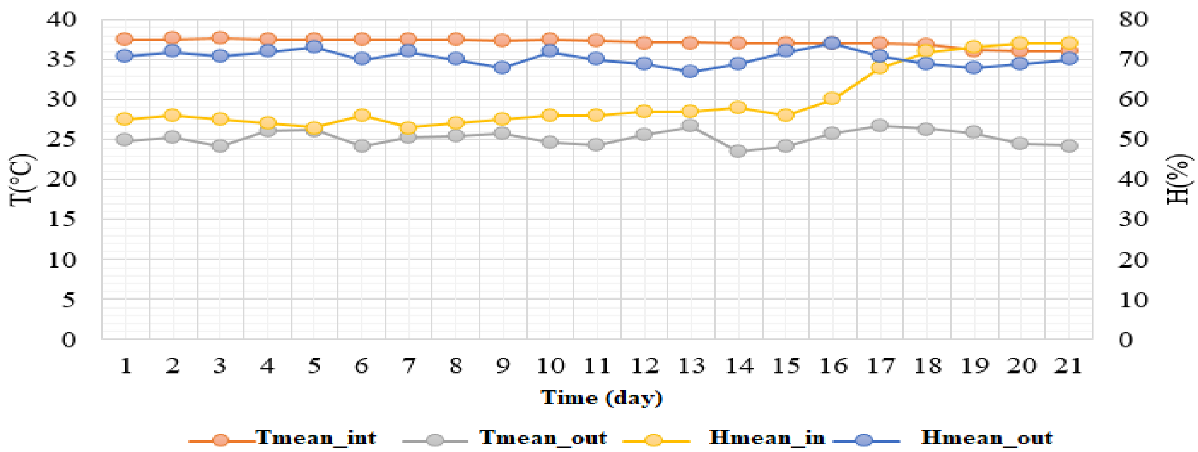

Figure 9: Average daily operating temperature and humidity curves

The figure of the average daily temperature and humidity curves for the 21 days of incubation and in the external environment shows that the temperature variation curve inside the incubator remained relatively uniform during the first 17 days of incubation, with a slight decrease during the last four days from the 18th to the 21st day. During the 21 days of incubation, the temperature inside the incubator varied from 36.10°C (21st day) to 37.65°C (3rd day), with an average of 37.20°C, this value is optimal for better egg hatch (Lourens A and al., 2005). That of the external environment varied from 23.50°C (14th day) to 26.70°C (17th day), with an average of 25.21°C.

The relative humidity inside the incubator varied from 53% (7th day) to 74% (20th day), with an average of 59.61%, this value remains favorable for the egg hatching process (Shaymaa A. Hassan; and 2022). That of the ambient environment varied from 67% (13th day) to 74% (16th day), with an average of 70.43%.

The images in the figures below show some stages in the construction of the incubator and its experimentation.


Photo 1: Turning system


Photo 2: Realization of the frame


Photo 3: Electronic system


Photo 4: Incubator completed


Photo 5: Hatching phase


Photo 6: Hatching phase

IV. Conclusion

Poultry farming is an important commercial activity in West Africa, particularly in urban and peri-urban centres. The development of the poultry sector, such as the production of broilers and laying hens, makes a great contribution to the fight against poverty thanks to the self-employment it generates. This is why the modernization of the design of incubators is today the subject of research. This work led to the following results:

- knowledge of the geometric parameters in centimeters the incubator (80×66×32.5);
- the choice of the various electronic and electrical components of the device;
- the various commands are programmed;
- knowledge of the daily heat balance relating to the incubator (2551.744 kJ);
- the operating diagram of the device is produced;
- the design and construction of the incubator;
- experimentation with the incubator by hatching 470 eggs out of 540, i.e. a rate of 87%;
- the average incubation temperature and humidity during the 21 days are known (37.20°C and 59.61%).

It appears from this study, to promote and popularize these types of artificial incubators throughout the country. Similarly, the continuation of research work by improving the prototypes while making them autonomous from the energy source point of view through the use of photovoltaic solar systems.

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