Smart Grid and Renewable Energy, 2024, 15, 267-275
https://www.scirp.org/journal/sgre
ISSN Online: 2151-4844
ISSN Print: 2151-481X

Experimental Study of Temperature and Humidity Variations in an Incubator Fitted with a Flat-Plate Collector

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How to cite this paper: Ouedraogo, G.W.P., Dianda, B., Kabore, B., Sawadogo, C.F.T. and Kam, S. (2024) Experimental Study of Temperature and Humidity Variations in an Incubator Fitted with a Flat-Plate Collector. *Smart Grid and Renewable Energy*, **15**, 267-275.
https://doi.org/10.4236/sgre.2024.1511015

Received: October 5, 2024
Accepted: November 5, 2024
Published: November 8, 2024

Abstract

In Burkina Faso, where livestock farming is widely practiced, particularly in rural areas without access to electricity, solar energy offers a viable alternative due to the country's abundant sunshine. To support poultry farmers in increasing their production, we developed a solar-powered incubator equipped with a flat-plate collector, requiring no grid electricity. This is a new approach that we want to experiment with because the incubators on the global market operate either with the electricity grid, photovoltaic, gas or oil and not a solar thermal concentrator. This solar concentrator represents the heat source of the device during the day. We plan to look for rocks with high thermal inertia in order to heat them during the day using another flat solar concentrator and then introduce them into the incubator at night to continue the incubation process. In 2022, we conducted a simulation to study temperature variation inside the incubator. In this work, we built a prototype to experimentally evaluate key hydrothermal properties such as air temperature and humidity. Furthermore, we will not introduce rocks into the incubator overnight but will let the system run overnight to see how the hygrothermal properties vary. The findings revealed temperature fluctuations from 25˚C to 65˚C, instead of the desired 36˚C to 38˚C, and humidity levels ranging from 15% to 57%, instead of the target 55% to 75%. Solutions have been proposed to enhance the system's performance.

Keywords

Solar Incubator, Flat-Plate Collector, Hygrothermal Properties

1. Introduction

Poultry farming is one of the sectors which is more developing in Burkina Faso due to the high demand for poultry and the inaccessibility of certain rural areas. Nowadays, in order to achieve higher yields, most poultry farmers use artificial incubators which operate on electricity or gas because hens can only incubate 12 eggs at a time [1]. The egg incubator is well known as the trendy technology for hatching eggs without involving the hens [2]. The artificial incubator creates the conditions for the foetus inside each egg to develop and hatch without the presence of the hen [3] [4]. Several studies have been carried out to determine the impact of heat on eggs [5]. A variation of between 1˚C and 1.5˚C can affect embryo development [6].

An egg incubator is a device designed to create an optimal environment for the development of fertilized eggs, with temperatures typically ranging from 36.5˚C to 38˚C [4] [7]-[9]. The temperature and humidity in the incubator, as reported by Seforo Mohlalisi [10], ranged from 36.9°C to 39˚C and from 39.8% to 66%, respectively. For optimal incubation results, it is recommended to maintain a relative humidity of 55% to 65% during the first 18 days, and up to 75% during the final three days of incubation [11] [12]. In an egg incubator, factors like humidity and temperature can be adjusted according to the stages of embryonic development [13].

Poultry farming is predominantly practiced in rural areas without access to the electricity grid. While some poultry farmers use photovoltaic solar energy to power their incubators, the cost of these systems remains relatively high. Traditional incubators are typically powered by either the electricity grid or photovoltaic systems, which convert electrical energy (AC or DC) into thermal energy to heat the eggs. However, given Burkina Faso's high solar potential, eggs can also be heated using a solar collector. The objective of this work is to design and assess the hygrothermal performance of an incubator equipped with a solar collector, both during the day and at night.

2. Description

The solar incubator consists of a flat plate collector, an incubation chamber and a digital screen for recording hygrothermal parameters.

The flat plate collector is the system that produces the heat source using solar radiation. It consists of a clear glass pane and an absorber. The pane has a surface area of $0.36m^2$ and is 5mm thick. The absorber is a black-painted steel plate with a surface area of $0.36\ m^2$.

The brooding chamber is where the eggs are placed in designated cells and also houses the chick box and water tank. Constructed from 20mm plywood, the chamber has a volume of $0.396\ m^3$ and can hold up to 360 eggs. A water tray is included to maintain humidity levels, while the chick tray is used to collect newly hatched chicks. **Figure 1** shows the constructed incubator equipped with a flat-plate collector.

Figure 1. Image of the incubator fitted with a flat-plate collector.

2.1. Operating Principle

The absorber heats up thanks to the solar rays that reach the flat collector through the glass, creating the greenhouse effect. This heat is transmitted to the hatching chamber throughout the day. The flat plate collector stops supplying heat to the chamber when the sun goes down. At this point, we will introduce rocks that have stored heat during the day, so that they become the source of heat at night. The heat required is provided by solar radiation and the heat stored in the rocks. In addition, a container filled with water is placed inside the incubator to provide humidity.

2.2. Experimental Protocol

Several experimental sessions were carried out to analyze temperature and humidity. The measurement sessions took place in April, which was characterized by high solar irradiation.

We chose to start the measurements in April, which is considered to be one of the hottest months of the year in Burkina Faso. The measurements were carried out during the day and at night covering all possible scenarios (incubator placed in the sun with its door closed and incubator placed in the sun with its door open). For each measurement session, we placed T-type thermocouples inside the incubator, the locations of which are shown in Figure 2. A pyranometer was placed on the window and a hygrometer at position 3 in the incubator as shown in Figure 2 to record humidity. A data logger was used to record temperature and solar radiation.

3. Results and Discussion

The measurement sessions gave us the results of changes in temperature and air

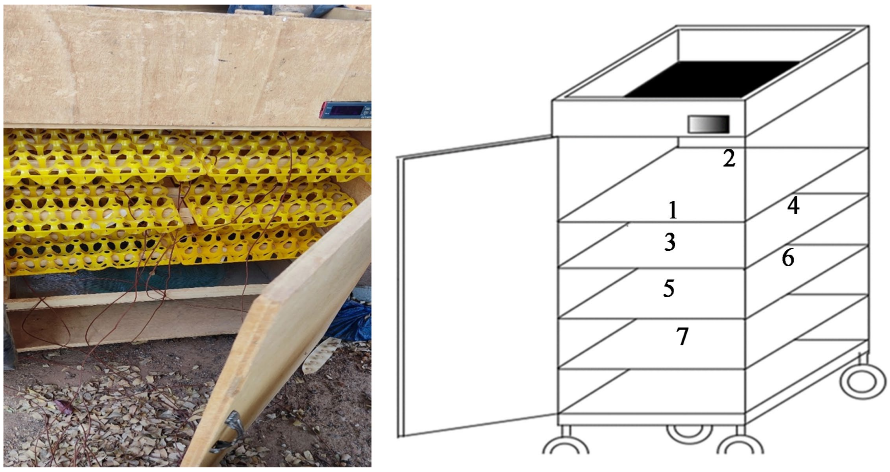

Figure 2. Location of the thermocouples in the incubator.

humidity inside the hatching chamber as a function of changes in solar radiation.

3.1. Incubator Exposed to the Sun with the Door Closed

The measurements were carried out from April 12 to April 14 and then from April 14 to April 17, 2023. The measurements from the day of April 15 and the night of April 15 to 16, 2023 were presented because they are those which best reflect the variation in the hygrothermal values of the whole.

Figure 3 presents the graphs depicting the temporal variations of temperature in incubator (Figure 3(a)), humidity (Figure 3(b)) and solar irradiance (Figure 3(c)).

3.1.1. Results for the Day of 15 April 2023

The variations in temperature and humidity over time are due to variations in solar radiation. The recommended temperatures for optimal brooding (36˚C to 38˚C) were recorded between 9:20 am and 10:10 am, a period lasting 50 minutes (Figure 3(a)). From 6:00 am to 9:19 am, the temperatures inside the incubator, regardless of its placement, ranged between 25˚C and 35˚C, which were below the recommended levels, similar to the ambient temperature. Between 10:10 am and 6:00 pm, a significant temperature rise was observed at every level of the incubator, peaking before eventually decreasing. This is the longest part of the day, with temperatures varying between 39˚C and 65˚C depending on the incubator's position. Such high temperatures are harmful to the embryo [14].

From Figure 3(b), it can be observed that the humidity level in the incubator remained well below the recommended range (55% to 75%) between 6:00 am and 8:50 am, as well as between 9:05 am and 6:00 pm. Only during the period from 8:50 am to 9:05 am did the humidity fall within the recommended range.

3.1.2. Results for the Night of 15 to 16 April 2023

During the night, the temperature inside the incubator dropped from 42˚C to 27˚C (Figure 4(a)), while at the same time the humidity level increased from 31%

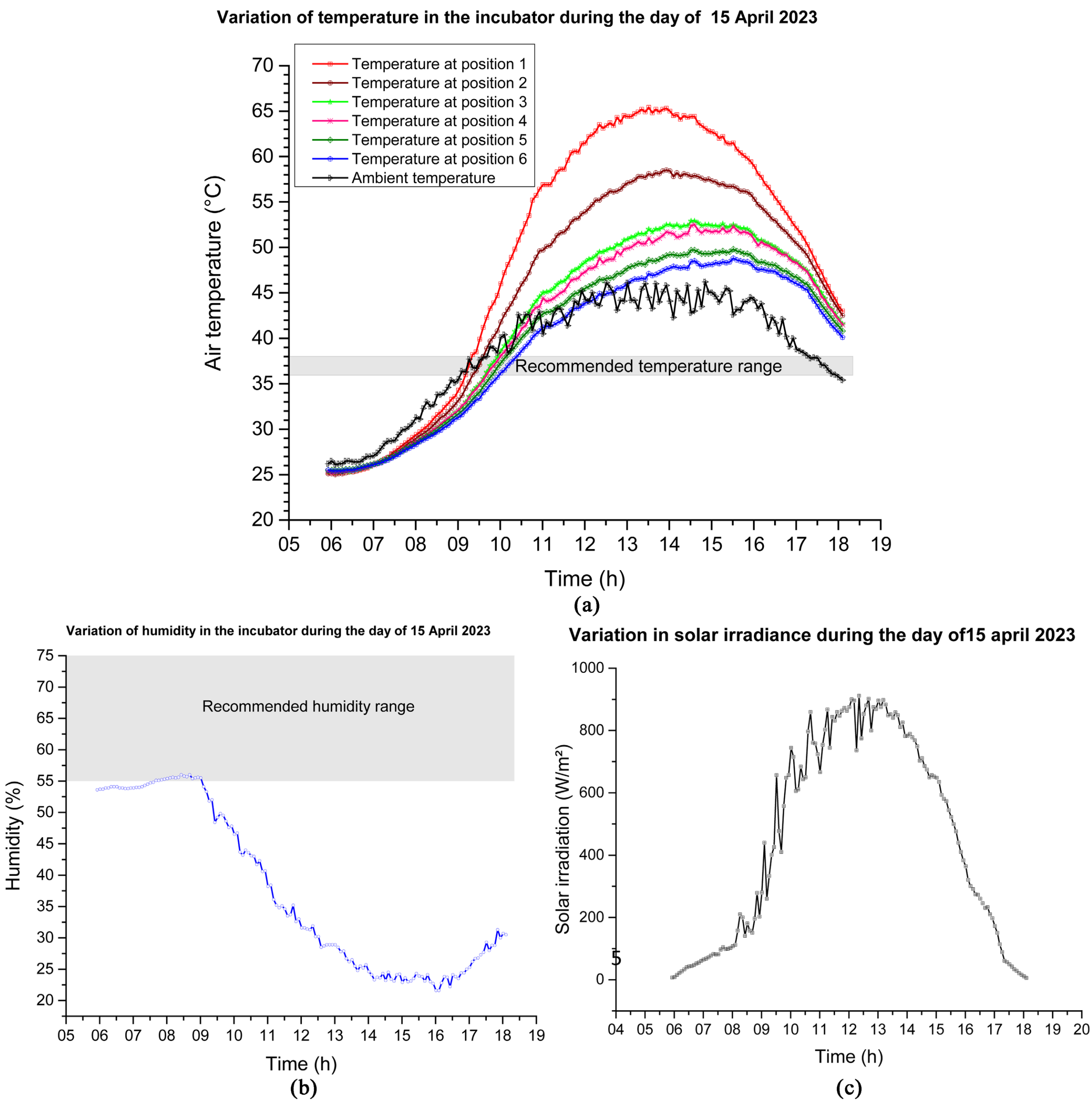

Figure 3. Temperature, humidity and irradiance graphs for 15 April.

to 44%, (**Figure 4(b)**) without reaching the recommended humidity range. It was only between 6:30 pm and 7:30 pm, *i.e.* one hour later, that the temperatures aligned with those recommended for good brooding.

3.1.3. Combined Results for the Day and Night

Figure 5 shows the temperatures (**Figure 5(a)**) and humidities (**Figure 5(b)**) over a 24-hour period.

Temperatures varied from one place to another in the incubator, creating a non-uniformity of temperature. During the 24 hours of measurement, it was only

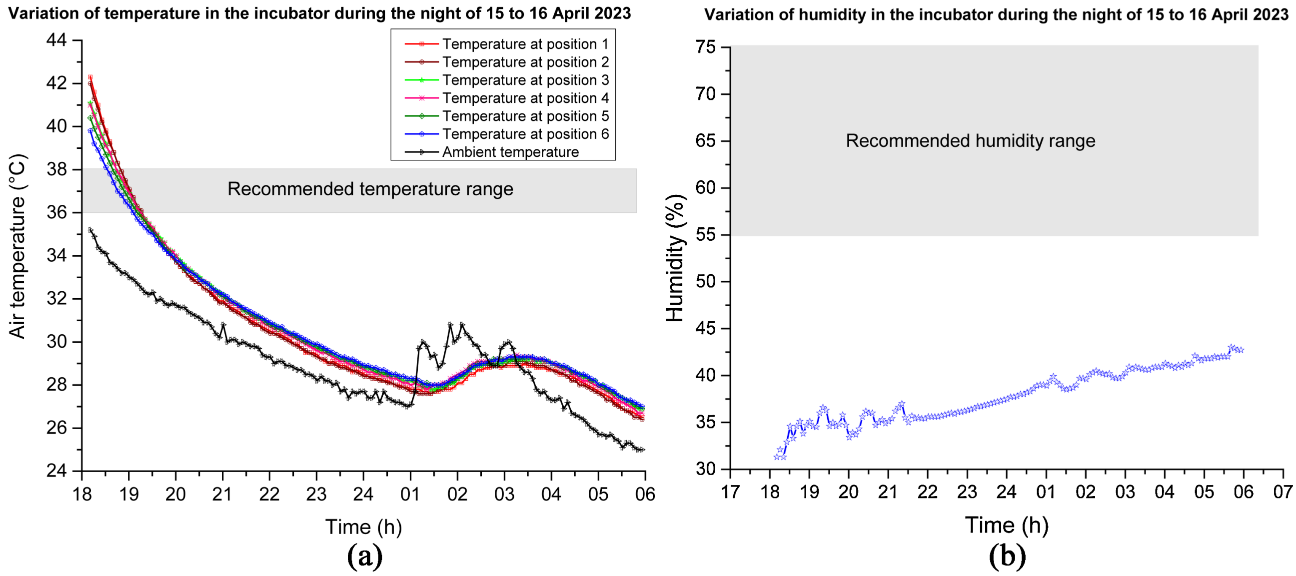

Figure 4. Temperature and humidity graphs for the night of 15 April to 16 April.

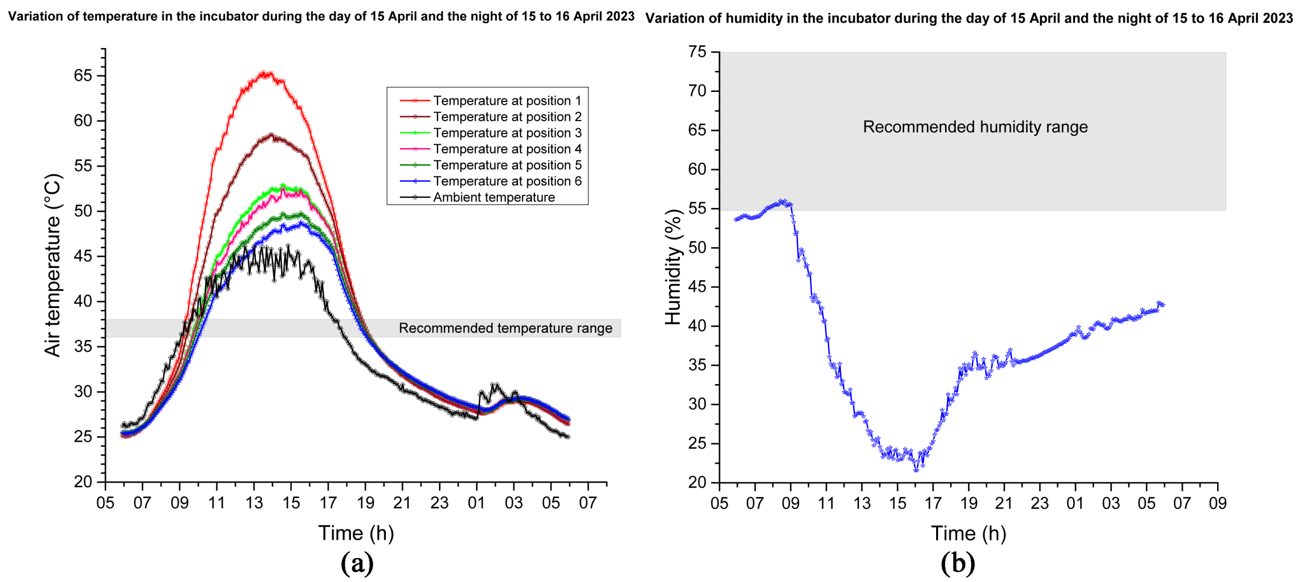

Figure 5. Changes in temperature and humidity inside the incubator from 15 April to 16 April.

during 1 h 50 mn that the temperatures aligned with those recommended (Figure 5(a)). We also observed that the ambient temperature is higher than the recommended temperatures between 10:00 am and 5:30 pm and lower between 6:00 am and 9:00 am and again between 6:00 pm and 6:00 am. The flat-plate collector helps to increase the air temperature in the incubator during the day, but during the night the opposite effect occurs, with rapid dissipation of the heat.

The reasons for the fluctuation of the hygrothermal parameters are due to the surface of the solar collector considered large that we intend to reduce and also to the impossibility of regulating the variation of the solar radiation. Even the values of the external temperature (ambient) are higher and are not within the recommended temperature range. This is due to our dry and hot climate.

3.2. Measurement Session in the Sun with the Door Open

The device was exposed to the sun with the door open to allow air to circulate. Figure 6 shows the temperature (Figure 6(a)) and humidity (Figure 6(b)) curves as a function of changes in solar radiation (Figure 6(c)).

We can see that temperatures varied from 25˚C to 56˚C, compared with 27˚C to 65˚C when the door was closed. This reduction can be explained by the fact that the air in the incubator is renewed. However, the temperature did not comply with the recommended temperature for the entire period of operation, *i.e.*, 22 hours out of 24 h of operation.

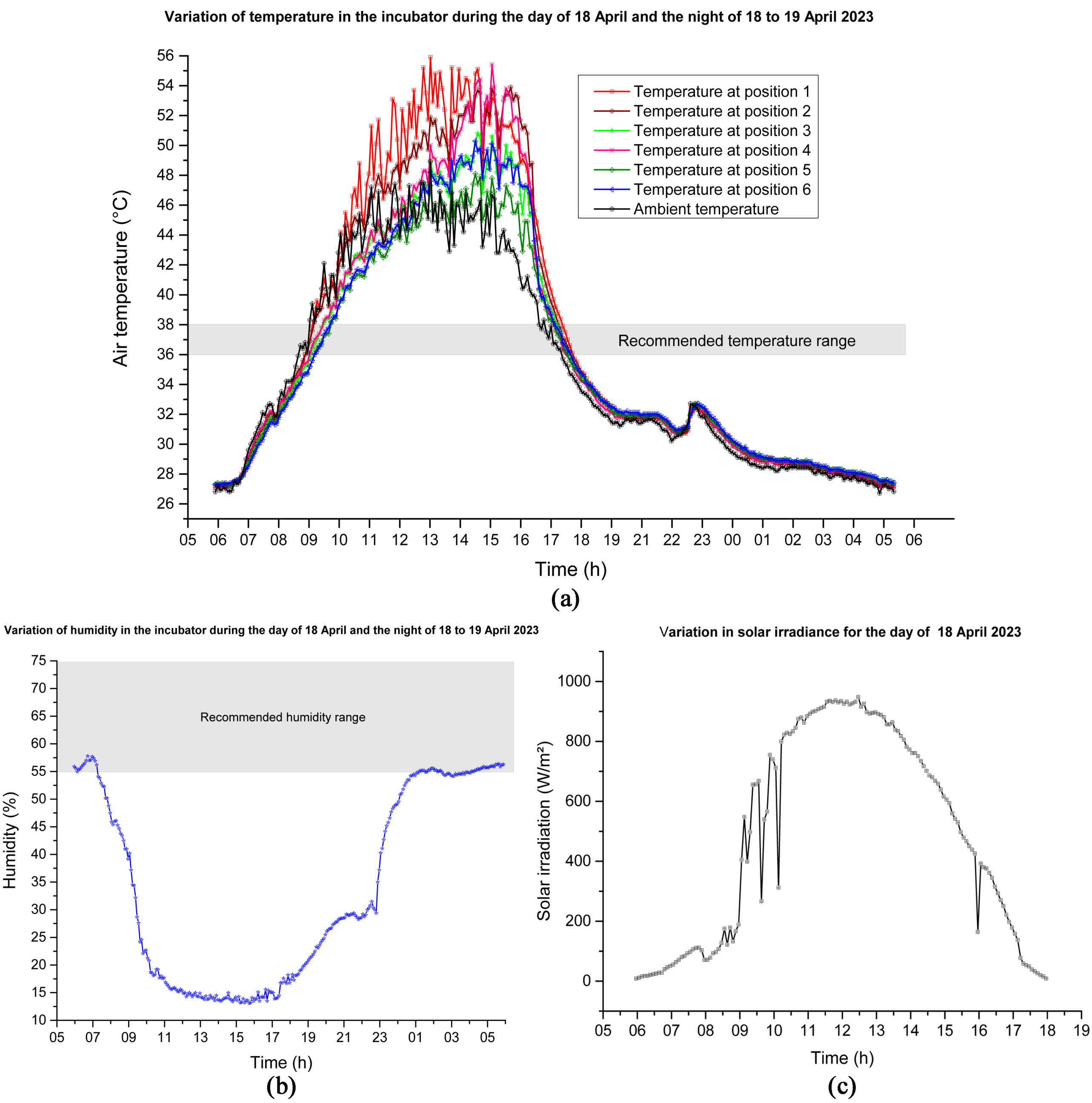

Figure 6. Variation in temperature, humidity and irradiation on 18 April.

We found that between 6am and 7.20 am on 18 April and between 12.40 am and 6 am on 19 April, the humidity level in the incubator was within the recommended range. However, it was still low compared with the maximum permitted humidity level. As a result, the humidity level inside the incubator did not comply for 17 hours out of a 24-hour period.

In addition, the times when the temperature aligns with the brooding temperature are different from the times when the humidity level is in line with the brooding humidity level. For good brooding, the temperature and humidity levels must simultaneously comply with the recommended values.

At the end of the two measurement phases, we obtained almost the same results overall. The temperatures in the incubator follow the same pattern as the solar radiation during the day. If irradiation increases or decreases, the temperature in the incubator increases or decreases, and the opposite is true for humidity levels. The temperatures obtained are also high during the day and low at night, whereas the recommended range is between 36˚C and 38˚C. Even the ambient temperature was higher than the recommended temperature range during the measurement days. Moreover, the experimental temperatures obtained are higher than the temperatures of 30˚C to 43˚C predicted by the simulation we carried out [15].

Humidity levels fall from 54% to 15% during the day. At sunset, the humidity level starts to rise but does not reach the recommended range when the incubator door is closed. When the door is open, the range is reached between 00:40 am and 6:00 am, but in most cases the humidity level remains very low.

There are no similar studies in the literature to compare our results obtained because this invention comes from our imagination.

4. Conclusions

In conclusion, we designed an incubator equipped with a flat plate collector, where the glass pane and absorber transmit heat to the brooding chamber. After conducting a series of performance tests, we observed that the measured values for temperature and humidity were frequently outside the optimal incubation range. Therefore, significant modifications are necessary to achieve ideal brooding conditions.

To enhance the system, we propose reducing the surface area of the flat plate collector, adding a cover to regulate solar exposure, creating openings between the glass and absorber for air renewal, integrating a humidification system, and incorporating a heat storage and retrieval system to address low night-time temperatures. These improvements are essential for optimizing the incubator's performance.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Mushagalusa, E.K. (2021) Conception et réalisation d'un incubateur d'œuf intelligent

a forte conservation de chaleur. Bachelor's Thesis, Université de Lubumbashi.

[2] Ramli, M.B., Lim, H.P., Wahab, M.S. and Zin, M.F.M. (2015) Egg Hatching Incubator Using Conveyor Rotation System. *Procedia Manufacturing*, **2**, 527-531. https://doi.org/10.1016/j.promfg.2015.07.091

[3] Uzodinma, E.O., Ojike, O., Etoamaihe, U.J. and Okonkwo, W.I. (2020) Performance Study of a Solar Poultry Egg Incubator with Phase Change Heat Storage Subsystem. *Case Studies in Thermal Engineering*, **18**, Article ID: 100593. https://doi.org/10.1016/j.csite.2020.100593

[4] Tiam Kapen, P., Youssoufa, M., Foutse, M., Manfouo, H. and Njotchui Mbakop, F.O. (2020) Design and Prototyping of a Low-Cost, Energy Efficient Eggs Incubator in Developing Countries: A Case Study of Cameroon. *Scientific African*, **10**, e00618. https://doi.org/10.1016/j.sciaf.2020.e00618

[5] French, N.A. (1997) Modeling Incubation Temperature: The Effects of Incubator Design, Embryonic Development, and Egg Size. *Poultry Science*, **76**, 124-133. https://doi.org/10.1093/ps/76.1.124

[6] Leksrisompong, N., Romero-Sanchez, H., Plumstead, P.W., Brannan, K.E. and Brake, J. (2007) Broiler Incubation. 1. Effect of Elevated Temperature during Late Incubation on Body Weight and Organs of Chicks. *Poultry Science*, **86**, 2685-2691. https://doi.org/10.3382/ps.2007-00170

[7] Salawu Ganiyat, I.R. (2020) Design of a Portable Solar Powered Solar Incubator. *International Journal of Engineering and Advanced Technology*, **9**, 2366-2369.

[8] Ipek, A., Sahan, U. and Sozcu, A. (2015) The Effects of Different Eggshell Temperatures between Embryonic Day 10 and 18 on Broiler Performance and Susceptibility to Ascites. *Revista Brasileira de Ciência Avícola*, **17**, 387-394. https://doi.org/10.1590/1516-635x1703387-394

[9] Mansaray, K.G. and Yansane, O. (2015) Fabrication and Performance Evaluation of a Solar Powered Chicken Egg Incubator. *International Journal of Emerging Technology and Advanced Engineering*, **5**, 31-36.

[10] Mohlalisi, S., Koetje, T. and Thamae, T. (2024) Design and Development of an Artificial Incubator. *Smart Agricultural Technology*, **7**, Article ID: 100387. https://doi.org/10.1016/j.atech.2023.100387

[11] Oke, O.E., Oyelola, O.B., Iyasere, O.S., Njoku, C.P., Oso, A.O., Oso, O.M., *et al.* (2021) In Ovo Injection of Black Cumin (Nigella Sativa) Extract on Hatching and Post Hatch Performance of Thermally Challenged Broiler Chickens during Incubation. *Poultry Science*, **100**, Article ID: 100831. https://doi.org/10.1016/j.psj.2020.10.072

[12] Yuhendri, M., Risfendra, Muskhir, M. and Hambali (2020) Development of Automatic Solar Egg Incubator to Increase the Productivity of Super Native Chicken Breeds. *Journal of Physics*: *Conference Series*, **1594**, Article ID: 012033. https://doi.org/10.1088/1742-6596/1594/1/012033

[13] Molenaar, R., Reijrink, I., Meijerhof, R. and Van den Brand, H. (2010) Meeting Embryonic Requirements of Broilers Throughout Incubation: A Review. *Revista Brasileira de Ciência Avícola*, **12**, 137-148. https://doi.org/10.1590/s1516-635x2010000300001

[14] Reyna, K.S. and Burggren, W.W. (2012) Upper Lethal Temperatures of Northern Bobwhite Embryos and the Thermal Properties of Their Eggs. *Poultry Science*, **91**, 41-46. https://doi.org/10.3382/ps.2011-01676

[15] Germain Wende Pouiré Ouedraogo, B. K. (2022). thermal simulation of a flat panel solar incubator for hen eggs. International journal of engineering science & re-search technology.