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Solar-Powered Egg Incubation: A Smart Step Towards Sustainable Poultry Farming

*A. Aruljothi[1] and Er. S. Barath Karthick[2]
[1]UG Scholar, Final Year, B. Tech – Poultry Technology (2023-2024 Batch), College of Poultry Production and Management, Hosur, Tamil Nadu, India
[2]Assistant Professor, Dept. of Food Business Management, College of Poultry Production and Management, Hosur, Tamil Nadu, India
*Corresponding Author's email: aruljothi123778@gmail.com

Successful poultry production begins with healthy chicks and egg incubation plays a major role in achieving good hatchability and chick quality. Conventional electric incubators maintain the temperature, humidity and ventilation required for embryo development (Adame & Ameha, 2023), but unreliable electricity can interrupt the incubation process, particularly in rural areas (Okonkwo et al., 2024). A solar-powered egg incubator offers an alternative by using sunlight to generate electricity for incubation. When combined with battery storage and automatic control systems, it can provide power during periods without sunlight and help to maintain suitable incubation conditions (Ullah et al., 2026). The addition of Internet of Things (IoT) technology further allows farmers to monitor temperature and humidity remotely (Pawar et al., 2026). This technology has potential for small-scale poultry farmers and rural hatcheries seeking energy-efficient and sustainable methods of chick production (Nadya et al., 2025).

Components and their functions

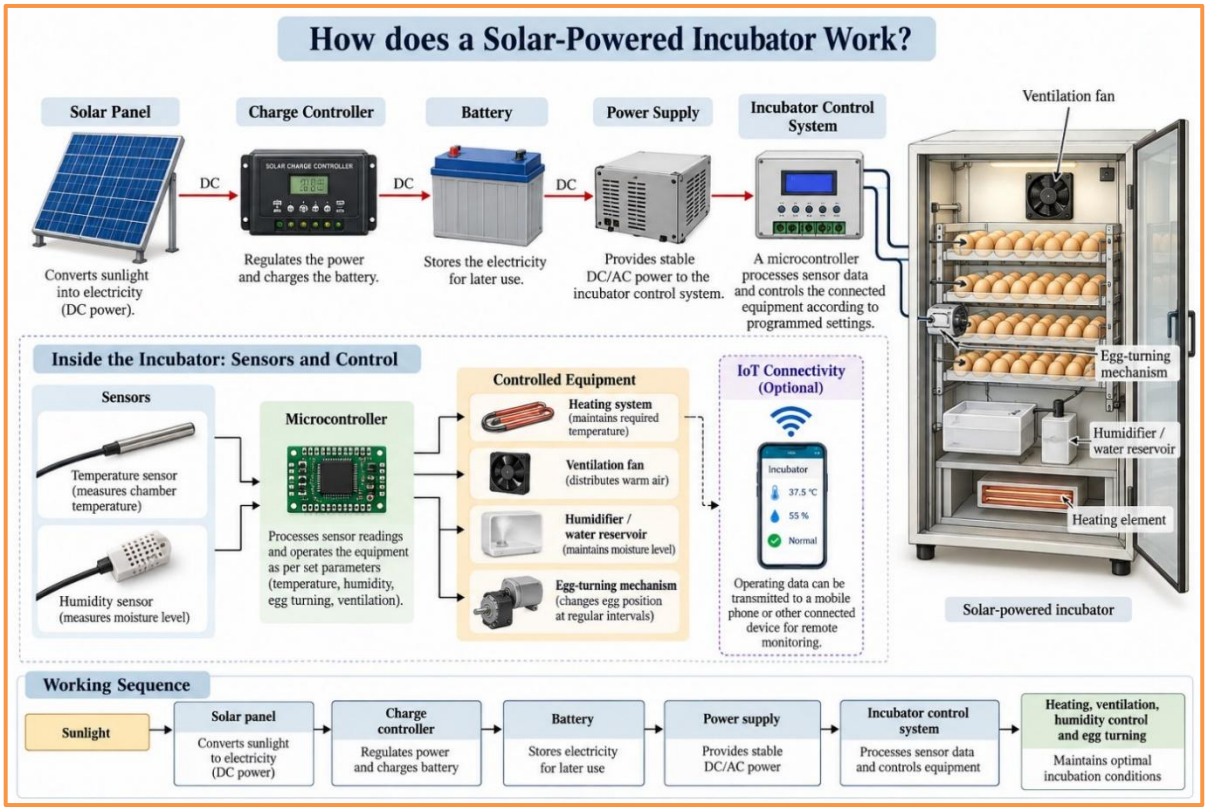
A solar-powered incubator consists of a solar power unit, an incubation chamber and a control system. Each component contributes to maintaining the conditions required for embryo development.

Component	Function
Solar photovoltaic panel	Converts sunlight into electrical energy.
Battery	Stores electricity for use at night or during periods of low sunlight.
Charge controller	Regulates battery charging and helps protect the battery.
Inverter	Converts DC electricity into AC electricity when required by the equipment.
Heating element	Provides the heat needed for incubation.
Thermostat and temperature sensor	Monitor and regulate the temperature of incubation chamber.
Humidity sensor or hygrometer	Measures the relative humidity inside the incubator.
Humidifier or water reservoir	Helps maintain the required humidity.
Ventilation fan	Circulates air and helps distribute heat uniformly.
Egg trays and turning mechanism	Hold eggs and turn them periodically during incubation.
Microcontroller	Processes sensor readings and controls connected equipment.
Display and IoT system	Displays operating conditions and supports remote monitoring in connected models.
Insulation material	Reduces heat loss and helps maintain stable conditions.

How does a solar-powered incubator work?

The solar panel converts sunlight into electricity, which passes through a charge controller to charge the battery (Cheepati & Balal, 2024). The stored energy supplies the incubator's heating, ventilation, humidity-control and egg-turning systems. Temperature and humidity sensors continuously measure the conditions inside the chamber. In an automated incubator, a microcontroller processes these readings and operates the connected equipment according to programmed settings. The ventilation fan distributes warm air, while the humidifier or water reservoir helps maintain moisture. The egg-turning mechanism changes the egg position at regular intervals. In IoT-enabled models, operating data can be transmitted to a mobile phone or another connected device, allowing farmers to observe the incubator without constantly opening the chamber (Yanti et al., 2022).

Working sequence: Solar panel → Charge controller → Battery → Power supply → Incubator control system → Heating, ventilation, humidity control and egg turning.



Maintaining suitable incubation conditions

The temperature, humidity, ventilation and egg-turning schedule must be properly managed throughout incubation. For chicken eggs, a typical forced-air incubator operates at approximately 37.5°C (Tona et al., 2022), although the correct setting depends on the incubator design and the manufacturer's or breeder's recommendations.

Parameter	General guideline	Importance
Temperature	Approximately 37.5°C in a typical forced-air incubator (Yalçın et al., 2022)	Supports normal embryo development.
Relative humidity during the first 18 days	Commonly around 50–60% (Adame & Ameha, 2023)	Supports appropriate moisture loss from the egg.
Relative humidity during the final three days	Commonly around 65–70% (Adame & Ameha, 2023)	Helps prevent the membranes from drying during hatching.
Egg turning	Regular turning during the first 18 days	Supports embryo development and helps prevent adhesion to the shell

Parameter	General guideline	Importance
		membranes. (Sarnella et al., 2024)
Ventilation	Adequate throughout incubation	Supplies oxygen and removes carbon dioxide and excess heat. (Malembeka & Kanyanga, 2025)
Incubation period	Approximately 21 days for chicken eggs (Sarnella et al., 2024)	Represents the usual incubation period before hatching.

These are general operating guidelines. Temperature should be measured at egg level, and sensors should be calibrated to ensure reliable readings.

Development of solar-powered incubator systems

Two practical approaches have been demonstrated for solar-powered egg incubation: an automated IoT-controlled system and an incubator constructed using locally available materials. (Abutu et al., 2025; Malembeka & Kanyanga, 2025). The IoT-controlled design used an insulated chamber measuring 620 × 500 × 500 mm, with a capacity of approximately 110 eggs. It incorporated three 15 W LED bulbs for heating, a 5 V DC ventilation fan, an ultrasonic mist maker, an ESP32 microcontroller, a DHT11 temperature and humidity sensor, an LCD display and an automatic egg-turning mechanism. The trays were programmed to turn every six hours. Its solar power system included a 300 W solar panel, a reported 12 V, 350 Ah battery, a 1 kW inverter and a charge controller. The combination of solar energy, automated control and remote monitoring was intended to support small-scale poultry production where electricity is unreliable. A second design focused on local construction and simpler equipment. It used a mild-steel frame, a wooden cabinet, a 100 W filament bulb, a 12 V, 75 Ah battery, a solar panel, a 500 W inverter, an automatic controller, a ventilation fan, a water reservoir and motor-driven egg trays. The incubator was designed for up to 120 eggs, with two trays holding 60 eggs each. These designs illustrate how solar incubation can be developed using different heating systems, construction materials and levels of automation.

Important performance findings

The automated incubator was evaluated using eggs stored for approximately one day and four days. Four incubation temperatures—36°C, 37°C, 38°C and 39°C—were tested. Relative humidity was maintained at approximately 60% during the first 18 days and 65% during the final three days. Egg turning was performed every six hours during the first 18 days, and candling was carried out on day 10.

The detailed hatchability results were as follows:

Incubation temperature	Hatchability of eggs stored about one day	Hatchability of eggs stored about four days
36°C	76%	72%
37°C	78%	74%
38°C	**80%**	74%
39°C	78%	70%

The highest reported hatchability for eggs stored for approximately one day was 80% at 38°C. For eggs stored for approximately four days, the highest value was 74% at both 37°C and 38°C. Hatchability declined at 39°C, particularly for the older eggs. Fertility rates in the present trial ranged from 84% to 88%. During a 24-hour no-load test, the automated incubator maintained average conditions of approximately 37.5°C and 62% relative humidity. This provided preliminary evidence of its ability to maintain operating conditions, although further testing is needed to establish temperature uniformity and performance under changing weather conditions. The second incubator was evaluated using only six eggs, despite having a designed capacity of 120 eggs. The recorded temperature ranged from 37.1°C to 38.0°C, while relative humidity ranged from 50.6% to 56%. Four eggs were fertile, and three chicks hatched. This corresponded to approximately 67% fertility and 75% hatchability among

fertile eggs. The results of the two systems should not be compared directly because their experimental methods and sample sizes differed. The six-egg trial provides only preliminary evidence and cannot establish the commercial performance of the larger design.

Economic considerations

Solar-powered incubation may reduce dependence on grid electricity (Nadya et al., 2025), but the actual cost-effectiveness depends on the solar system, battery capacity, maintenance and number of chicks successfully produced. The automated incubator study reported the following economic estimates, which should be checked against the full citation of that study:

Economic indicator	Reported value
Incubator construction cost	₹6,800
Solar power system cost	₹39,000
Assumed working life	10 years
Annual maintenance allowance	₹1,300
Net present worth	₹35,948.10
Internal rate of return	103.122%
Benefit–cost ratio	1.38
Assumed discount rate	10%

These values were based on the study's economic assumptions and should not be interpreted as guaranteed returns for poultry farmers. Before constructing a similar system, the actual electricity demand, solar-panel output, battery capacity, equipment prices and maintenance expenses should be verified.

Advantages for poultry farmers

Solar-powered incubators offer several potential benefits (Peprah et al., 2022):

- ***Reduced dependence on grid electricity:*** Useful in rural locations with frequent power interruptions (Peprah et al., 2022).
- ***Energy storage:*** Batteries can supply electricity during the night and periods of low sunlight, if appropriately sized (Sulanjari et al., 2025).
- ***Automation:*** Automatic egg turning and environmental control reduce repetitive manual work (Pawar et al., 2026).
- ***Remote monitoring:*** IoT-enabled systems allow farmers to observe operating conditions and identify abnormal readings (Ruswanti et al., 2026).
- ***Flexible construction:*** Different designs can use locally available materials and components (Malembeka & Kanyanga, 2025).
- ***Sustainable energy use:*** Solar power provides a renewable alternative to conventional electricity (Peprah et al., 2022).

However, these advantages depend on correct system design, installation and maintenance.

Challenges and improvements

Despite its potential, solar-powered incubation requires careful engineering. Insufficient sunlight, inadequate battery capacity, inaccurate sensors and uneven heat distribution can affect incubation conditions (Liu et al., 2026). Prolonged power interruptions may be particularly harmful because developing embryos require a stable environment (Masia et al., 2025).

Challenge	Recommended improvement
Insufficient solar energy during cloudy weather	Provide correctly sized battery storage and a suitable backup power source.
Uneven temperature inside the chamber	Improve insulation, fan placement and air circulation; check temperature at multiple egg-level locations.
Inaccurate temperature or humidity readings	Calibrate sensors against reliable reference instruments.
Excessive energy consumption	Measure actual power demand and optimise heating and insulation.

Challenge	Recommended improvement
Inadequate humidity control	Monitor humidity and adjust the humidifier or water surface as required.
Uncertain commercial performance	Conduct repeated trials using larger egg batches.
Unclear profitability	Record real equipment, maintenance and operating costs.
Limited chick-quality data	Measure hatchability, chick survival and chick quality using clearly defined methods.

Future designs could incorporate more accurate sensors, mobile alerts, automatic backup-power switching and improved insulation. Trials should also evaluate battery life, energy consumption and hatchability under different weather conditions.

Future scope in poultry farming

Solar-powered incubation can be further improved through the integration of energy-efficient heating, IoT-based monitoring, automatic alarms and better environmental control. Research can focus on comparing solar-powered and conventional incubators under equivalent conditions. Important evaluation measures include temperature stability, relative humidity, energy consumption, backup duration, fertility, hatchability of fertile eggs, chick quality and cost per chick. These measurements would help determine whether the system is suitable for small farms or larger hatchery operations.

Conclusion

Solar-powered egg incubation combines renewable energy with environmental control to address electricity-related challenges in poultry farming (Peprah et al., 2022). Automated systems can monitor incubation conditions, turn eggs and support remote observation (Pawar et al., 2026), while locally constructed models offer flexibility in design and material selection. The reported trials demonstrate promising possibilities, including hatchability of about 78% in an IoT-controlled solar incubator (Beerge et al., 2025). However, further validation is necessary because the studies had limitations in sample size, performance reporting and economic assumptions. The successful adoption of this technology will depend on accurate temperature and humidity control, reliable backup power, efficient energy use and larger-scale performance testing. With these improvements, solar-powered egg incubators could become a useful option for sustainable chick production, especially in rural areas where electricity supply is unreliable.

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