Engineering Research Express

PAPER

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To cite this article: Prem kumar T *et al* 2025 *Eng. Res. Express* **7** 035501

Engineering Research Express

RECEIVED
25 March 2025

REVISED
17 June 2025

ACCEPTED FOR PUBLICATION
20 June 2025

PUBLISHED
1 July 2025

PAPER

Temperature and humidification control studies on solar assisted egg incubator

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Keywords: air heater, greenhouse effect, humidity, solar egg incubator, temperature

Abstract

A solar-assisted egg incubator with a solar air heater, humidifier, and incubation components was developed and tested. The system was developed to provide efficient temperature and humidity control using solar energy. The incubator featured feedback control for temperature regulation through an induced draft fan at the outlet of the solar air heater. A relative humidity hygrometer sensor was included to manually control the humidifier setup. The solar air heater was designed with dual black paint-coated copper plates for double-pass airflow, an acrylic cover for greenhouse effect enhancement, and six convex lenses for concentration effects. The system successfully maintained an incubator temperature between 36.9 °C to 38.5 °C and a relative humidity of 60%–65%. The solar air heater achieved an average temperature rise of 4 °C with an average solar radiation of 403 W m^{-2}, a total heat gain of 48.3 W, and an efficiency of 77.5%. The setup was most effective for the first 18 days of incubation, while conventional incandescent lamp heating and humidification were recommended for the final three days. The developed solar-assisted incubator demonstrated effective temperature and humidity control using renewable energy. Future improvements, such as tracking mechanisms, full automation, solar photovoltaic integration, and multiple humidifiers, are recommended to enhance the system's sustainability.

Introduction

Global warming, climate change, fuel reserve depletion etc are few important reasons to avail the use of renewable energies like solar, wind, hydro energy etc Particularly due to abundance availability in the tropical regions, solar energy can be harnessed for numerous applications like power production, water heating, air heating, cooking, refrigeration, distillation, drying of fruits etc (Kumar *et al* 2019, Naveen *et al* 2022, Sliti *et al* 2023, Phutane and Jhala 2024). One of the applications where solar energy could be incorporated is egg hatching incubators.

Egg hatching incubators are essential in the field of poultry-farming due to the ability of simultaneous hatching of several eggs, something that is not possible in the natural process. These are machines that efficiently hatch eggs by supplying the appropriate environment and conditions for incubation. Until they hatch, such criteria are to be continuously upheld. Hatching spaces are given the right amount of humidity and temperature and ventilation is also to mimic the natural environment (Okonkwo *et al* 1993, Bolaji 2008). With the use of solar collectors, the incubation temperature may be reached using a renewable energy source from the sun. The operational costs, environmental sustainability and portability of switching from non-renewable to renewable energy sources might all be significantly enhanced where the access to conventional power may be restricted. Furthermore, solar-powered incubators with many sensors provide simple parameter control.

Evans *et al* (1998) developed solar powered incubator for wild life conservation integrated with auxiliary heating system. King (2011) fabricated and tested a solar poultry egg incubator with a capacity of 100 eggs to assess its efficiency. The average outlet collector temperature during the incubation stage was 72.4 °C on the day with the maximum sun radiation and 51.8 °C on the day with the least solar radiation with a collector thermal efficiency of 68.7%. Incubating chamber was maintained between the temperature range of 37 °C to 39.5 °C. Using both forced and natural convection, the thermal performance of the solar heater was assessed in four distinct configurations by Saxena *et al* (2013). When compared to traditional solar air heaters using both forced and natural convection, the thermal performance of all innovative designs was shown to be superior. Abraham *et al* (2014) proposed a novel method for designing solar poultry incubators that may be used to hatch eggs using photovoltaic cells, therefore minimizing power consumption and optimizing the use of solar electricity, a sustainable energy source. Incubator power consumption was reduced by 75% by using solar energy with a profitable design, which may lead to a breakthrough in this industry. Mansaray and Yansaneh (2015) aimed to assess the efficiency of a solar photovoltaic powered chicken egg incubator through design, fabrication, and testing. During the incubation period, the incubating chamber was kept at an average relative humidity (RH) of 67.3% and a temperature range of 36.8 °C to 37.9 °C. According to the data, the percentage of eggs that were fertile and hatchable were 43.3% and 23.1%, respectively.

Ramli *et al* (2015) conducted trial run experiment on quail eggs demonstrated that a steady temperature of 37.5 °C and 49.86% relative humidity (RH) were attained in the incubation chamber. Consequently, it has been demonstrated that using a conveyor rather than rotating the eggs 45 degrees can simulate natural hatching and resulted in a greater hatching rate of 94.17%. Olasunkanmi *et al* (2015) developed an egg incubator for controlling the hatching parameters using electrical system and adopted mechanical systems for changing the position of eggs up and down. With a hatchability percentage of 94 quail eggs were tested for 17 days. The system was able to maintain the required temperature and humidity during the process. Ogunwande *et al* (2015) developed an incubator powered by biogas fuel which maintained an incubator temperature in the range of 36–39.4 °C. Water pans were set on the incubator floor to obtain the desired relative humidity range of 50%–70%. Thirty chicken eggs were used in each of the three incubation attempts. The hatchability (efficiency) of the machine was 59.7%, whereas 23.9% of the viable eggs were unhatched and 17.9% died at the embryonic stage, according to the data.

Kyeremeh and Peprah (2017) designed and constructed an incubator using a heat source through incandescent bulb to hatch 14,000 quail eggs. Relays are used in the Arduino microcontroller-based incubator system to regulate the air circulation fans, heaters, and tray-turning mechanism. Agbo *et al* (2018) used solar energy to provide heat energy for egg hatching during day time and to run PV system to charge batteries to provide power during night to maintain the temperature inside the incubator at 37 °C. The incubation chamber, control system, and solar powered system were the key components of the solar powered chicken egg incubator that was constructed by Osanyinpeju *et al* (2018) for 150 eggs. The hatchability of the viable eggs collected was 44%, but the fertility of the loaded eggs was 64%. In order to boost the output of super native chicken seedlings raised in Nagari Salareh Aia, an automated egg incubator was suggested by Yuhendri *et al* (2019). With eight 5-Watt incandescent light bulbs serving as the heater, this egg incubator has the capacity to house 200 chicken eggs. The outcomes of the trial demonstrated that the egg incubator has performed as expected.

Ogbu and Oguike (2019) studied viable egg's capacity to hatch which depends on a number of elements, including the egg's habitat, the laying bird, its nutrition, and the equipment used during hatchability procedures. These variables result in issues related to poor hatchability, such as premature embryonic mortality, egg rots, dead-in-shell chicks, extended pre-incubation storage, and malfunctioning incubators and hatcheries. Tiam Kapen *et al* (2020) developed an incubator system for 600 eggs with a hatching rate of 87.27% with a chamber temperature of 37.5 °C and a humidity of 45.5% after a preheating stage of 30 min. Uzodinma *et al* (2020) developed solar incubator incorporated with phase change material with a chamber temperature of 36–39 °C and relative humidity between 50 and 75% with an average egg hatchability of 62.37%. Ganiyat and Afolake (2020) fabricated solar poultry incubator which was inexpensive, lightweight, easy to operate, and requires very little maintenance. The tray tilt angle of the setup was 46.58°, and the average range of values recorded for the humidity was 56.15% with and hatching rate of 95%. Yuhendri *et al* (2020) fabricated high performance incubator setup for 200 chicken eggs with a 300 WP solar panel and 200 Ah battery for continuous electrical power. Fredrick *et al* (2021) developed a smart egg incubator which was able to hatch eggs in 21 days with systems to monitor temperature and humidity. The temperature in the system was maintained within the range of 37 °C to 39 °C which was the common requirement of egg hatching. Considering the following factors: temperature, humidity, ventilation, and an egg turning mechanism, the incubator was initially constructed by Niranjan *et al* (2021) with the setter and hatcher combined into a single unit. It also incorporated forced air incubation and still air incubation, both of which were controlled by a controller.

Rahman *et al* (2022) simulated the incubator system in MATLAB using fuzzy PID control, which has improved the temperature increase and settling times in comparison to the traditional egg incubator. There was

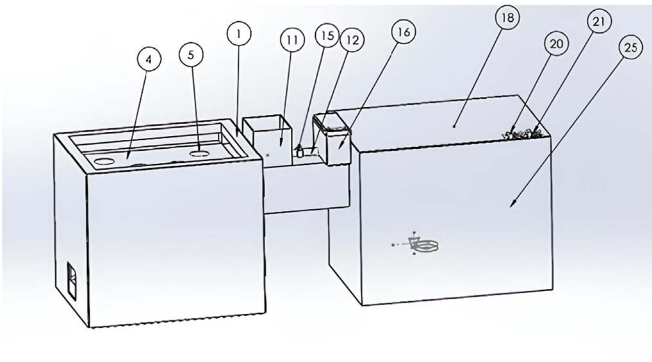

Figure 1. Schematic view of overall setup of the solar assisted egg incubator.

a significant reduction in power usage (974 W) and power bill savings over a period of 21 days. Energy efficiency of this system is demonstrated via calculations. Peprah *et al* (2022) constructed a novel egg incubator that runs on energy from a stand-alone solar system. The developed incubator underwent a number of tests to assess its functionality. Hatchability percentages were 97.14%, 95.45%, 95.64%, and 95.24% were noted. Suresh *et al* (2022) suggested the optimum temperature for egg hatching from 37 °C to 38.9 °C and multiple movements of eggs along with appropriate humidity. Muleta (2023) evaluated the performance of incubator with a heat storage system and observed a hatchability percentage of 27% for the temperature range of 36.5 to 39.5 °C inside the incubator chamber. Okonkwo *et al* (2024) identified the energy sources used in the incubation of chicken eggs and calculated the hatchability rate of the incubators based on the energy source employed. The studies evaluated, 50% of them recognized grid-supplied electricity as the energy source for hatchability, which ranged from 80.9% to 98.39% for chicken eggs. The unpredictable nature of power supply and non-existent in rural regions, particularly in developing countries, strongly suggested that further research has to be done on alternative energy sources (Al-Hashmi *et al* 2025, Borerwe and Longe 2025, Singh *et al* 2025, Srivastava 2025) to make them more viable. Egg incubators are very critical in providing sustainable solutions for modern day requirements in meeting the growing demand gap of egg requirements. Much research has been done in meeting optimum temperature, humidity, egg rotation and ventilation of egg incubators along with novel design and automation control. Few researchers have integrated solar energy with egg incubators mainly in the form of photovoltaics which can provide an energy source to maintain incubator temperature and relative humidity (Ikpeseni *et al* 2022, Sleem *et al* 2024) Very few have concentrated on the solar air heater integration with egg incubators which can provide simplicity, better thermal efficiency and cost effectiveness. Hence the present study focuses on the temperature and humidification control of the solar assisted incubator.

Material and fabrication

Solar air heater with humidifier and incubator setup was fabricated with locally available, low cost materials to get the quicker break even period. Figure 1 describes the overall setup of the solar assisted egg incubator. Figure 2 describes the exploded view of solar assisted egg incubator. Figure 3 depicts the illustration of solar air heater part.

Solar assisted egg incubator contained three main segments namely solar air heater, humidifier and incubator setup. The output of the solar air heater was fed to the humidifier and the final output was given to the incubator setup. Solar air heater composed of wooden frame which was covered with five mica sheets with internally covered aluminium sheets to promote multiple reflections. The front mica sheet contains inlet suction port at the bottom segment.

Solar air heater comprised of upper and lower copper plates arranged horizontally with annular gap such that sucked air has two passes and touches the copper plates along the flow. Copper plates were coated with black paint (Asian bituminous paint with composition of bitumen, solvents and additives with absorptance of 0.93 and emittance of 0.9) to increase the absorptivity of it and hence better heat transfer occurs. Solar air heater comprised of top transparent acrylic sheet to promote greenhouse effect and hence multiple reflection of transmitted solar radiation is feasible inside the solar air heater component. Acrylic sheet held six convex lenses and hence it concentrated solar radiation to the focal point where copper plates are positioned. Different focal point convex lenses were allotted to take care of plurality of copper plates as it was positioned horizontally at different distance from acrylic sheet. Concentration of solar radiation helped to attain higher temperature by copper plates.

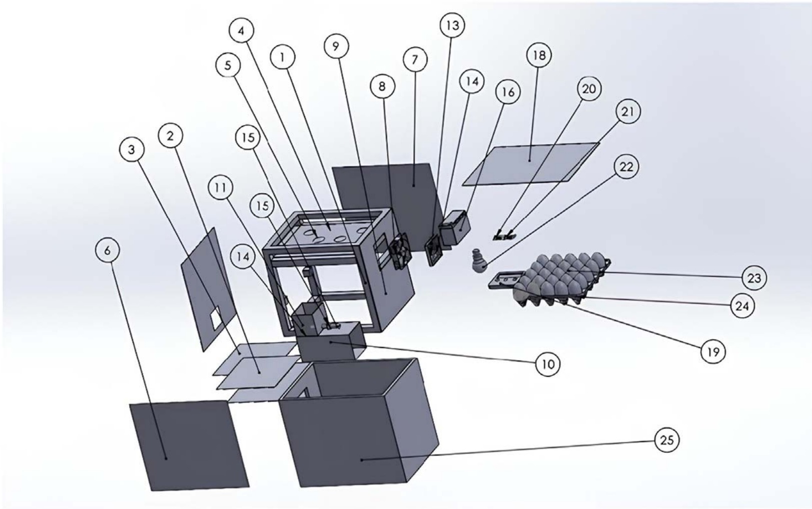

Figure 2. Exploded view of solar assisted egg incubator.

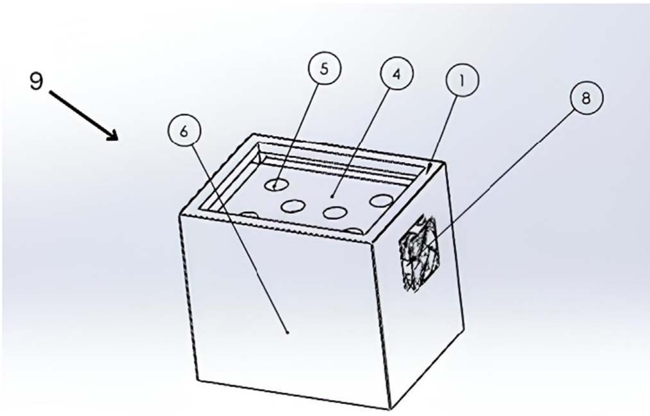

Figure 3. Schematic view of the solar air heater part.

Solar air heater contained the induced draft fan powered by battery at the outlet to create negative pressure inside the heater to suck the air from atmosphere. The hot air was pushed to the duct of the humidifier. Figure 4 depicts the humidifier part of the incubator setup. Hot air from solar air heater was paved through the humidifier segment which contains the water tank where water is stored and connected with water nozzle fixed in a frame provided with control valve. Control valve was operated manually based on the feedback of relative humidity of incubator box. Humidifer was designed to handle 0.0243 kg s^{-1} of moist air which contains 0.0055 kg s^{-1} of dry air and 0.0187 kg s^{-1} of pure water considering atmospheric temperature of 33 °C, 33% relative humidity to required condition of 37 °C, 60% relative humidity. The designed moisture was 10 grams of moisture per kg of dry air. Considering 7 h of operation, the tank was designed with 7 litre capacity.

Figure 5 depicts the view of incubator parts. Incubator receives hot and humid air from the humidifier set up. Incubator was covered with lateral surfaces of incubator box and top acrylic cap which contains eggs on egg holder for hatching. It was also provided with conventional incandescent bulb working based on thermostat sensor 2 to take care of chamber temperature during non-sunshine hours. It also contained thermostat sensor 1 which gave feedback to solar air heater fan. It also contained hygrometer which gives relative humidity feedback to control the control valve of humidifier manually.

Solar assisted egg incubator contained solar air heater where the air was sucked with the help of induced draft fan through the inlet port in the outer box of solar air heater. The solar air heater comprised of black coated copper plates which was heated by concentrated solar radiation due to the plurality of convex lenses which was placed such that the position of its focal point was exactly occupied by copper plates. Multiple reflection of solar radiation on the copper plates was achieved by green-house effect with the help of transparent acrylic sheet

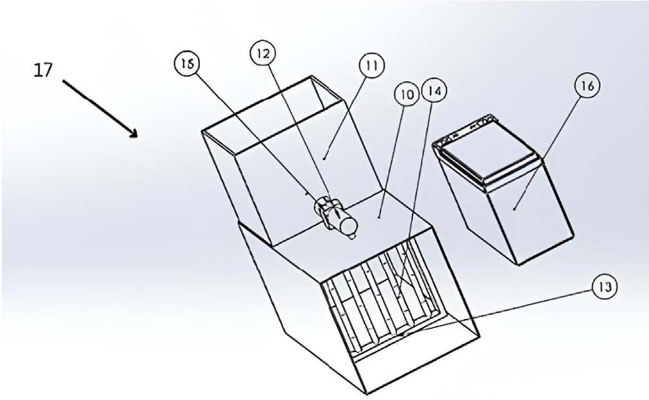

Figure 4. Schematic view of the humidifier part.

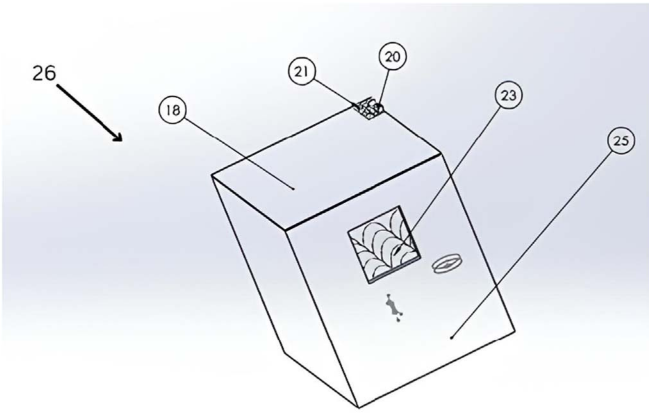

Figure 5. Schematic view of the incubator component.

Table 1. Parts of the solar assisted incubator.

1. Outer frame	15. Control valve
2. Lower copper plate	16. Battery
3. Upper copper plate	17. Humidifier
4. Acrylic sheet	18. Top acrylic cap
5. Convex lenses	19. Hygrometer
6. Mica sheets	20. Thermostat sensor 1
7. Aluminium sheets	21. Thermostat sensor 2
8. Induced draft fan	22. Conventional incandescent bulb
9. solar air heater	23. Eggs
10. Duct	24. Egg holder
11. water tank	25. Lateral surface of Incubator box
12. Outlet pipe	26. Incubator
13. Outer frame	27. Solar assisted egg incubator
14. Vertical water frames with nozzles	

which houses the plurality of convex lenses too. The black coated copper plate arrangement along with convex lenses housed transparent sheet heats air by convection. Table 1 includes the parts of solar assisted incubator.

Hot air was sent to humidifier set up where the water was sprayed using tank and nozzle setup to provide hot humid air suitable for hatching eggs. Incubator set up was provided with conventional incandescent bulb to

Figure 6. Experimental setup of the present study.

Table 2. Specifications of Sensor module XHM452.

Specification	Description
Type	XHM452 (Sensor SHT20)
Input voltage	12-volt DC
Temperature Range, Accuracy, Control precision & Response time	−40(°C) to 120 (°C), ±0.3 °C, 0.1 °C & 8 s
Humidity Range, Accuracy, Control precision & Response time	0% to 99.9%, ±3% & 0.1% & 12 s
Temperature and humidity range	Adjustable
Temperature feedback Control	Automatic to ID fan
Humidity feedback control	Manual to control valve
Control type	Relay

provide heat during non-sunshine hours which works based on the feed-back temperature inside the incubator chamber. Incubator box was also provided with thermostat sensors to automatically control the switching pattern of induced draft fan of solar air heater part and provided with relative humidity sensor to manually control the humidity with the control valve of humidifier using the set points in the relative humidity sensor (semi-automatic). The specification of sensor module is shown in the table 2. The experimental setup and sensor module used for the present study is shown in figure 6.

The research findings and discussion

Devices like pyranometer, thermocouples, hygrometer were calibrated and used to measure the total solar radiation, temperatures at heater inlet, outlet and incubator temperature and relative humidity of incubator. An anemometer was used to measure the airflow inside the heater which was induced by induced draft fan kept at the outlet of the solar air heater part. A data logger was used to continuously record the temperatures and solar radiation readings throughout the experiment time period.

During the operation of solar assisted egg incubator, solar radiation passed through the acrylic plate of solar air heater and the black painted copper plate absorbed it. Six convex lenses were aligned in the acrylic plate to concentrate the sunlight into a copper plate, and hence the temperature raise in the copper plate will be better. This allowed the air to obtain higher temperature while exiting the solar air heater. The duct was attached into

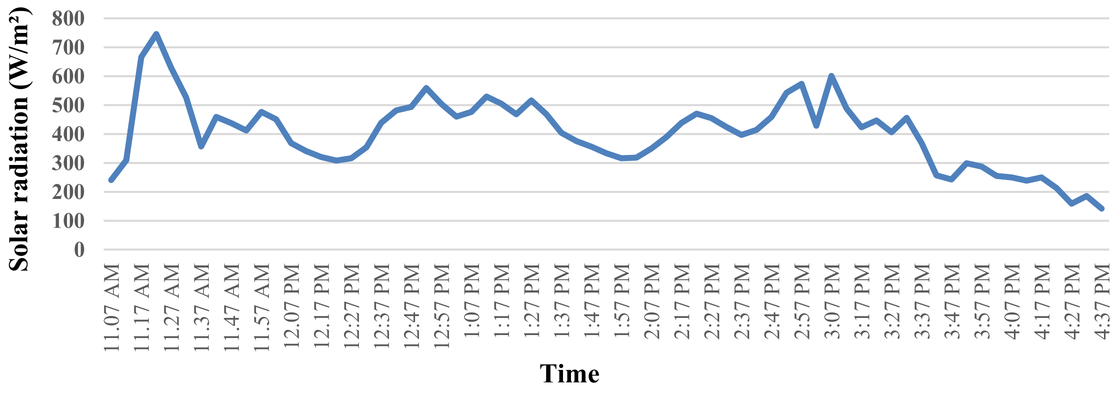

Figure 7. Solar radiation versus time.

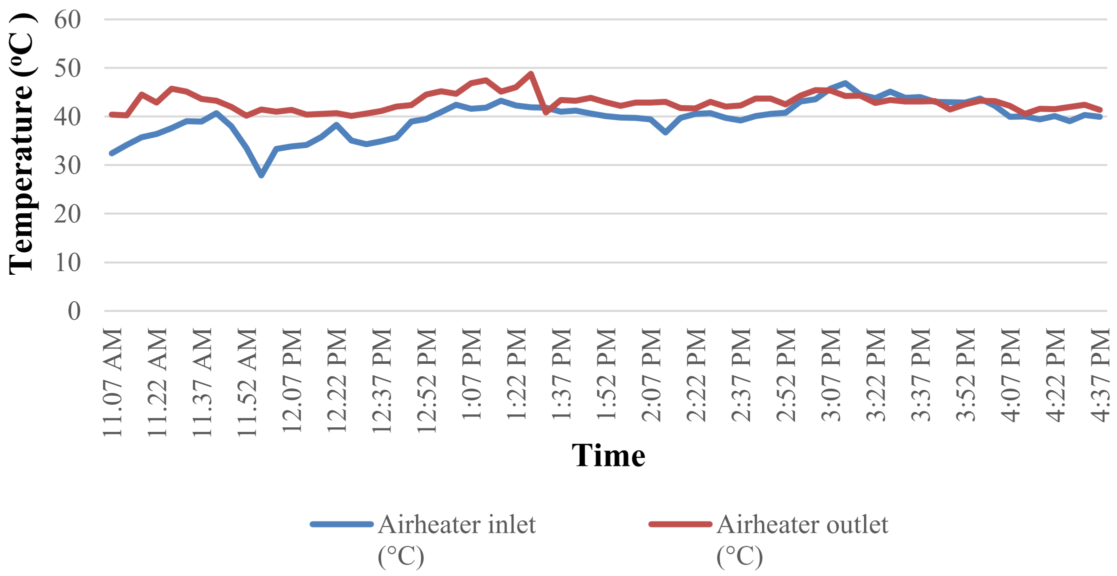

Figure 8. Air heater temperature versus time.

the solar air heater outlet, and transferring the hot air into the incubator system. This duct was connected to a humidifier setup by featuring a solenoid control valve, controlling water flow into a cotton bed within the duct.

The solenoid valve and the air heater fan has been connected in the XHM452 type sensor module to control the temperature and humidity inside the incubator. The sensor module relative humidity set point to cut-off the solenoid valve was 65% (manually operated). Then it will be switched ON when the humidity reaches 55% to increase the humidity inside the incubator. Similarly the sensor module cut-off the air heater fan when the temperature reaches 38.5 °C. The induced draft air heater fan will be switched ON when the temperature reaches 37 °C. The temperature of the air heater inlet, outlet and the incubator temperature was stored

in the data logger system, which helped to perform the efficiency calculation. The humidity of the incubator was recorded manually for every 15 min, which the humidity displaced in the sensor module.

Figure 7 indicates the effect of solar radiation throughout the day. The radiation was varied between 150 W m^{-2} to 750 W m^{-2}. As expected, the radiation was maximum near to the noon and it started to decline continuously after 3 pm. Figure 8 indicates the inlet air temperature, outlet air temperature with respect to the solar air heater with respect to time. The inlet air temperature varied from 27 °C to 46 °C whereas the outlet air temperature varied from 40 °C to 47.6 °C. One important observation which can be made is after 3.07 pm the temperature difference between outlet and inlet air was not significant. It was also noted that the plate temperature was not significant after that time period. One of the main differences observed is the shading effect of solar air heater itself and effect of convex lenses is not efficient for more non-parallel rays due to absence of tracking.

Figure 9 indicates the incubator temperature with respect to time. It was maintained by means of keeping the temperature less than the 38.5 °C with the help of feedback from the thermostat sensor kept inside the incubator

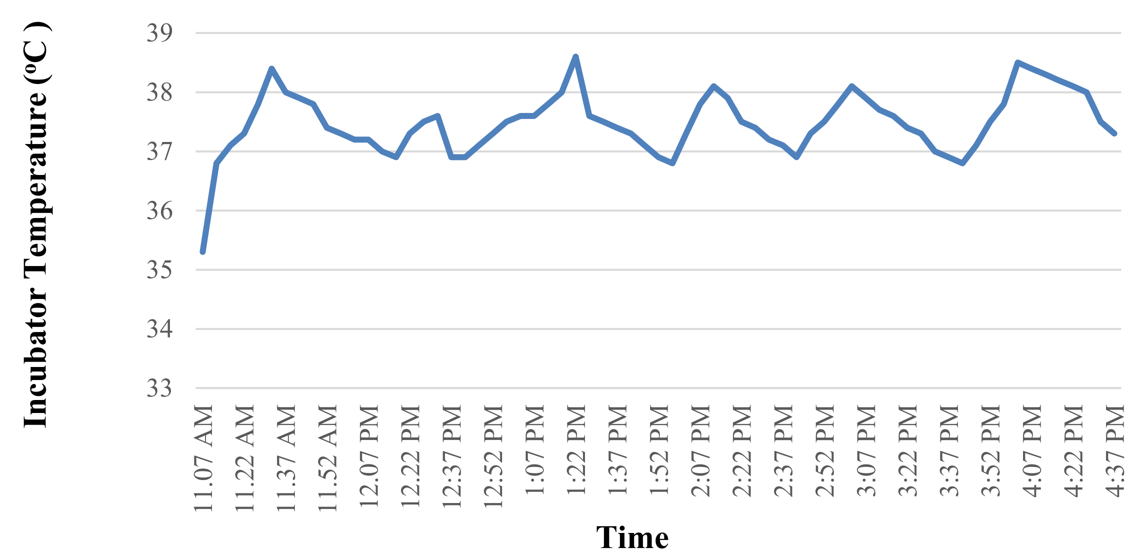

Figure 9. Air heater temperatures versus time.

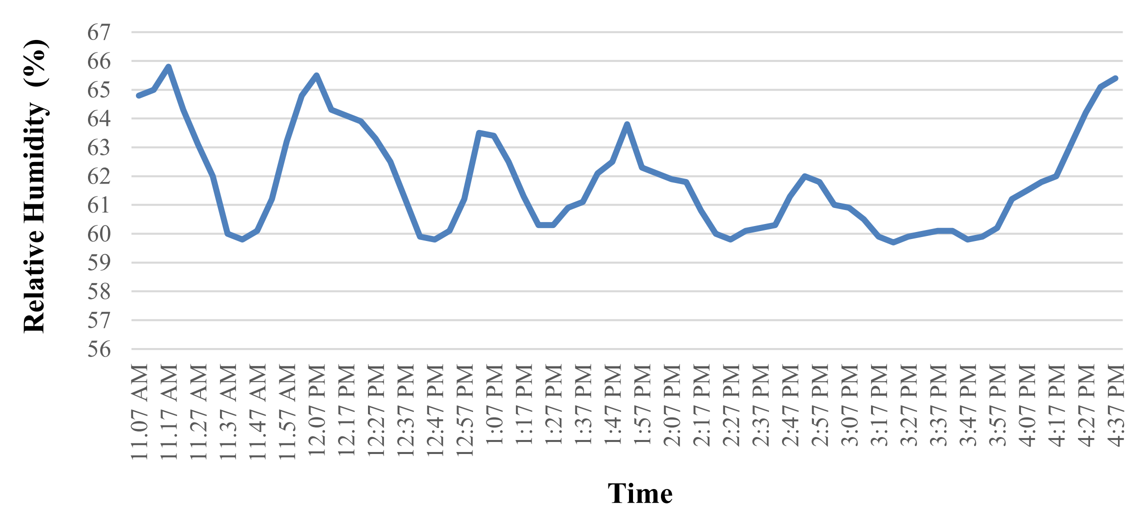

Figure 10. Humidity versus time.

box. The incubator temperature depends on various factors but mainly depends on the humidity and outlet air temperature. Its dependency with respect to various factors needs to be addressed in the future work. Figure 10 indicates the incubator relative humidity with respect to time. The incubator humidity was well maintained within the 65% which is sufficient for initial days of incubation. The hygrometer feedback from the sensor was used to regulate the control valve from the tank and hence relative humidity can be varied. The present humidity control feedback was semi-automatic (manually controlling the control valve based on the feedback from humidity sensor and its set points) and fully automated control valve will be installed in the future.

The efficiency of the solar air heater was found out with the help of average parameters throughout the day as shown in table 3 with the help of equations (1)–(3).

$$\text{Efficiency of solar air heater}(\eta) = \text{Total heat gain by air/Total Inlet heat} \quad (1)$$

$$\text{Total Inlet Heat} = \text{Inlet aperture Area} \times \text{Average Solar Radiation} \quad (2)$$

$$\begin{aligned}\text{Total heat carried by air} = {} & \text{Density of air} \times \text{Outlet duct area} \times \text{Average velocity} \\ & \times \text{Specific heat at constant pressure} \\ & \times \text{Change in temperature}\end{aligned} \quad (3)$$

Considering the aperture area of 0.12 m^2 ,the total input heat gained by solar energy is 37.5 W with average solar radiation of 403.3 W m^{-2} . Considering the outlet duct area of 0.014 m^2, average air velocity of 0.725 m s^{-1}

Table 3. Performance of the solar air heater.

Outlet duct area (m^2)	Average air velocity (m/s)	Average mass flow rate (kg/s)	Average inlet air temperature (°C)	Average outlet air temperature (°C)	Average solar radiation (W/m^2)	Total Input heat (W)	Total heat carried by air (W)	Solar air heater efficiency (%)
0.0144	0.725	0.0113	39.6	42.9	403.3	48.3	37.5	77.55

(mass flow rate of 0.0113 kg s^{-1}), average inlet air temperature of 39.6 °C and outlet temperature of 42.9 °C, the total heat carried by air was 48.3 W with the heater efficiency of 77.5%. Although the heater efficiency is high, it dropped significantly after 3 pm due to the lack of tracking, which needs to be considered as future scope.

Conclusions

Design, fabrication and testing of solar air heater with humidifier for egg hatching incubator application has been adopted. As per Tamil Nadu Agricultural Poultry Department (Tamil Nadu Agricultural University 2024) the required temperature range during first 18 days of egg hatching is between 37.5 °C to 37.62 °C and during last three days the expected temperature is 36.9 °C. The present setup developed an average incubator temperature of 37.7 °C, with a range between 36.9 °C to 38.5 °C based on setpoints, feedback and control system. Given the limited expectations, more accuracy may be achieved with a narrow range of temperature settings, a higher precision control system, and a shorter reaction time, where the high cost can be offset by mass production. The advanced control system can also assist to operate during cold weather with the help of proposed conventional incandescent bulb setup.

Dedicated humidifier setup provided the moisture to increase the humidity (relative humidity of 55 to 65%) of incoming air to the incubation space. It was noted that these output parameters can be used only for the first 18 days of egg hatching. For the last three days the required level of moisture as per the poultry department (65 to 75%) has to be maintained conventionally. Multiple humidifiers can be considered in the future to take care of the last three days requirement. At present the humidifier system is provided with semi-automatic control system (thermostat with a manual operation of control valve) which has to be made complete automatic for better control. Separate air suction from atmosphere to humidifier can be explored to have better control of parameter compared to present system.

Present system can be used only during maximum sunshine hours (6 h per day) due to unavailability of the tracking system. It was highly recommended to use automatic tracking to completely utilise the benefits of the present system. The complete sustainability can be achieved by the incorporation of solar photo voltaic cells to charge the battery system during off peak hours.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

No funding is available for this work.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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