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Analysis of the Uniformity of the Temperature of a Multi-Level Egg Incubator with a Multiple Heating System

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Abstract

Aceh Province has great potential in the poultry sector, but maintaining stable egg incubation temperature in a humid tropical climate remains a major challenge. This study aims to analyze the homogeneity of temperature distribution in a multi-level incubator with a dual heating system (heater plate and incandescent lamp) under real-world conditions in Aceh. Quantitative experimental methods were used to measure temperatures at several points on four levels of the incubator rack with a capacity of 400 eggs. Variations in the number of incandescent lamps and the use of zinc plates as a conductive medium were tested to determine their effects on heat distribution and hatchability. The results showed that increasing the number of lamps and using zinc plates reduced the temperature difference between observation points, increasing the uniformity of incubation temperature with an optimal temperature range of 37°C–38°C. The egg hatch percentage reached 98% in all treatments. This study emphasizes the importance of a simple yet effective dual heating system design to maintain stable incubation temperature in a humid tropical climate. These findings contribute to the development of adaptive and sustainable incubation technology for small-scale farmers in Aceh.

A. Introduction

Aceh Province has measurable potential in the poultry sector, particularly in chicken and duck farming, as reflected in official poultry egg and meat production statistics (BPS, 2026; BPS Aceh, 2026). This subsector can contribute to animal protein supply and rural household income, especially for small- and medium-scale farmers (Alam et al., 2025). In this context, production efficiency is an important factor in maintaining the sustainability of poultry farming. One crucial stage determining production success is the egg hatching process, because hatchability directly influences the number and quality of chicks that can be raised for subsequent production cycles (Boleli et al., 2016; Lourens et al., 2005).

Successful egg hatching is greatly influenced by temperature stability and uniformity during incubation (Buranawit et al., 2025; Elliott et al., 2025). Optimal development of poultry embryos occurs within a relatively narrow temperature range. Temperature irregularities can reduce hatchability, slow embryo development, trigger abnormalities, and even cause embryo death (Pasri et al., 2025). Aceh's geographical conditions and humid tropical climate, with its high temperature and humidity fluctuations, add to the complexity of maintaining stable incubation temperatures. In practice, many farmers in Aceh use self-assembled incubators designed with cost in mind. However, these simple designs often fail to ensure even temperature distribution throughout the incubation chamber.

As production capacity demands increase, multi-tiered egg incubators have become a practical technical solution for increasing hatching capacity in limited spaces by utilizing vertical rack arrangements (Yadav et al., 2021). However, this configuration can potentially lead to differences in heat distribution between shelves due to variations in air circulation, heat source position, and the thermal interaction between the egg, surrounding air, and incubator surfaces (Boleli et al., 2016; French, 1997). Vertical temperature gradients may occur between the top, middle, and bottom shelves, resulting in unequal incubation conditions for the eggs being incubated, particularly when airflow and heating distribution are not uniform across the cabinet (Boz, 2019). This non-uniformity has direct implications for hatchability because poultry embryo development depends on stable incubation temperature, with the optimal range generally around 37°C–38°C for chicken eggs (Lourens et al., 2005; Yalçın et al., 2022). Therefore, temperature differences between shelves can contribute to variations in embryo development, hatch window, chick quality, and hatchability between incubation positions (Boz, 2019; Boleli et al., 2016).

To address heat distribution issues, a dual heating system combining a heater plate and an incandescent lamp is widely used by small-scale farmers due to its relative simplicity, cost-effectiveness, and availability locally. The heater plate serves as the primary heat source, generating stable heat radiation and conduction, while the incandescent lamp acts as a supplementary heater, helping maintain the temperature when ambient temperatures drop. Conceptually, this combination of two heat sources is expected to improve temperature homogeneity and reduce temperature differences between rack levels. However, using two heating elements in a single system can also potentially lead to imbalanced heat distribution if not properly designed and controlled. Differences in power output, installation position, and heat release characteristics of each element can cause temperature variations at specific points within the incubator.

Temperature distribution in an incubator is the result of the interaction of heat transfer mechanisms through conduction, convection, and radiation, as well as the thermal exchange between the egg, surrounding air, heat source, and incubator surfaces (French, 1997; Van Brecht et al., 2003; Boleli et al., 2016). Air flow within the incubator chamber is influenced by the position of the heat source, the configuration of the shelves, the obstruction caused by egg trays, and the air circulation system (Van Brecht et al., 2003; Mukhtar et al., 2023). Therefore, evaluating incubator performance is not sufficient by simply measuring the average temperature; it is necessary to analyze temperature uniformity at various points and shelf levels. A multipoint measurement approach and temperature variation analysis are essential for comprehensively assessing the homogeneity of heat distribution and identifying possible hot spots or cold zones inside the incubator chamber (Van Brecht et al., 2003; Cobb-Vantress, 2020).

Although extensive research on egg incubation has been conducted, significant research gaps remain. Previous studies have provided substantial evidence on the importance of incubation temperature for embryo development, hatchability, chick quality, and post-hatch performance (Decuypere & Michels, 1992; Lourens et al., 2005; Boleli et al., 2016; Yalçın et al., 2022). However, many of these studies have focused on biological responses to incubation temperature, commercial-scale incubators, or automated control systems under relatively controlled conditions. These studies do not fully reflect the real-world conditions of farm-scale incubators in humid tropical regions like Aceh, where farmers often use simple, low-cost, and locally assembled incubation systems. Furthermore, previous research has tended to focus on the effect of temperature on embryo biological performance, without in-depth analysis of the spatial distribution of temperature in simple and economical multi-level incubators with dual heating systems.

Research gaps are also evident from a methodological perspective. Few studies have systematically evaluated spatial temperature uniformity in simple multi-level incubators using statistical analysis of temperature variation between observation points, particularly in systems combining heater plates and incandescent lamps. Existing technical studies have discussed heat propagation, airflow simulation, or temperature uniformity in egg incubators, but empirical evaluation of shelf-level thermal homogeneity in simple farmer-scale incubators remains limited (Mukhtar et al., 2023). From an application perspective, design recommendations based on empirical testing results and readily adoptable by local farmers with limited resources are still very limited.

This study aims to analyze the homogeneity of temperature distribution at several observation points inside a multi-tiered incubator with a dual heating system under environmental conditions in Aceh. The main focus of the study is to evaluate the extent to which the combination of heater plates and incandescent lamps is able to minimize temperature differences within the incubation chamber and maintain stable incubation temperatures. The novelty of this research lies in a comprehensive analysis of the spatial distribution of temperature in a farmer-scale multi-tiered incubator using a quantitative approach contextualized to a humid tropical climate. This study not only tests the stability of the average temperature but also assesses spatial temperature uniformity between observation points as an indicator of the performance of the dual heating system. Thus, the research's novelty is based on the integration of simple design technical aspects, statistical analysis of temperature distribution, and the local environmental context.

This research contributes to the development of heat transfer studies in simple incubation systems. Practically, the research results are expected to yield recommendations for more optimal and adaptive heating configurations to the conditions in Aceh Province. Improving temperature uniformity has the potential to increase hatching rates, poultry productivity, and sustainable farmer income. Therefore, this research has both academic value and strong social relevance in supporting the strengthening of the poultry farming sector in the tropical region such as Aceh.

B. Method

This study uses an experimental quantitative approach to objectively analyze temperature uniformity in a multi-level egg hatching incubator with a dual heating system. This method was chosen to address issues related to heat distribution and incubation temperature stability within the optimal range of approximately 37°C–38°C required for chicken embryo development and hatchability (Lourens et al., 2005; Yalçın et al., 2022). Recent poultry incubation and embryo-related studies also emphasize that incubation conditions, breeder or egg characteristics, physiological responses, and chick quality are closely associated with hatching performance, supporting the need for controlled and measurable incubation experiments (Agbehadzi et al., 2025; Arslan et al., 2025; Bakhshalinejad et al., 2025; Barik et al., 2025; Elhussiny et al., 2025; Khani et al., 2025; Ma et al., 2025; Meijer et al., 2025; Trela et al., 2025; Wang et al., 2025; Wishna-Kadawarage et al., 2025; Zhou et al., 2025).

The research object is a single incubator measuring 120 cm × 80 cm × 125 cm with a capacity of 400 eggs divided into four shelves, each holding 100 eggs. The study was conducted in the context of a small-scale farm, taking into account humid tropical climate conditions so that the design and testing procedures can be replicated in real conditions.

Although the incubator has four rack levels with a total capacity of 400 eggs, temperature analysis in this study was based on measurements taken at four observation points inside the incubation chamber. Therefore, the reported temperature differences represent spatial variation between measurement points rather than a complete shelf-by-shelf thermal profile.

Incubators are constructed as enclosed spaces made of plywood or wood, which have low thermal conductivity, enabling them to withstand changes in ambient temperature. The heating system consists of a heating plate and an incandescent lamp placed inside the incubation chamber. The incandescent lamp serves as a radiant heat source, while the heating plate conducts heat through conduction, with subsequent distribution through air convection within the incubator. Ventilation, a water container to maintain humidity, egg racks, and thermal insulation are designed to support stable incubation conditions. The temperature is regulated using a thermostat within a range of 37°C–38°C.

Measurements were taken using digital thermometers and tube thermometers at several points on each shelf, a hygrometer to monitor humidity, and a stopwatch to record the observation time. Temperature data was recorded periodically to obtain an overview of the spatial and temporal temperature distribution. Analysis was performed by calculating the average, deviation, and temperature difference between shelves to determine the level of heat homogeneity based on the principles of conduction, convection, and radiation.

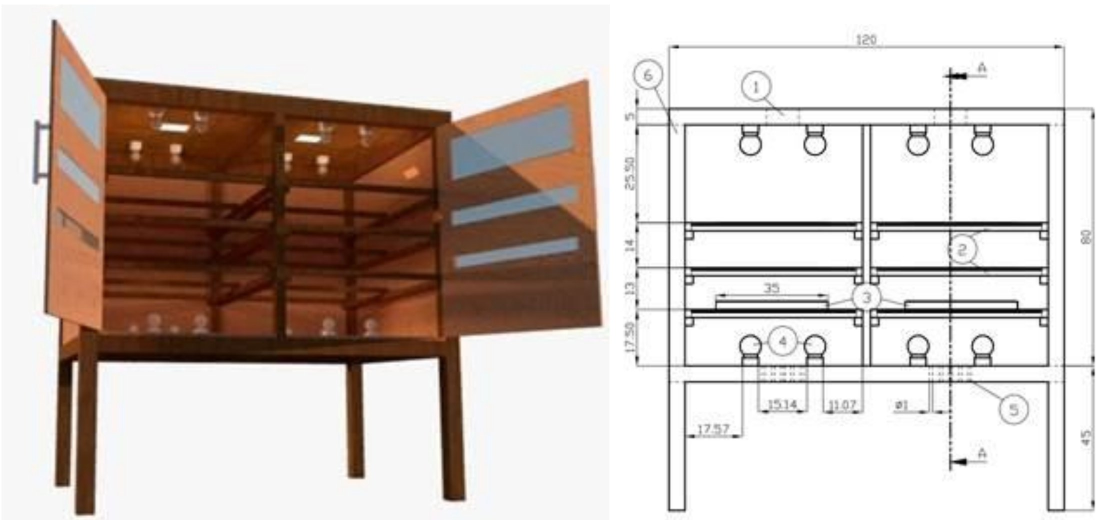

Figure 1. Research Equipment Design

Figure 1 shows the main components of an egg incubator. Number (1) indicates the upper air vent that regulates circulation and maintains temperature stability in the incubation chamber. Number (2) is the egg rack where the eggs are arranged to achieve even heat distribution. Number (3) is the water container to maintain humidity during the incubation process. Number (4) indicates the incandescent lamp or heating plate as the main heat source. Number (5) is an additional air vent that helps distribute air evenly, while number (6) is the thermal insulation on the incubator wall to reduce heat loss and maintain a stable temperature.

This approach integrates engineering and animal science, taking into account local environmental and economic conditions, making it interdisciplinary. The systematic and measurable procedures allow for replication of the research and serve as a basis for evaluating the performance of multi-level incubators with dual heating systems.

C. Results and Discussion

1. Results

The data in Table 1 shows a change in temperature difference (°C) along with variations in the number of incandescent light bulbs. In conditions without the use of zinc plates under the lamps, the temperature difference measured at four observation points for 4 light bulbs was 0.8°C. When the number of light bulbs was increased to 8, the temperature difference decreased to 0.5°C, and at 12 light bulbs the temperature difference was recorded at 0.3°C.

Table 1. Test results between the number of light bulbs and temperature difference (°C) with or without using a zinc plate under the lamp.

No	Number of light bulbs	Temperature difference (°C) without using a zinc plate under the lamp	Temperature difference (°C) by using a zinc plate under the lamp
1	4	0.8	0.7
2	8	0.5	0.4
3	12	0.3	0.2

When using zinc plates under the lamps, a decreasing temperature difference pattern was also observed. For four lamps, the temperature difference was 0.7°C. When the number of lamps increased to eight, the temperature difference was recorded at 0.4°C, and at 12 lamps, it dropped to 0.2°C. These data indicate that for each variation in the number of lamps, the use of zinc plates resulted in a smaller temperature difference compared to the use without zinc plates. In general, increasing the number of light bulbs from 4 to 12 correlated with a decrease in the temperature difference within the incubator. Furthermore, with the same number of bulbs, the condition with the zinc plate showed a lower temperature difference than the condition without the zinc plate.

Table 2. Test results between the number of holes in the zinc plate and the temperature difference (°C) with or without using a zinc plate under the heating plate.

No	Number of holes in the zinc plate under the heating plate	Temperature difference (°C) without using a zinc plate under the heating plate	Temperature difference (°C) by using a zinc plate under the heating plate
1	1	0.8	0.7
2	3	0.6	0.5
3	5	0.5	0.4
4	7	0.4	0.3
5	9	0.3	0.2

The data in Table 2 shows that the temperature difference was carried out by varying the number of holes in the zinc plate placed under the heating plate. The variations in the number of holes tested were 1, 3, 5, 7, and 9 holes. In conditions without a zinc plate under the heating plate, the temperature difference for 1 hole was recorded at 0.8°C. When the number of holes was increased to 3, the temperature difference decreased to 0.6°C. At 5 holes, the temperature difference was 0.5°C, at 7 holes it was 0.4°C, and at 9 holes it reached 0.3°C.

When using a zinc plate under the heating plate, the measured temperature difference showed a lower value for each variation in the number of holes. For 1 hole, the temperature difference was 0.7°C. At 3 holes, it dropped to 0.5°C, at 5 holes to 0.4°C, at 7 holes to 0.3°C, and at 9 holes to 0.2°C. These data indicate that increasing the number of holes in the zinc plate is associated with a decrease in the measured temperature difference between observation points. Furthermore, for each variation in the number of holes, the condition with the zinc plate resulted in a smaller temperature difference than the one without it.

Temperature measurements were taken at four points: T1 (a digital thermometer under an incandescent lamp), T2 (a digital thermometer in the center of the incubator), T3 (a digital thermometer in another central position), and T4 (a digital thermostat under an incandescent lamp). In all treatment variations, the incubator's operating temperature was controlled within a range of 37°C to 38°C according to the thermostat setting.

Observations showed that the incubator took 1 minute to reach its highest temperature of 38°C after being turned on. Meanwhile, after the incandescent lamp was turned off, the temperature dropped from 38°C to 37°C in 3 minutes. This pattern was consistent across all variations in the number of light bulbs and zinc plate configurations tested.

The temperature difference between observation points in each treatment is reflected in the temperature difference values presented in Table 1. In variations with a higher number of lamps and a greater number of zinc plate holes, the range of temperature differences between points tends to be smaller than other variations.

Table 3. Percentage of hatching (%) of poultry eggs on light bulbs with or without using a zinc plate under the lamp.

Testing	Number of Eggs	Number of Hatches	Hatch Percentage (%)
Without zinc plate under the lamp	50	49	98
With zinc plate under the lamp	50	49	98

The data in Table 3 shows the egg hatch percentages under two conditions: without a zinc plate under the lamp and with a zinc plate under the lamp. Fifty eggs were used in each treatment, resulting in a total of 100 eggs tested.

In conditions without a zinc plate under the lamp, 49 of the 50 eggs incubated hatched successfully, resulting in a hatching percentage of 98%. In conditions with a zinc plate under the lamp, 49 of the 50 eggs tested also hatched successfully, resulting in a hatching percentage of 98%. Thus, the hatching percentage for both treatments was the same, at 98%. Based on the data obtained, there was no difference in the number of hatched eggs between the treatments without zinc plates and with zinc plates.

Overall, the data shows that variations in the number of light bulbs and the number of holes in the zinc plate are related to changes in the temperature difference value inside the incubator room. An increase in the number of light bulbs from 4 to 12 units is followed by a decrease in the temperature difference from 0.8°C to 0.3°C in conditions without zinc plates, and from 0.7°C to 0.2°C in conditions with zinc plates. Similarly, an increase in the number of holes from 1 to 9 holes is followed by a decrease in the temperature difference from 0.8°C to 0.3°C without zinc plates, and from 0.7°C to 0.2°C with zinc plates.

Measurements of the temperature rise and fall times showed a consistent thermal response, with a time of 1 minute to reach 38°C and 3 minutes to return to 37°C. The percentage of egg hatching in both treatment conditions was recorded at 98%, with 49 out of 50 eggs hatching in each treatment.

2. Discussion

Within the framework of heat transfer theory, temperature homogeneity in an enclosed space is influenced by the interaction of conduction, convection, and radiation (Incropera et al., 2011). In egg incubators, these mechanisms interact with airflow patterns, tray configuration, heat source position, and heat exchange between the eggs and the surrounding air, so air temperature is not always uniformly distributed throughout the chamber (Van Brecht et al., 2003). In the present system, incandescent lamps act as radiant heat sources, while the zinc plate functions as a conductive medium that absorbs and redistributes heat before it is transferred to the air through convection. Similar incubator studies show that heat source configuration and airflow rate affect heat propagation and temperature distribution inside the incubation chamber. Therefore, the finding that increasing the number of heat sources correlates with a decreasing temperature gradient can be interpreted as the effect of more distributed heat release, which reduces localized radiation intensity and promotes more uniform thermal conditions.

However, this discussion does not stop at the linear conclusion that "more lights is better." In the context of system design, increasing the number of heat sources also has the potential to increase energy consumption and the risk of temperature fluctuations if control is unstable. Therefore, the significance of this finding lies in the balance between the number of heat sources and the capacity of the incubator chamber. This study shows that at certain room dimensions, a more diffused distribution of radiation can reduce the temperature difference without causing significant overshoot above the thermostat's setting limits. This indicates the existence of a thermal equilibrium point influenced by the room volume, total power, and internal configuration.

The role of the zinc plate in the dual heating system also offers interesting conceptual implications. Theoretically, metal materials with relatively high thermal conductivity are able to absorb heat quickly and distribute it over a larger area. In this study, the presence of the zinc plate is associated with a reduction in the temperature difference between points. Analytically, this can be understood as the effect of conducting heat distribution before it is transferred to the air through convection. Without the zinc plate, radiation from the lamp tends to create a localized heat zone around the source, resulting in a larger temperature gradient. With the plate, the heat energy is first redistributed across the conductor surface, so that the air moving over it receives a more even heat distribution.

Varying the number of holes in the zinc plate reveals an additional dimension of air circulation control. Physically, the holes in the plate allow interaction between heat radiation and airflow, thereby modifying the convection pattern within the incubator chamber. From the perspective of natural convection, temperature differences create density variations in the air, which then generate upward and downward air movement (Incropera et al., 2011). The gradual decrease in temperature difference with an increasing number of holes suggests that micro-ventilation in the plate may facilitate heat distribution by reducing airflow resistance and improving internal circulation. This interpretation is consistent with previous incubator studies showing that airflow pattern, tray configuration, and heat source arrangement influence temperature uniformity inside the incubation chamber. Therefore, simple design modifications, such as perforation in the conductive plate, can affect the thermal dynamics of the incubator.

The system's thermal response, reflected by the temperature rise and fall times within the operating range of 37°C–38°C, indicates relatively stable thermal inertia. In a closed thermal system, the rate of temperature rise is influenced by heat input, chamber volume, and the heat capacity of internal components, while the rate of temperature decline is affected by heat loss through the wall, ventilation openings, and internal air exchange (Incropera et al., 2011). The ability of the system to reach the target temperature in a short time and maintain it within a controlled range indicates that thermal insulation, zinc plate heat capacity, and thermostat control worked together to stabilize the incubation environment. From an engineering perspective, this stability is important because avian embryo development requires controlled incubation temperature with minimal thermal fluctuation to support normal development and hatchability (Lourens et al., 2005).

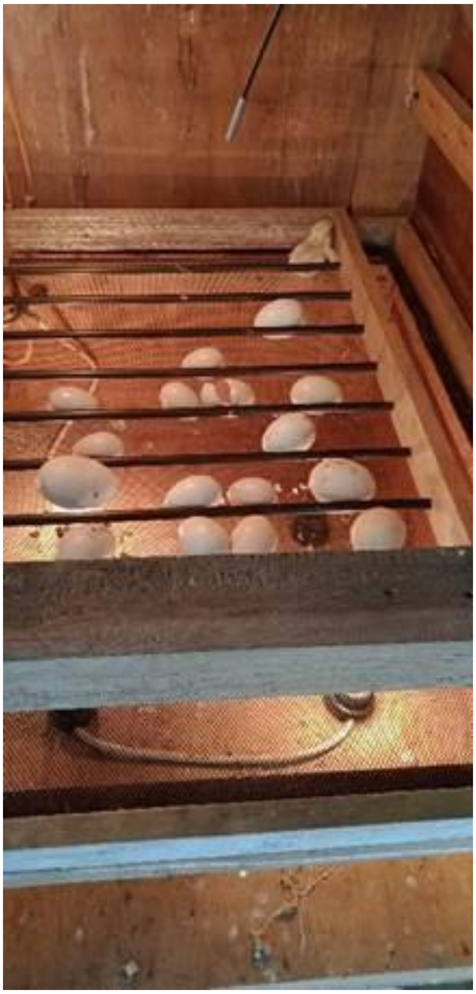

Figure 2. Hatching Chicken Eggs

Figure 2 above shows a multi-level egg incubator with an incandescent lamp heat source that regulates the temperature evenly within the incubation chamber. The placement of incandescent lamps above and below the egg racks promotes heat distribution through radiation and convection, helping maintain optimal temperature stability. The wooden frame and enclosed design contribute to thermal insulation, reducing temperature fluctuations caused by the external environment. This configuration aligns with the principles of heat transfer analyzed in the study, demonstrating the effectiveness of the dual heating system in producing uniform and optimal incubation conditions for embryo development until hatching.

Although hatching rates for both treatments were similar, the discussion does not necessarily conclude that the use of zinc plates is irrelevant. Analytical approaches require understanding that hatchability is influenced by many factors, including egg quality, humidity, and long-term temperature stability. Better temperature homogeneity potentially provides a greater safety margin against external environmental variations, although no significant differences in hatch rates have been observed in limited testing. Therefore, the practical implications of zinc plate use relate more to long-term system stability and operational consistency than simply comparing a single incubation cycle.

This discussion also needs to be placed within the geographic and social context of the research. The incubator was designed for small-scale farming conditions in humid tropical regions such as Aceh, where ambient temperature and humidity may vary during daily operation (BPS Aceh, 2026). In this context, the system's ability to maintain temperature homogeneity is crucial, particularly for locally assembled incubators used to support poultry production. Official statistics also indicate that poultry production remains part of Aceh's agricultural sector, reinforcing the practical relevance of simple and adaptive incubation technology for local needs (BPS, 2026). The low-conductivity plywood or wood enclosure can act as a simple insulating layer by reducing heat loss to the environment, consistent with basic heat transfer principles (Incropera et al., 2011). This demonstrates the integration of simple engineering principles with the biological requirements of poultry embryos.

The interdisciplinary approach combining engineering and animal science is reflected in the way variables are measured and analyzed. Physical parameters such as temperature difference, thermal response, heat distribution, and chamber stability are linked to biological parameters such as hatchability and embryo development. Previous studies have shown that incubation temperature affects embryo development, hatchability, and post-hatch chick performance (Lourens et al., 2005; Boleli et al., 2016). Therefore, incubator effectiveness cannot be understood solely from a mechanical or biological perspective. It depends on the match between thermal characteristics and the physiological needs of the embryo. This discussion avoids a reductionist approach that assesses success solely through a single indicator, and instead places the data within a systemic framework.

Overall, this demonstrates that the configuration of the number of lamps, the use of zinc plates, and the variation in holes influence temperature homogeneity through the interacting mechanisms of radiation, conduction, and convection. The stability of the system's thermal response indicates the suitability of the design to incubation needs. In the context of small-scale farming, this simple yet quantitatively tested design provides a rational basis for optimizing multi-level incubators. Thus, this discussion confirms that temperature uniformity analysis is not merely a technical evaluation, but rather part of a systematic effort to improve the efficiency and sustainability of poultry production through a measurable and contextual scientific approach.

D. Conclusion

This study significantly contributes to the understanding of temperature distribution in a multi-story egg incubator with a dual heating system in a humid tropical environment, particularly in Aceh Province. Quantitative analysis shows that increasing the number of heat sources and the use of zinc plates improve temperature homogeneity through integrated radiation, conduction, and convection mechanisms. These results not only strengthen the theoretical basis for heat transfer in enclosed spaces but also provide practical solutions that can be implemented by small-scale farmers to improve the efficiency and sustainability of poultry production. This study highlights the importance of simple yet adaptive designs to local conditions, which support stable incubation and livestock productivity. Given the limitations of scale and environmental variation, further research is recommended to explore the optimization of air circulation systems and the influence of humidity factors on incubation performance. Interdisciplinary approaches that combine engineering and biology aspects need to be expanded to support innovation in more efficient and sustainable incubation technologies. Thus, this study combines academic contributions and practical applications relevant to the development of the poultry farming sector in tropical regions.

Declaration of Competing Interest

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

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