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Comparative Analysis of Housing Systems: Microclimate, Production Performance, and Economic Efficiency in Broiler Housing System

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Abstract. Microclimate conditions significantly influence broiler production efficiency in tropical climates. This study evaluated microclimate conditions and their impact on production and economic efficiency in open, semi-closed, and closed housing systems. Secondary data from PT NHI's customer farmers were collected throughout the rearing period, covering daily body weight gain, feed consumption, mortality, and microclimate parameters. The research was conducted on three commercial farms representing each housing system in West Java. Microclimate parameters (temperature, relative humidity, heat stress index) and production performance (body weight, FCR, mortality, production index) were measured over one production cycle. Data were analyzed using ANOVA with post-hoc tests (Tukey HSD or Games-Howell, selected based on homogeneity of variance). Correlation analysis used Pearson correlation. Economic analysis calculated Income Over Feed Cost (IOFC) using standard formulas: IOFC = (Body Weight × Price of Chicken) - Feed Cost. Results showed that the closed-house system maintained significantly better microclimate conditions, exhibiting a significantly lower mean temperature-humidity index (THI) deviation (-0.47°C) compared to the semi-closed (0.51°C) and open house (2.27°C) systems. The closed-house system achieved significantly higher final body weight (2397.6 g/bird), production index (434), and income over feed cost (Rp 31,238/bird) compared to other systems. Correlation analysis revealed strong negative relationships between temperature parameters and production performance ($p<0.01$). The closed-house system demonstrated superior microclimate control, leading to significantly improved production efficiency and economic returns.

Keywords: broiler, housing system, microclimate, production efficiency, economic analysis

Abstrak. Kondisi mikroklimat berpengaruh nyata terhadap efisiensi produksi ayam broiler di wilayah beriklim tropis. Penelitian ini bertujuan untuk mengevaluasi kondisi mikroklimat serta pengaruhnya terhadap kinerja produksi dan efisiensi ekonomi pada sistem kandang open house, semi closed house, dan closed house. Data sekunder diperoleh dari peternak mitra PT NHI selama periode pemeliharaan, meliputi pertambahan bobot badan harian, konsumsi pakan, mortalitas, serta parameter mikroklimat. Penelitian dilaksanakan pada tiga peternakan komersial yang masing-masing mewakili satu sistem kandang di wilayah Jawa Barat. Parameter mikroklimat yang diamati meliputi suhu, kelembapan relatif, dan indeks cekaman panas, sedangkan performa produksi yang diukur meliputi bobot badan, feed conversion ratio (FCR), mortalitas, dan indeks produksi. Seluruh parameter diamati selama satu siklus produksi. Data dianalisis menggunakan uji ANOVA yang dilanjutkan dengan uji lanjut (post-hoc) Tukey HSD atau Games–Howell, sesuai dengan hasil uji homogenitas ragam. Analisis korelasi dilakukan menggunakan korelasi Pearson. Analisis ekonomi dihitung berdasarkan Income Over Feed Cost (IOFC) dengan rumus: IOFC = (Bobot Badan × Harga Ayam) – Biaya Pakan. Hasil penelitian menunjukkan bahwa sistem kandang closed house mampu mempertahankan kondisi mikroklimat yang secara nyata lebih baik, ditunjukkan oleh nilai deviasi indeks suhu–kelembapan (THI) yang lebih rendah (-0,47°C) dibandingkan dengan sistem semi closed house (0,51°C) dan open house (2,27°C). Sistem closed house menghasilkan bobot badan akhir yang secara signifikan lebih tinggi (2397,6 g/ekor), indeks produksi yang lebih baik (434), serta nilai income over feed cost tertinggi (Rp 31.238/ekor) dibandingkan sistem kandang lainnya. Analisis korelasi menunjukkan hubungan negatif yang kuat antara parameter suhu dan performa produksi ($p<0{,}01$). Secara keseluruhan, sistem kandang closed house menunjukkan kemampuan pengendalian mikroklimat yang lebih unggul sehingga mampu meningkatkan efisiensi produksi dan keuntungan ekonomi secara signifikan.

Kata kunci: broiler, sistem kandang, iklim mikro, efisiensi produksi, analisis ekonomi

Introduction

Broiler production in tropical regions faces significant challenges due to heat stress, which adversely affects growth performance and economic returns. The housing system plays a crucial role in modifying microclimate conditions to optimize bird comfort and performance. In Indonesia, three main housing systems are commonly used: open, semi-closed, and closed houses, each with varying capabilities to control environmental conditions.

Maintaining optimal microclimate conditions (temperature, humidity, air velocity) within poultry houses is paramount for broiler production efficiency and welfare. In tropical climates like Indonesia, where ambient temperatures often exceed the avian thermoneutral zone (TNZ), heat stress becomes a significant challenge. The TNZ for broilers narrows with age, ranging from 32-35°C for broiler birds. However, conventional open-sided housing systems, which are still prevalent, frequently expose birds to temperatures 3-8°C above the TNZ during peak hours. This thermal stress triggers a cascade of biological mechanisms: to dissipate heat, birds reduce voluntary feed intake and divert energy from growth to thermoregulation via panting, directly impairing feed conversion ratio (FCR). Concurrently, chronic heat stress compromises gut integrity and suppresses immune function, increasing susceptibility to pathogens and elevating mortality rates. These physiological disruptions culminate in substantial economic losses, primarily through increased feed costs per unit of gain and higher bird condemnation.

The objectives of this study were: (1) To evaluate and compare microclimate conditions (temperature, relative humidity, heat stress index) in the three housing systems; (2) To analyze production performance (body weight, FCR, mortality) and economic efficiency (Income Over Feed Cost/IOFC) across these systems; and (3) To quantify the correlation between specific microclimate parameters and key performance indicators. While the superiority of environmentally controlled (closed) houses over open-sided systems is often asserted, comprehensive quantitative data directly linking specific microclimate deviations in open, semi-closed, and closed systems to key production (FCR, mortality, final weight) and economic (Income Over Feed Cost) outcomes in Indonesia's commercial context remains scarce. Most studies focus on isolated parameters, leaving a gap in a holistic, data-driven analysis of the direct microclimate-performance-economy continuum.

Previous studies have established the general superiority of closed-house systems. Hamiyanti et al. (2023a) demonstrated significant production improvements in closed houses in Indonesia, while Liu et al. (2020) extensively documented the physiological impacts of heat stress on broilers. However, a key limitation in the existing literature is the predominant focus on isolated performance metrics, such as final body weight or feed conversion ratio, often within a single housing system. There is a notable lack of comprehensive, comparative studies that simultaneously investigate the interlinked triad of microclimate conditions, full-spectrum production parameters (including the integrated Production Index), and economic efficiency across different housing systems within the same geographic and managerial context. This gap makes it difficult for farmers to make fully informed investment decisions based on a holistic cost-benefit analysis.

This study strengthens the existing data by addressing this precise gap. We provide a synchronized evaluation of how specific microclimate deviations (temperature, humidity, HSI) in open, semi-closed, and closed houses in West Java directly cascade into physiological effects (mortality), production outcomes (body weight, FCR, PI), and ultimately, financial returns (IOFC). By quantifying direct correlation between environmental control and profitability, this research provides a critical evidence-based framework for stakeholders to justify investments in advanced housing technology, moving beyond mere technical superiority to demonstrated economic viability.

This gap in literature underscores the importance of our study. There is a critical need for a holistic assessment that simultaneously evaluates the microclimate, zootechnical performance, and economic viability of all three major housing systems within the same geographic and temporal context. This study is vital to provide Indonesian farmers and stakeholders with empirically-grounded, comprehensive data to inform capital investment decisions and management practices. This study addresses this need by providing a complete evaluation of microclimate conditions, production performance, and economic efficiency across different housing systems under Indonesian conditions.

Therefore, the novelty of this study lies in its integrated and quantitative approach to establish explicit causal links. We precisely quantify microclimate deviations from the ideal TNZ across three distinct housing systems and statistically correlate these deviations with measurable impacts on production performance and, ultimately, farm-level profitability. The primary objective of this research is to conduct a comparative analysis to determine how microclimate conditions in open, semi-closed, and closed housing systems directly influence broiler production efficiency and economic returns.

Materials and Methods

This comparative study was conducted from January to September 2025. Data collection took place across three independent commercial broiler farms, each representing a distinct housing system, located within the West Java region of Indonesia. A purposive sampling method was employed to select the farms, based on the following stringent technical criteria to ensure a valid comparison:

a. Operational farms with a proven production record of at least five consecutive cycles.
b. Farms using the same broiler strain (Cobb 500).
c. Farms implementing a standardized vaccination and health management program as per company guidelines.
d. Clear distinction in housing infrastructure, strictly adhering to the definitions of open, semi-closed, and closed systems.

The selected farms and their specifications were:

a. Open House (OH): A single farm (Farm A) in Cikampek. The house was a single-level, open-sided, raised-floor structure (90m L × 8m W × 2m H) with an asbestos roof and a capacity of 75,000 birds and a stocking density of 9 birds/m². No mechanical ventilation or cooling system was present.
b. Semi-Closed House (SCH): A single farm (Farm B) in Cianjur. The house was a three-tier, curtain-sided structure (120m L × 14m W × 2m H) with a concrete frame, tarpaulin walls, and an asbestos roof. It was equipped with axial fans for supplementary ventilation. Total capacity was 75,000 birds with a stocking density of 15 birds/m².
c. Closed House (CH): A single farm (Farm C) with a tunnel-ventilation system. The house was a single-level, insulated structure (100m L × 12m W × 2m H) with evaporative cooling pads and exhaust fans. Total capacity was 55,000 birds with a stocking density of 16 birds/m².

Each farm was managed as a single analytical unit (n=1 housing system). To ensure robustness, data were collected from five consecutive flock cycles per housing system, which served as statistical replicates. All flocks raised Cobb 500 strain and were harvested at a uniform age of 33 days. Birds were fed standard commercial diets from PT NHI, following a phased feeding program: prestarter feed from day-old to 10 days of age, and starter feed from day 12 until harvest.

Microclimate data, using Kestrel 3000 thermometer, were recorded three times daily (08:00, 14:00, and 20:00). The total number of microclimate observation data (n) utilized in the analysis is 150 per housing type. The data points represent the average daily values derived from microclimate measurements taken at three specific times each day: 08:00, 14:00, and 20:00. These measurements were carried out across five distinct rearing periods. The observation period encompassed the growth phase from 1 to 30 days of age for each rearing cycle. Consequently, the total sample size is calculated as n = 5 (rearing periods) x 30 (days) = 150 daily average data points per housing type. Each data unit (n) in the final dataset represents the average daily microclimate measurement for its respective rearing period and housing type. A total of 150 data points per housing system were obtained from nine locations within each house, distributed to cover the side, middle, and feed mill areas, over one full production cycle. The temperature-humidity index (THI) was calculated from these readings.

Production performance data, including final body weight (BW) and feed conversion ratio (FCR), were calculated on a per-flock basis for each of the five cycles (n=5 per system), with the production index (PI) and mortality derived from these values. The Performance Index (PI) was calculated using the standard formula (Cobb-Vantress 2021)

$$PI = \frac{Liveability\ (\%) x\ Final\ BW\ (kg)}{FCR\ x\ Age\ at\ Harvest\ (d)} x100$$

Economic Analysis: Income Over Feed Cost (IOFC) per bird (IDR/bird) Sinurat et al. (2022) was calculated as:

$$IOFC = (Final\ BW\ (kg) x\ Live\ Bird\ Price\ (IDR/kg) - (FCR\ x\ Feed\ Price\ (IDR/kg))$$

All data were analyzed using IBM SPSS Statistics software (Version 25.0). To determine the differences between groups, One-Way ANOVA performed for variables exhibiting homogeneity of variances. Conversely, Welch's ANOVA utilized as a more suitable alternative for variables with heterogeneous variances. If the analysis results indicated a statistically significant difference ($p < 0.05$), a post-hoc test was conducted. The Tukey HSD test was applied to variables with homogeneous variances, while the Games–Howell test was employed for variables with heterogeneous variances. Correlation analysis performed to determine the relationship between microclimate parameters and production efficiency parameters. The correlation coefficient measured using the following methods: Pearson Correlation was applied if the data exhibited a normal distribution. Spearman Correlation was used if the data did not exhibit a normal distribution. Simple Linear Regression Analysis was also performed to model and predict the influence of the microclimate variables on the broiler production efficiency variables

Results and Discussion

Analysis of Temperature Across Housing Systems

The research data show that the Open House system recorded in Table 1 and the highest average temperature at 30.98°C, with a range of 28.10–35.50°C. The Semi Closed House system had an average temperature of 29.08°C with a range of 25.10–32.60°C, while the Closed House system exhibited the lowest average temperature at 28.15°C with a range of 23.00–32.00°C. Analysis of variance using Welch ANOVA indicated a highly significant difference in temperature among the housing systems ($p < 0.01$). The Games–Howell post hoc test confirmed these significant differences across all pairwise comparisons ($p < 0.01$). The Open House system consistently showed the highest temperatures, followed by the Semi Closed House system, while the Closed House system maintained the lowest temperatures. The largest difference, 2.83°C between the Open House and Closed House systems, highlights the effectiveness of Closed House technology in maintaining a more stable thermal environment that is closer to the thermoneutral zone of broilers. These findings align with Zakaria et al. (2024) who reported that Closed House facilities are capable of maintaining an average temperature of 25.17–28.13°C, significantly lower than that of conventional housing systems.

Table 1. Microclimate Results in Different Housing Systems

Housing Systems	N	Mean	Std. Deviation	Minimum	Maximum
Temperature (°C) **					
Open House	150	30.98[a]	1.11	28.10	35.50
Semi Closed House	150	29.08[b]	1.92	25.10	32.60
Closed House	150	28.15[c]	2.52	23.00	32.00
Relative Humidity (%) **					
Open House	150	75.75[a]	3.91	69	88
Semi Closed House	150	73.34[b]	4.08	65	84
Closed House	150	73.51[b]	3.90	60	82
Heat stress Index**					
Open House	150	163[a]	3.730	156	179
Semi Closed House	150	158[b]	1.687	155	162
Closed House	150	156[c]	3.773	148	165
Temperature Deviation (°C) **					
Open House	150	2.27[a]	2.46	-2.30	9.50
Semi Closed House	150	0.51[b]	0.96	-1.20	3.60
Closed House	150	-0.47[c]	0.54	-2.00	0.70

Note: [abc] the same superscript letters indicate an insignificant difference ($p>0.05$). Conversely, different letters indicate a significant difference ($p<0.05$). ** = very significantly different ($p<0.01$).

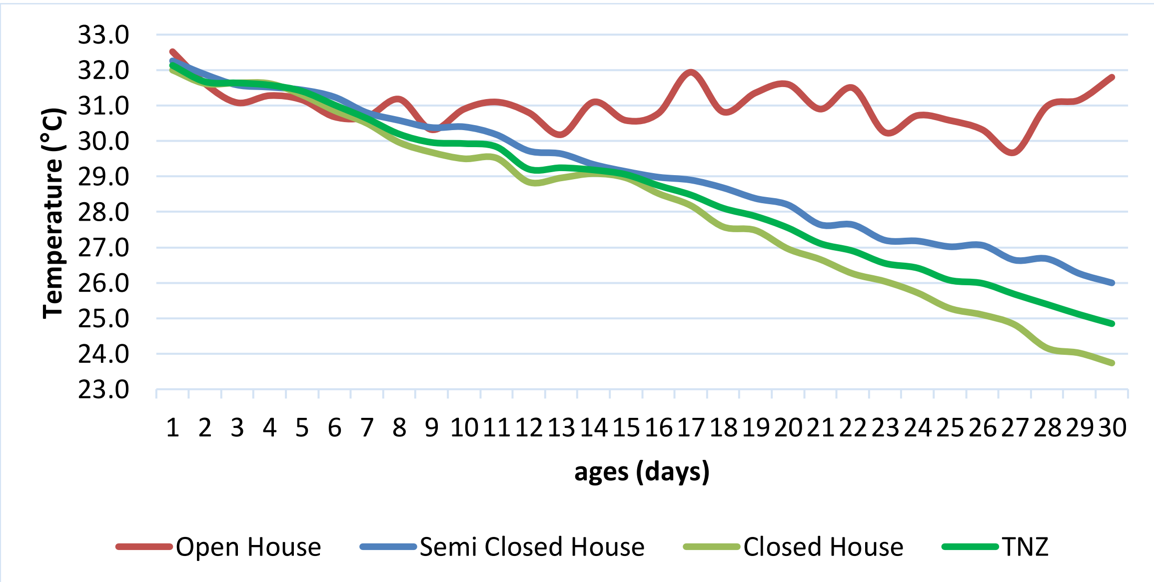

Figure 1. Average Temperature Comparison Chart

Temperature deviation in this study is defined as the difference between the actual temperature inside the house and the Thermoneutral Zone (TNZ) described in Figure 1. A larger deviation indicates that the house environment is further from the ideal temperature required by broiler chickens. Based on descriptive analysis, the highest average temperature deviation was observed in the Open House system at 2.27°C, followed by the Semi Closed House at 0.51°C, while the Closed House showed a negative deviation (-0.47°C), indicating that the actual temperature was slightly below the TNZ. These findings are consistent with Deng et al. (2024), who reported that daily temperature fluctuations in open housing systems may reach 2.27–5.80°C, whereas closed housing systems maintain fluctuations of only around ±1.2°C. The Welch ANOVA analysis showed a highly significant difference in temperature deviation among housing systems ($p < 0.01$). The Games–Howell post-hoc test confirmed that all pairwise comparisons between housing types exhibited significant differences ($p < 0.01$). The Open House system had the largest temperature deviation, which was 1.76°C higher than the Semi Closed House and 2.74°C higher than the Closed House. Additionally, the temperature deviation in the Semi Closed House was significantly higher than that in the Closed House, with a difference of 0.98°C. These results indicate that the Closed House system is the most effective in maintaining temperatures close to the TNZ, resulting in the lowest temperature deviation and the highest environmental stability. The Semi Closed House represents an intermediate level of stability, whereas the Open House exhibits the greatest deviation, reflecting the lowest microclimate stability among the three housing systems.

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Analysis of Relative Humidity Across Housing Systems

Research data indicate that the Open House system exhibited the highest average relative humidity (RH), measuring 75.75% with a range of 69–88%. The Semi Closed House system recorded an average RH of 73.34% with a range of 65–84%, while the Closed House system showed an average RH of 73.51% with a range of 60–82%. One-Way ANOVA revealed a highly significant difference in RH among the housing systems ($p < 0.01$). Tukey HSD post hoc test confirmed that RH in the Open House system differed significantly from both the Semi Closed House and Closed House systems ($p < 0.01$), whereas no significant difference was detected between Semi Closed House and Closed House systems ($p > 0.05$). These findings demonstrate that the Open House system tends to maintain higher humidity levels compared to the other housing types. This pattern aligns with Hamiyanti et al. (2023b), who reported that relative humidity in open housing systems tends to be higher (76.8 ± 6.2%) than in closed housing systems (65.2 ± 3.1%). Generally, the recommended RH range for most broiler production phases is 50–70% (Cobb-Vantress 2021). The average RH across all three housing systems consistently exceeded this recommended range (average >70%), indicating a substantial environmental challenge under tropical Indonesian conditions. This suggests that none of the housing systems evaluated (Open House, Semi Closed House, or Closed House) were able to sufficiently reduce RH to levels considered ideal for optimal broiler performance, resulting in suboptimal humidity conditions. Excessively low humidity (<40–45% RH) increases the risk of dehydration, respiratory issues, and heightened exposure to dust or aerosolized particles (Sun et al. 2023). Conversely, excessively high humidity (70–>80% RH) impairs the birds' ability to dissipate heat through evaporation, exacerbates heat stress, promotes microbial growth, accelerates litter degradation, and raises the incidence of respiratory diseases and foot disorders (Apalowo et al. 2024). Furthermore, elevated humidity can act as an environmental stressor by increasing ammonia levels, ultimately compromising poultry health (Bahari et al. 2025). These findings collectively support the conclusion that high RH in the Open House system imposes greater environmental stress compared to the Semi Closed House or Closed House systems.

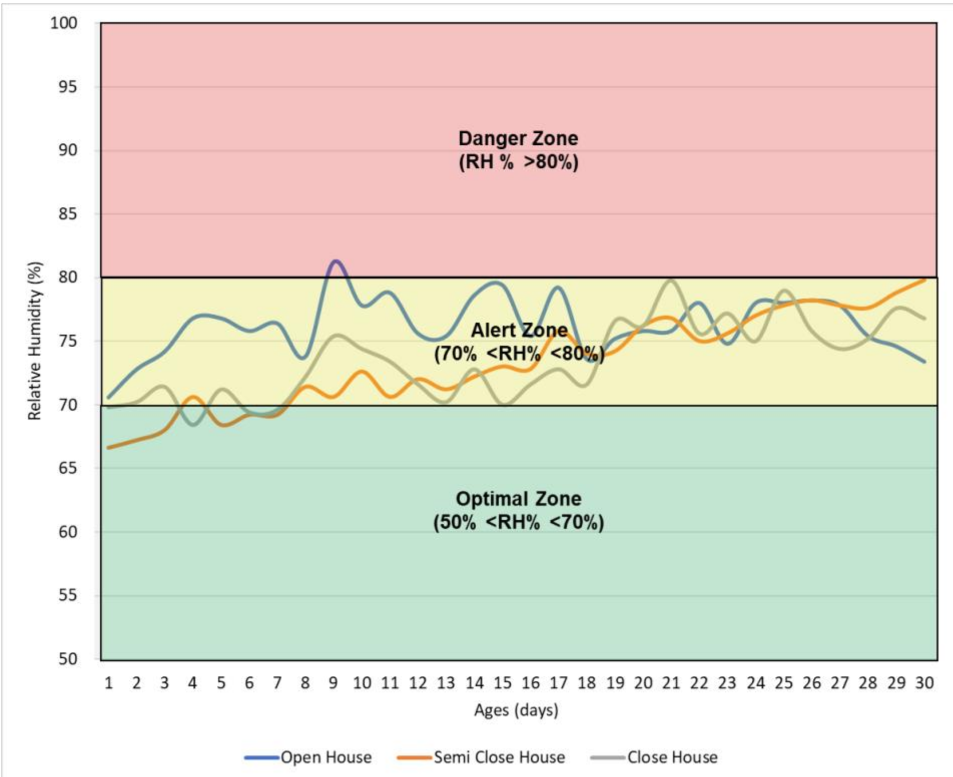

Figure 2. Average Relative Humidity Comparison Chart

Heat Stress Index (HSI) Analysis

Heat Stress Index (HSI) is an important indicator for assessing the level of heat stress in broiler chickens. Yasa et al. (2019) classified HSI severity as follows: HSI <150 indicates normal conditions without heat stress; HSI 151–155 marks the onset of performance decline characterized by reduced feed intake; HSI 155–160 reflects more severe performance deterioration accompanied by increased water intake and reduced body weight; HSI 160–165 is associated with the emergence of mortality and damage to vital organs such as the lungs and cardiovascular system; while HSI >170 represents a condition with a very high risk of mortality. Descriptive statistics from this study which reported in Figure 3 show that the Open House system recorded the highest average HSI, at 163 (range 156–179). The Semi Closed House system had an average HSI of 158 (range 155–162), while the Closed House system demonstrated the lowest value, with an average HSI of 156 (range 148–165). Welch ANOVA revealed a highly significant difference in HSI among the housing systems ($p < 0.01$). The Games–Howell post hoc test further confirmed significant differences across all pairwise comparisons ($p < 0.01$). The Open House system exhibited the highest HSI values, followed by the Semi Closed House system, with the lowest observed in the Closed House system. The largest difference, 7.307 points between the Open House and Closed House systems, underscores the effectiveness of climate-control technology in Closed House facilities for maintaining a more stable thermal environment that approximates the physiological comfort zone of broilers. Overall, the mean HSI values across all three housing systems remained above the ideal threshold (<150), indicating that under tropical Indonesian conditions—characterized by high temperatures, high humidity, and pronounced daily fluctuations—broilers continue to face a substantial risk of heat stress even when environmental control systems such as Closed House technology are implemented. These findings highlight that microclimate management remains a major challenge in broiler production in tropical climates.

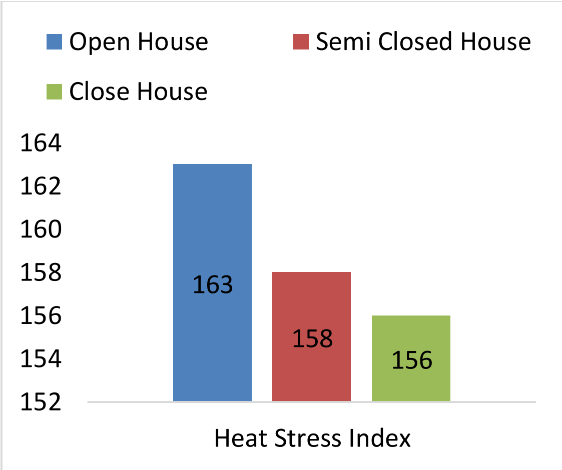

Figure 3. Average Heat Stress Index Comparison Chart

Production Performance

Average Slaughter age and Final Body Weight

Final body weight is a key performance indicator in broiler production, reflecting both biological efficiency and economic outcomes. Slaughter age and final weight differed notably across housing systems. Open House broilers were slaughtered at an average of 30.64 ± 0.36 days, Semi Closed House at 30.47 ± 0.67 days, and Closed House at a significantly longer 35.82 ± 3.21 days. The Closed House system also produced the highest final body weight (2.397 kg/bird), followed by Semi Closed House (1.837 kg/bird) and Open House (1.683 kg/bird). Final body weight and average slaughter age reported in Table 2.

Final body weight gain reported as one of production performance indicator, meanwhile average slaughter age between cage system due to data obtained from commercial field practice. Flock performance and market situation determined harvest time and managerial decision (Honig et al. 2024). The different harvest time is one of confounding factor which limit direct biological comparison to final body weight and income over feed cost (IOFC) in the

Table 2. Production Performance Results in Different Housing Systems

Housing Systems	N	Mean	Std. Deviation	Minimum	Maximum
Average Slaughter Age (days) *					
Open House	5	30.64^{b}	0.36	30.31	31.21
Semi Closed House	5	30.47^{b}	0.67	29.69	31.26
Closed House	5	35.82^{a}	3.21	32.29	39.46
Final Body Weight (kg/head) *					
Open House	5	1,683^{c}	52.12	1,605	1,745
Semi Closed House	5	1,837^{b}	79.35	1,766	1,955
Closed House	5	2,397^{a}	328.93	1,990	2,824
Depletion (%) **					
Open House	5	7.24^{c}	0.786	6.39	8.25
Semi Closed House	5	5.12^{b}	0.534	4.54	5.83
Closed House	5	3.14^{a}	1.081	1.78	4.20
***Feed Conversion Ratio* (kg) ^{ns}**					
Open House	5	1.540^{a}	0.055	1.482	1.617
Semi Closed House	5	1.471^{a}	0.033	1.434	1.512
Closed House	5	1.491^{a}	0.055	1.428	1.574
Feed Efficiency (%) ^{ns}					
Open House	5	65.0^{a}	2.29	61.85	67.49
Semi Close House	5	68.0^{a}	1.54	66.14	69.75
Close House	5	67.1^{a}	2.47	63.47	70.07
Production Index**					
Open House	5	332^{c}	19.139	302	351
Semi Closed House	5	389^{b}	17.550	370	414
Closed House	5	434^{a}	29.180	405	482

Note: ^{abc} same superscript letters indicate an insignificant difference (p>0.05). Conversely, different letters indicate a significant difference (p<0.05). ns = non significantly different (p>0.05). *= significantly different (p<0.05). **= very significantly different (p<0.01).

same age. The controlled microclimate condition in close house system associated with longer average harvest time than other cage systems. This data is presented as an overview of actual broiler production system performance, without harvest age standardization as observed in controlled experimental trials.

Feed Conversion Ratio and Feed Efficiency

Based on the descriptive analysis, the average FCR in the Open House system was 1.540 ± 0.055 (range 1.482–1.617), while the Semi Closed House system showed the best FCR value of 1.471 ± 0.034 (range 1.434–1.512). The Closed House system recorded an average FCR of 1.491 ± 0.055 with a range of 1.428–1.574. A similar pattern was observed for feed efficiency (FE), where the Open House system had the lowest value at 64.99 ± 2.29% (61.85–67.49%), followed by the Closed House at 67.12 ± 2.47% (63.47–70.07%), and the highest value was recorded in the Semi Closed House at 68.00 ± 1.55% (66.14–69.75%). ANOVA results indicated that differences in FCR and FE among housing systems were not statistically significant (p > 0.05). Although statistical analysis (ANOVA) indicated no significant difference (p > 0.05) in Feed Conversion Ratio (FCR) among the three housing systems, a noteworthy numerical trend was observed. The Semi-Closed House recorded the most favorable mean FCR value (1.471), followed by the Closed House (1.491), and the Open House (1.540). Liu et al. (2020) through a meta-analysis, reported that increasing temperature from 21°C to 32°C elevated FCR by

0.17 points due to enhanced heat stress. Meanwhile, Laili et al. (2022) found that Closed House systems with stable temperature control improved feed efficiency by 3–12% compared to conventional housing. Collectively, these findings confirm that superior feed efficiency in closed housing systems is a consistent phenomenon in tropical regions, primarily driven by their superior ability to reduce environmental stress and optimize metabolic energy utilization.

Statistical analysis indicated no significant difference in FCR among the three housing systems ($p = 0.114$). This lack of significance can be attributed to two primary factors: a relatively small sample size (n=5 per system) for this integrated end-of-cycle metric, and the high inherent variability in commercial FCR measurement, which can obscure subtle differences. Despite statistical non-significance, the numerical trend is economically meaningful: Semi-Closed (1.471), Closed (1.491), and Open (1.540) houses. The mechanism by which closed and semi-closed systems optimize feed efficiency involves mitigating heat stress. In the Open House, birds expend significant energy on panting and reducing feed intake to lower metabolic heat production. The controlled environments of Closed and Semi-Closed Houses minimize this energy waste. The Closed House's tunnel ventilation provides a wind-chill effect, while the Semi-Closed House's fans improve air movement, both aiding in sensible heat loss and allowing birds to maintain a higher and more efficient feed intake for growth

Depletion Rate (%)

Based on the descriptive analysis, the average depletion rate in the Open House system was 7.24 ± 0.79%, with values ranging from 6.39% to 8.25%. In the Semi Closed House system, the depletion rate was lower, with an average of 5.12 ± 0.53% (range 4.54–5.83%). Meanwhile, the Closed House system showed the lowest depletion rate at 3.14 ± 1.08%, with a minimum of 1.78% and a maximum of 4.20%. ANOVA results indicated that the housing system had a highly significant effect on broiler depletion rates ($p < 0.01$). Tukey HSD post-hoc comparisons further revealed that the Open House system had the highest depletion rate (7.24 ± 0.79%), which differed significantly ($p < 0.05$) from the Semi Closed House (5.12 ± 0.53%) and differed very significantly ($p < 0.01$) from the Closed House (3.14 ± 1.08%). Semi Closed House system also differed significantly from the Closed House ($p < 0.05$), with Closed Houses consistently exhibiting lower depletion. These findings illustrate a consistent decline in depletion rates as the level of environmental control increases across housing systems. This pattern aligns with previous studies showing that Closed House systems achieve much lower depletion rates for example, 2.13% at 30 days of age substantially below the typical depletion observed in Open Houses (often exceeding 7%) (Suasta et al. 2019; Hamiyanti et al. 2023a). Enhanced microclimate control through mechanical ventilation and evaporative cooling has been shown to reduce mortality and improve performance stability in Closed House (Hamiyanti et al. 2023a; Maulana et al. 2024; Zakaria et al. 2024). Furthermore, Rahul and Pramod (2016) reported that acute heat stress can increase mortality by 8–10% due to disruption of physiological homeostasis.

Biological mechanism of heat stress and mortality, the higher mortality in the Open House (7.24%) compared to the Closed House (3.14%) is a direct physiological consequence of chronic heat stress. When ambient temperature exceeds the birds' thermoneutral zone, three key pathological mechanisms are activated. Oxidative stress, panting increases reactive oxygen species (ROS) production while reducing blood flow to organs. This damages cells and weakens the immune system (Oke et al. 2024). Electrolyte imbalance, hyperventilation causes respiratory alkalosis and excessive loss of potassium and sodium (Chaiyabutr, 2004) through renal compensation, disrupting nerve and heart function. Circulatory collapse, blood is diverted to the skin for cooling, lowering blood pressure and forcing the heart to work harder, often leading to acute heart failure (Rostagno, 2020). Logical explanation for the mortality gradient, the mortality rates directly reflect each system's ability to buffer environmental stress. Closed house acts as a complete buffer. Active cooling and ventilation maintain the thermoneutral zone, preventing the heat stress cascade. Result lowest mortality (3.14%). Semi-Closed House acts as a partial buffer. Curtains and fans provide inconsistent relief, leading to intermittent heat stress and moderate physiological strain. Result: Intermediate mortality (5.12%). Open House provides no buffer. Birds endure chronic, severe heat stress, triggering the full pathological sequence daily.

Production Index (PI)

Performance Index (PI) in broiler production is categorized as poor (<300), fairly good (326–350), very good (351–400), and excellent (>400) (Abdurrahman et al. 2022). Descriptive results as reported in Figure 4 showed that the Close House system achieved the highest PI (434.00), followed by Semi Close House (389.00) and Open House (332.60). ANOVA indicated a highly significant effect of housing system on PI ($p < 0.01$), and Tukey HSD confirmed significant differences among all systems ($p < 0.05$). The Close House system outperformed the Open House by +101.4 points ($p < 0.01$) and the Semi Close House by +45.0 points ($p < 0.05$), while the Semi Close House exceeded the Open House by +56.4 points. These results show that greater microclimate control contributes directly to improved efficiency and broiler performance. Findings align with Hamiyanti et al. (2023a), reporting PI values > 400 in tropical Closed House systems. Semi Close House, with an intermediate PI, reflects partial environmental control and moderate performance improvement, whereas the substantially lower PI in Open House systems underscores their limitations due to heat stress, higher mortality, and reduced feed efficiency.

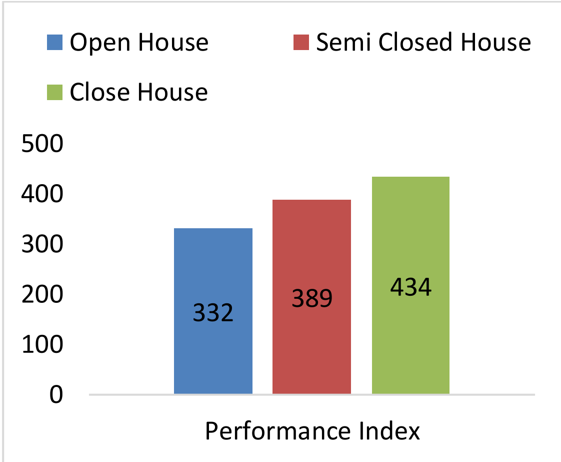

Figure 4. Performance Index Comparison Chart

The Performance Index (PI), a composite metric of livability, weight, and efficiency, was calculated using the standard industry formula (Cobb-Vantress 2021): PI = [Livability (%) × Live Weight (kg)] / [FCR × Age (days)] × 100. A highly significant difference was found ($p < 0.01$), with the Closed House achieving the highest PI (434.00), followed by the Semi-Closed (389.00) and Open (332.60) Houses. This result explicitly demonstrates that PI is dominantly influenced by final body weight and livability (mortality), the two parameters where the Closed House excelled. Although its age at harvest was longer, the superior weight and survival resulted in a far higher overall efficiency score in line with Hamiyati et al. (2023). The financial implication of this PI difference is substantial. For a standard 25,000-bird flock, the 101.4-point PI advantage of a Closed House over an Open House can translate to tens of millions of Rupiah additional gross margin per cycle, primarily driven by the higher total live weight produced and sold.

Economic Analysis

Descriptive analysis showed that the highest IOFC value was obtained in the Close House system, with an average of Rp31,238.00 ± 3,875.81 per bird (range Rp26,986.00–

Rp37,224.00). The Semi Close House system recorded an average IOFC of Rp24,269.60 ± 973.73 per bird (Rp23,630.00–Rp25,973.00), while the Open House system exhibited the lowest IOFC, namely Rp21,318.80 ± 1,141.71 per bird (Rp19,335.00–Rp22,240.00). Welch ANOVA test confirmed a significant difference in IOFC values among the three housing systems ($p = 0.001$). The Games–Howell post hoc test further indicated that all pairwise comparisons differed significantly ($p < 0.05$). IOFC in the Close House system was significantly higher than in both the Semi Close House and Open House systems, with respective differences of Rp6,968.40 and Rp9,919.20 per bird. The Semi Close House system also showed a significantly higher IOFC than the Open House system, with a difference of Rp2,950.80 per bird. These significant differences indicate that improvements in biological performance in the Closed House system including higher final body weight, more efficient FCR, and lower mortality directly contribute to increased net income after feed costs. This finding aligns with Laili et al. (2022), who reported that the more stable microclimate in Closed House systems enhances feed conversion and reduces losses due to mortality. Furthermore, Adaszyńska-Skwirzyńska et al. (2025) noted that every 0.1-point improvement in FCR can increase IOFC by 8–12%.

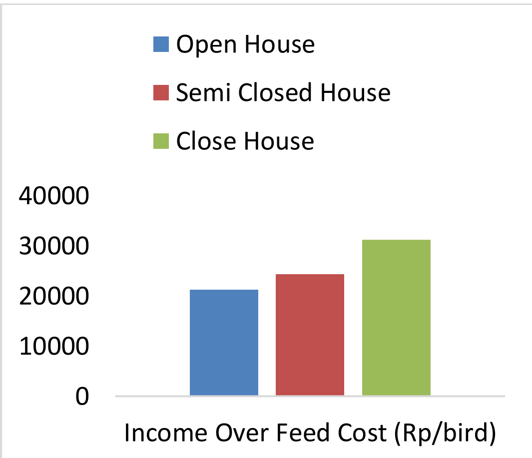

Figure 5. Income Over Feed Cost Comparison Chart

The Income Over Feed Cost (IOFC) provides a direct economic lens, showing a very significant advantage for the Closed House at Rp 31,238 ± 3,876 per bird, compared to Rp 24,270 ± 974 (Semi-Closed) and Rp 21,319 ± 1,142 (Open) ($p = 0.01$) (Figure 5). This metric directly feeds into Return on Investment (ROI) calculations for modern housing. The ~Rp 10,000/bird higher IOFC in a Closed House can justify the higher capital cost, with a typical payback period of 3-5 years depending on scale and construction costs.

Correlation Analysis

Results of the analysis in Table 3 indicate that temperature, humidity, HSI, and temperature deviation exhibit strong and consistent relationships with broiler production performance. Temperature, HSI, and temperature deviation show very strong negative correlations with final body weight, IP, and IOFC (r ranging from –0.79 to –0.93; $p < 0.001$), indicating that higher heat stress is associated with lower performance and profitability. These parameters also display very strong positive correlations with depletion ($r = 0.88–0.92$; $p < 0.001$), suggesting an increased risk of mortality as microclimatic conditions deteriorate. Humidity demonstrates a similar pattern, showing strong correlations with final body weight ($r = –0.663$), FCR ($r = 0.806$), FE ($r = –0.796$), IP ($r = –0.837$), and IOFC ($r = –0.632$), all of which are statistically significant ($p < 0.05$). This indicates that high humidity worsens metabolic and feed efficiency, ultimately reducing production performance (Zhou et al. 2020). Overall, all microclimate indicators show that heat stress and instability in temperature–humidity consistently increase mortality, reduce final body weight, worsen FCR, decrease feed efficiency, and have highly significant impacts on IP and IOFC.

Table 3. Correlation between Microclimate and Performance Production

Microclimate	Performance Production	Correlation Coefficient	Sig.
Temperature	Average Slaughter Age	-0,706**	0,003
	Final Body Weight	-0,934***	< 0,001
	Depletion	0,897***	< 0,001
	Feed Conversion Ratio	0,504	0,055
	Feed Efficiency	-0,500	0,058
	Production Index	-0,887***	< 0,001
	Income Over Feed Cost	-0,793***	< 0,001
Relative Humidity	Average Slaughter Age	-0,098	0,727
	Final Body Weight	-0,663**	0,007
	Depletion	0,825***	< 0,001
	Feed Conversion Ratio	0,806***	< 0,001
	Feed Efficiency	-0,796***	< 0,001
	Production Index	-0,837***	< 0,001
	Income Over Feed Cost	-0,632*	0,011
Heat Stress Index	Average Slaughter Age	-0,434	0,106
	Final Body Weight	-0,849***	< 0,001
	Depletion	0,922***	< 0,001
	Feed Conversion Ratio	0,681**	0,005
	Feed Efficiency	-0,674**	0,006
	Production Index	-0,921***	< 0,001
	Income Over Feed Cost	-0,769***	< 0,001
Temperature Deviation	Average Slaughter Age	-0,703**	0,003
	Final Body Weight	-0,924***	< 0,001
	Depletion	0,880***	< 0,001
	Feed Conversion Ratio	0,473	0,075
	Feed Efficiency	-0,469	0,078
	Production Index	-0,874***	< 0,001
	Income Over Feed Cost	-0,790***	< 0,001

Note: *Correlation is significant at the 0.05 level. **Correlation is significant at the 0.01 level. ***Correlation is significant at 0.001 level.

Integrated Regression Analysis of Environmental Impact on Performance and Economics

The regression analyses consistently demonstrate that heat stress is the primary driver of both production (Figure 6) and economic losses (Figure 7) in tropical broiler farming. The models confirm that high environmental temperatures force birds to allocate energy toward thermoregulation rather than growth, thereby undermining feed efficiency and increasing mortality. Although relative humidity contributes to these outcomes, its principal role lies in exacerbating heat load by impairing evaporative cooling through panting. The composite Heat Stress Index (HSI), which integrates both temperature and humidity, emerged as the most physiologically relevant predictor. It captures the combined environmental load to which broilers respond, rather than isolated microclimate parameters. This explains why closed-house systems designed to regulate the entire thermal load achieved substantially superior production performance and economic outcomes.

The model confirms that HSI, as a composite indicator, explains 84.9% of the variation in the Performance Index (IP). Each 1-point increase in HSI reduces IP by 12.361 points. This finding aligns with Ryder et al. (2014), who reported that HSI is a powerful predictor of broiler performance decline, with values exceeding 160 causing an exponential reduction in IP. Similarly, the Heat Stress Index explains 59.1% of the variation in Income Over Feed Cost (IOFC), where each 1-point increase in HSI decreases IOFC by IDR 1,046 per bird. This result reinforces Ryder et al. (2014), who observed that increases in HSI from the thermoneutral to the stress zone can reduce broiler profitability by up to 30%. In conclusion, the regression models provide robust and quantitative evidence that controlling the thermal environment is not merely a technical enhancement but a fundamental economic necessity for profitable broiler production in tropical climates.

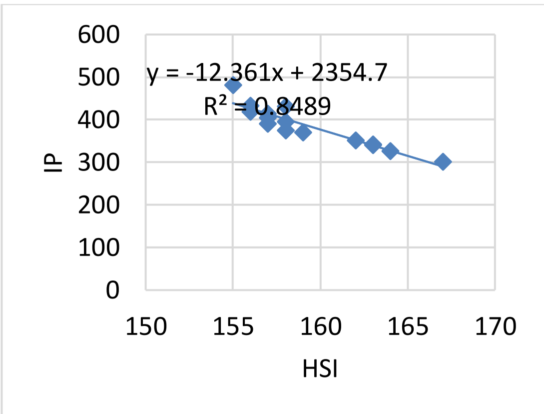

Figure 6. Linear Regression Curve HSI Impact on Performance Index

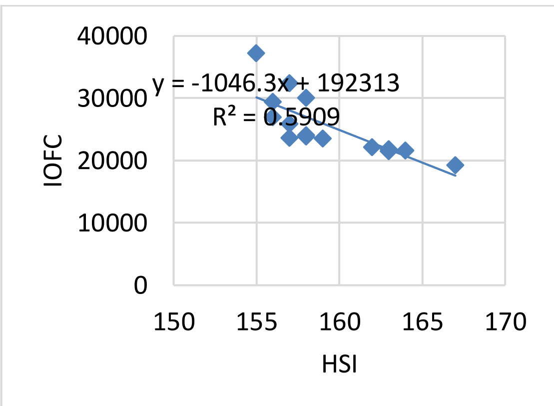

Figure 7. Linear Regression Curve HSI Impact on Income Over Feed Cost

The strong negative correlations between microclimate parameters (Temperature, HSI, Temperature Deviation) and both PI (r ≈ -0.87 to -0.92) and IOFC (r ≈ -0.77 to -0.79) are interpreted as strong associative evidence, not direct causation. They confirm that poorer environmental conditions are consistently linked with worse economic and production outcomes. However, correlation does not equal causation. Other confounding or contributing factors acknowledged in this relationship include: stocking density (which affects heat load and stress), variations in slaughter age (a management decision impacting FCR and weight), and fluctuations in feed price (a major external input to IOFC). The strength of the correlations suggests that microclimate is a dominant, but not sole, driver within the studied systems. Future research controlling for these variables could help isolate the precise causal weight of each factor.

Conclusions

This study demonstrates that the closed-house system is the most effective broiler housing option in tropical climates. Its superior environmental control maintained a stable thermoneutral zone, resulting in the highest final body weight (2397.6 g), best efficiency (PI 434), lowest mortality, and a 46% higher IOFC (Rp 31,238) compared with the open-house system. Strong negative correlations between poor microclimate and performance (r = –0.887 to –0.921) further confirm that controlling heat stress is essential. Therefore, investment in closed-house housing is the most reliable strategy to optimize productivity and profitability in tropical broiler production.

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