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Design, Simulation, and Mechanical Evaluation of Modular Aluminium-Based Goat Housing for Tropical Conditions

Full Paper

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Abstract

The development of durable and climate-resilient livestock infrastructure is critical for sustaining productivity in tropical goat farming systems. This study presents the design, structural simulation, mechanical characterization, and field fabrication of a modular goat housing system using Aluminium Alloy 6063-T5 (AA 6063-T5) and Galvanized Iron (GI) components. The housing frame, constructed with 28 mm × 1.7 mm grooved hollow aluminium pipes, was assessed through tensile and Brinell hardness tests, yielding an average tensile strength of 266.3 MPa and hardness of 60 HB. Finite Element Analysis (FEA) under live loads ranging from 294 N to 686 N demonstrated that the structure remained within elastic limits, with a safety factor above 1.2 under typical load conditions. The modular goat housing maintained integrity under static and behavioural loading scenarios, while offering improved hygiene and reduced maintenance via corrosion-resistant GI mesh flooring. Behavioural comparisons from prior studies affirmed enhanced animal comfort and thermal regulation in aluminium-based structures. The findings validate the potential of AA 6063-T5 as a lightweight, low-maintenance alternative to wood for sustainable livestock housing. The study recommends structural reinforcement for high-load scenarios and further field validation to support wider adoption among small-scale farmers.

Keywords: - Goat welfare, intensive farming systems, aluminium alloy 6063-T5, modular design, structural optimization

1. Introduction

In tropical regions, ensuring animal welfare in intensive dairy goat farming is increasingly challenging due to rising temperatures, humidity, and climate variability. Goat housing plays a critical role in protecting animals from environmental stressors such as excessive heat, rainfall, and poor air quality, which significantly affect productivity, reproductive performance, and animal comfort (Sejian et al., 2018 & Silanikove, 2000). In Southeast Asia, including Malaysia, traditional housing systems typically built from wood remain common due to their low upfront cost and ease of construction. However, these wooden structures are often prone to pest attacks, high moisture absorption, poor ventilation, and short service life, ultimately leading to higher long-term maintenance costs (Awang et al., 2020). Fig. 1 shows the goat housing from wooden material.

Fig. 1: Goat housing from wooden material

To overcome these challenges, goat housing using corrosion-resistant, modular materials such as Aluminium Alloy 6063-T5 and Galvanized Iron (GI) have been explored. This is because, Aluminium is not only lightweight and durable but also thermally conductive and recyclable. This will make it an attractive solution for climate-adaptable agricultural infrastructure. On the other hand, GI mesh panels, offer high mechanical strength and hygiene support by allowing efficient waste separation. These design improvements directly contribute to SDG 9 and SDG 13 by promoting resilient infrastructure and adaptive farming strategies.

This study presents a structural and mechanical assessment of AA 6063-T5 hollow pipes for goat housing frameworks, incorporating both simulation (FEA) and experimental methods (tensile and hardness testing). It also draws on previous physiological observations (Omar et al., 2025) comparing animal responses in wooden and aluminium-based housing, validating aluminium's effectiveness in enhancing thermal comfort. The goal is to establish AA 6063-T5 as a commercially viable, sustainable material for modular goat housing units suitable for small-scale farmers and semi-urban adoption. This aligns with the broader aim of achieving sustainable livestock development under SDG 2 by improving food security through better farm productivity and animal welfare.

2. Literature Review

2.1 Goat Housing and Animal Welfare in Tropical Climates

Animal welfare is a key indicator of sustainability in farming systems (Broom, 2021), with critical metrics including behavioral patterns, health indicators, and physiological responses such as rectal temperature, heart rate, and respiratory rate (Munoz et al., 2019). These physiological markers, along with biochemical indicators such as blood cortisol and glucose levels, have been validated as effective stress parameters in goats (Daramola et al., 2012). Previous studies have shown that high ambient temperatures and humidity levels negatively impact goat behavior and lactation potential (Fonseca et al., 2016 & Henn et al., 2021). Research by Omar et al. (2025) revealed that goats housed in aluminum-based structures exhibited better respiratory responses and lower heat stress indicators compared to those housed in wooden enclosures.

Goat housing design needs good design to improve heat, reduces disease transmission, and supports normal behavioural expression (Silanikove & Koluman, 2015). However, in Malaysia and similar Southeast Asian settings, housing systems are often designed without proper ventilation, drainage, or material longevity in mind. This results in elevated Temperature-Humidity Index (THI) values above the stress threshold of 78–83 for goats (de Souza et al., 2020), compromising animal welfare.

2.2 Material Innovation for Modular Goat Housing

AA 6063-T5 is a heat-treated aluminum alloy known for its excellent corrosion resistance, mechanical strength, and formability. Its properties make it suitable for modular structural applications in high-humidity environments (Qin et al., 2021). Previous studies on AA 6063-T5 have highlighted its favorable strength-to-weight ratio, making it suitable for structural applications in small ruminant housing (Georgantzia et al., 2021 & Kroehnke et al., 2019). In agricultural structures, this alloy is often preferred for its ability to retain mechanical stability under repeated loading conditions, with reported safety factors exceeding typical design thresholds.

Galvanized Iron (GI), especially in the form of mesh panels, complements aluminium's lightweight structure by providing strong, hygienic flooring and fencing solutions. GI components resist rust even when frequently exposed to goat waste and washdown routines, helping maintain a cleaner microenvironment (Akhtar et al., 2017). The integration of these two materials not only increases structural integrity but also enhances portability, ease of installation, and sanitation—factors critical for climate-smart agriculture (Alvarenga et al., 2023). Together, these innovations contribute to SDG 13 by reducing the environmental burden of short-lifespan wooden materials and improving resource efficiency in livestock infrastructure. In addition, emerging technologies in smart livestock farming—such as IoT-based sensors and automated data collection—have shown promise in improving animal welfare and productivity in confined housing systems (Kumar et al., 2021)

3. Methodology

This research employed an integrated methodological approach encompassing digital modelling, structural simulation, laboratory testing, and prototype fabrication to assess the technical feasibility of using Aluminium Alloy 6063-T5 (AA 6063-T5) and Galvanized Iron (GI) in the development of modular goat housing for intensive farming in tropical climates.

3.1 Design Concept and CAD Development

The initial design phase involved translating user requirements gathered through consultations with local farmers and the Malaysian Department of Veterinary Services (DVS)—into a functional layout using SolidWorks CAD software. Critical design parameters included a raised floor height of 900 mm for effective ventilation, anti-climb GI mesh panels for enclosure security, and accessible feeding and maintenance zones. The structural frame incorporated hollow aluminium pipes (28 mm diameter, 1.7 mm thickness), while the walls and flooring were constructed using galvanized iron mesh panels. The housing unit was designed to accommodate three adult dairy goats, each allocated approximately 1 m² of floor space in accordance with Department of Veterinary Service (DVS) recommendations. The complete housing structure measured 1200 mm in width, 4800 mm in length, and 3500 mm in height. Fig. 2 illustrates the goat housing.

Fig. 2: SolidWorks goat housing structure featuring AA 6063-T5 hollow pipes for framing and GI mesh for floor and fencing panels

3.2 Structural Simulation via Finite Element Analysis (FEA)

To predict the structural behavior of the aluminium framework under operational loads, a finite element analysis was conducted using SolidWorks Simulation. A static linear analysis was carried out by applying point loads of 294N, 490.5N, and 686N representing minimum, average, and maximum live loads based on the body weight of adult goats. Fig. 3 shows the finite element analysis (FEA).

Boundary conditions simulated a simply supported beam scenario with a central vertical load applied to induce maximum bending stress. The simulation outputs included the Von Mises Stress contours, Total displacement values, Equivalent strain distribution, and calculated factors of safety (FOS). Mesh refinement and convergence checks were performed to ensure numerical reliability of the simulation results.

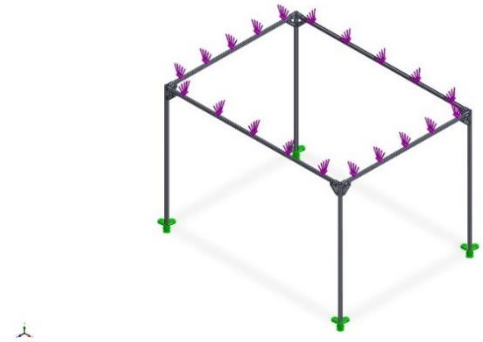

Fig. 3: FEA shows stress distribution on the aluminium frame under varying static loads (294 N, 490 N, and 686 N)

3.3 Mechanical Characterization of AA 6063-T5

To validate the simulation findings, experimental tests were conducted on aluminium pipe samples supplied by a certified local manufacturer. Specimens were machined to a length of 240 mm and tested in accordance with ASTM B557 standards using a Universal Testing Machine (UTM). For tensile testing, each specimen was marked with a 50 mm gauge length. Load-elongation curves were generated to determine tensile strength and percentage elongation. Brinell Hardness was evaluated using a 10 mm diameter carbide ball under a 500 kgf load, in compliance with ISO 6506-1 standards. These tests provided quantitative validation for the mechanical properties assumed in the simulation stage.

3.4 Prototype Fabrication

Following the completion of digital modelling and material validation, a full-scale prototype of the goat housing unit was fabricated in a site as Fig. 4. Assembly processes employed standard cutting and fastening techniques. Grooved aluminium pipes were joined using 6 mm Allen bolts to form the structural frame, while galvanized iron mesh panels were affixed using corrosion-resistant fasteners. The modular nature of the design enabled straightforward transport and installation at the designated test site.

Fig. 4: Goat housing used AA6063-T5 and Galvanized Iron

4. Results and Discussion

This section presents the outcomes of simulation, laboratory testing, and the integration of structural findings.

4.1 Structural Response Under Load

The finite element analysis (FEA) revealed that the aluminium frame constructed from AA 6063-T5 responded linearly to applied loads of 294 N, 490.5 N, and 686 N, which simulate the live weight range of adult dairy goats. The stress distribution was concentrated at the middle of the horizontal frame pipe, consistent with expectations under centrally applied vertical loads.

The maximum Von Mises stress observed was 1.68×10^8 N/m² under a 686 N load, while the lowest was 7.21×10^7 N/m² under a 294 N load. Correspondingly, total displacement values ranged from 9.90 mm to 23.11 mm.

These results indicate that the structure remains within the elastic deformation region for typical operational loads, although the highest displacement at 686 N suggests the need for reinforcement under dynamic or extreme load conditions.

Table 1: Results of minimum and maximum stress, displacement and strain for single pipe

Load (N)	Stress (N/m^2)		Displacement (mm)	
	Max	Min	Max	Min
294	7.206×10^7	5.329×10^3	9.905	0
490	1.201×10^8	8.883×10^3	16.51	0
686	1.681×10^8	1.243×10^4	23.11	0

4.2 Mechanical Properties of AA 6063-T5

Experimental testing of the customized AA 6063-T5 pipe confirmed the material's mechanical integrity. The average tensile strength recorded was 266.3 MPa, with elongation within the acceptable ductile range. Brinell Hardness testing yielded an average value of 60 HB, exceeding the typical hardness range for standard AA 6063-T5 (usually 45–55 HB). This enhancement may be attributed to the grooved surface profile and improved extrusion consistency, contributing to superior deformation resistance under mechanical loading.

These results validate the suitability of AA 6063-T5 for goat housing applications requiring lightweight yet robust structural components, especially in environments with high humidity and potential corrosion exposure.

4.3 Safety Factor Evaluation

The calculated factor of safety (FOS) varied with load magnitude. Under a load of 294 N, the structure demonstrated a FOS of 2.0, which is considered highly safe. At 490.5 N (representing average adult goat weight), the FOS remained at 1.2, acceptable for static conditions. However, at 686 N, the FOS dropped to 0.9, indicating potential risk of structural failure under excessive loading or dynamic impact.

To maintain structural reliability and adhere to safety design thresholds (typically ≥1.5 for live animal loads), it is recommended that additional reinforcement be introduced such as increasing the number of cross pipes or reducing span length between joints.

4.4 Integration with Goat Behavioural Data

Behavioural observations from previous studies (Omar et al., 2025) complement the structural findings of this research. Goats housed in aluminium-based enclosures exhibited improved respiratory comfort and reduced thermal stress indicators compared to those in traditional wooden housing. These findings suggest that the integration of AA 6063-T5 not only meets mechanical requirements but also contributes to enhanced animal welfare, particularly in tropical climates with fluctuating heat and humidity.

5. Conclusion and Recommendations

This study successfully designed, simulated, fabricated, and evaluated a modular goat housing unit optimized for intensive tropical farming systems. The structure, developed using Aluminium Alloy 6063-T5 and Galvanized Iron components, exhibited strong mechanical performance, with tensile strength reaching 266.3 MPa and Brinell Hardness averaging 60 HB. Finite Element Analysis (FEA) confirmed that the frame could safely support average live goat loads (up to 490.5 N), with a factor of safety above 1.2 under static conditions. Structural deformation remained within acceptable limits, although reinforcement is advisable for higher or dynamic loading scenarios.

To enhance structural reliability, especially under unpredictable load distribution due to goat movement, it is recommended to reinforce the midspan or increase the number of support pipes to ensure the safety factor remains above 1.5. Furthermore, the housing unit's integration of galvanized iron mesh flooring improved hygiene and durability, while behavioral data from prior studies confirmed improved animal comfort and thermal regulation in aluminium-based enclosures. For broader validation and adoption, long-term field testing involving more animals and diverse climatic conditions is encouraged to evaluate durability, animal adaptation, and maintenance requirements over time. Overall, the findings support the suitability of AA 6063-T5 and GI mesh in creating lightweight, modular, and welfare-focused housing that aligns with the needs of small-scale farmers and sustainable livestock development goals.

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References

Akhtar, M., Rehman, S., Ali, M., & Khan, M. A. (2017). Corrosion resistance of aluminium and galvanized iron structures in livestock housing environments. *Materials and Design*, *120*, 63–72. https://doi.org/10.1016/j.matdes.2017.01.050.

Alvarenga, F. A. P., Sejian, V., Silva, L. K. X., & McManus, C. (2023). Climate-smart housing design for small ruminants: A review on thermal comfort and environmental sustainability. *Journal of Cleaner Production*, *397*, 136717. https://doi.org/10.1016/j.jclepro.2023.136717.

Awang, R., Mohamed, S. B., Wan, C., Abdullah, N., Noorakma, W., & Mohamad, N. R. (2020). A Sustainable Dairy Goat housing Design Using Composite Material for Domestic Farming in Malaysia. *International Journal of Advanced Science and Technology*, *29*(6s), 2885–2893.

Broom, D. M. (2021). Farm Animal Welfare: A key component of the sustainability of farming systems. *Veterinarski Glasnik*, *75*(2), 145–151. https://doi.org/10.2298/VETGL210514007B.

Daramola, J. O., Adeloye, A. A., Fatoba, T. A., & Soladoye, A. O. (2012). Physiological and biochemical responses of West African Dwarf goats to transportation stress. *Small Ruminant Research*, *104*(1-3), 1–5.

de Souza, J. B., Mota, R. A., & Oliveira, M. C. (2020). Behavioural and physiological indicators of heat stress in goats: A review. *Tropical Animal Health and Production*, *52*(5), 2693–2703. https://doi.org/10.1007/s11250-020-02335-w.

Fonseca, J. F., Torres, C. A. A., Maffili, V. V., Moraes, E. A., & Manso Filho, H. C. (2016). Effects of thermal stress on reproductive parameters in small ruminants. *Tropical Animal Health and Production*, *48*(6), 1025–1032. https://doi.org/10.1007/s11250-016-1040-4.

Georgantzia, E., Gkantou, M., & Kamaris, G. S. (2021). Aluminum alloys as structural material: A review of research. *Engineering Structures*, *227*, 111372. https://doi.org/10.1016/j.engstruct.2020.111372.

Henn, J. J., McClain, A. M., & Sullivan, B. W. (2021). Temperature and humidity effects on livestock behavior and productivity in tropical climates. *Environmental Research Letters*, *16*(3), 034012. https://doi.org/10.1088/1748-9326/abe7c2.

Kroehnke, J., Lambertz, C., & Gauly, M. (2019). Design of modular livestock housing using aluminium framing. *Journal of Agricultural Engineering*, *50*(2), 65–73.

Kumar, N., Singh, H., & Rana, R. (2021). Smart livestock farming: Potential applications and challenges. *Sensors*, *21*(7), 2206. https://doi.org/10.3390/s21072206.

Munoz, C. A., Campbell, A. J. D., Hemsworth, P. H., & Doyle, R. E. (2019). Evaluating the welfare of extensively managed sheep. *PLOS ONE*, *14*(6), e0218603. https://doi.org/10.1371/journal.pone.0218603.

Omar, F., Kari, A., Awang, R., & Komilus, C. F. (2025). Physiological responses of Saanen does: A comparative study of traditional wooden and aluminium galvanized iron housing system in a tropical climate. *Jurnal Ilmu Ternak dan Veterinar*, *30*(1), 59–67.

Qin, X., Zhang, Y., & Wang, L. (2021). Application of lightweight materials in sustainable agricultural engineering. *Renewable Agriculture and Food Systems*, *36*(1), 45–54.

Sejian, V., Bhatta, R., Gaughan, J. B., Dunshea, F. R., & Lacetera, N. (2018). Adaptation of animals to heat stress. *Animal*, *12*(s2), s431–s444. https://doi.org/10.1017/S1751731118001945.

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science*, *67*(1-2), 1–18.

Silanikove, N., & Koluman, N. (2015). Impact of climate change on the welfare and productivity of small ruminants. *Small Ruminant Research*, *123*, 27–34. https://doi.org/10.1016/j.smallrumres.2014.11.005.