



Smart Livestock Housing: An Automated Approach to Animal Safety and Microclimate Regulation

¹M. M. Kolap, ²Sonal Durgule, ³Yash Jadhav, ⁴Saniya Khot

^{1,2,3,4} Department of Electronics & Telecommunication, Dr. J. J. Magdum College of Engineering, Jaysingpur
Email: yashjadhva045@gmail.com

Peer Review Information	Abstract
<p><i>Submission: 10 April 2026</i></p> <p><i>Revision: 01 May 2026</i></p> <p><i>Acceptance: 22 May 2026</i></p> <p>Keywords</p> <p><i>Livestock Management, Microclimate Automation, IoT-Enabled Farming, Thermal Regulation, Solar-Powered Systems, Cattle Welfare, Embedded Sensing.</i></p>	<p>Rapid developments in embedded electronics have enabled the construction of compact, affordable, and responsive sensing platforms. This work presents a self-regulating system aimed at sustaining a health-conducive habitat for cattle by dynamically managing thermal comfort, illumination, and intruder deterrence. A fogging unit actuated by DHT11-based temperature readings, along with ambient light regulation through LDR sensing and perimeter surveillance via ultrasonic and motion detection modules, forms the core of this framework. The entire platform is energized by photovoltaic panels supplemented with a battery reserve capable of sustaining at least twelve hours of uninterrupted service, thereby enabling round-the-clock autonomous operation.</p>

Introduction

Prolonged exposure to elevated ambient temperatures constitutes one of the most pressing threats to dairy cattle productivity, manifesting as reduced milk output, compromised immune function, and elevated physiological stress. This challenge is particularly pronounced in arid zones such as north-western Rajasthan, where extreme summer heat severely undermines the viability of dairy operations. Conventional mitigation strategies—such as driving herds toward natural water bodies—are impractical during peak heat periods or on farms with no access to such resources.

As the scale of modern livestock operations grows, the need for intelligent, automated housing management has become increasingly evident. Contemporary barn design must account for year-round climate variability, requiring robust ventilation architectures and

protective shading that shield animals from both extreme cold and summer radiation. The barn's internal climate—its microclimate—plays a decisive role in determining herd health and output.

Ventilation systems are central to this function: they not only eliminate excess moisture and noxious gases but also regulate condensation and air circulation. When ambient heat and humidity rise beyond tolerable thresholds, the animal's own thermoregulatory capability is overwhelmed, resulting in overheating and associated production losses. Dairy cattle perform optimally within a narrow temperature band of roughly 4.5–21°C, with peak efficiency observed between 16 and 18°C. Research confirms that while moderate temperature rises (15–25°C) cause modest productivity decline, severe heat exposure can drastically reduce both fertility and milk yield. Automated monitoring and actuation therefore represent a practical and

scalable path to safeguarding cattle welfare and farm economics.

Methodology

The developed framework operates as an autonomous sensing-and-actuation network that continuously evaluates the cattle shed environment and triggers corrective actions without any manual input. Renewable solar energy drives the system, supplemented by battery backup for nocturnal and overcast-period coverage.

1. System Architecture

The platform comprises five integrated subsystems:

- Energy Unit: Photovoltaic panel, charge controller, rechargeable battery, and dual-voltage (12 V / 5 V) regulation circuitry.
- Processing Core: ATmega328-based microcontroller responsible for sensor polling and actuator coordination.
- Sensing Layer: DHT11 (thermal and hygroscopic data), LDR (illuminance), ultrasonic transducer (water reservoir level), and PIR/acoustic sensor (movement and intrusion detection).
- Output Peripherals: LCD display, GSM text-alert module, audible buzzer, fogging assembly, and LED lighting array.
- Relay Interface: Solid-state relays bridging the microcontroller to high-current loads including the fogger and lighting circuits.

2. Operating Principles

Environmental measurements are gathered continuously and evaluated against configurable set-points. The decision logic is straightforward: thermal excess triggers the cooling fogger; diminished light levels activate the artificial illumination circuit; detected movement initiates the alarm and dispatches an SMS notification; and insufficient water reserves prompt a low-tank alert message to the operator.

3. Operational Sequence

The system follows a structured eight-step workflow:

- Step 1 – Energy Initialization: The solar array charges the battery, which in turn feeds regulated voltages to all subsystems.
- Step 2 – Sensor Activation: All peripheral sensors are powered on and begin sampling their respective physical quantities.

- Step 3 – Data Acquisition: Sensor readings are streamed to the microcontroller at a rapid polling rate, enabling near-instantaneous responsiveness.
- Step 4 – Threshold Comparison: Each sampled value is evaluated against pre-configured limit values stored in the controller's memory.
- Step 5 – Actuation Decision: Conditions breaching set-points trigger appropriate actuator commands (fogger on, lights on, alarm trigger, or SMS dispatch).
- Step 6 – Relay-Driven Output: Relay modules energize or de-energize target loads based on the controller's logical outputs.
- Step 7 – User Notification: The LCD panel presents a continuous readout of temperature, humidity, and system state, while the GSM module forwards critical alerts as text messages.
- Step 8 – Cyclic Reprocessing: The entire sensing-processing-actuation loop repeats without interruption, assuring perpetual autonomous operation.

4. Monitored Variables

- Temperature and Relative Humidity — sampled via DHT11; temperature is the single most critical parameter for livestock wellbeing.
- Ambient Light Intensity — captured by an LDR, enabling automatic day/night lighting transitions.
- Water Tank Level — measured using ultrasonic ranging to infer fill state from the sensor-to-surface distance.
- Motion and Acoustic Activity — detected via PIR or sound sensors at shed entry points for intrusion awareness.
- Power Status — solar generation and battery charge are monitored to optimize energy draw.

5. Hardware Subsystem Description

Each hardware element serves a distinct role within the unified system:

DHT11 Sensor: Quantifies interior temperature and humidity; positioned centrally within the shed for representative readings.

Light-Dependent Resistor: Converts ambient illuminance to an analog voltage signal used for automatic lighting control.

Cooling Fogger: Engages automatically when measured temperature surpasses the configured thermal limit, dispersing fine water mist to lower ambient temperature.

Ultrasonic Module: Mounts atop the water tank; calculates fill level from measured echo return time and flags low-level conditions.

PIR/Sound Sensor: Installed near access points; outputs a discrete HIGH signal upon detecting unusual movement or acoustic events.

Solar Panel + Battery: Serves as the sole power source; the battery ensures continuity during nighttime hours and overcast weather.

Microcontroller (Arduino/ESP32): Orchestrates all sensor reading, threshold evaluation, and actuator control tasks.

GSM Module: Optionally transmits real-time SMS notifications regarding security events or water level conditions.

6. Software Architecture

The firmware implements the following functional modules:

- **Sensor Polling Routines:** Acquisition loops for DHT11 digital output, LDR analog-to-digital conversion, ultrasonic echo timing, and PIR digital state reading.
- **Control Logic Engine:** Threshold-based decision trees that map sensor readings to actuator commands.
- **Messaging Stack:** GSM AT-command sequences for SMS generation triggered by alarm or low-water conditions.
- **Power Monitoring:** Battery voltage sampling to prevent deep discharge and optimize solar utilization.
- **Optional Dashboard:** If IoT connectivity is enabled, sensor data may be published to a cloud broker or mobile application for remote oversight.

Development environments supported include the Arduino IDE, Embedded C/C++, or MicroPython, depending on the selected hardware board.

7. Data Acquisition Methodology

Sensor signals arrive at the microcontroller either as digital streams (DHT11, PIR) or as analog voltages that are digitized internally via the built-in ADC (LDR). Data is refreshed every few seconds, affording rapid reaction to environmental shifts. Prior to deployment, each sensor undergoes calibration against reference instruments, and multiple successive readings are averaged to suppress transient noise and measurement artefacts. Processed data is simultaneously logged to the LCD, used in actuation decisions, and forwarded via GSM where applicable.

Challenges And Limitations

Several practical constraints were identified during system evaluation:

- **Harsh Environmental Exposure:** Livestock sheds harbor dust, condensation, and mechanical disturbances that can degrade sensor performance over time without adequate protective enclosures.
- **Solar Dependency:** Prolonged cloud cover or monsoon conditions may curtail renewable power generation, placing greater demand on battery capacity and potentially shortening operational intervals.
- **Sensor Grade Limitations:** Entry-level devices such as the DHT11 exhibit constrained accuracy ranges and may not meet precision requirements for high-performance farm analytics.
- **Cellular Coverage Gaps:** Rural deployments frequently suffer from weak mobile network signals, which may delay or prevent GSM alert delivery.
- **Capital Expenditure:** Initial procurement and installation of the full hardware stack—photovoltaic panel, microcontroller, sensors, and relay board—may represent a prohibitive upfront cost for small-scale or subsistence farmers.
- **Routine Upkeep:** Sensor surfaces require periodic cleaning, wiring integrity must be verified, and battery cells will eventually need replacement; neglecting maintenance erodes system reliability.
- **Spatial Coverage Constraints:** A single installation covers a finite footprint; expansive facilities will require multiple interconnected units, compounding both cost and administrative complexity.
- **Skill Requirements:** Successful installation, configuration, and fault diagnosis presuppose basic electronics and programming competency, potentially necessitating formal training for farming personnel.
- **Component Failure Risk:** Any single hardware failure can impair overall system functionality; redundancy measures and periodic diagnostic routines are therefore essential.

Results And Discussion

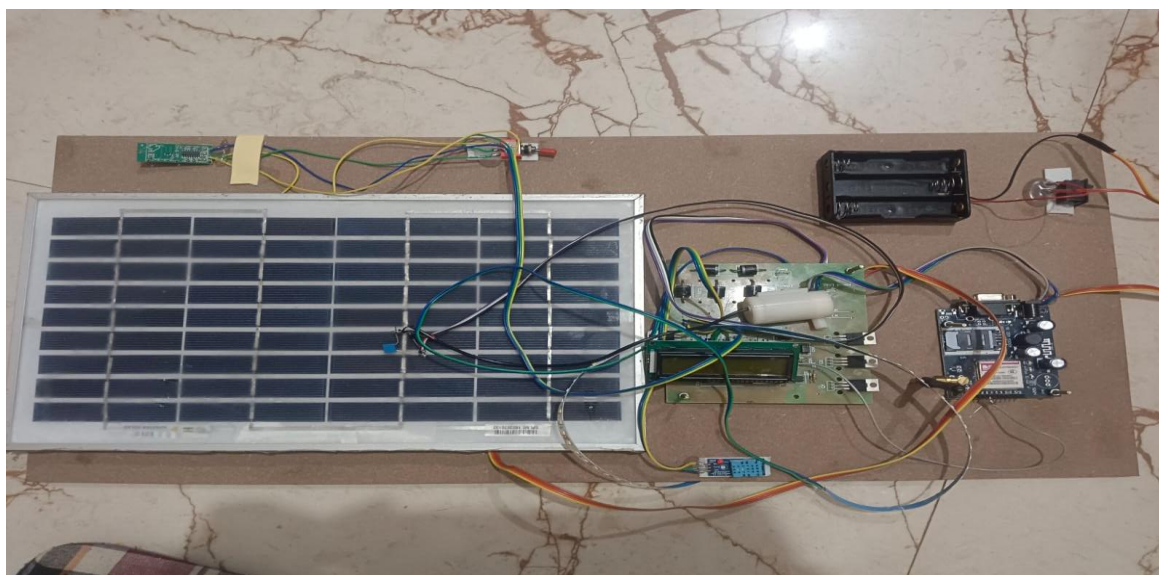
Bench and field testing confirmed that the integrated system reliably sustains target environmental conditions within the cattle enclosure. The fogging unit engaged promptly

and consistently whenever thermal readings exceeded the defined upper limit, yielding a measurable reduction in perceived heat stress. Automated light switching proved responsive under varying ambient conditions, eliminating the need for manual intervention. Perimeter monitoring with PIR sensing successfully triggered both audible alarms and SMS dispatches upon simulated intrusion events. Ultrasonic-based tank monitoring accurately flagged low-water scenarios before reserves were completely exhausted. Throughout all trials, the solar-battery power arrangement maintained continuous system operation without external grid support. Performance characterized across four dimensions:

- **Response Speed:** Actuator reactions to threshold crossings were near-instantaneous, confirming suitability for real-time livestock management.

- **Measurement Fidelity:** Despite using economy-grade sensors, recorded values fell within an acceptable error margin for practical farm applications.
- **Operational Continuity:** No unplanned outages were recorded during the test window, validating the energy architecture.
- **Automation Gain:** Manual labor associated with cooling, lighting, and security tasks was substantially reduced, demonstrating the system's operational efficiency advantage.

Minor measurement deviations were noted under conditions of high particulate density and strong ambient airflow, reinforcing the need for weatherproofed sensor housings in production deployments.



Conclusion

This study presents a self-contained, solar-powered livestock environment management system that autonomously coordinates thermal regulation, illumination control, water monitoring, and intruder detection within a cattle shed. By consolidating these functions into a single embedded platform driven by an ATmega328 microcontroller and a suite of low-cost sensors, the work demonstrates that meaningful improvements in animal welfare and farm productivity are achievable without heavy capital investment or continuous human oversight.

The use of renewable energy not only reduces operating costs but also extends applicability to off-grid rural sites where reliable grid power is unavailable. Experimental outcomes validate

that automated fog cooling, responsive lighting, and GSM-based alerting collectively alleviate the burdens of heat stress management and security supervision. The architecture is inherently scalable, allowing incremental expansion as farm size and budget permit.

Future development pathways are well defined and include the embedding of an IoT gateway for cloud-based telemetry, the replacement of economy sensors with precision-grade alternatives, the integration of computer-vision-based health monitoring via IP cameras, and the application of machine-learning algorithms to anticipate environmental deterioration before threshold breaches occur. Collectively, these enhancements would position the system as a comprehensive smart-farming solution fully

aligned with the demands of precision dairy management.

Future Work

- IoT Gateway Integration: Publishing live sensor telemetry to internet-accessible dashboards for remote monitoring and device control.
- Dedicated Mobile Application: A smartphone interface offering real-time data visualization, push-alert management, and manual actuator override.
- Cloud-Based Data Repository: Persistent logging of sensor histories to support trend analysis, anomaly detection, and evidence-based management decisions.
- AI-Driven Predictive Control: Training regression or time-series models on historical sensor data to anticipate threshold violations and preemptively activate cooling or ventilation.
- High-Fidelity Sensor Upgrade: Substituting DHT11 with calibrated temperature-humidity probes; supplementing with gas-phase sensors for ammonia and carbon dioxide detection.
- Adaptive Ventilation Mechanisms: Incorporating variable-speed fan arrays and motorized vent actuators under closed-loop control.
- Vision-Based Cattle Monitoring: Deploying IP cameras and computer vision algorithms to assess animal health metrics and detect behavioral anomalies indicative of illness.
- Wireless Sensor Mesh: Deploying multiple sensor nodes communicating over Wi-Fi or Zigbee protocols to achieve comprehensive coverage in large facilities.
- Hybrid Energy Architecture: Combining photovoltaic generation with grid connection or diesel backup to guarantee power availability under all weather conditions.

References

A. Arbel, O. Yekutieli, and M. Barak, "Combined forced-ventilation and fogging systems for greenhouse cooling," *Biosystems Engineering*, vol. 84, no. 1, pp. 45–55, 2003.

C. Arcidiacono, "Analysis and simulation of thermo-hygrometric comfort conditions in farrowing rooms with evaporative cooling," *Rivista di Ingegneria Agraria*, vol. 2, pp. 23–33, 2006 (in Italian).

P. Axaopoulos, P. Panagakis, and S. Kiritsis, "Computer simulation for assessing the thermal microenvironment of growing pigs under summer conditions," *Transactions of the ASAE*, vol. 35, no. 3, pp. 1005–1009, 1992.

G. L. Hahn, J. A. Nienaber, and J. A. DeShazer, "Effect of air temperature on swine performance and behavior," *Applied Engineering in Agriculture*, vol. 3, no. 2, pp. 295–302, 1987.

A. Haeussermann et al., "Assessment of control approaches for fogging systems installed in pig production facilities," *Transactions of the ASABE*, vol. 50, no. 1, pp. 265–274, 2007.

P. Liberati and P. Zappavigna, "Dynamic computational model for optimizing the internal climate of swine buildings," *Transactions of the ASABE*, vol. 50, pp. 2179–2188, 2007.

P. Liberati, "Influence of roofing geometry on thermal stress in dairy cattle housing," *Journal of Agricultural Engineering*, vol. 4, pp. 21–27, 2008.

P. Liberati, M. Spiga, and P. Zappavigna, "Roof ventilation optimization for livestock buildings," *International Communications in Heat and Mass Transfer*, vol. 36, pp. 432–437, 2009.

E. M. Lucas, J. M. Randall, and J. F. Meneses, "Evaporative cooling potential for pig production in Portugal during heat stress periods," *Journal of Agricultural Engineering Research*, vol. 76, no. 4, pp. 363–371, 2000.

Acknowledgment

The authors extend their sincere appreciation to Prof. M. M. Kolap for his patient mentorship, rigorous technical guidance, and unwavering encouragement throughout all phases of this project. His critical insights were instrumental in refining both the conceptual design and the practical implementation of the system.

Gratitude is also expressed to the Head of the Department and faculty colleagues within the Department of Electronics and Telecommunication Engineering at Dr. J. J. Magdum College of Engineering, Jaysingpur, for facilitating access to the laboratory infrastructure and providing institutional support.

The authors further acknowledge their teammates for their dedication, cooperative spirit, and consistent effort, as well as their families for the moral support that sustained this endeavor to completion.