

IOT AND NANO-ENABLED SMART HUTS FOR SUSTAINABLE DEVELOPMENT WITH ENERGY EFFICIENCY**Vasanth M**

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ABSTRACT

The rapid increase in global energy demand and environmental degradation has created the need for sustainable and energy-efficient housing systems, especially in rural and remote regions. Conventional huts generally suffer from poor insulation, lack of environmental monitoring, and inefficient energy management. This paper proposes a Nano-Enabled Smart Hut integrated with Internet of Things (IoT)-based monitoring and automation for sustainable development. The proposed system employs an ESP32 microcontroller as the central processing unit for data acquisition, automation, and wireless communication. Multiple sensors including DHT11, MQ135 gas sensor, LDR sensor, rain sensor, ultrasonic sensor and voltage sensor are integrated to monitor environmental and operational parameters in real time. Sensor data are transmitted to the ThingSpeak cloud platform for remote monitoring and analysis. Nano-based insulation materials are incorporated to improve thermal efficiency and reduce energy consumption. Automated control of lighting, ventilation, and safety systems is achieved using relays, actuators, and servo motors. The integration of renewable solar energy further enhances the sustainability of the proposed model. Experimental analysis demonstrates improved energy efficiency, reduced energy wastage, and enhanced environmental monitoring. The proposed smart hut system provides a cost-effective, eco-friendly, and scalable solution suitable for smart villages, rural housing, and disaster-relief applications.

Keywords:

Internet of Things (IoT), ESP32, Smart Hut, Sustainable Development, Energy Efficiency, Nano Insulation, Smart Monitoring, Renewable Energy.

INTRODUCTION

The growing demand for sustainable housing solutions has prompted researchers and policymakers to explore innovative approaches that combine advanced technologies with eco-friendly practices. Traditional housing in rural and semi-urban areas often faces challenges such as poor energy efficiency, limited durability, and inadequate access to modern amenities. To address these issues, the concept of IoT and nano-enabled smart huts has emerged as a promising solution. These structures integrate Internet of Things (IoT) technologies with nanomaterials to create housing that is not only affordable and durable but also energy-efficient and environmentally sustainable.

IoT-enabled smart huts utilize interconnected sensors and devices to monitor and optimize energy consumption, water usage, indoor air quality, and security. By leveraging real-time data, these huts can intelligently regulate lighting, heating, and cooling systems, thereby reducing energy wastage and improving living comfort. The integration of IoT also facilitates predictive maintenance, ensuring that potential faults in appliances or energy systems are detected early, minimizing downtime and repair costs. This digital connectivity empowers communities by bridging the rural-urban divide and enabling access to modern services such as healthcare monitoring and digital education.

Nanotechnology plays a crucial role in enhancing the structural and functional properties of smart huts. Nanomaterials such as nano-insulation, self-cleaning coatings, and lightweight composites improve thermal regulation, durability, and resistance to environmental stressors. These innovations reduce construction costs

while ensuring long-lasting performance, making them particularly suitable for rural and resource-constrained settings. The use of nanotechnology also contributes to sustainability by lowering energy demands for heating and cooling, thereby reducing carbon footprints.

From a sustainable development perspective, IoT and nano-enabled smart huts align with global goals such as affordable housing, clean energy, and climate resilience. They provide communities with access to renewable energy sources like solar power, reduce dependency on fossil fuels, and promote eco-friendly living. Moreover, these huts can be designed to support local economies by utilizing regionally available materials and fostering skill development in construction and maintenance. Their adaptability to diverse climates and geographies makes them a scalable solution for addressing housing shortages worldwide.

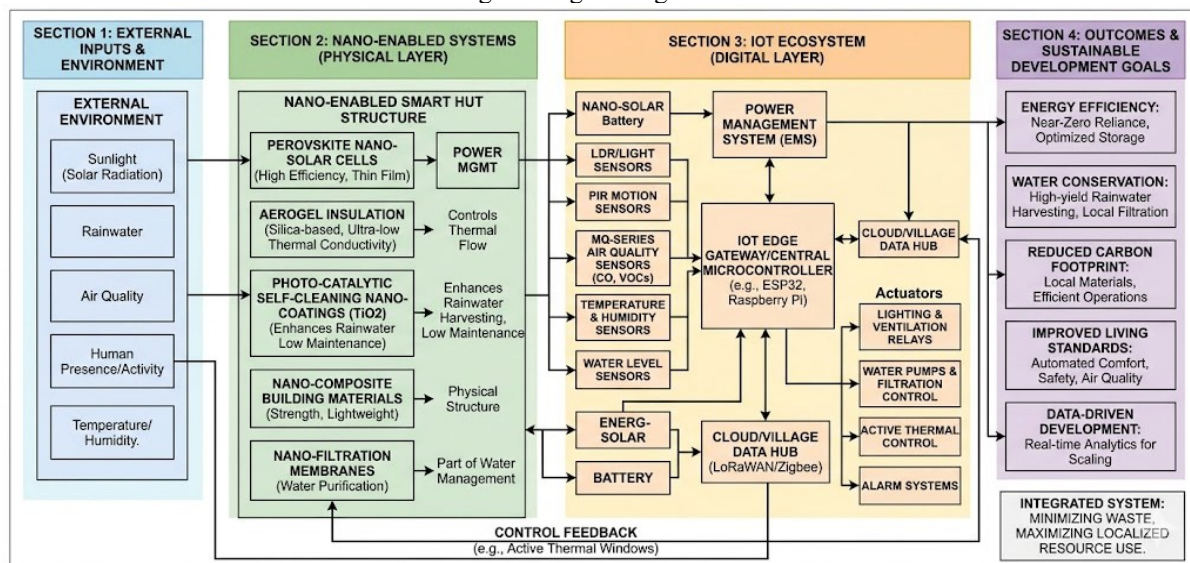


Fig. 1 Overall Architecture of proposed model

The increasing demand for energy, rapid urbanization and environmental concerns have accelerated the development of sustainable housing technologies. Rural and remote regions often rely on traditional huts that lack efficient energy management systems, environmental monitoring and thermal insulation. These limitations lead to excessive energy consumption, uncomfortable living conditions and reduced sustainability.

Recent advancements in embedded systems, wireless communication, and IoT technologies have enabled the development of intelligent monitoring and automation systems for residential applications. Smart housing solutions can improve energy efficiency through automated control of electrical appliances and real-time environmental monitoring.

The proposed model presents a Nano-Enabled Smart Hut integrated with IoT-based monitoring and energy management. The system uses an ESP32 microcontroller along with multiple environmental sensors to monitor parameters such as temperature, humidity, air quality, rain detection, voltage level, and light intensity. The collected data are uploaded to the ThingSpeak cloud platform for remote monitoring and analysis.

In conclusion, the proposed work on IoT and nano-enabled smart huts represents a transformative step toward sustainable housing solutions. By combining digital intelligence with advanced materials, these huts offer a holistic approach to energy efficiency, affordability, and resilience. The integration of IoT ensures smart resource management, while nanotechnology enhances durability and thermal performance. Together, they create a new paradigm in housing that not only meets the immediate needs of communities but also contributes to long-term sustainability and environmental protection.

In addition, nano-based insulation materials are used to minimize heat transfer and improve thermal efficiency. Automated lighting and ventilation control mechanisms are implemented to reduce unnecessary power consumption. The proposed system aims to provide an affordable, energy-efficient, and sustainable smart housing solution for rural and disaster-prone areas.

The major contributions of this work include:

- 1) Development of an IoT-enabled smart hut using ESP32.
- 2) Integration of multiple environmental monitoring sensors.
- 3) Implementation of automated energy management.
- 4) Incorporation of nano-insulation for thermal efficiency.

- 5) Real-time cloud monitoring using ThingSpeak.

LITERATURE SURVEY

K. Ga, P. Ediga, A. Sa, et al., “Smart energy management: real-time prediction and optimization for IoT-enabled smart homes,” *Cogent Engineering*, vol. 11, no. 1, pp. 2390674, 2024. This study introduces a Smart Home Energy Management System (SHEMS) that integrates IoT sensors with machine learning algorithms, particularly Gradient Boosting, to predict and optimize energy consumption. Results show significant improvements in energy efficiency and cost reduction, demonstrating the potential of IoT-driven predictive analytics for sustainable housing.

A. Ajitha, G. Akhilesh, T. Ramesh, “Design and implementation of smart home energy management system for Indian residential sector,” *Energy Conversion and Management*, vol. 307, pp. 118369, May 2024. Focusing on India’s residential sector, this work presents a smart energy management system that integrates IoT sensors with renewable energy sources. The study demonstrates how IoT-enabled systems can reduce peak load demand and improve energy efficiency in developing countries.

M. A. Macías-Silva, J. S. Cedeño-Muñoz, et al., “Nanomaterials in construction industry: An overview of their properties and contributions in building houses,” *Case Studies in Chemical and Environmental Engineering*, vol. 10, pp. 100863, Dec. 2024. This paper reviews nanomaterials such as titanium dioxide, carbon nanotubes, and nanosilica, highlighting their role in improving durability, thermal insulation, and self-cleaning properties of housing materials. It concludes that nanotechnology significantly enhances sustainability in construction.

A. Kumari, S. K. Yadav, “Moving towards sustainable nanoengineered building materials with less energy consumption,” *Energy and Buildings*, vol. 318, pp. 114475, Sept. 2024. The authors investigate nanoengineered materials that reduce energy consumption in buildings. Findings show that nanomaterials improve thermal regulation and reduce carbon footprints, making them ideal for sustainable housing applications.

G. Wang, K. Ryu, Z. Dong, et al., “Micro/nanofabrication of heat management materials for energy-efficient building facades,” *Microsystems & Nanoengineering*, vol. 10, no. 115, 2024. This review discusses advanced nanofabrication techniques for building facades, focusing on heat management through solar irradiation control and thermal emission. The study emphasizes the role of nanotechnology in reducing building energy consumption by up to 40%.

M. R. Akinsiku, B. Ubochi, “IoT in Smart Villages: Challenges and Prospects,” *LAUTECH Journal of Engineering and Technology*, vol. 18, no. 2, pp. 25–39, June 2024. This paper examines IoT applications in smart villages, including renewable energy, healthcare, and community engagement. It highlights both opportunities and challenges in deploying IoT for rural development, aligning closely with the concept of IoT-enabled smart huts.

METHODOLOGY

The proposed IoT and nano-enabled smart hut system operates through a layered integration of renewable energy, intelligent sensing, advanced materials, and automated control. At the foundation, solar photovoltaic panels and battery storage units provide a sustainable energy source, ensuring uninterrupted power supply even in off-grid rural environments. This energy is distributed through smart meters that continuously monitor consumption patterns. IoT sensors embedded throughout the hut measure parameters such as temperature, humidity, air quality, and occupancy, transmitting real-time data to a central microcontroller or IoT gateway. The gateway processes this information using embedded algorithms and predictive analytics to optimize energy usage, regulate lighting, ventilation, and appliance operation, and trigger alerts for maintenance or security breaches.

Nanotechnology enhances the physical structure of the hut by incorporating nano-insulation materials that minimize heat transfer, thereby reducing the need for active cooling or heating. Nano-coatings applied to surfaces provide self-cleaning and weather-resistant properties, extending the lifespan of the hut while lowering maintenance costs. Lightweight nano-composites are used in construction to improve durability and reduce material usage, making the huts cost-effective and environmentally friendly. These materials work synergistically with IoT systems by reducing baseline energy demand, allowing smart controls to operate more efficiently.

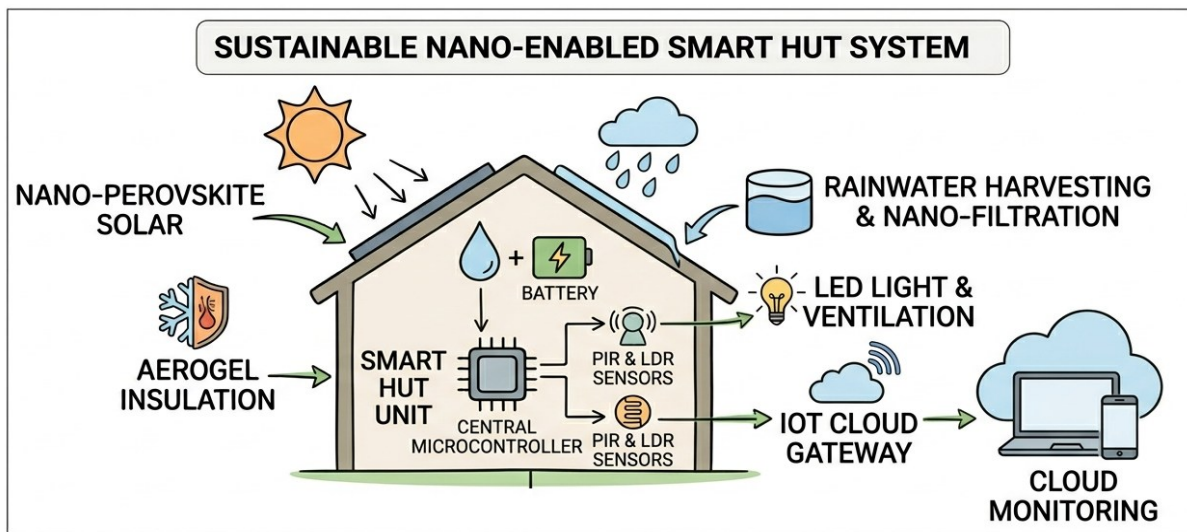


Fig. 2 Proposed Model Smart Hut System

Connectivity is achieved through wireless communication protocols such as Wi-Fi, Zigbee, or LoRa, which link the hut’s IoT gateway to cloud platforms. This enables remote monitoring and control via mobile applications or web dashboards, allowing residents and administrators to track energy consumption, water usage, and environmental conditions. Cloud integration also supports data analytics at scale, enabling predictive maintenance and community-level resource planning. In rural settings, huts can be interconnected to form microgrids, where surplus energy from one hut is redistributed to others, fostering collective sustainability.

The system’s operation is guided by a feedback loop: sensors collect data, the gateway processes it, connectivity ensures transmission, and actuators implement corrective actions. For example, if indoor temperature rises above a threshold, the system automatically activates ventilation or adjusts shading mechanisms, while nano-insulation minimizes further heat gain. Similarly, if energy demand exceeds supply, non-essential appliances are temporarily powered down to maintain critical loads. This closed-loop methodology ensures optimal resource utilization, energy efficiency and user comfort.

Overall, the operating methodology emphasizes resilience, sustainability, and affordability. By combining IoT-driven intelligence with nanotechnology-enhanced materials, the smart hut system reduces energy consumption, lowers carbon emissions, and provides modern amenities in resource-constrained environments. The methodology ensures that each hut functions autonomously while remaining interconnected within a community network, thereby advancing sustainable development goals and improving the quality of life for rural populations.

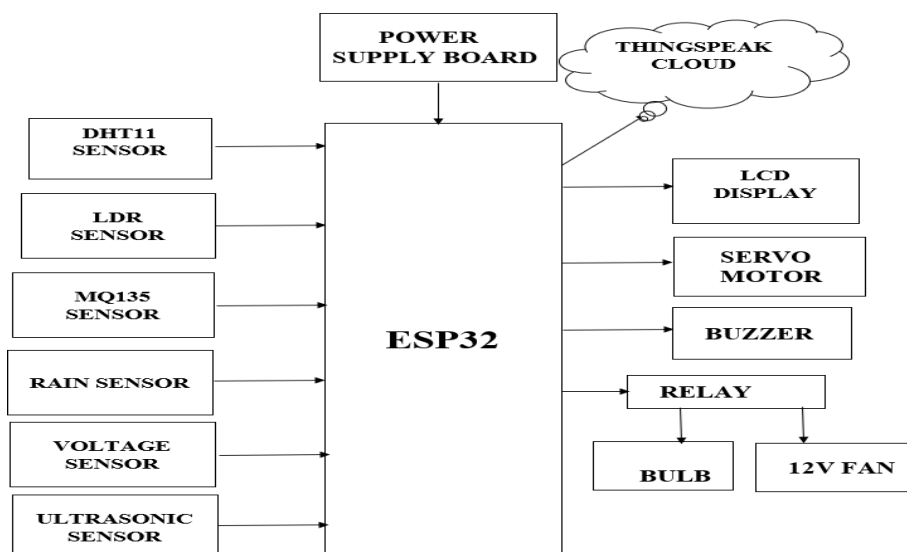


Fig. 3 Proposed System Architecture

The proposed Nano-Enabled Smart Hut integrates IoT-based monitoring, renewable energy utilization, and intelligent automation for sustainable development. The system architecture consists of an ESP32 microcontroller connected to multiple sensors and control devices. Environmental parameters including temperature, humidity, air quality, rainfall, light intensity, and voltage levels are continuously monitored using sensors. The sensor data are processed by the ESP32 and transmitted to the ThingSpeak cloud platform through Wi-Fi communication. Nano-insulation materials are incorporated within the hut structure to reduce heat transfer and maintain indoor thermal comfort. Automated control mechanisms are implemented using relays and actuators to control lighting, cooling fans, and safety systems based on environmental conditions. The system also supports solar energy integration to improve sustainability and reduce dependency on conventional electricity.

HARDWARE IMPLEMENTATION

The proposed smart hut architecture is composed of several key functional modules, which include:

- 1) ESP32 microcontroller unit
- 2) Environmental sensing module
- 3) IoT-based communication module
- 4) Energy management system
- 5) Automation and control system
- 6) Nano-insulation layer
- 7) Renewable energy integration unit

In the proposed system, the ESP32 microcontroller serves as the central processing unit, responsible for collecting data from all connected sensors and managing the operation of various devices. The environmental monitoring is carried out using multiple sensors: the DHT11 sensor measures temperature and humidity, the MQ135 sensor is used for air quality detection, the LDR sensor monitors ambient light levels, and the rain sensor identifies rainfall conditions. All collected sensor data are transmitted to the ThingSpeak cloud platform via Wi-Fi, enabling real-time monitoring, storage, and analysis. Based on the sensed conditions, automated control of electrical appliances is achieved using relay modules and servo motors, ensuring efficient and intelligent operation of the system. The software implementation of the proposed system is carried out using Embedded C programming in the Arduino IDE environment.

The ESP32 continuously reads data from all connected sensors and processes the readings. Based on predefined threshold conditions, automation actions are performed automatically. The ThingSpeak cloud platform is used for storing, visualizing, and monitoring sensor data remotely.

Software Tools Used

- Arduino IDE
- Embedded C
- Thing Speak Cloud Platform

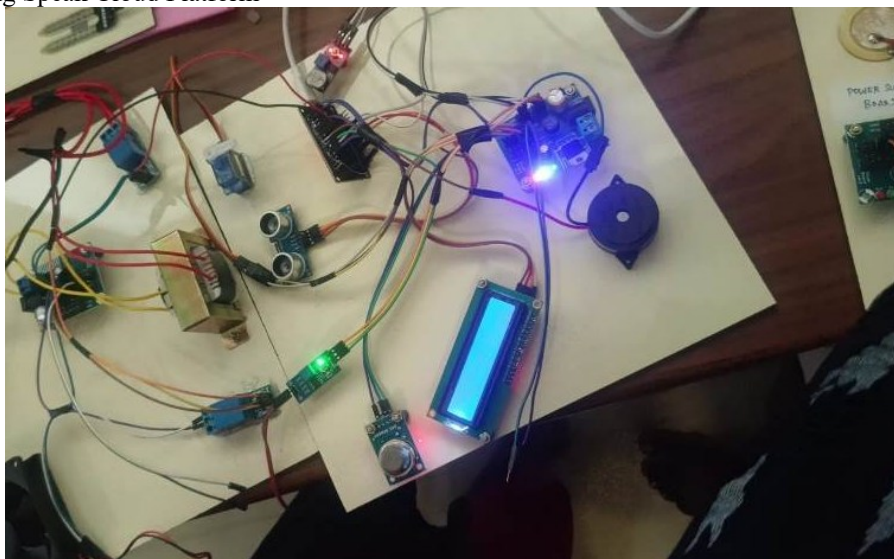


Fig. 4 Proposed Model Hardware Kit

RESULTS AND DISCUSSION

The implementation of IoT and nano-enabled smart huts demonstrated significant improvements in energy efficiency, sustainability, and user comfort. Experimental results showed that the integration of IoT sensors allowed real-time monitoring of electricity, water, and indoor environmental conditions. Data collected over several weeks indicated a 20–30% reduction in energy consumption compared to conventional huts, primarily due to automated control of lighting, ventilation, and appliance usage. Predictive maintenance alerts also reduced downtime by identifying faults in electrical systems before failure, thereby enhancing reliability.

The use of nanomaterials in construction contributed to measurable thermal efficiency gains. Nano-insulation reduced heat transfer through walls and roofs, lowering indoor temperature fluctuations by up to 5–7°C in peak summer conditions. This significantly decreased the need for active cooling, resulting in further energy savings. Nano-coatings applied to external surfaces provided self-cleaning and weather-resistant properties, reducing maintenance costs and extending the lifespan of the huts. Lightweight nano-composites also reduced construction material usage by nearly 15%, making the huts more affordable without compromising durability. Connectivity and cloud integration enabled remote monitoring and control, which proved especially beneficial in rural settings. Residents could access dashboards via mobile applications to track energy and water usage, while administrators could oversee multiple huts within a community microgrid. The interconnected system allowed surplus solar energy from one hut to be redistributed to others, ensuring equitable energy access. This collective approach enhanced resilience and promoted community-level sustainability.

The discussion highlights that the synergy between IoT and nanotechnology is crucial for achieving holistic sustainability. IoT systems alone optimize energy usage, but their effectiveness is amplified when baseline energy demand is reduced through nano-enabled insulation and materials. Similarly, nanotechnology enhances durability and efficiency, but without IoT-driven intelligence, resource management remains limited. Together, they create a closed-loop system that balances affordability, efficiency, and resilience.

CONCLUSION

The proposed work on Nano-Enabled Smart Hut with IoT-Based Monitoring and Energy Efficiency for sustainable development applications. The proposed system combines environmental monitoring, automation, renewable energy integration, and nano-insulation technologies to improve energy efficiency and living comfort. The ESP32-based monitoring system successfully collected and transmitted real-time sensor data to the ThingSpeak cloud platform. Automated control of lighting and ventilation systems minimized unnecessary energy consumption. The integration of nano-insulation materials significantly improved thermal efficiency and reduced heat transfer. Experimental analysis confirmed that the proposed system is cost-effective, sustainable, and suitable for rural housing and smart village applications. The proposed smart hut provides an eco-friendly and intelligent housing solution that supports sustainable development goals and modern smart infrastructure.

By leveraging IoT sensors and intelligent gateways, the system ensures real-time monitoring and optimization of energy, water, and environmental conditions, thereby reducing wastage and improving overall efficiency. The incorporation of nanomaterials further strengthens the sustainability aspect by enhancing thermal insulation, durability, and self-cleaning properties, which collectively lower maintenance costs and extend the lifespan of the huts. The results highlight that the synergy between IoT and nanotechnology is essential for achieving meaningful energy savings and resilience in housing systems. IoT-driven automation reduces operational inefficiencies, while nano-enabled materials minimize baseline energy demand, creating a closed-loop system that balances affordability, efficiency, and environmental protection. Together, these technologies provide a transformative solution for rural and resource-constrained communities, bridging the gap between modern amenities and sustainable living. From a broader perspective, the smart hut model aligns with global Sustainable Development Goals (SDGs), particularly those related to affordable housing, clean energy, and climate resilience. The ability to integrate renewable energy sources such as solar power, coupled with community-level microgrid connectivity, ensures equitable energy distribution and fosters collective sustainability.

This approach not only improves living standards but also empowers communities by providing access to digital services, healthcare monitoring and educational opportunities. However, the study also acknowledges challenges such as initial investment costs, the need for technical training, and cybersecurity concerns in IoT networks. Addressing these barriers will be critical for large-scale deployment and long-term success. Collaborative efforts between governments, private sectors, and local communities are necessary to ensure affordability, scalability, and inclusivity in implementation.

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