International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

Iot for Smart Homes and Energy Conservation Technologies, Applications, Challenges, and Future Perspectives

Mr. Rajani Venkata Krishna[1], Ms. Zunaira Banu[2], Ms. Maheen Asla[3], Mr. Mustafa Masood[4], Mr. Mohammed Tanfeezuddin[5], Mr. Syed Khaja Pasha[6]
[1]Associate Professor, EEE, Lords Institute of Engineering and Technology, Himayathsagar, Hyderabad.
[2,3,4,5,6]UG Scholars, CSE-DS, Lords Institute of Engineering and Technology, Himayathsagar, Hyderabad, Telangana
Emails: *r.venkatakrishna@lords.ac.in[1], banuzunaira359@gmail.com[2], aslamaheen03@gmail.com[3], mustafamasood382@gmail.com[4], mtanfeez5@gmail.com[5], khajapashasyed95@gmail.com[6]*

Abstract
The Internet of Things (IoT) is transforming residential environments by connecting electrical appliances, sensors, smart meters, controllers, and communication networks to enable intelligent monitoring and automated control. Smart homes use IoT technologies to improve energy efficiency, reduce unnecessary electricity consumption, enhance user convenience, and support sustainable living. This paper presents a review of IoT-based smart-home systems with particular emphasis on sensing technologies, home automation, energy monitoring, communication protocols, and data privacy. It discusses how temperature, occupancy, light, and current sensors can be integrated with microcontrollers and intelligent control systems to optimize lighting, heating, ventilation, air conditioning, and other household loads. The paper also examines technologies such as Wi-Fi, Bluetooth Low Energy, Zigbee, Thread, and Matter, along with cloud-based and edge-computing approaches. Despite their advantages, IoT-enabled homes face challenges related to interoperability, cybersecurity, installation costs, reliability, and user privacy. The review concludes that combining secure communication, local intelligence, interoperable devices, and energy-aware automation can contribute to more efficient, reliable, and sustainable residential energy management.

Keywords: *Internet of Things, smart homes, energy conservation, wireless sensor networks, home automation, smart meters, energy monitoring, cybersecurity, privacy, sustainable buildings.*

1. Introduction
The rapid advancement of Information and Communication Technologies (ICT), wireless communication, and the Internet of Things (IoT) has significantly transformed the way energy is monitored, managed, and consumed in modern residential buildings. With the continuous growth in population, urbanization, and the increasing demand for electricity, energy conservation has become a major concern worldwide. Residential buildings account for a considerable share of global energy consumption due to the extensive use of lighting systems, heating, ventilation, air conditioning (HVAC), household appliances, and electronic devices. Traditional home energy management systems often rely on manual operation and conventional electrical control mechanisms, which may lead to unnecessary energy consumption, inefficient resource utilization, and increased electricity costs. Therefore, the integration of intelligent technologies into residential environments is essential for achieving efficient energy management and sustainable living. The Internet of Things (IoT) is an emerging technology that enables physical devices, sensors, appliances, and control systems to communicate and exchange data through the internet. By integrating IoT-based devices into residential buildings, conventional homes can be transformed into smart homes capable of monitoring environmental conditions, detecting occupancy, controlling electrical appliances, and optimizing energy consumption automatically. IoT-enabled smart home systems utilize various technologies, including wireless sensor networks (WSNs), Wi-Fi, Bluetooth Low Energy (BLE), Zigbee, Z-Wave, cloud computing,

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

edge computing, and artificial intelligence (AI). These technologies facilitate real-time data collection, remote monitoring, intelligent decision-making, and automated control of household electrical systems. In smart homes, IoT-based energy management systems play a significant role in reducing electricity consumption and improving overall energy efficiency. Smart meters and energy monitoring sensors measure real-time power consumption of individual appliances and provide detailed information about energy usage. Intelligent lighting systems automatically adjust illumination based on occupancy and natural daylight availability, while smart thermostats regulate indoor temperature according to user preferences and environmental conditions. Similarly, smart plugs and automated controllers can disconnect electrical appliances when they are not in use. These functionalities help minimize energy wastage, reduce peak electricity demand, and improve consumer awareness regarding energy consumption patterns.

2. Literature Review

The Internet of Things (IoT) has become an important technology for developing intelligent and energy-efficient residential environments. Over the past decade, several researchers have investigated IoT-based smart home automation, Home Energy Management Systems (HEMS), wireless sensor networks, artificial intelligence, renewable energy integration, and intelligent electricity consumption monitoring. These studies have focused on reducing energy wastage, improving household energy efficiency, automating electrical appliances, and optimizing electricity consumption. Bindushree G. T. presented a literature review focusing on the integration of IoT technologies into residential energy management systems. The study examined smart home architectures, sensing technologies, communication protocols, energy optimization algorithms, and user interface designs. It also discussed the importance of real-time monitoring and automated energy control for reducing electricity consumption. The research identified security, privacy, scalability, user acceptance, and interoperability as major challenges affecting the implementation of IoT-based energy management systems. George and Selvakumar investigated the role of smart home energy management systems in supporting sustainable energy utilization in India. Their research discussed [1] the importance of energy-efficient residential technologies, renewable energy integration, and the economic aspects of adopting smart home energy management solutions. The study particularly highlighted the financial challenges associated with transitioning from conventional residential electrical systems to advanced energy management infrastructure in developing countries. Rehman et al. conducted a systematic literature review of smart home energy [2] management models using research published between 2018 and 2024. The study examined energy optimization techniques, renewable energy integration, demand-side management, battery storage, and intelligent control strategies. The authors discussed the role of advanced computational methods in improving energy utilization and reducing residential electricity costs. The research also identified opportunities for improving energy forecasting, consumer participation, and data security [3].

3. Methodology

The proposed methodology consists of eight major stages. Initially, previous research studies related to IoT-based smart homes and energy management are examined to identify existing technologies and research gaps. Subsequently, the important energy-consuming household appliances and environmental parameters are identified. Suitable IoT sensors, controllers, and communication protocols are then selected for developing the proposed conceptual framework. The collected information is transmitted through wireless communication networks to an IoT gateway or processing platform [4]. The processing system analyzes energy consumption patterns and evaluates the operating conditions of household appliances. Based on predefined conditions and intelligent optimization techniques, suitable control decisions are generated. Finally, the system provides energy consumption information,

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

appliance status, and performance feedback through a mobile application or web dashboard.

3.1.Selection of IoT Hardware and Sensor Technologies

This stage focuses on selecting appropriate hardware components for the proposed smart home energy management framework. An ESP32 microcontroller can be considered as the primary controller because it provides integrated Wi-Fi and Bluetooth connectivity, [5] sensor interfacing capabilities, and sufficient processing resources for basic automation operations. PIR sensors are used for detecting human presence, temperature and humidity sensors monitor indoor environmental conditions, and LDR sensors measure the availability of natural illumination. Voltage and current sensors or compatible smart energy meters are used to monitor electrical parameters. Relay modules and smart switches provide the interface between the controller and household appliances. The selection of these components is based on their measurement [6-8] accuracy, communication capabilities, operating voltage, power requirements, reliability, compatibility, and cost effectiveness. Appropriate electrical isolation and protection mechanisms are essential when interfacing low-voltage IoT controllers with household AC appliances.

3.2. Selection of Communication Technologies

Communication technology plays an important role in connecting smart home devices and ensuring reliable data transmission. The proposed methodology considers Wi-Fi, Zigbee, Bluetooth Low Energy (BLE), and MQTT-based communication according to the requirements of individual devices. Wi-Fi is suitable for connecting the main controller to the internet and transferring monitoring information to cloud platforms. Zigbee and BLE can be used for low-power communication between sensors and IoT gateways. MQTT is considered a lightweight messaging protocol that enables efficient exchange of information between connected devices and the energy management platform. The selection of communication protocols depends on network coverage, power consumption, transmission reliability, scalability, data rate, and device compatibility. A suitable communication architecture helps maintain continuous monitoring and coordinated control of residential electrical appliances.

3.3.Data Acquisition and Real-Time Monitoring

The data acquisition stage involves continuously collecting information from sensors and electrical measurement devices installed within the residential environment. Temperature, humidity, illumination, occupancy, voltage, current, and power consumption are measured at predefined intervals. The ESP32 controller collects the sensor readings and prepares the information for transmission through the selected communication network. The collected data can be stored locally or transferred to cloud-based databases for further analysis. Real-time monitoring provides information about individual appliance operating conditions and overall household electricity consumption. Historical data can also be used to identify peak consumption periods, unnecessary appliance operation, and variations in household energy demand.

3.4.Intelligent Decision-Making and Energy Optimization

The intelligent decision-making stage determines the appropriate operating conditions of household appliances based on the collected sensor information and user-defined preferences. The system compares real-time sensor measurements with predefined threshold values to generate suitable control commands. For example, when a PIR sensor detects human presence and the LDR sensor identifies insufficient natural illumination, the controller activates the lighting system. Similarly, when the indoor temperature exceeds a predefined setpoint, the controller can activate the fan or air-conditioning system. If no occupancy is detected for a specified period, unnecessary electrical appliances can be switched OFF automatically. Artificial Intelligence and Machine Learning techniques can further improve this process by analyzing historical electricity

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

consumption patterns and predicting future energy requirements. Algorithms such as Artificial Neural Networks (ANN), Random Forest, Support Vector Regression (SVR), and Reinforcement Learning can be explored for energy forecasting, appliance scheduling, and load optimization. The main objective of this stage is to minimize unnecessary electricity consumption while maintaining the comfort and operational requirements of residential users.

4. Integration Of Renewable Energy Sources

The proposed methodology also considers the integration of renewable energy sources, particularly solar photovoltaic (PV) systems, with IoT-based smart home energy management. Solar PV panels generate electrical energy from sunlight, which can be utilized to supply household loads or charge battery storage systems. IoT-enabled monitoring devices can measure solar power generation, battery voltage, charging status, and household electricity demand. The energy management controller can prioritize the utilization of available solar energy and coordinate battery charging and discharging according to household requirements. When solar generation is insufficient, electricity can be supplied from the utility grid. Similarly, during periods of excess solar generation, the surplus energy can be stored in batteries or exported to the grid, depending on the installed system configuration and applicable regulations. This integration improves renewable energy utilization and reduces dependence on conventional grid electricity. As shown in Figure 1 Home Energy Management.

4.1.Solar PV-Integrated Smart Home Energy Management Diagram

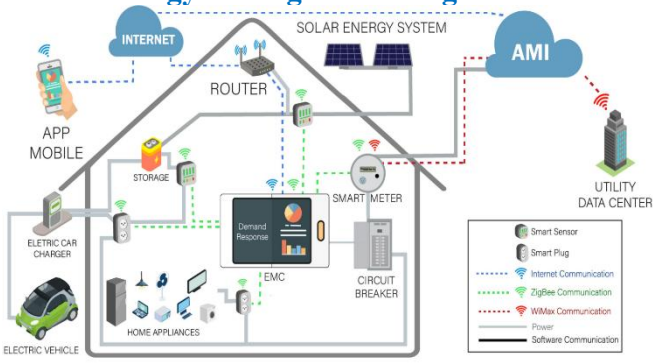


Figure 1 Home Energy Management

4.2.Software and Data Management Framework

The software framework is responsible for collecting, processing, storing, analyzing, and displaying information obtained from the IoT devices. Embedded programming using Arduino IDE or compatible development environments can be used to configure the ESP32 controller and interface different sensors and actuators.

MQTT or HTTP protocols can facilitate communication between the controller and cloud-based platforms. Platforms such as Thing Speak, Blynk, and Firebase can be considered for real-time monitoring, data visualization, and remote appliance management. Cloud computing provides centralized data storage and historical energy consumption analysis, whereas edge computing enables faster local processing and control decisions. The combination of these technologies supports reliable monitoring, intelligent automation, and efficient energy management.

4.3.Complete System Integration

The final stage combines all the selected hardware and software components into a unified smart home energy management framework. Environmental sensors, occupancy detectors, smart meters, and appliance controllers are connected to the IoT controller. The collected information is transmitted through the communication network to the processing and monitoring platform. The system evaluates household operating conditions, identifies unnecessary electricity consumption, and generates suitable control commands. AI-based optimization can be incorporated to improve appliance scheduling and predict future energy requirements. Renewable energy sources and battery storage can also be integrated to improve overall energy utilization. The proposed framework provides a conceptual foundation for developing an intelligent residential energy management system that combines monitoring, automation, predictive analysis, and renewable energy integration.

4.4.Applications of IoT in Smart Homes and Energy Conservation

1. Smart Lighting Control: Automatic ON/OFF of lights using motion and light

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

sensors.

2. Smart HVAC Control: Intelligent control of fans, air conditioners, and temperature based on room conditions.
3. Smart Energy Monitoring: Real-time monitoring of household electricity consumption using smart meters.
4. Appliance Automation: Remote and automatic control of refrigerators, washing machines, televisions, and other appliances.
5. Home Security: Monitoring through CCTV cameras, motion sensors, smoke detectors, and gas leakage sensors.
6. Solar Energy Management: Monitoring solar power generation and optimizing battery storage.
7. AI-Based Energy Prediction: Predicting electricity demand using AI and machine learning algorithms.
8. Demand Response Management: Shifting electrical loads from peak hours to off-peak hours.
9. Smart Water Management: Automatic control of water pumps and heaters using sensors.
10. Voice-Controlled Automation: Operating household appliances through voice assistants.
11. Remote Monitoring: Monitoring and controlling home appliances through mobile applications.
12. Energy Optimization: Reducing electricity wastage through intelligent scheduling and automated control.
13. Smart Battery Management: Monitoring battery charging, discharging, and energy storage.
14. Smart Grid Integration: Coordinating household electricity consumption with smart grid requirements.

Conclusion

IoT technology plays an important role in developing intelligent and energy-efficient residential environments. Integration of smart sensors, communication networks, cloud computing, and automated control systems enables real-time monitoring and optimization of household electricity consumption. Applications such as intelligent lighting, smart HVAC systems, appliance scheduling, and renewable energy integration provide opportunities to reduce unnecessary energy usage and improve occupant comfort. However, cybersecurity, privacy, interoperability, initial investment, and network reliability remain significant challenges. The integration of Artificial Intelligence, Machine Learning, edge computing, and smart grid technologies is expected to improve the efficiency and reliability of future IoT-based smart homes. Overall, IoT-enabled energy management systems offer a promising approach toward sustainable residential buildings and intelligent electricity utilization.

Future Research Directions

- AI-driven autonomous home energy management.
- Secure and privacy-preserving IoT communication.
- Integration of solar PV and battery storage.
- Low-cost smart energy monitoring systems.
- Intelligent demand response and load forecasting.
- Development of interoperable smart home platforms.

References

[1]. Energy-efficient smart home systems: Infrastructure and decision-making process, Internet of Things, vol. 5, pp. 153–167, 2019.
[2]. Energy management solutions in the Internet of Things applications: Technical analysis and new research directions, Cognitive Systems Research, vol. 67, pp. 33–49, 2021.
[3]. B. G. T. Bindushree, "IoT-based energy management in smart homes: A literature review," World Journal of Advanced Research and Reviews, vol. 16, no. 3, pp. 1392–1400, 2022.
[4]. Occupancy detection and localization strategies for demand modulated appliance control in Internet of Things enabled home

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2026.0414
e ISSN: 2584-2854
Volume: 04 Issue: 10
October 2026
Page No: 2944 - 2949

energy management system, Renewable and Sustainable Energy Reviews, vol. 167, 112731, 2022.

[5]. T. George and A. I. Selvakumar, "Smart home energy management systems in India: A socio-economic commitment towards a green future," Discover Sustainability, vol. 5, article 101, 2024.

[6]. U. U. Rehman et al., "Future of Energy Management Models in Smart Homes: A Systematic Literature Review of Research Trends, Gaps, and Future Directions," Energy Systems, vol. 9, pp. 1169–1198, 2025.

[7]. H. M. A. et al., "An effective IoT-based demand response for energy-efficient smart homes," Energy Informatics, vol. 8, article 125, 2025.

[8]. M. Rokonuzzaman et al., "Artificial intelligence, IoT, and solar PV-integrated home energy management systems: A review," Results in Engineering, vol. 29, article 108954, 2026.