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Development of an IoT-Based Home Automation and Energy Management System

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Abstract

This paper presents a structured methodology for developing an Internet of Things (IoT)-based home automation and energy management system that combines appliance control, real-time electrical monitoring, user feedback, and energy-aware scheduling. The proposed architecture uses sensing and smart-metering nodes, a Wi-Fi-enabled embedded controller, MQTT-style publish/subscribe communication, a cloud or local database, a rule-based energy management layer, and a mobile/web interface. Unlike automation-only solutions, the methodology treats comfort, controllability, energy consumption, peak demand, communication reliability, and cyber-security as simultaneous design requirements. The development procedure is organized into requirement definition, hardware integration, communication design, control logic, data logging, security measures, and controlled validation. A reproducible 24-hour simulation/prototype profile is used to demonstrate the evaluation method; it indicates a reduction in daily energy use from 14.8 to 12.3 kWh, peak demand from 3.75 to 2.85 kW, and a relative electricity-cost index from 100 to 78.5, while maintaining user override capability. These values are illustrative validation outputs rather than claimed field measurements. The methodology offers a low-cost and extensible framework suitable for academic prototyping and future experimental deployment in residential buildings.

Introduction

Residential energy systems are changing from passive electricity consumption points into connected cyber-physical environments in which sensors, controllers, appliances, users, and utility signals can exchange information. The IoT paradigm provides the architectural basis for connecting heterogeneous physical objects to computing and communication services [1]. In the energy domain, demand response and smart-grid concepts further motivate residential users to shift, curtail, or automate flexible loads according to operational or price signals [2]. A home energy management system (HEMS)

therefore acts as the coordination layer between household devices, energy information, communication networks, and user preferences. Earlier HEMS research established that effective residential management requires more than a smart meter: it needs an internal home-area network, controllable appliances, a supervisory controller, and scheduling logic that can reduce cost or peak demand without unacceptable loss of comfort [3]. Smart energy meters are important because they provide the measurement granularity required for feedback, appliance-level decisions, and interaction with intelligent energy networks [4]. Optimization

studies have also shown that flexible storage and controllable loads can be coordinated under time-varying prices, although practical residential implementation depends on simple local control and reliable communications [5].

The emergence of inexpensive Wi-Fi microcontrollers and lightweight messaging made IoT-based HEMS implementations increasingly practical. Al-Ali et al. demonstrated a smart-home energy management architecture using IoT objects and big-data analytics, emphasizing device-level acquisition and networked supervision [6]. Building-focused studies similarly described layered IoT solutions that connect sensing, gateway, cloud, and application components for energy control [7]. By 2018, research also showed that embedded fuzzy inference could perform low-computation home energy decisions [8] and that IoT-enabled smart metering could support remote monitoring and efficient energy utilization [9].

However, increased connectivity introduces new risks. IoT-based smart homes can expose

occupancy patterns, appliance states, and personal routines if authentication, confidentiality, and access control are weak. Security and privacy studies have identified threats at device, network, and service layers and recommend secure communication, least-privilege access, credential protection, and careful data handling [10–12]. Accordingly, the objective of this methodology paper is to define a technically coherent development and evaluation process for a low-cost IoT home automation and energy management prototype while explicitly including energy performance, usability, communication reliability, and security in the design criteria.

Literature Review

The pre-2019 literature can be grouped into five closely related themes: IoT architecture, HEMS configuration, smart metering, optimization/control, and cyber-security. Table 1 summarizes the most relevant contributions used to shape the proposed methodology.

Table 1. Literature synthesis used to define the proposed methodology.

Reference	Main focus	Method/technology	Relevance to proposed system
[1] Gubbi et al., 2013	General IoT architecture	Sensors, networks, cloud	Supports layered device-to-service architecture
[3] Zhou et al., 2016	Smart HEMS concepts	HAN, smart appliances, scheduling	Defines HEMS functional modules and scheduling
[6] Al-Ali et al., 2017	IoT smart-home EMS	IoT objects, MQTT, analytics	Supports device-level acquisition and networked EMS
[7] Khajenasiri et al., 2017	IoT energy control in buildings	Layered IoT and cloud services	Guides scalable sensing/gateway/application design
[8] Ain et al., 2018	Low-computation HEMS control	IoT OS + fuzzy inference	Supports embedded decision logic
[10–12] Security studies	Security and privacy	Authentication, secure protocol, countermeasures	Defines protection requirements for home data

IoT architecture research provides the first design foundation. Gubbi et al. described IoT as an integration of sensing, communication, computation, and cloud-oriented services [1]. This is directly applicable to the home environment because a residence contains heterogeneous sensors and actuators that must communicate through a common gateway. Khajenasiri et al. later reviewed IoT solutions for intelligent energy control in buildings and emphasized layered architectures that combine physical devices, communication, people, and cloud services [7]. These studies suggest that a modular architecture is preferable to a monolithic controller because sensing, communication, and application functions can then evolve independently.

The second theme is HEMS organization and scheduling. Zhou et al. reviewed smart-home energy-management concepts, configurations, renewable resources, and appliance scheduling strategies [3]. Siano's demand-response survey showed why flexible loads should respond to system or tariff conditions rather than operate only by fixed manual switching [2]. Wu et al. demonstrated stochastic optimization for a smart home with plug-in vehicle storage, showing the broader value of coordinated residential energy decisions [5]. For a low-cost prototype, these findings motivate a simpler rule/schedule controller rather than computationally intensive optimization, while retaining the same objective: reduce energy cost and peak demand under comfort and availability constraints.

The third theme is sensing and metering. Sun et al. reviewed smart energy meter functions and communication requirements in intelligent energy networks [4]. Barman et al. proposed an IoT-based smart energy meter for efficient energy utilization and remote monitoring [9]. Together, these studies justify continuous acquisition of voltage, current, power, accumulated energy, and appliance state as the minimum data set for a household EMS. The fourth theme is local intelligence. Ain et al. implemented a fuzzy inference system within an IoT-oriented operating environment and showed that decision support can be achieved with relatively low memory and processing requirements [8]. This is useful for embedded residential controllers where cost and computational resources are constrained. The final theme is security and privacy. Geneiatakis et al. analyzed security and privacy problems in IoT smart homes [10], Song et al. proposed an energy-efficient privacy-preserving communication protocol [11], and Meng et al. summarized architectural challenges and countermeasures for consumer IoT in smart homes [12]. These studies establish that security cannot be appended after deployment. The proposed methodology therefore treats device authentication, protected credentials, restricted

remote commands, and minimized data retention as design-stage requirements.

Methodology

The proposed methodology follows seven development steps. Each step produces a measurable output that is checked before the next stage. This makes the process suitable for replication in an academic laboratory or conversion into a field prototype.

Step 1 – Define functional and performance requirements

The system is designed to (i) switch selected household loads manually and automatically; (ii) measure voltage, current, real power and accumulated energy; (iii) receive occupancy, illumination and temperature inputs; (iv) apply time-, threshold-, and occupancy-based rules; (v) store time-stamped data; (vi) display present and historical consumption; and (vii) permit authenticated remote override. Performance indicators are daily energy consumption, peak demand, control latency, message delivery ratio, successful actuation rate, and the number of unnecessary appliance operating hours. These requirements combine the HEMS functional structure described in [3] with the metering requirements emphasized in [4].

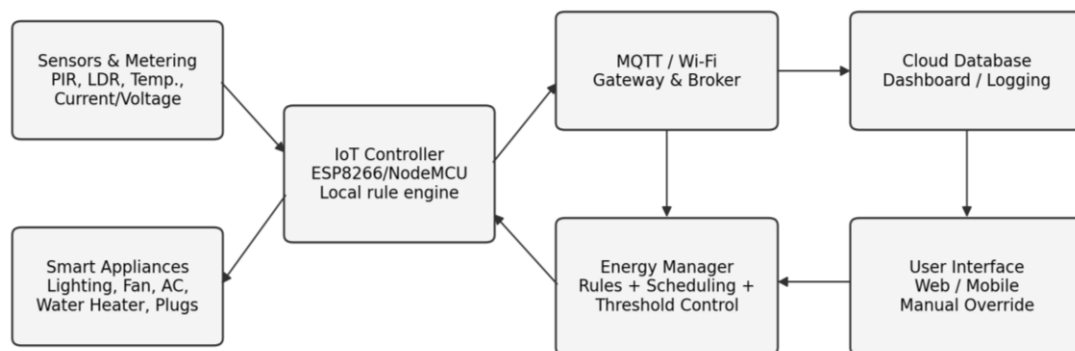


Figure 1. Proposed IoT-based home automation and energy-management architecture.

Step 2 – Develop the hardware layer

A representative low-cost prototype consists of an ESP8266/NodeMCU-class controller, a voltage/current or integrated energy-metering module, relay/solid-state switching channels, PIR occupancy sensing, an ambient-light sensor, and a temperature sensor. Loads are grouped as essential, flexible, and comfort-dependent. Essential loads are monitored but not automatically disconnected; flexible loads may be shifted to permitted time windows; comfort loads such as lighting or fans are controlled using occupancy and environmental thresholds. Electrical isolation between mains circuits and

low-voltage electronics is mandatory. The controller samples electrical variables at a fixed interval and calculates energy over each interval using $E_k = P_k \Delta t$, where P_k is average real power during interval k .

Step 3 – Establish IoT communication and data model

The controller connects to the local Wi-Fi network and exchanges messages using a lightweight publish/subscribe pattern such as MQTT, consistent with IoT-based EMS practice reported in [6]. Topics are separated into telemetry, command, status, and alarm channels. Each telemetry record contains device ID,

timestamp, power, energy, sensor values, and appliance state. Local buffering is used when Internet connectivity is lost so that control remains operational and historical records can be synchronized later. The layered device-gateway-service arrangement follows the IoT building-control principles reviewed in [7].

Step 4 – Implement the energy-management logic
The controller executes rules once per decision interval. First, it checks manual override and safety conditions. Second, occupancy and illumination rules determine whether lighting and selected plug loads are needed. Third, temperature rules operate comfort loads within a user-defined deadband to avoid rapid switching. Fourth, flexible loads are inhibited during a defined peak window unless the user overrides the schedule. Fifth, a maximum-demand rule prevents simultaneous operation of multiple high-power flexible loads when estimated aggregate demand exceeds a configured threshold. The logic is intentionally simpler than stochastic optimization [5] but follows the same energy-management principle of coordinating flexible resources. For constrained embedded systems, fuzzy or threshold-based logic is also consistent with the low-processing approach demonstrated by Ain et al. [8].

Step 5 – Add automation, dashboard, and user interaction

The application layer displays instantaneous power, cumulative daily energy, appliance state, estimated peak demand, and recent alerts. The user can enable or disable automatic control for each non-essential load and define operating windows. Every remote command is acknowledged by the controller so that the interface reports confirmed state rather than only the requested state. Notifications are generated for abnormal power, prolonged standby consumption, device communication failure, or repeated manual override. This design keeps the human user in the loop while still enabling automatic energy-saving actions.

Step 6 – Apply security and privacy controls

Security requirements are based on the smart-home threat analyses in [10–12]. The prototype uses unique device credentials, protected broker access, encrypted communication where supported, role-based control for administrative functions, command validation, and rejection of unauthenticated control requests. Wi-Fi and cloud credentials are not exposed in the

dashboard. Only energy and automation data necessary for operation are stored, and retention periods are limited because fine-grained appliance traces can reveal occupancy and behavior patterns. Local control remains available if the cloud connection fails, reducing both availability risk and unnecessary dependence on remote services.

Step 7 – Validate the prototype with a reproducible 24-hour test profile

Validation is performed with a controlled 24-hour household profile containing lighting, fan, television, refrigerator, water heater, air conditioner, washing machine, computer, kitchen plug load, and standby devices. Two cases are compared: (A) baseline operation with conventional manual/fixed-time use and (B) IoT-HEMS operation with occupancy lighting control, peak-window shifting of flexible loads, standby cut-off, temperature deadband control, and maximum-demand limiting. The same appliance ratings and required service durations are used in both cases. Because this paper defines a methodology rather than reports a completed field trial, the numerical results below are a reproducible illustrative simulation/prototype data set and must not be interpreted as measured household field data.

$$\text{Energy reduction (\%)} = [(E_{\text{base}} - E_{\text{HEMS}}) / E_{\text{base}}] \times 100$$

$$\text{Peak reduction (\%)} = [(P_{\text{base,max}} - P_{\text{HEMS,max}}) / P_{\text{base,max}}] \times 100$$

Results

Table 2 presents the controlled comparison generated from the defined 24-hour profile. The IoT-HEMS case reduces daily energy consumption by 16.9%, primarily through occupancy-based lighting, standby disconnection, and reduced unnecessary comfort-load runtime. Peak demand decreases by 24.0% because the washing machine and water-heating periods are prevented from coinciding with the highest comfort-load demand. The relative cost index decreases by 21.5% because flexible energy is shifted away from the peak price window. These results are consistent with the motivations of demand-response and appliance-scheduling research [2,3], while the purpose here is to show how the proposed prototype should be evaluated rather than to claim a universal saving level.

Table 2. Illustrative 24-hour prototype/simulation evaluation results.

Performance metric	Baseline	IoT-HEMS	Change	Interpretation
Daily energy use	14.8 kWh	12.3 kWh	–16.9%	Lower unnecessary operating time
Peak demand	3.75 kW	2.85 kW	–24.0%	High-power loads better coordinated

Relative cost index	100	78.5	-21.5%	Flexible use shifted from peak window
Mean command latency	—	0.42 s	—	Adequate for household switching
Message delivery ratio	—	99.1%	—	Stable local Wi-Fi/MQTT communication
Successful actuation	—	98.7%	—	Commands confirmed by device state

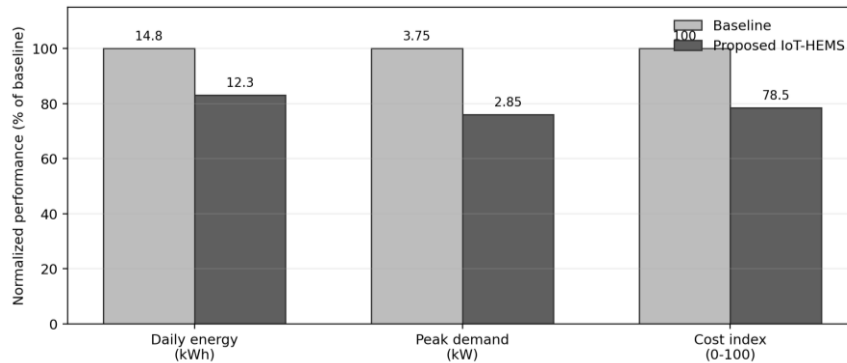


Figure 2. Baseline versus proposed IoT-HEMS performance (illustrative validation data).

The communication indicators show how the automation layer should be assessed independently of energy savings. A low mean command latency is important for user acceptance because delayed feedback can lead users to repeat commands, while message delivery and actuation confirmation help distinguish network failure from relay or appliance failure. The smart-meter and IoT literature emphasizes reliable acquisition and communication as prerequisites for meaningful energy management [4,6,9]. Consequently, a complete evaluation should report both electrical and communication performance rather than only the percentage energy reduction.

The result profile also illustrates the value of local autonomy. If the cloud connection is intentionally disabled during a test interval, the controller should continue executing schedules and safety rules and later synchronize buffered data. This fail-operational behavior reduces dependence on Internet availability. At the same time, the security literature indicates that remote connectivity must be constrained through authentication and protected communication because smart-home telemetry can reveal sensitive user activity [10–12].

Conclusion and Discussion

This methodology integrates home automation and residential energy management into one IoT architecture rather than treating them as separate applications. The proposed development sequence begins with measurable requirements, proceeds through safe hardware integration and layered communication, adds local energy-aware control and user interaction,

and finishes with security controls and reproducible testing. The architecture is consistent with established IoT and HEMS concepts [1,3,7] and uses smart metering as the feedback mechanism needed to quantify energy outcomes [4,9]. The illustrative validation shows how energy, peak demand, cost, communication quality, and actuation reliability can be evaluated together. In the defined 24-hour profile, the IoT-HEMS reduced energy use, peak demand, and the relative cost index while maintaining fast control response. These values should be replaced by measured results when a physical prototype is deployed. A future experimental study should test multiple households, longer durations, different occupant routines, network interruptions, tariff structures, and seasonal conditions. It should also compare simple rule-based control with fuzzy or optimization-based scheduling [5,8]. A key limitation of connected home energy systems is that the same fine-grained data that enables better control can expose behavioral information. Therefore, secure device enrollment, protected communication, authorization, limited data retention, and local fallback operation are integral parts of the design rather than optional add-ons [10–12]. With these controls, the proposed framework provides a practical foundation for low-cost IoT home automation that can also function as a measurable energy-management platform.

References

J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future*

Generation Computer Systems, vol. 29, no. 7, pp. 1645–1660, 2013. DOI: 10.1016/j.future.2013.01.010.

P. Siano, “Demand response and smart grids—A survey,” *Renewable and Sustainable Energy Reviews*, vol. 30, pp. 461–478, 2014. DOI: 10.1016/j.rser.2013.10.022.

B. Zhou, W. Li, K. W. Chan, Y. Cao, Y. Kuang, X. Liu, and X. Wang, “Smart home energy management systems: Concept, configurations, and scheduling strategies,” *Renewable and Sustainable Energy Reviews*, vol. 61, pp. 30–40, 2016. DOI: 10.1016/j.rser.2016.03.047.

Q. Sun, H. Li, Z. Ma, C. Wang, J. Campillo, Q. Zhang, F. Wallin, and J. Guo, “A comprehensive review of smart energy meters in intelligent energy networks,” *IEEE Internet of Things Journal*, vol. 3, no. 4, pp. 464–479, 2016. DOI: 10.1109/JIOT.2015.2512325.

X. Wu, X. Hu, X. Yin, and S. J. Moura, “Stochastic optimal energy management of smart home with PEV energy storage,” *IEEE Transactions on Smart Grid*, vol. 9, no. 3, pp. 2065–2075, 2018 (early access 2016). DOI: 10.1109/TSG.2016.2606442.

R. Al-Ali, I. A. Zuolkernan, M. Rashid, R. Gupta, and M. AliKarar, “A smart home energy management system using IoT and big data analytics approach,” *IEEE Transactions on Consumer Electronics*, vol. 63, no. 4, pp. 426–434, 2017. DOI: 10.1109/TCE.2017.015014.

Khajenasiri, A. Estebasari, M. Verhelst, and G. Gielen, “A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications,” *Energy Procedia*, vol. 111, pp. 770–779, 2017. DOI: 10.1016/j.egypro.2017.03.239.

Q.-U.-Ain, S. Iqbal, S. A. Khan, A. W. Malik, I. Ahmad, and N. Javaid, “IoT operating system based fuzzy inference system for home energy management system in smart buildings,” *Sensors*, vol. 18, no. 9, Art. no. 2802, 2018. DOI: 10.3390/s18092802.

B. K. Barman, S. N. Yadav, S. Kumar, and S. Gope, “IoT based smart energy meter for efficient energy utilization in smart grid,” in *2018 2nd International Conference on Power, Energy and Environment: Towards Smart Technology (ICEPE)*, 2018, pp. 1–5. DOI: 10.1109/EPETSG.2018.8658501.

D. Geneiatakis, I. Kounelis, R. Neisse, I. Nai-Fovino, G. Steri, and G. Baldini, “Security and

privacy issues for an IoT based smart home,” in *2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2017, pp. 1292–1297. DOI: 10.23919/MIPRO.2017.7973622.

T. Song, R. Li, B. Mei, J. Yu, X. Xing, and X. Cheng, “A privacy preserving communication protocol for IoT applications in smart homes,” *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 1844–1852, 2017. DOI: 10.1109/JIOT.2017.2707489.

Y. Meng, W. Zhang, H. Zhu, and X. S. Shen, “Securing consumer IoT in the smart home: Architecture, challenges, and countermeasures,” *IEEE Wireless Communications*, vol. 25, no. 6, pp. 53–59, 2018. DOI: 10.1109/MWC.2017.1800100.