Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 3, 2026

AN OCCUPANCY-AWARE IOT-BASED FRAMEWORK FOR REAL-TIME MONITORING AND OPTIMIZATION OF ENERGY CONSUMPTION IN SMART HOMES

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DOI: https://doi.org/10.5281/zenodo.21425169

Keywords

Article History
Received: 31 January 2026
Accepted: 16 March 2026
Published: 30 March 2026

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Abstract

The swift development of the Internet of Things (IoT) is changing conventional living conditions to smart ones. The present study deals with the issue of critical concern of manual control of appliances, large energy wastefulness, and safety hazards in traditional residential houses which specifically affect the aged and handicapped. We introduce a comprehensive IoT-powered Home Automation System created on the basis of ESP32 microcontroller, which is intended to achieve the best energy consumption and ease of use. The system has a multi modal system of control, with users being able to control the appliances in the house with voice assistants (Amazon Alexa and Google Home), the ESP Rainmaker mobile app, and conventional infrared (IR) remotes. One of the innovations of this project is that it can be configured to be able to perform the so-called Hybrid Control, that is, it will provide reliability to the system when supported by physical switches, as well as by offline IR control in case of a lack of internet. Moreover, the system also involves real-time energy monitoring and feedback system to enhance sustainable consumption. As acknowledged by experimental testing, the suggested solution will offer a smooth, reactive, and affordable method to modernize the homes and to decrease the amount of energy overhead and to increase the level of life quality among the vulnerable user groups.

1. INTRODUCTION

Home automation is an idea that has been of great concern over recent years with technological advancements taking place at a very high rate. Internet of Things (IoT) has been one of the most important transformations in the manner in which we can relate with the spaces we live in. The interconnection of objects and devices that are used daily to the internet leads to IoT, and it has introduced a new generation of opportunities in the field of automation of homes. The capability to exchange messages between devices, appliances and their owners has been the new landmark of a smart home and has fundamentally changed the manner in which we comfortably live and manage our homes [1-4].

Among the key tenets of home automation is the ability to offer residents of their homes the tools and mechanisms by which they can have convenient control over most of their homes, including lighting and climate control, security, and entertainment. Such degrees of control can greatly increase the quality of life and encourage the saving of energy that will eventually positively impact on the lives of homeowners and nature at large [5-7].

Home automation systems have been enhanced with a range of technologies and communication protocols in order to support the changing needs of modern homeowners. These are Bluetooth, Wi-Fi and cellular networks, which allow the transmission of knowledge remotely, sensing and administration, thereby giving the user unparalleled control and access to their homes [8-11].

Automation has also gone a long way in the industrial sector where automated assembly lines are common in the automobile and bottling factories. Nonetheless, automation in residential houses, especially in Pakistan, is not widely used. This is not automated in homes, which presents the following challenges.

The physical effort and time of controlling the household appliances manually cannot be considered as convenient due to which elderly people and people with disabilities find it especially difficult. There is an urgent necessity of having a more accessible and user-friendly solution. When leaving home without turning off the home appliances one may end up wasting electrical energy. This does not only result in high utility bills but affects the environment negatively. The lack of proper home automation systems can be a source of safety concern, since there are always cases when appliances or systems could be mismanaged and this can present a danger [12].

Thus, the main issue considered in this study is the creation of an IoT-based home automation mechanism that can address these issues. The system must provide convenience and comfort to every resident, particularly the older generation and the disabled, as well as provide energy efficiency and improve home safety.

1.1 AIM AND OBJECTIVES

This project will design an IoT based home automation system that will be highly efficient and user friendly through the use of ESP32 microcontroller. This system will enable the users to easily manipulate and monitor the use of appliances at home using a number of interfaces, such as voice commands, mobile applications, manual switches, and IR remote control. The project is aimed at improving the overall quality of life and helping to achieve sustainable living in contemporary houses by adding energy-efficient features and real- time feedback mechanisms.

The project is expected to attain the following objectives:

1. Create a powerful and dependable home automation system powered by ESP32 microcontroller and a set of sensors and make sure it is compatible with numerous devices and appliances used in the house.
2. Combine the home automation system with the latest voice assistants, including Alexa and Google Home, to allow voice-activated control and monitoring of the appliances with the primary focus on the seamless and user-friendly experience.
3. Install manual switch support and remote control with IR and make sure that the operation is not interrupted and the user is offered with the flexibility and convenience of control, even in the case of absence of internet connection.
4. Provide the opportunity to monitor energy consumption and analyze appliance use in real-time with the help of a convenient interface that can be accessed through the ESP Rainmaker IoT cloud platform and enable users to make decision-related choices about energy consumption.
5. Encourage energy saving by integrating the following features into the appliances: automatic power turn-off, reduce temperature, and smart scheduling, and aim to assist the customers to conserve energy and minimize their effects on nature.
6. Carry out intensive testing and evaluation of home automation system to determine the level of reliability, responsiveness, and satisfaction of the users. Make sure that the system will be of the highest quality and we are able to work in a variety of homes.

2. LITERATURE REVIEW

This study covered some related and past studies on the systems or devices available in assisting the Elderly and the disabled persons in their day-to-day life. Numerous studies were dedicated to a number of technologies and methods that can be useful to access and control Home Appliances remotely regardless of their location across the globe, some of the earlier studies were also done with the use of the Arduino Uno, NodeMCU, raspberry, OpenCV, GSM, NLP, ML and so many.

The research paper [13] explores the creation of a cloud computing-integrated, Internet of Things (IoT)-based home automation system (HAS). The main objective is to give users the opportunity to remotely handle a variety of home appliances using a special Android app. The foundation of this ground-breaking system is Internet of Things (IoT) technology, which is defined by physically interconnected items that are outfitted with electronics, sensors, actuators, and network connectivity. By simplifying data sharing and improving daily living through automation, it provides a transformative solution. This Research paper [14] examines how a Home Automation System (HAS) built with Internet of Things (IoT) technology, specifically Wi-Fi-capable microcontrollers, might be developed. In the research paper [15] Internet of Things (IoT) is used to offer a smart, energy-efficient home automation system. This system makes use of cutting-edge technology to provide remote access and management of home appliances from any location in the globe, including web-based and Android-based platforms. The key component of the system is a wireless Internet connectivity module with a static IP address that is wired to the main supply unit of the house. To improve accessibility and security, users may control the system using voice commands using Google Assistant or a web-based application.

The study article [16] presents the Internet of Things (IoT), artificial intelligence (AI), and voice-controlled home automation system that is based on natural language processing (NLP). The overall aim is to come up with an effective and cost-efficient home automation solution that allows customers to interact with home items through voice commands. It is a step further which offers a complete solution of voice-based technology, unlike the common smart home solutions which only focus on basic functions such as on/off switching. The study article [7-9] proposes the Internet of Things (IoT)-driven smart security and home automation platform that relies on IoT technology to enhance the comfort and security of the home. The system will offer real-time control and monitoring of security and appliances in the household with the use of various sensors, cameras, and Raspberry Pi as a server and controller. The current research article [17-19] discusses the use of a reasonably priced and efficient Wi-Fi chip, ESP8266, in home automation. ESP8266 addresses compatibility issues with traditional protocols such as X10, Ethernet, ZigBee, and Z- Wave to develop an energy and cost-efficient system of home automation.

3. DESIGN AND METHODOLOGY

The study is concerned with the design and techniques of the ESP32 based IoT-based Home Automation System project. We are assessing the tools, technology and components of the development process. We also discuss the model specifications of the project along with the operational procedures of the software and hardware components of this project. The last point of this study leads to a detailed evaluation of the design of the project, which gives a full picture of its structure and functionality.

3.1 METHODOLOGY

The project integrates ESP Rainmaker framework to create an operable Home Automation System based on IoT using ESP32. Under this system, users have the opportunity to use relays and fan speed in many ways, including default switches, an IR handset, voice commands via Alexa and Google Home, and offline local control. Moreover, to monitor real-time feedback, one can use the ESP Rainmaker App and Google home, as well as Amazon Alexa. The approach to the current project IoT based Home Automation System with ESP32 can be divided into a number of major modules, each of which can be used to perform a certain task, such as Project Components, Circuit Design, Sensor and Devices Integration, Software Programming, Source Code Implementation, and Device configuration with ESP Rainmaker App, voice assistant integration, PCB Design, device control, device monitoring. This has been an all-inclusive methodology that offers a clear cut and organized way of comprehending and applying the project of IoT based Home Automation System using ESP Rainmaker.

3.2 FLOW CHART OF PROJECT

The given flowchart demonstrates how the IoT based smart home automation system will work. During the boot sequence, the ESP32 searches for available Wi-Fi networks. With the presence of Wi-Fi, the system uses the ESP Rainmaker cloud to remotely control devices and the speed of fans by using voice assistants such as Amazon Alexa or Google Home. It also provides immediate feedback. In case the Wi-Fi is not connected, the system switches to local control via push buttons or infrared remote. This arrangement will make the home appliances capable of using them manually in the event that the internet goes off.

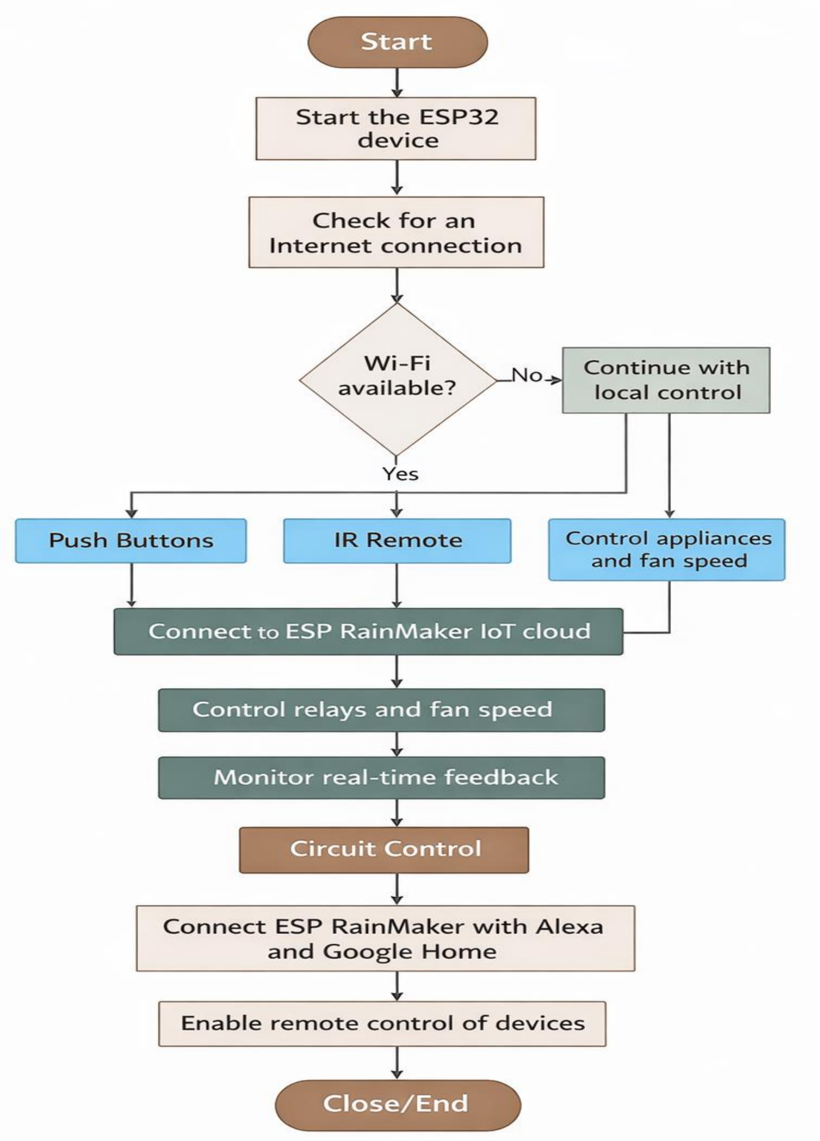


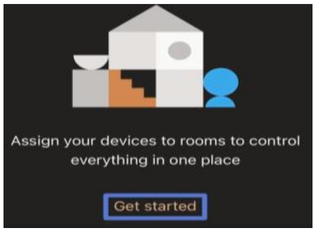
Figure.1 Flow chart of Framework for Monitoring and Optimization of Energy Consumption in Smart Homes

3.3 SYSTEM DESIGN

In designing the system, different software and hardware tools and components are involved, which are discussed below one by one.

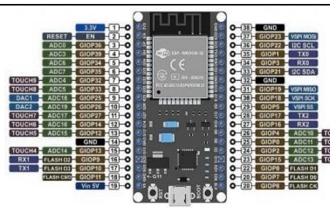
3.3.1 SOFTWARE DESCRIPTION

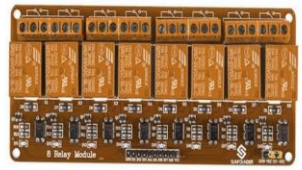
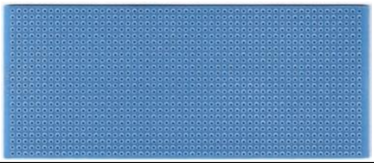
Table 1: Software Description

S. No.	Software	Purpose for the Project	Official Website	Figure
1	ESP Rainmaker	To connect and control ESP32-based devices via cloud and integrate with voice assistants.	ESP Rainmaker	ESP RAINMAKER
2	Google Home	To control appliances using voice commands through Google Assistant.	Google Home	
3	Amazon Alexa	To operate home appliances using voice commands through Alexa-enabled devices.	Amazon Alexa	alexa
4	Arduino IDE	To write and upload code to the ESP32 microcontroller for communication with devices.	Arduino IDE	ARDUINO

3.3.2 HARDWARE DESCRIPTION

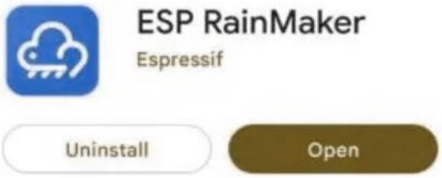
Table 2: Hardware Description

S. No	Component	Short Description	Specifications / Features	Figure
1	ESP32 Devkit V1	Main microcontroller with Wi-Fi & Bluetooth used to control appliances and connect to IoT platforms.	32-bit CPU, Wi-Fi/Bluetooth, 25 DIO pins, 4MB Flash, 520KB SRAM, 240MHz Clock Speed	

2	**8-Channel Relay Module**	Used to control multiple AC/DC appliances via low-voltage signals from ESP32.	8 SPDT relays, 10A 250VAC, opto-isolated inputs, 5V operating voltage	
3	**DHT11 Sensor**	Measures temperature and humidity, sends digital data to ESP32.	5V, Temp: 0–50°C ±2°C, Humidity: 20–90%RH ±5%RH, Digital output	
4	**TSOP1838 IR Receiver**	Receives IR signals from remote, allows wireless control of devices.	38kHz frequency, 5V, built-in amplifier, high noise immunity	
5	**Push Buttons**	Used for manual/tactile control of appliances through ESP32 GPIO pins.	Connected to GPIO (D13, D12, D14, D27), LOW signal triggers relay	
6	**IR Remote**	Sends infrared commands to control appliances wirelessly through TSOP1838.	Multiple control buttons, wireless IR signals, compatible with TSOP1838	
7	**4-Step Fan Regulator**	Manual speed controller for ceiling fan, used as backup if Wi-Fi fails.	4 levels (Off, Low, Medium, High), rotary switch	
8	**Vero Board**	Used for soldering and assembling all electronic components neatly.	Pre-drilled copper tracks, durable, laminated for corrosion resistance	

3.3.3 ADDING DEVICES IN ESP RAINMAKER APP

After programming the ESP32 microcontroller using C++ language with the help of Arduino IDE, now Adding Devices in ESP Rainmaker App.

• **Step 1: Downloading and Installing ESP Rainmaker** 	• **Step 2: Generating the QR Code** 

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• Step 3: Opening the QR Code URL in Browser

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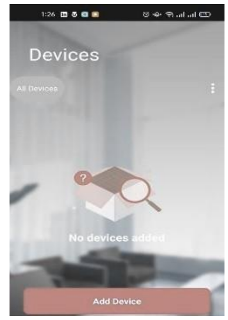
• Step 4: Adding Devices in ESP Rainmaker



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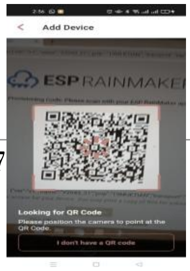
• Step 5: Scanning the QR code.



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• Step 6: Entering the Wi-Fi credentials.

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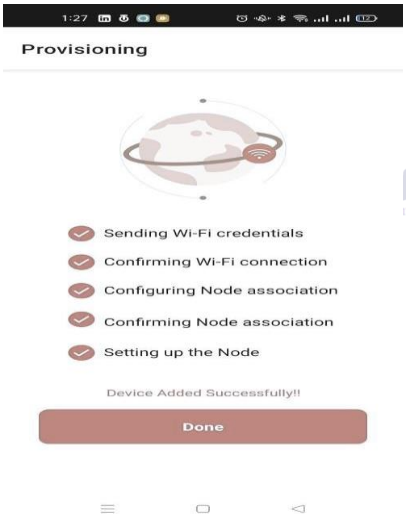
• Step 7



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• Step 8:] P Rainmaker dashboard.

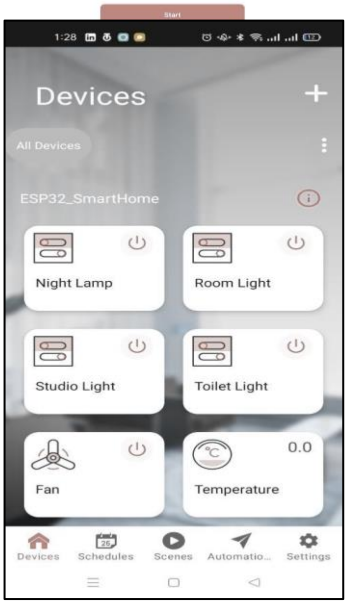

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Table 3: Adding Devices in Esp Rainmaker App (8 Steps)

3.4 DISPLAYING ADDED DEVICES

Navigate to "Devices" – "Switches" after opening the Amazon Alexa app. All of the newly added devices are listed in the Alexa app. You can now use the Alexa app to control the appliances if the ESP32 is linked to Wi-Fi. For this project, you may utilize the Amazon Alexa App to operate the appliances instead of using any Alexa devices like the ECHO DOT.

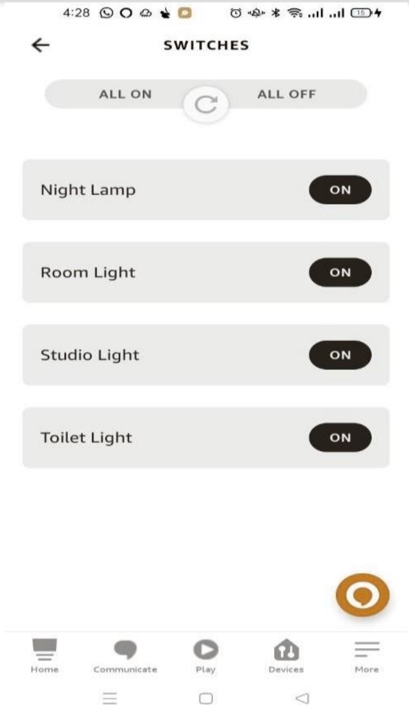

Figure 2: Displaying added devices.

3.5 CIRCUIT DESIGN OVERVIEW

This project's circuit design includes an Internet of Things (IoT)-based Home Automation System that makes use of the ESP32 microcontroller's capabilities, integrated sensors, and a number of control interfaces to provide effective and useful control over lights, fan speed, and appliances. This cutting-edge system offers a complete approach to setting up a smart home.

The 4-channel relay module is controlled by the D23, D22, D21, and D19 GPIO in this extremely basic design.

To manually operate the relay module, GPIO D33, D32, D15, and D4 are connected to a 4-step selector switch, while GPIO D13, D12, D14, and D27 are connected to switches.

Instead of utilizing pull-up resistors with each push button, I've used the Arduino IDE's INPUT_PULLUP function.

According to the source code, the relay will turn on in response to a LOW signal applied to the relay module's control pins and will switch off in response to a HIGH signal sent to the same control pin.

D35 and IR remote receiver (TSOP1838) are linked. Additionally, RX2 (GPIO16) is linked to the DHT11 sensor.

To power the circuit, I utilized a 5V 5Amp mobile charger.

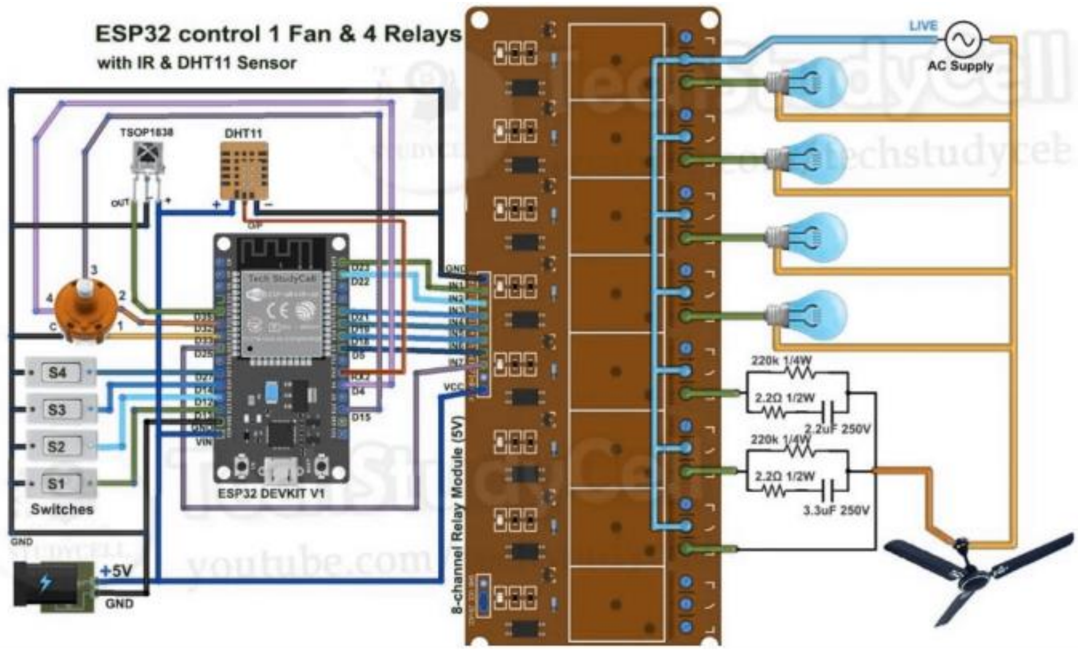

Figure 3: Circuit design

4. IMPLEMENTATION AND TESTING

In this research we explore the useful features of our IoT-based Home Automation System. The hardware and software testing sections make up the two main sections of this research. By carefully inspecting and assessing our system, we hope to confirm that it works flawlessly with a range of control techniques. These tests provide the base of detailed analysis of system performance in real-life conditions as they will guarantee the functionality and strength of the system in a variety of control platforms.

4.1 HARDWARE TESTING

In hardware testing, we shall test appliances with local control like Push Buttons, IR Remote and 4 step fan regulators.

4.1.1 CONTROLLING APPLIANCES USING PUSHBUTTONS

The photograph depicts push buttons to manually regulate lights, and a fan in a miniature of a house. By making the circuit complete or by making the circuit broken, the appliances are switched on or off using the buttons.

Figure 4: Turning on Appliances with Push Buttons

4.1.2 CONTROLLING APPLIANCES USING IR REMOTE

The pictures demonstrate the application of an IR remote which allows controlling lights and a fan in a small house model wirelessly. The remote transmits a signal to an IR receiver that switches appliances on or off.

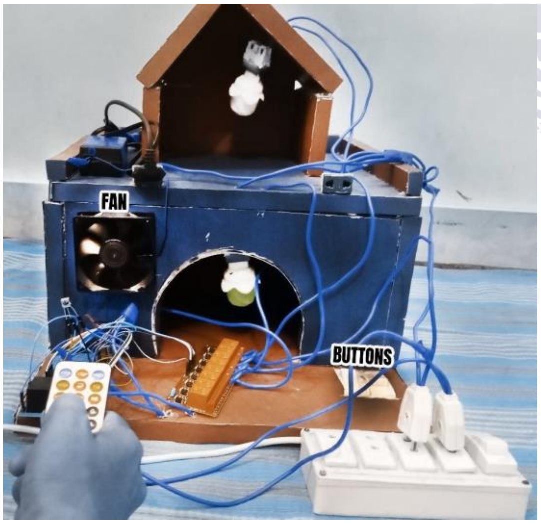

Figure 5: Shutting Down Appliances with IR Remote

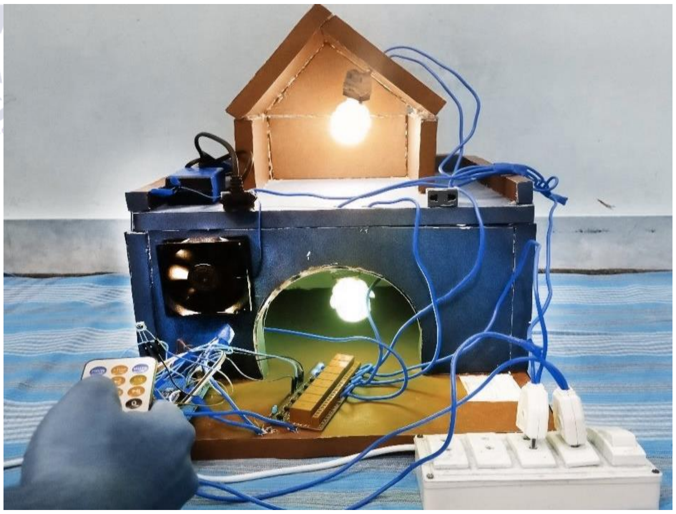

Figure 6: Turning on Appliances with IR Remote

4.2 SOFTWARE TESTING

During the software testing we will test the appliances on such online platforms as ESP Rainmaker, Amazon Alexa and Google Assistant.

4.2.1 CONTROLLING AND MONITORING APPLIANCES USING ESP RAINMAKER

The image demonstrates some ESP Rainmaker that allows controlling the work of such appliances as lights and a fan by use of a smartphone application. It also supports real-time monitoring e.g. temperature monitoring of smart home management.

Figure 7: Turning on Appliances with ESP Rainmaker

Figure 8: Shutting Down Appliances with ESP Rainmaker

Figure 9: Controlling Fan Speed with ESP Rainmaker

Figure 10: Monitoring Temperature with ESP Rainmaker

ISSN (e) 3007-3138 (p) 3007-312X Volume 4, Issue 3, 2026

4.2.2 CONTROLLING APPLIANCES USING GOOGLE ASSISTANT

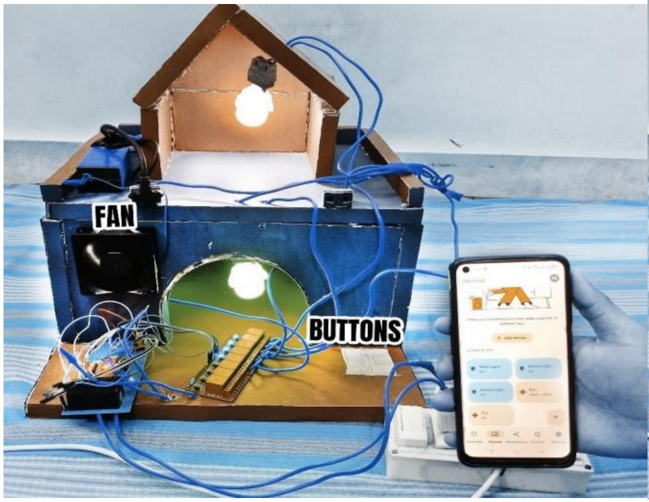

Figure 11: Turning on Appliances with Google Assistant

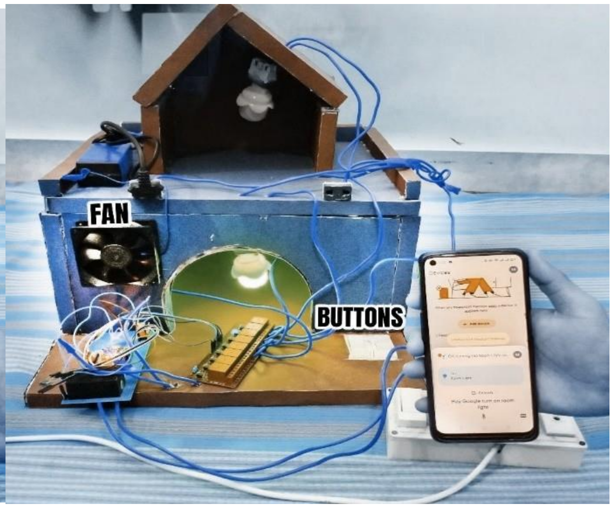

Figure 12: Turning on Appliance using Voice with Google Assistant

The photos depict the application of Google Assistant to manage appliances using voice. Simple voice commands allow users to switch on and off lights and fans, which allows their hand-free control of the smart home.

4.2.3 CONTROLLING APPLIANCES USING AMAZON ALEXA

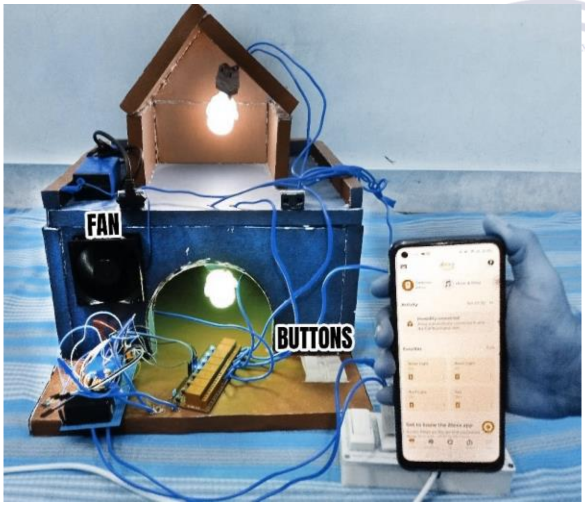

Figure 13: Turning on Appliances with Amazon Alexa

Figure 14: Turning on Appliances using Voice with Amazon Alex

The above figures depict Amazon Alexa as a control of appliances. The miniature house system allows users to control lights and a fan using the Alexa application or voice-activated commands, thereby allowing smart, hands-free control.

5. CONCLUSION

The ultimate aim of research is to enhance the standards of living of the elderly and disabled who find it hard to operate the household appliances manually, consume excessive power when their houses are unoccupied, and security concerns in houses that are not automated. This project came up with a state-of-the-art Internet of Things (IoT)-based home automation system with the primary aim of simplifying our lives. It shows how revolutionary IoT technology can be despite the initial intended home and office purposes of the technology. It has integrated the formerly wired world into the wireless world and made regular household appliances smart with the ESP32. This project has shown to be able to remotely control home appliances, lights and fan speed. Although the number of devices it can control is still limited, it is effective in the conservation of energy and offers enhanced control of the objects in the home. It is important to point out that its ability to handle the number of devices is small and yet the potential of this technology is immense. This project is a foot forward to an IoT future in a world where smart technology and connection are now essential in daily living. The potentials of the improvement, development, and incorporation of new and innovative features are almost endless.

REFERENCES

Sharma, M., Joshi, S., Bisht, P. and Prasad, M., 2026. Energy Efficiency and Sustainability in Smart Homes: A Study of Challenges and Barriers in Sustainable Building Materials and Smart Homes Design.

Olagundoye, O.O., Bamisile, O., Joseph Ejiyi, C., Bamisile, O., Ni, T. and Onyango, V., 2026. A Review of Artificial Intelligence Techniques for Low-Carbon Energy Integration and Optimization in Smart Grids and Smart Homes. *Processes*, *14*(3), p.464.

Karamoozian, M., Hong, Z., Karamoozian, A., Abbasnejad, B. and Rahimian, F., 2026. Predictive Automation of Window Ventilation in Green Buildings: A Data-Driven Framework for Integrating IoT Sensors, Machine Learning, and Occupant Behavior Modeling. *Indoor Air*, *2026*(1), p.3775422.

Naidu, B. Amarnath, K. Vanisree, Rama Prasanna Dalai, N. Babu, R. Suriya, and M. Soma Sabitha. "Next-Generation IoT-Enabled Smart Home Framework: A Secure, Scalable and Energy-Efficient Solution for Intelligent Living Environments." *Proceedings Copyright* 767: 773.

Haq, I.U. and Sharma, N., 2026. AI and Quantum-Driven IoT Frameworks for Sustainable 6G/7G Smart Homes. In *Deep Quantum Neural Networks: AI for 6G/7G Communication Systems* (pp. 129-142). Singapore: Springer Nature Singapore.

Abduljabbar Rashid, S., Al Mashhadany, Y. and Amer Ahmed Alrawi, A., 2026. Experimental Demonstration of Cost-Effective Real-Time Risk Prediction and Energy Management System for Fog-Cloud-IoT Architecture in Smart City Applications. *F1000Research*, *15*, p.293.

Utkarsh, S., Saini, Y. and Gupta, R.P., IoT driven energy optimization: Transforming smart solutions for sustainable infrastructure. In *Disruptive Technologies* (pp. 164-199). CRC Press.

Jaleel, U. and Shrivastav, M., 2026, January. Smart home automation: Embedded AI for enhanced user experience. In *AIP Conference Proceedings* (Vol. 3345, No. 1, p. 020121). AIP Publishing LLC.

Bozorgi, M., Assaf, G.J. and Katsanis, C.J., 2026. Configuration and Execution of Scalable IoT Architecture for Smart Home Automation. *Internet of Things*, p.101900.

Mukherjee, S., Das, R., Aditya, A., Mohapatra, H. and Mohanta, B.K., 2026. AIoT-Adopted Sustainable Smart Eco-Friendly Home Systems. In *AIoT-Driven Sustainable Manufacturing and Operational Initiatives* (pp. 39-54). CRC Press.

Alshibaki, R., Omar, I., Farfoura, M. and Slehat, S.S., 2026. IOT For Energy Efficiency in Smart Universities: AComplete Review. *Journal of Sustainable Smart Systems in Education & Environment*, *1*(01), pp.69-86.

Kiruthika, V. and Karishma, T.J., 2025, November. An IoT-Integrated Occupancy Detection Approach for Smart Environments. In *2025 International Conference on Intelligent Computing, Information and Control Systems (ICOIICS)* (pp. 511-516). IEEE.

Abhilash, G., Venkatesh, H., Ugargol, A.C., Chaithra, K., Santhoshini, S. and Poongothai, C., 2026. A unified framework for smart home automation and energy analytics through matter and Modbus integration. In *E3S Web of Conferences* (Vol. 692, p. 01015). EDP Sciences.

Fizza, G., Kadir, K., Nasir, H. and Rashid, M., 2025, October. Occupancy Driven Optimization for Comfort and Energy Management in Smart Building. In *TENCON 2025-2025 IEEE Region 10 Conference (TENCON)* (pp. 1103-1107). IEEE.

DARWISH, H., KHAPPER, K.V., GOKARAJU, B. and TESIERO, R., 2026. Smart Control for Smarter Buildings: A Review of Traditional and Intelligent HVAC Control Strategies Toward Energy Sustainability.

Kumar, P., 2025. Anomergy-A novel strategic data-driven framework for detecting anomalies in residential community using temporal intelligence. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, *13*, p.101049.

Zhang, W., Li, J., Tien, P. and Calautit, J.K., 2025. Vision-based Occupancy Detection in Indoor Environments: A Comparison of Standard RGB and Thermal Cameras. *Journal of Building Engineering*, p.114215.

Elanchezhiyan, E., Kalaiselvi, K. and Banumathy, D., 2026. A Novel Hybrid Ledger Approach for Smart Grid Cyber Security and Energy Redistribution Using CryptoGrid.