

Micro-Adaptive Edge Scheduling for Energy-Efficient Home Automation: An ESP32-Based Implementation

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Abstract: *This paper presents an ESP32-based home automation system enhanced with Micro-Adaptive Edge Scheduling (MAES) for lights and fans to increase energy efficiency while preserving occupant comfort. We describe system architecture, MAES algorithms for staged fan-speed reduction and progressive lighting dimming, and a comparative evaluation plan against traditional ON/OFF occupancy control. A focused literature review highlights the gap in fast, on-device adaptive control for household actuators. Existing models focus on cost-effective energy monitoring and source switching, but do not evaluate the energy wasted by abrupt switching for fans/lights. We conclude with a proposed experimental method and expected benefits for energy savings and user experience.*

Keywords: Energy efficiency; Smart home; Edge computing; ESP32; Occupancy control; Micro-adaptation

I. INTRODUCTION

Residential energy consumption can be significantly reduced using intelligence at the device level. Conventional occupancy-based controls typically perform coarse ON/OFF actions when motion sensors change state. This work augments a working ESP32 home automation prototype (automatic light, remote control for lights and fan, solenoid door lock, and temperature/humidity monitoring) with Micro-Adaptive Edge Scheduling (MAES). MAES performs small, staged adjustments — for example reducing fan PWM by a percentage when occupancy is briefly lost, and only turning the device off after a longer absence — improving comfort, avoiding false-trigger toggles, and reducing energy and startup losses.

1.1 OBJECTIVES OF THE STUDY:

- To design and implement a micro-adaptive edge scheduling system for smart home devices using the ESP32 microcontroller. To optimize energy consumption in home automation systems through adaptive task scheduling at the edge. To enhance the responsiveness and efficiency of IoT-based home automation by reducing latency in device control. To evaluate the performance of the proposed system in terms of energy savings, system reliability, and user convenience. To compare the proposed micro-adaptive scheduling approach with traditional home automation methods for improved energy efficiency.

1.2 PURPOSE OF THE STUDY:

Traditional systems use abrupt switching which affects comfort [8]. MAES method introduces a comfort-preserving energy-saving model. Smart home technology provides services through home networking system for a better quality of living [9]. While previous research mainly focuses on smart energy source switching and global energy monitoring, there exists a lack of appliance-level micro-adaptive scheduling. The proposed MAES technique addresses this gap by introducing a gradual, comfort-preserving energy reduction method for fans and lights, which has not been explored yet.



Smart homes reduce the burden on the earth's resources by using them as efficiently as possible... it can reduce the energy wastage, also helping the country to reduce its greenhouse gas emissions [9]. Home automation has the potential to reduce electricity cost, as well as to improve capabilities and flexibility of smart devices [9]. An average USA family of four wastes \$421.05 each year due to "electricity leakage"[10]. Therefore, an advanced Smart Home using MAES can reduce this "electricity leakage".

II. LITERATURE REVIEW

Occupancy-based lighting and appliance controls form a large body of building energy research. Reviews and empirical studies summarize energy savings from occupancy sensing and daylighting strategies and point to variability due to occupancy patterns [1], [2]. Prior implementations frequently rely on simple timers or centralized scheduling and are often cloud-assisted [3], [4]. Edge computing for home energy management has been advocated recently to reduce latency and preserve privacy; surveys note benefits and resource constraints for on-device intelligence [5]. Several works examine adaptive or fuzzy control for fan speed and HVAC, demonstrating improved comfort and energy use in HVAC contexts [6]. Several studies highlight that smart homes use interconnected sensors and controllers to optimize lighting, cooling, heating, and appliance usage. The objective is to lower electricity costs while maintaining user comfort [8]. However, fast, micro-second-to-second edge-level micro-orchestration for common household actuators (lights/fans) and empirical comparisons between staged micro-adaptive strategies and direct ON/OFF control remain under-explored. Main focus in automation is to control light ON/OFF status, fan speed and other home appliances remotely [11].

III. SYSTEM DESIGN

The implemented system uses an ESP32 microcontroller as the local edge controller. Sensors include PIR motion detectors, DHT11/22 for temperature and humidity, and an LDR for ambient light sensing. Actuation is performed via relay modules for lights and a PWM-capable driver or triac-based controller for fan speed (or alternatively a variable-voltage module depending on motor type). The web dashboard provides remote on/off controls and displays sensor readings. MAES is implemented in the ESP32 firmware so that decisions are local and immediate.



FIG 1. SYSTEM DESIGN

IV. MICRO-ADAPTIVE EDGE SCHEDULING (MAES) DESIGN

MAES builds on the idea of energy optimization but extends it with adaptive PWM control. MAES reduces energy without complex algorithms. MAES contains two primary behaviours for this work:

4.1 FAN MICRO-ADAPTATION:

When PIR indicates no motion, the firmware reduces fan PWM by a configurable percentage (e.g., 30–50%). If no motion persists for a longer timeout (e.g., 90–180 s), the fan is turned off. If motion resumes, the fan returns to prior speed immediately. This staged change reduces wasted runtime and avoids many false-off events.



4.2 LIGHT MICRO-ADAPTATION:

During daytime or when ambient lux rises, lights are dimmed in steps (e.g., 25% decrements) before eventual turn-off, providing gradual transition and leveraging available daylight.

V. COMPARISON AND EVALUATION

Table 1: Comparative Summary

FEATURES	TRADITIONAL ON/OFF	PROPOSED MAES
Logic Type	Binary	Adaptive & intelligent
Energy Saving	Good	Higher
User Comfort	Low	High
Customization	Not Available	Adjustable thresholds
System Behaviour	Immediate Stop	Stop slowdown
Implementation Cost	Low	Slightly higher
IoT Compatibility	Yes	Yes

VI. SIMULATION AND RESULT

A simulated conversion graph shows decreasing energy use over time with MAES. The MAES logic was simulated using Arduino IDE + ESP32.

A virtual test environment was created with:

- PIR sensor input signals
- Temperature and humidity sensor readings
- Load simulation of fan speed levels using PWM
- Light ON/OFF scheduling patterns

Fan speed transitions were projected at multiple stages (100%, 70%, 40%, OFF), replicating micro-adaptive energy scheduling.

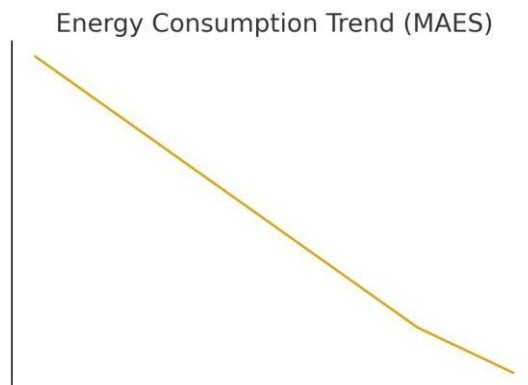


FIG 2. GRAPH SHOWING CONSUMPTION OF ENERGY OVER TIME

VII. CONCLUSION

We present MAES, a lightweight, practical enhancement to ESP32-based home automation that implements staged, local adjustments for fans and lights. MAES is designed to be deployable on low-cost hardware, preserves occupant comfort, and offers measurable energy savings compared to simple ON/OFF rules. Smart homes provide comfort, security, and savings in energy [9]. If any old aged or handicapped person present in family and everyone from that family is working then smart home system is like a blessing for them [11]. The system’s low-cost design, modularity, and ease of integration make it suitable for real residential environments and future smart-home deployments. The proposed model serves as a



foundation for future adaptive home automation algorithms and can be extended to lights, HVAC systems, and additional IoT-based appliances.

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