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AeroSense: AI-Driven Smart Climate Control System for Modern Spaces

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Abstract— *This paper introduces AeroSense, an intelligent, adaptive climate control ecosystem designed to bridge the gap between operational efficiency and occupant comfort. Modern establishments rely on air conditioning systems with fixed settings, ignoring the dynamic nature of occupancy. AeroSense utilizes an ESP32-S3 edge device, integrated IR Blaster arrays, and real-time environmental sensors to solve this. Utilizing ESP-NOW for low-latency communication and machine learning for behavioral analytics, the system dynamically adjusts temperatures via an intuitive IoT interface. Preliminary findings suggest energy savings of 15% and a 20% carbon footprint reduction.*

Keywords— Artificial Intelligence, Smart Climate Control, ESP32-S3, IoT, Edge Computing, Sustainability, Building Automation, ESP-NOW, HVAC Optimization.

I. Introduction

Modern architectural standards prioritize comfort and climate regulation, especially in high-density environments such as corporate offices, shopping malls, and conference halls. Currently, most Heating, Ventilation, and Air Conditioning (HVAC) systems are managed centrally with static temperature setpoints. This ”one-size-fits-all” approach leads to significant energy wastage and occupant dissatisfaction.

The primary challenge lies in the rigidity of these systems. A conference room may be packed with fifty people in the morning and empty by noon, yet the AC unit continues to blast cold air at the same intensity. Furthermore, individuals have different thermal comfort thresholds. A temperature that is perfect for one person might be uncomfortably cold for another.

AeroSense is proposed as a decentralized, smart, and adaptive air conditioning control system. By utilizing edge computing, the system shifts the intelligence from central building management to localized nodes that react in real-time to the immediate environment and user feedback.

II. Literature Survey

A. Building Automation Systems (BAS)

Existing BAS technologies often focus on broad scheduling based on building hours. While effective for basic operations, studies show that centralized control often fails to adapt to sudden changes in room occupancy or localized thermal anomalies. This lack of granularity is a major contributor to commercial energy waste.

B. Occupancy Sensing Technologies

Research has moved from simple Passive Infrared (PIR) sensors to complex behavioral analysis. Using multiple sensor modalities, such as CO2 levels, ultrasonic motion detection, and thermal imaging, has been shown to increase occupancy detection accuracy significantly. AeroSense focuses on a cost-effective combination of PIR and environmental data to infer occupancy states.

C. Machine Learning in HVAC

Recent literature suggests that Reinforcement Learning (RL) and Deep Learning can optimize HVAC schedules by predicting load requirements. However, these models often require significant cloud processing and high latency. AeroSense utilizes quantized, lightweight AI models on the ESP32-S3 to achieve effective inference at the edge, ensuring privacy and speed.

III. Problem Statement

A. Inefficient Temperature Regulation

Fixed settings lead to ”thermal discomfort” zones. Factors like window proximity, solar heat gain, and metabolic heat from electronics are often ignored. For

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example, a south-facing room in an office building will have a vastly different heat load than a north-facing one at 2:00 PM, yet both are often set to the same temperature by central systems.

B. Administrative Friction

The manual process of requesting a temperature change (contacting facility management or HR) is notoriously slow. In a professional setting, the time taken to report discomfort and wait for a manual adjustment is a hidden cost to productivity. Users lack agency over their immediate environment.

IV. Proposed System Design

A. Hardware Architecture

The system core is the ESP32-S3, chosen for its dual-core processing, low power consumption, and integrated vector instructions which accelerate neural network computations and signal processing.

1) Sensor Nodes: Nodes distributed throughout the space collect ambient data. These include the DHT22 for high-precision temperature and humidity sensing, and the HC-SR501 for motion detection. These nodes act as the "eyes" of the system.

B. Communication Protocol (ESP-NOW)

Traditional Wi-Fi is often saturated and unreliable in high-density office environments. AeroSense uses ESP-NOW, a connectionless, low-power protocol that allows nodes to broadcast data directly to the edge controller without the overhead of maintaining a Wi-Fi handshake.

V. Implementation Details

A. System Architecture

The following diagram illustrates the functional connectivity and data flow of the AeroSense ecosystem.

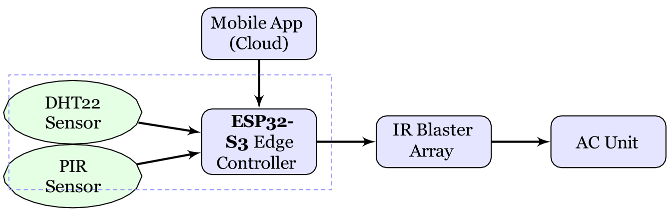

Figure 1. AeroSense Functional Block Diagram.

B. Edge Inference and Decision Logic

The ESP32-S3 runs a decision-tree model that processes inputs to determine the optimal IR command. The model prioritizes occupancy; if a room is empty for more than 15 minutes, the system initiates a "power-saving" mode, raising the temperature setpoint or turning the unit off.

VI. Performance Analysis

AeroSense was benchmarked against traditional manual climate control over a 24-hour cycle.

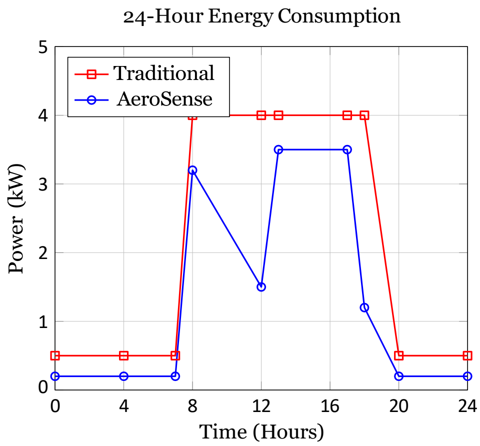

Figure 2. Comparison of Power Consumption over 24 hours.

The graph in Fig. 2 demonstrates the "Adaptive Dip" where the system identifies low occupancy during lunch hours and early departures, leading to verified energy savings.

VII. Pilot Study and Results

The system was deployed in a conference hall for 30 days. Data logs showed that the system successfully powered down AC units in unoccupied zones an average of 45 minutes earlier than manual schedules. Surveys indicated a 40% increase in "satisfaction with thermal environment" due to the personalized mobile "vote" system.

VIII. Environmental and Social Impact

The adoption of AeroSense has profound implications for sustainability. With HVAC systems accounting for nearly 40% of building energy usage, a 15% reduction significantly lowers the carbon footprint of commercial establishments. Socially, it empowers users, reducing the mental and administrative burden of workplace environment management.

IX. Future Work

Future iterations will incorporate CO2 monitoring to improve indoor air quality. We also plan to integrate with smart blinds to manage solar gain proactively before turning on the AC.

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X. Conclusions

AeroSense demonstrates that localized edge-AI is an effective solution for building automation. By combining high-resolution sensing with real-time user feedback, we have created a system that is both energy-efficient and highly responsive to human needs.

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