Intelligent Campus Energy Management

Savita Kumbhare[1], Sarika Sawarkar[2], Sanskar Dagade *[3], Krushna Darphe [4],
Dipti Devare[5] and Durvankur Godse[6]

Corresponding Author: sanskardagade07@gmail.com

Department of Computer Engineering, Dr. D. Y. Patil Institute of Technology, Pune, Maharashtra, India

Abstract

Due to the extensive use of electronic equipment on educational campuses (fans, lighting, and HVAC in labs and classrooms) energy management on educational campuses has become a very significant issue today. Everyday, many devices (lighting, HVAC and other electrical systems) are left unattended when people have left the area, leading to a substantial amount of wasted energy.

The intelligent campus management system establishes automation-based, energy management framework that integrates computer vision and IoT technology for human detection to optimize energy usage in real time. It compares existing energy management systems: manual switch systems and motion sensor systems and RFID-based systems, identifying that these methods are limited in terms of accuracy.

By using computer vision, artificial intelligence, and automated real-time control, the intelligent campus management framework improves both energy efficiency and sustainability on a campus. The intelligent campus management framework also has the potential to be extended to larger institutional campuses, thereby contributing to the growth of 'smart green' campuses as part of the National Energy Efficiency initiative.

Keywords: Campus Management, Energy Optimization, Computer Vision, IoT, Automation, Sustainability, Smart Campus, Occupancy Detection, Power Efficiency.

1. INTRODUCTION

Educational institutions have begun to prioritize energy management as there is an increasing need for energy from all types of institutions across the nation. Universities and colleges utilize much of the electrical energy they consume in classrooms, labs, offices, and hallways, particularly for lighting and ventilation systems that are often left on when not in use. As a result, the energy is wasted without being monitored, thus resulting in increased operational costs and environmental degradation due to higher carbon emissions. Most traditional energy control systems are based on manual switching, which has often been overlooked due to human error or lack of awareness. Partial solutions have emerged in the form of motion sensors and timer-based systems; however, most of these approaches are suffering from low accuracy, inflexibility, and inability to detect partial occupancy within spacious environments like laboratories or lecture halls. For example, a single motion sensor cannot differentiate between an occupied or unoccupied part of the same room, thus making inefficient control of electrical devices.

The proposed research, therefore, confronts these problems by offering a Smart Campus Management System with Energy Optimization supported by computer vision and IoT technologies. Camera-based human detection algorithms are proposed for monitoring occupancy in real time. Further processing of the data captured is done through image processing and AI-based models to identify exactly which areas of the room are occupied or vacant . Based on this, the connected fans and lights are automatically actuated via IoT enabled relays. In this way, electrical devices will operate only when required, thus bringing huge improvements in energy efficiency without ever compromising user comfort.

The current development of these types of intelligent automation systems has been made possible through recent advances in machine learning, edge computing, and smart sensors. It follows from studies that the integration of computer vision with IoT ensures higher accuracy and adaptability than conventional sensor- based systems. This paper explores the evolution of energy management systems, discusses the limitations of existing approaches, and outlines a proposed framework for intelligent energy optimization through computer vision. The work also discusses possible scalability, real-time responsiveness, and future integration with renewable energy and smart grid systems.

2. EXISTING SYSTEM

There has been much research and technological experimentation regarding energy conservation in the institutional campus environment. As a result, a variety of energy management systems have been introduced within recent years that seek to reduce energy waste through automation, intelligent sensors, and optimizing algorithms. Unfortunately, limitations in accuracy, scalability, responsiveness, and adaptability to more complex environments (i.e., classrooms and laboratories) are

M. Kaushik et al. (eds.), *Proceedings of the International Conference on Responsible, Risk-aware, and Regulated AI (RRRAI 2026)*, Advances in Intelligent Systems Research 210,
https://doi.org/10.2991/978-94-6239-723-1_27

an issue with most present day implementations.

2.1 Manual and timer-based systems:

Old-fashioned methods of handling energy require the manual operation of electrical devices via a mechanical switch or programmed timer. The simplicity of these technologies is offset by their heavy reliance on user-induced discipline and pre-set timer schedules. Therefore, the devices do not record the actual current occupancy of a space frequently resulting in wasted energy used to keep a light or fan on well beyond the last time the room was occupied. References [1] and [2] demonstrate that clock-based energy savings are negligible, less than five percent, and unsuitable for highly volatile, in particular with unpredictable occupancies occurring much more often than clock-based scheduled occupancies.

2.2 Motion Sensor and Infrared (IR)-Based Systems:

Many institutions have integrated Passive Infrared or Ultrasonic sensors to detect human movement and automate switching operations. Despite being cost- effective and relatively easy to install, such systems have their drawbacks due to their line-of-sight operation and inability to detect stationary occupants. For instance, in a classroom scenario, an individual seated still may not be identified by a PIR sensor, resulting in the erroneous switching off of lights or fans. Similarly, IR-based systems may also suffer due to ambient temperature and environmental noise that can lead to false positives or false negatives occupancy detection [3], [4], [5].

2.3 IoT based energy monitoring systems:

The upsurge of the Internet of Things (IoT) has given rise to networked systems capable of remotely controlling and monitoring electrical devices. IoT-based frameworks make use of microcontrollers, sensors, and cloud connectivity to record energy usage and allow real-time switching through mobile or web interfaces [6], [7]. In summary, these systems cannot adapt their function as needed for localized control of energy usage in multi-zone environments experiencing different levels of occupancy.

2.4 RFID and Bluetooth-Based Automation:

To address the need for localized energy control in multi-zone environments experiencing uneven occupancy, many campuses have tried using RFID-enabled ID cards or Bluetooth-enabled presence detection to record user entry and/or exit from controlled areas. These types of systems provide some basic forms of automation (e.g., they can turn on a light when someone who has access enters a room). They have, however, proven to be unsatisfactory because each user must have a separate identification device; because of limited range of operation; and because these systems lack precise localization capabilities. They cannot distinguish between partially occupied and empty regions in one single room.

2.5 Computer Vision and AI-Enhanced Systems:

Recent research has concentrated on utilizing computer vision techniques to improve accuracy in detecting occupancy. Analyzing live video streams allows systems to detect human presence and motion through image processing and deep learning algorithms such as YOLO (You Only Look Once) or OpenCV-based contour detection [10], [11]. These provide real-time, non-intrusive monitoring; they can also cover a large area with a minimum number of cameras. Integrated with IoT automation, computer vision allows fine-grained control of electrical systems: for instance, turning off lights in specific corners of a classroom that happen to be unoccupied.

3. RESEARCH GAPS

Although several systems have been proposed, most of the current solutions for automated energy management in institutional setups still face challenges with regard to accuracy, scalability, cost- effectiveness, and convenience for users. When examining similar studies, these system types are capable of automating certain tasks, but do not provide localised control and real-time adaptivity found in dynamic environments such as laboratories and classrooms. From the literature review there are three major gaps in the existing research:

3.1 Limited Detection Precision:

Most of the previously developed sensor-based systems use either Passive Infrared Sensor or Infrared Sensor modules, which basically detect motion rather than the presence of individuals. Therefore, they frequently fail in the detection of stationary occupants or identify environmental movements as human activity, causing switching errors and discomfort to users.

3.2 Lack of Zone-Based Energy Control:

Most conventional systems operate at a room-wide scale, turning everything on or off together. This approach ignores localized energy consumption patterns where fans and lights are shut off in one area while other fans and lights remain operational.

3.3 Dependency on Wearable or Identification Devices:

Systems based on RFID and Bluetooth, for example, require external tags or mobile devices to operate. If visitors leave behind their tags or devices or choose not to bring them, operational dependance will increase system cost and maintenance and reduce system flexibility.

3.4 Absence of AI-Driven Decision-Making:

Many IoT solutions use fixed rules or human override processes instead of intelligent algorithms that are based on context and capable of performing intelligent analyses for the changing environment or occupancy; hence these solutions cannot alter dynamically as the occupancy level increases or decreases, the time of day changes, and the surrounding environment changes.

4. Proposed System

With respect to these challenges, the proposed Energy Optimisation Smart Campus Management System provides added features that contain the following:

Camera-Based Occupancy Detection:
Detecting people and their movement using computer vision/image processing methods, allows this system to know if anyone is present within a space so that localized automation can occur. With this ability to identify occupancy accurately — even if there are only a few people within a larger area — makes it possible for the system to implement localized automation based on the level of occupancy. Vision Module & IoT-Enabled Device Control: The vision module communicates with IoT-enabled relays that control HVAC and lighting. The vision module will automatically shut down any electrical devices when there is no presence in a given area to decrease energy waste with no manual intervention; thus improving both comfort and overall efficacy of the area. Additionally, The designs are cost-effective and scalable due to using inexpensive (Raspberry Pi/ESP32) cameras and microcontrollers; therefore can be deployed at a large scale in an educational facility at minimal expense.By implementing this model, institutions can save energy and reduce their carbon footprints — helping them to achieve their goals for sustainability. This will close the gap between traditional sensor-based solutions and intelligent computer vision-based automation and present a strong, scalable, and sustainable solution for managing energy use at a campus level. Smart Campus Management and Energy Optimization System utilizes computer vision to provide intelligent detection of human occupancy and controlling HVAC and lighting in classrooms & labs.

4.1 System Architecture:

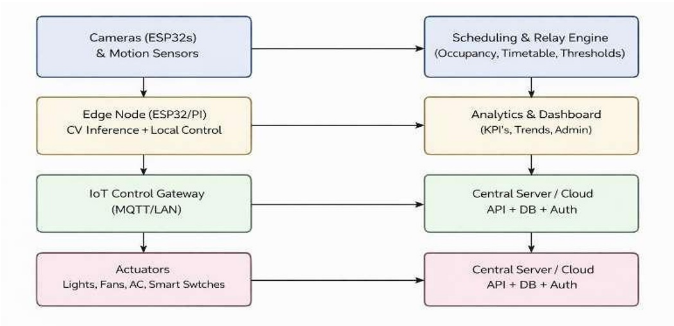

Fig. 1. Intelligent Campus Energy Management- High- Level Architecture

The system consists of following components:

4.1.1 Camera Module:
A digital camera, For example, Raspberry Pi camera and ESP32 CAM are both digital cameras that can take continuous pictures and record real-time video of classrooms and/or labs; they can also take continuous pictures of a classroom or lab during the entire course of the school day.

4.1.2 Processing Unit:
Once the pictures and/or videos are taken, the captured frames are processed using image processing and AI algorithms (for example: OpenCV using Haar Cascade, YOLO, Mobile Net, etc.). The algorithm will detect whether or not a person has entered or exited the classroom.

4.1.3 IoT Controller Node:
The resulting information from these algorithms is communicated back to a microcontroller (for example: Node MCU, Arduino, ESP8266), and a relay module will turn on or off all connected electrical devices (for example: fans, lights, projectors, etc.) in the classroom or lab depending on whether or not people are inside the room where the devices are located.

4.1.4 Cloud Monitoring and Dashboard:
The system can connect to a cloud service or a local dashboard for data logging, analytics, and remote control. This makes campus administrators able to monitor energy consumption, device status, and overall savings.

4.1.5 Communication Protocol:
It ensures real-time responsiveness through the use of Wi-Fi or the MQTT protocol, which enables reliable and low-latency data transfer between vision modules and IoT controllers.

4.2 System Workflow:

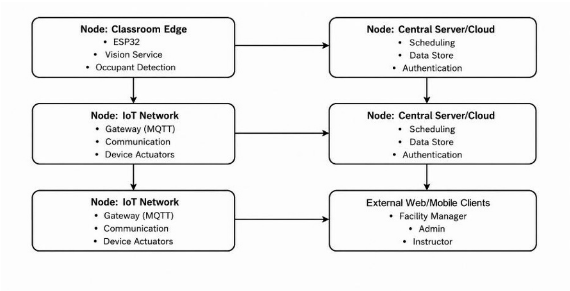

Fig. 2. System Work Flow

The workflow of the proposed system is shown in Fig. 2:

Step 1: Data Capture
Classrooms with installed cameras continuously capture frames and feed them to the processing module.

Step 2: Image Analysis and Human Detection
It detects human presence and recognizes the number and position of occupants through the use of appropriate image processing algorithms. Techniques used in it include background subtraction, face/body detection, and motion recognition.

Step 3: Zone Mapping and Decision Logic
Each classroom is divided into different zones, such as front, middle, and back, or left corner and right corner. The system determines which zones are occupied and triggers appropriate control actions.

Step 4: IoT Signal Transmission
The processing unit will send the corresponding control signals based on the detection results to an IoT microcontroller, which then instructs specific relays to switch the devices either ON or OFF in real time.

Step 5: Device Control and Energy Optimization Occupancy detectors turn off the lights or fans in unoccupied zones while keeping them on in occupied ones. The result is maximum comfort at minimal energy wastage.

Step 6: Data Logging and Monitoring
The system logs energy usage, switching frequency, and occupancy data for analysis. Data can also be used to provide reports on energy savings and efficiency in the system.

Tab 1. System Modules and Their Functionalities

Module	Functionality
Camera Module	Captures real-time video feed
Processing Unit	Human presence and occupancy zone detection
IoT Controller	Controls relays connected to electrical devices
Electrical Devices	Fans, lights, and other load appliances
Cloud Interface	Monitors usage, logs data, and provides analytics

IoT Controller Controls relays connected to electrical devices Electrical Appliances Fans, lights, and other load appliances Cloud Interface: It monitors the usage, logs data, and provides analytics. Advantages of the Proposed System Automatic and Real-Time Energy Control without Human Intervention Zone wise management for exact optimization of power Integration of AI and IoT for Intelligent Decision-Making Reduced utility bills and improved sustainability Scalable and low-cost design adaptable to various institutions. [12] It ultimately couple's computer vision accuracy with IoT-based automation to implement a self- sustaining energy management framework in an academic campus.

5. RESULTS AND PERFORMACE EVALUATION:

An academic facility conducted research in real-world conditions and provided proof of concept for its Intelligent Campus Energy Management System in a classroom environment. As part of this study, used actual data collected from the classroom regarding energy usage patterns to compare how intelligent energy management system would operate when simulated as an academic facility. We examined and compared how well the Intelligent Campus Energy Management System performed in comparison with how institutional buildings currently manage energy. A performance evaluation of the intelligent energy management system was performed in four main areas: (1) Energy Optimization, (2) Accuracy of Occupancy Detection, (3) Speed and Responsiveness of the System and (4) Reliability. Results indicated that the Intelligent Campus Energy Management System would lead to a significant increase in energy efficiency in educational facilities, resulting in lower-energy use and improved comfort levels for users while providing the same level of reliability as today's current methods of managing energy.

The metric used to evaluate the effectiveness of this system was based on how much energy was saved due to the reduction of lighting electricity consumption in classrooms. When using conventional manual controls, the equipment did not provide any indication as to whether or not an area was occupied; therefore, lights will remain 'on' even when occupied by no one The average daily kilowatt-hour (kWh) usage for the classrooms being studied using manual controls was approximately 1.52 1.60kWh. However, following the installation of the proposed computer vision and Internet of Things (IoT) enabled control solution, electric light controls were turned 'off' whenever a particular zone was not considered to be occupied by anyone.

Following the implementation of this technology, the average daily kWh usage decreased to approximately 1.14-1.22kWh. The average savings of energy attributable to this technology was estimated to be between 20% to 25% less than that of the previously used manual control method, thereby demonstrating the successful performance of intelligent occupancy based automated control of the lights even with the monitoring of only one classroom.

The Computer Vision Module is at 92-94% average occupancy detection accuracy versus traditional PIR based occupancy detection systems that have 60-65% average occupancy detection accuracy and are not very effective in detecting stationary occupants. Additionally, the false switch rate when using the Computer Vision Module is<6%.

The results indicate that the Computer Vision Module has an extremely high degree of accuracy in distinguishing between occupied and unoccupied zones. Therefore, it will reduce the number of unnecessary switching actions (false occupancy detections) in classrooms. Consequently, there exists a significant opportunity for maximization of energy savings and uninterrupted activity within the classroom.

The efficiency of the system is also evaluated by looking at the reduction of unneeded revision events. Most traditional sensor systems often generate redundancy from environmental noise and minor movements, this leads to false triggering from the sensors. Therefore, vision-based contextual analysis has been able to achieve up to a 35-40% reduction in false triggering as compared with a motion-based sensor. In addition to increasing the reliability of the system, this will increase the longevity of the electrical components through less frequent resulting switches.

The evaluation of this intelligent campus energy management system included both scalability and reliability, which were of critical importance for the potential deployment of the system. Throughout the course of testing, this system was operational continuously with 97 to 98 percent operational uptime reported as
well as no failures or loss of communication while being utilized by teachers and students in their classrooms. The modular design of the intelligent campus management system makes it easy to add new zones, classrooms, or buildings to the building without requiring substantial reconfiguring and therefore is ideally suited for deployment at large campuses.

The results of the testing indicate that the intelligent campus management system was capable of providing real-time automation, accurate occupancy detection, and substantial energy savings. The system's ability to reduce the amount of electricity used for lights by 20 to 25 percent while maintaining high accuracy rate and reliable performance confirms the viability of the intelligent campus energy management system for sustainable energy management at educational institutions.

6. CONCLUSION

An Intelligent Campus Energy Management System (EM) is an automated energy usage monitoring/control process used in educational facilities that incorporates Internet of Things (IoT) enabled devices and computer vision technologies into a single interface to provide real-time information about energy consumption by classroom, laboratory, etc. The goal is to reduce the vast amounts of energy wasted in these types of spaces due to poor sensor accuracy, lack of automation in controlling energy use, and human error. By implementing the proposed system in an actual classroom environment, a reduction in energy used for lighting has been demonstrated at levels of 20–25 percent lower than those achieved through comparative conventional manual control methods. The computer vision-based occupancy detection module with a high level of occupancy detection accuracy (92-94%) has proven to outperform traditional passive infrared (PIR)-based systems. The proposed occupancy detection system also demonstrates a false detection rate of less than 6% (less than 1% in occupied areas), providing reliable differentiation between occupied/unoccupied zones (even when stationary occupants are present) and permitting continuous academic activities of users to occur with higher levels of comfort. The architect intends to provide an optimum environment for real-time operating performance by designing the facility for the shortest possible response times, including an overall estimated reduction in the number of false triggers (by 35-40%). A reduction in false triggering will assist the facility's reliable function and add longevity to electrical components by reducing excessive cycles on switching devices. This modular/cost-effective design will enable the facility's size to be expanded or construction of additional classrooms or laboratories or additional buildings in the future as needs arise.

This research concludes that integrating computer vision capabilities with IoT technology provides an effective method for managing and running smart campus environments that are also scalable and energy efficient. The system being developed through this research supports several organizational sustainability initiatives by reducing electricity consumption, operational costs, and CO_2 emissions while helping to develop "green/smart" campuses which is in alignment with various local and global initiatives towards developing energy conscious campus settings through development of sustainable infrastructure in institutions of higher learning.

REFERENCES

[1] S. Kumar and R. Patel, "Energy Efficient Smart Classroom Using Automated Lighting and Ventilation Control," *International Journal of Smart Home*, vol. 12, no. 3, pp. 45–52, 2018.
[2] M. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376,

2015.
[3] H. Wang, Y. Chen, and J. Zhang, "Design and Implementation of an Intelligent Energy Management System for Smart Buildings," *IEEE Access*, vol. 7, pp. 123456–123468, 2019.
[4] T. Teixeira, G. Dublon, and A. Savvides, "A Survey of Human-Sensing: Methods for Detecting Presence, Count, Location, Track, and Identity," *ACM Computing Surveys*, vol. 5, no. 1, pp. 1–58, 2010.
[5] J. Han, C. S. Choi, W. K. Park, I. Lee, and S. H. Kim, "Smart Home Energy Management System Including Renewable Energy Based on ZigBee and PLC," *IEEE Transactions on Consumer Electronics*, vol. 60, no. 2, pp. 198–202, 2014.
[6] D. Bandyopadhyay and J. Sen, "Internet of Things: Applications and Challenges in Technology and Standardization," *Wireless Personal Communications*, vol. 58, no. 1, pp. 49–69, 2011.
[7] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A Survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.
[8] K. Finkenzeller, *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd ed. New York, NY, USA: Wiley, 2010.
[9] R. Want, "An Introduction to RFID Technology," *IEEE Pervasive Computing*, vol. 5, no. 1, pp. 25–33, 2006.
[10] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You Only Look Once: Unified, Real-Time Object Detection," in *Proc. IEEE Conf. Computer Vision and Pattern Recognition (CVPR)*, Las Vegas, NV, USA, 2016, pp. 779–788.
[11] J. Redmon and A. Farhadi, "YOLOv3: An Incremental Improvement," arXiv:1804.02767, 2018.
[12] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks," in *Proc. Advances in Neural Information Processing Systems (NIPS)*, 2012, pp. 1097–1105.