An Energy Management System in Smart Classroom Using CupCarbon Simulator

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ABSTRACT

A smart classroom involves integrating smart materials, smart communication and participation, smart evaluation, and smart physical surroundings to enhance the teaching and learning process. One key feature is the Energy Management System (EMS), which aims to reduce the energy consumption in the classroom. This paper proposes an EMS for a smart classroom using the CupCarbon Wireless Sensor Network (WSN) simulator. The study simulates WSN protocols—WiFi, Zigbee, and LoRa—on a campus building at the National Institute of Technology (ITN) Malang, Indonesia, which provides essential communication infrastructure for the EMS. The EMS algorithm controls the operation of the lighting and Air Conditioner (AC) in the classroom based on the occupancy and outdoor temperature. The EMS algorithm is easily implemented on the CupCarbon simulator. The results from five days of simulation show that the LoRa protocol with the mediator achieves the highest energy efficiency in the WSN at 67.93%. The occupancy-based evaluation method also results in a significant energy reduction of 51.55%.

Keywords-smart classroom; energy management; CupCarbon simulator; wireless sensor networks; occupancy

I. INTRODUCTION

A smart campus is a university campus that leverages the concept of smartness to enhance the effectiveness of teaching, research, and student learning processes for the institution and its surrounding areas [1-3]. The smart concept incorporates innovative technology, the Internet of Things (IoT), and intelligent systems. Several features of the intelligent campus encompass the smart classrooms, automated canteens, energy management systems, intelligent transportation (such as smart parking and campus transit), security and safety measures (including fire detection and evacuation protocols), and advanced healthcare facilities [2]. A smart classroom is a component of a smart campus, where the environment provides data to teachers and students to enhance the teaching and learning process [4]. The main areas in a smart classroom include smart material, smart communication and participation, smart evaluation, and smart physical surroundings [5]. The smart physical surroundings comprise multiple sensors that monitor the environment, including temperature, humidity, radiation, gases, sound levels, and lighting. The integration of sensors and Artificial Intelligence (AI) technology has been developed in the smart classroom [6, 7].

Another important feature of the smart campus and smart classroom is the EMS, which is part of the modern electrical infrastructure known as the smart grid, where the information and communication technology are integrated with the electrical networks [8]. The centralized EMS in the education building was developed using the Supervisory Control and Data Acquisition (SCADA) system [9]. The techno-economic analysis of the hybrid renewable energy system in the campus building was conducted using the HOMER software [10]. A comparison of various machine learning techniques for predicting the energy consumption in the office rooms, classrooms, and laboratories of an educational building was investigated in [11]. Open-source technologies, such as the Message Queuing Telemetry Transport (MQTT) protocol and the Node-RED programming tool, were adopted to develop the building's energy consumption monitoring system [12, 13]. The integration of the IoT and WSN within distributed energy systems has led to the development of the Internet of Energy (IoE) [14].

The smart lighting control in the classroom was developed in [15], where dual passive infrared sensors were used to detect and count the students entering and leaving the classroom. The system automatically switches the lighting on and off to save energy in the classroom. The smart thermostat was integrated into the building's EMS, ensuring thermal comfort while minimizing the electricity expenses [16]. It included temperature, humidity, carbon dioxide (CO_2), energy sensors, a microcontroller, speed control, and an infrared emitter. The speed control was used to regulate the ventilator's speed, while the infrared emitter was employed to control the heat pump by simulating the infrared remote device. The microcontroller is connected to the cloud server using the MQTT protocol. In [17], the optimization algorithm reduced the AC emissions by 16%. The motion detection and room management system was proposed to improve the energy efficiency in a university building [18]. Installed motion detection sensors in the underground parking and lecture rooms achieved daily lighting energy savings of 77.6% and 32.4%, respectively, and also reduced the daily AC energy use by 27.9%. The dormitory room management system on campus decreased the daily electricity consumption by 28.2%. In [19], a machine learning technique was employed to predict occupancy and optimize the thermal comfort in the campus lecture theater. The campus building's occupancy-based energy consumption was modeled using an embedded platform and IoT technology [20]. In this model, the lamp in the room was turned on or off based on the occupant's status, lighting conditions, and the probability of the occupant switching the lamp on or off. The AC was switched on or off depending on the occupant's status, room temperature, and the probability of the occupant turning it on or off. Authors in [21] examined the awareness of occupants regarding the energy efficiency of the campus building. The results showed that the lecturer, followed by the staff, achieved the highest level of understanding compared to the students.

Implementing EMS and IoT in campus buildings is vital for saving energy on smart campuses. There is no standard architecture for developing the EMS in campus buildings. Since it involves multiple technologies, such as EMS, IoT, and WSN, it is common to use a simulation software to test the proposed approach beforehand. In this paper, the EMS in the smart classroom is simulated using the CupCarbon simulator [22-24]. The goal is to evaluate the performance of the wireless communication protocols used in the proposed EMS in the classrooms, specifically in the campus building of the 2nd campus of the ITN, Malang, Indonesia. For this purpose, CupCarbon is employed to simulate WSNs using WiFi, Zigbee, and LoRa protocols. CupCarbon is an excellent simulator suitable for this task.

The main contributions of our work are:

- It proposes an EMS for the smart classroom by adopting the WSN technology.
- • The proposed system is implemented on the CupCarbon simulator, which simulates the WSN technology based on the actual geographic conditions of the campus building at the 2nd campus of the ITN.
- • It assesses the performance of three popular WSN protocols (WiFi, Zigbee, LoRa) in decreasing the power consumption of the communication devices.
- • It examines the effectiveness of occupancy-based control methods for lighting and AC in reducing the energy consumption.

II. METHOD

The typical wireless communication protocols used in campus buildings are WiFi [25], Zigbee [26], and LoRa [27]. Thus, the proposed work focuses on evaluating the wireless network protocols used in the EMS of the smart classroom. A primary consideration for the communication network is the energy consumption of the radio module. The CupCarbon simulator provides a tool to simulate this energy consumption. Furthermore, the classroom energy efficiency algorithm, such as occupancy-based lighting and AC control, can be easily simulated in CupCarbon.

A. *CupCarbon Simulator*

CupCarbon is a simulator that can be used to study, design, visualize, and simulate various algorithms of the WSN in a real urban environment [22–24]. It is utilized to simulate the energy management of the streetlights in a road network [28], cotton plant pest detection [29], a traffic accident management system [30], and a smart city [31]. The main applications of CupCarbon are shown in Figure 1, including road networks, Smart Cities, Energy management, Mobility, Network performance, and 3D visualization [28].

The architecture of CupCarbon is depicted in Figure 2. It consists of eight main modules: 2D/3D City Model, Mobility, Communication Script, Network Device, Radio Channel Propagation, Propagation and Connection Matrix, Interferences, and Simulation [23]. The 2D/3D City Model is the central component of the simulator, representing buildings, roads, and other locations. The Mobility module simulates the mobile devices that a given trajectory or script can identify. The Communication Script module is the Sen-Script language used to program each node. The Network Device module is used to simulate the WSNs. The Radio Channel Propagation module calculates the channel attenuation and determines whether the communication is possible through the Propagation and Connection Matrix. The Interference module simulates the interference that impacts the message delivery. The Simulation module is the core of the simulator, using discrete event simulation, where events are generated by the script's instructions or natural occurrences.

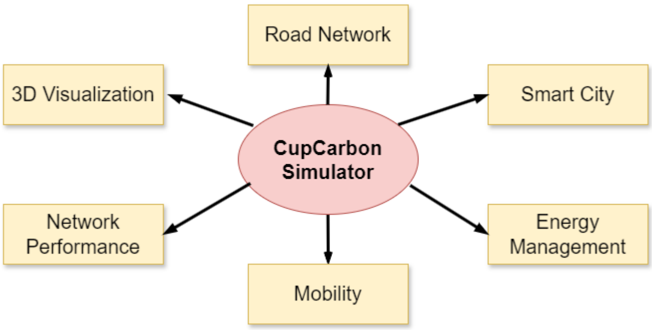


Fig. 1. Main applications of the CupCarbon.

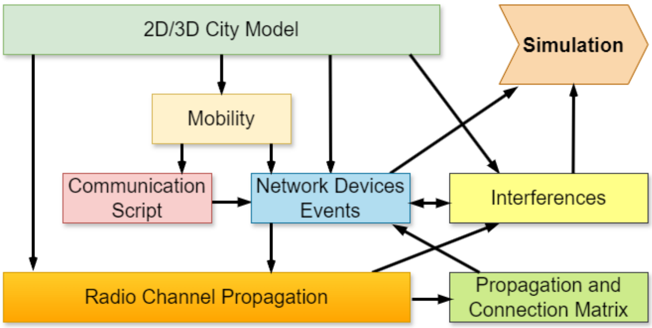


Fig. 2. Architecture of CupCarbon.

B. *Energy Management System in Smart Classroom Using CupCarbon Simulator*

The proposed EMS in the smart classroom aims to reduce the energy consumption of the lighting and AC in the classrooms. The classrooms are in three lecture buildings: Lecture Building 1, Lecture Building 2, and Lecture Building 3. Each lecture building has five classrooms, where the lighting and AC are controlled and monitored by the control room located in a different building. The WSN has been adopted to establish the communication infrastructure for monitoring and controlling the energy consumption. This study examines two approaches, as demonstrated in Figures 3 and 4, where a WSN node is positioned in each classroom. In Lecture Building 1, the nodes are denoted as S11, S12, S13, S14, and S15. The nodes in other lecture buildings are denoted accordingly. The WSN master is denoted as S4, while the mediators are denoted as S1, S2, and S3. In the first approach, as portrayed in Figure 3, the nodes and master communicate via the mediators. In this approach, a mediator is placed in each lecture building. The mediator is an intermediate device for exchanging communication data between the node and the master. In the second approach, as illustrated in Figure 4, the nodes communicate directly with the master without the use of intermediaries. It is worth noting that this work evaluates the energy usage performance of wireless communication protocols (WiFi, Zigbee, LoRa). CupCarbon provides a powerful method that effectively addresses this task.

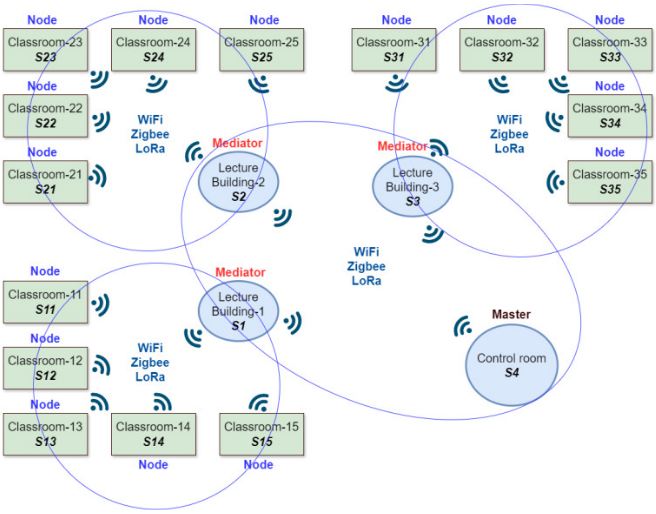


Fig. 3. Architecture of WSN in EMS with mediators.

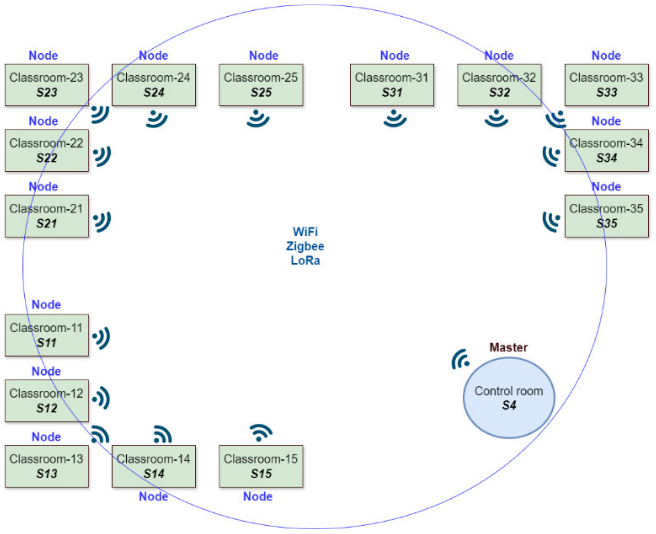


Fig. 4. Architecture of WSN in EMS without mediators.

The flowcharts of the proposed EMS of the master and node are displayed in Figures 5 and 6, respectively. As shown in Figure 5, the master (Control Room) retrieves the outdoor temperature and room occupancy from the database and then sends them to the respective node. After sending the data, the master will receive the data containing the power and energy consumed by the room. As presented in Figure 6, a node initially receives temperature and occupancy data. When the room is occupied, the lamps are turned ON. The AC will be turned ON when the room is occupied and the temperature is above 24 °C. After controlling the lamp and AC, the node sends the power and energy consumption data to the master.

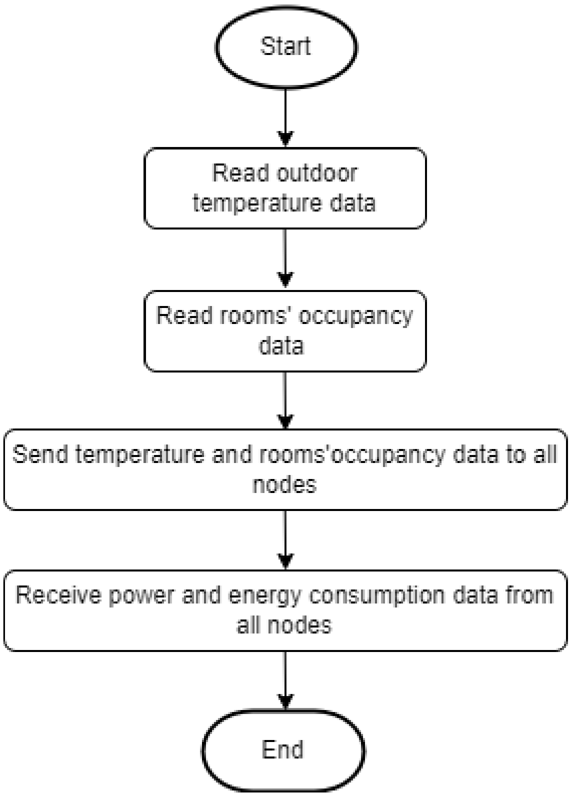


Fig. 5. Flowchart of the EMS of the master.

In this work, the AC power is calculated using the temperature data modeled in [32], where the AC power is a linear function of both the outdoor and room temperatures, as shown in:

$$P_{AC} = C \times (T_{out} - T_{room}) \qquad (1)$$

where P_{AC} is the AC power (W), C is a constant (set to 80 W/°C in this simulation), T_{out} is the outdoor temperature (°C), and T_{room} is the room temperature (°C). In this work, the dataset for the room and outdoor temperatures is prepared in advance. However, it is beneficial to use the model presented in (1), as it accounts for the variation in the room temperature caused by the window opening, the number of occupants, and the outdoor temperature fluctuations due to the external climate changes to model the AC power consumption.

Figure 7 illustrates the data transfer between the nodes and the master through the mediator. The master transmits the outdoor temperature data and classroom occupancy status (whether occupied or not) to the mediator. The mediator then forwards this information to the nodes. The nodes send their power and energy consumption data to the mediator, which subsequently relays this information to the master. However, in the case of a WSN without a mediator, the aforementioned data exchanges are directly exchanged between the master and the nodes.

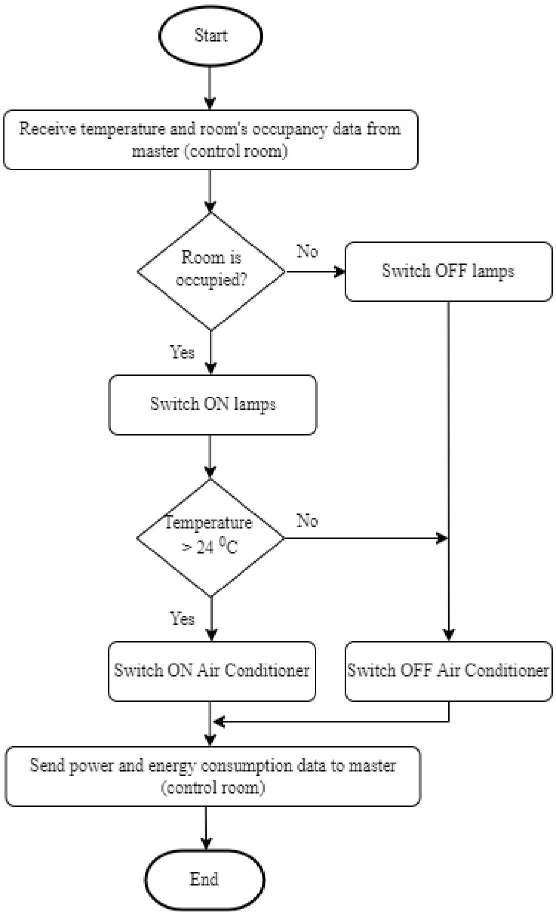


Fig. 6. Flowchart of the EMS of the node.

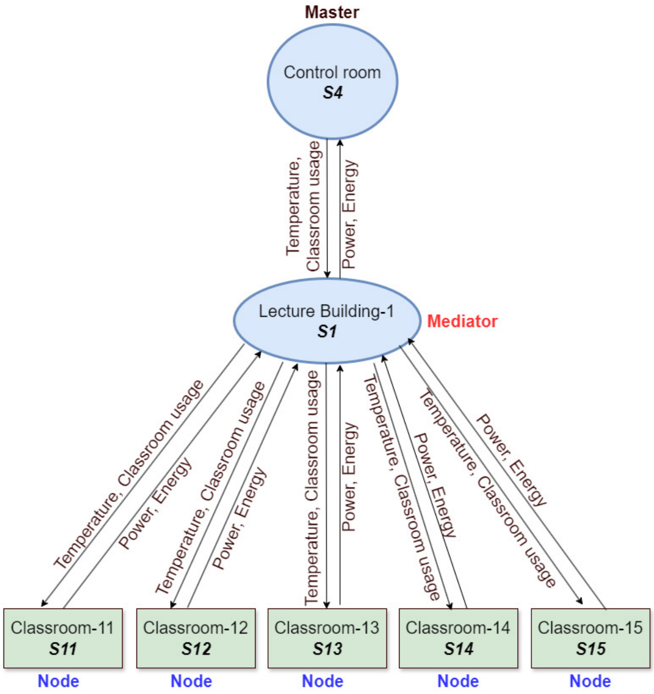


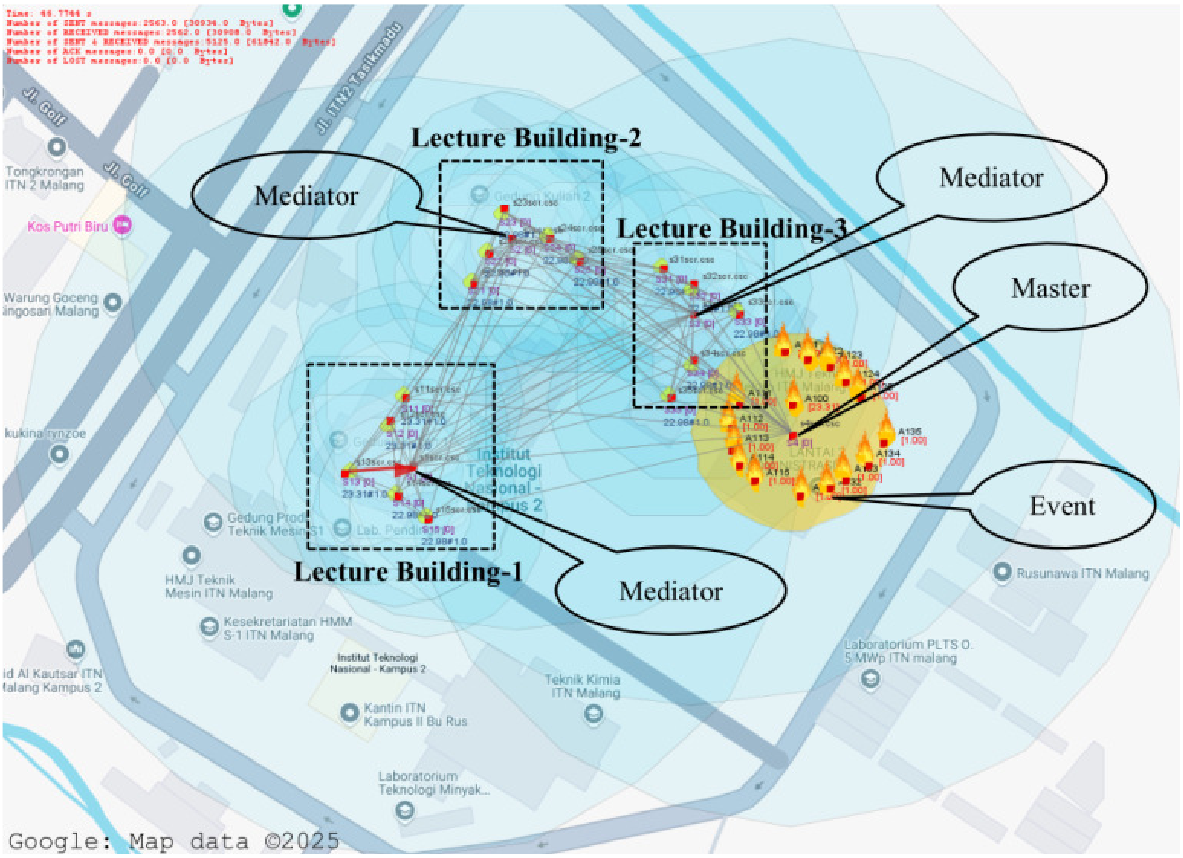
Fig. 7. Data transfer between the nodes and the master.

The implementation of the proposed EMS with and without mediators in CupCarbon is depicted in Figures 8 and 9, respectively. The Google map of the ITN campus is displayed on the main screen of CupCarbon. This makes it easy to locate the WSN nodes that represent the actual geographic conditions using the CupCarbon simulator. The event shown is one that can simulate natural phenomena, such as temperature and gas sensors. This work uses the event to generate outdoor temperature data and classroom usage information, as previously described. The red boxes highlight the node, mediator, master, and event. The green color of the node indicates that the corresponding classroom's lighting and AC are turned on. The red arrow shows the current data transfer happening during the simulation. The radio parameters used in the simulation are listed in Table I. The radio radius is indicated by the light blue circle in Figure 8 and the light green circle in Figure 9. In the absence of a mediator, the master communicates directly with the nodes, thereby extending the radio range to 120 m, in contrast to the 100-m range observed in the mediator-based approach.

This work evaluates two control methods for lighting and AC in classrooms. The first method, called the Fixed Time method, operates the lighting and AC on a set schedule; for example, the lighting turns on from Monday to Friday, 7:00 a.m. to 6:00 p.m. The AC is also activated from Monday to Friday, 7:00 a.m. to 6:00 p.m., when the outdoor temperature exceeds 24 °C. The second method, known as the Occupancy-based method, adjusts the lighting and AC based on the occupancy. The latter is determined by the data generated by the event generator in the CupCarbon simulator. In real-world applications, the occupancy data can be obtained from the classroom sensors or the lecture schedule.

TABLE I. RADIO PARAMETERS USED

Method	Standard	Device ID	Radius (m)	Spreading factor
With mediator	Zigbee, WiFi	S11 to S15, S21 to S25, S31 to S35	30	NA
		S1,S2,S3,S4	100	
	LoRa	S11 to S15, S21 to S25, S31 to S35	30	7
		S1,S2,S3,S4	100	
Without mediator	Zigbee, WiFi	S11 to S15, S21 to S25, S31 to S35	30	NA
		S4	120	
	LoRa	S11 to S15, S21 to S25, S31 to S35	30	7
		S4	120	



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Time: 46.7744 s
Number of SENT messages:2563.0 [30934.0  Bytes]
Number of RECEIVED messages:2562.0 [30908.0  Bytes]
Number of SENT & RECEIVED messages:5125.0 [61842.0  Bytes]
Number of ACK messages:0.0 [0.0  Bytes]
Number of LOST messages:0.0 [0.0  Bytes]
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Fig. 8. Implementation of energy management in CupCarbon with mediators.

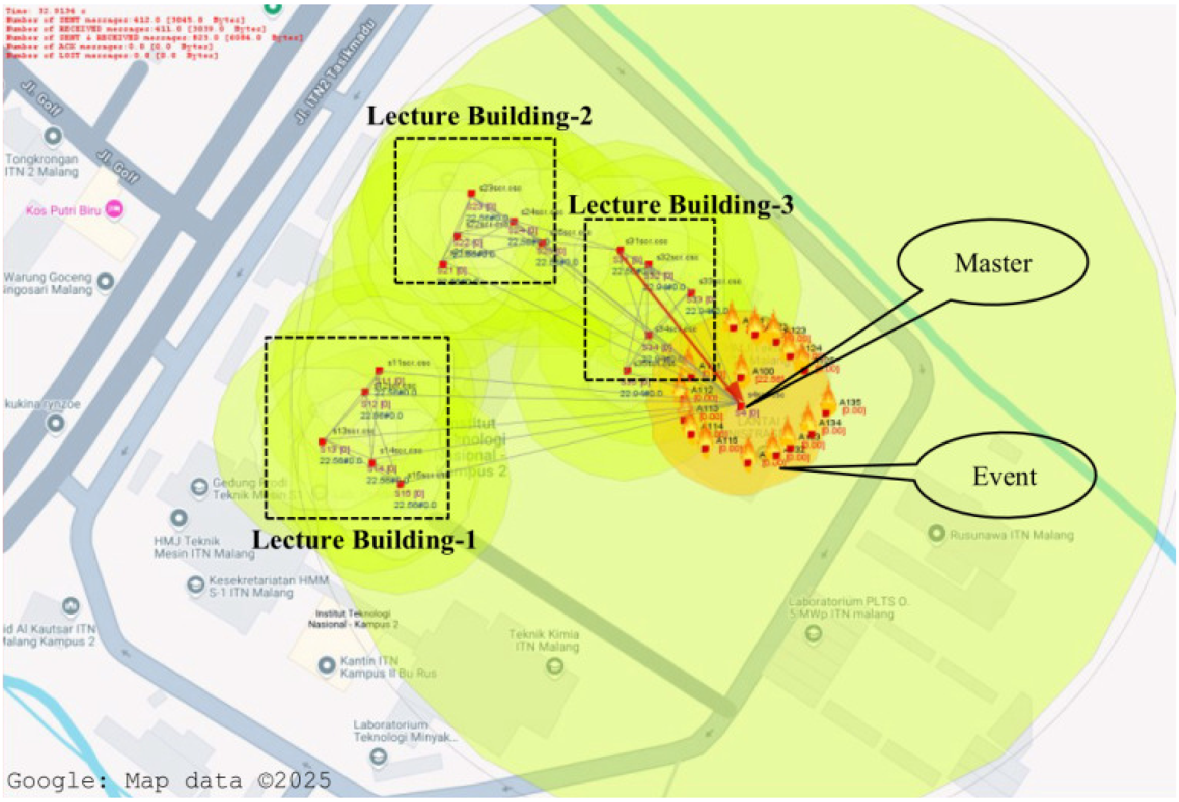

Fig. 9. Implementation of energy management in CupCarbon without mediators.

III. RESULTS AND DISCUSSION

The proposed approach evaluates the energy consumption of WSNs and the energy management system. The evaluation of WSN energy consumption aims to determine the most efficient WSN protocol (Zigbee, WiFi, LoRa) that achieves the lowest battery consumption. The evaluation of the EMS aims to measure the effectiveness of the occupancy-based method in reducing the energy consumption in the smart classroom. The simulation proceeds as follows: CupCarbon's time interval is set to 1 s, representing 10 min of real data. Simulating five days takes 12 min. All scenarios, as detailed in Table II, are covered in these twelve simulations.

TABLE II. SIMULATION SCENARIOS USED FOR EVALUATION

No	WSN protocol	WSN communication method	Energy management method
1	Zigbee	With mediator	Fixed time
2	Zigbee	With mediator	Occupancy-based
3	Zigbee	Without mediator	Fixed time
4	Zigbee	Without mediator	Occupancy-based
5	WiFi	With mediator	Fixed time
6	WiFi	With mediator	Occupancy-based
7	WiFi	Without mediator	Fixed time
8	WiFi	Without mediator	Occupancy-based
9	LoRa	With mediator	Fixed time
10	LoRa	With mediator	Occupancy-based
11	LoRa	Without mediator	Fixed time
12	LoRa	Without mediator	Occupancy-based

A. *Evaluation of WSN Energy Consumption*

Tables III and IV show the energy consumption of WSNs for fixed-time and occupancy-based control methods, respectively. Both Zigbee and LoRa have low energy consumption, with only slight differences between them. However, WiFi consumes more energy than Zigbee and LoRa. For all WSN protocols, the node's energy consumption is higher without the mediator than with it. This is because, without the mediator, the node must communicate directly with the master over a long distance, requiring more power than communicating with the mediator over a shorter distance. Comparing the mediator (S1, S2, S3) with the master (S4), it was found that each mediator's energy consumption is higher than that of the master. This is because each mediator communicates with five nodes, while the master only communicates with three mediators. Consequently, the mediators' on-time communication is longer than the master's, leading to higher energy consumption. This is also supported by the very high power consumption of the master (S4) without a mediator, due to the long on-time communication when the master interacts with fifteen nodes.

Table V compares the energy consumption of WSNs. The efficiency of adding a mediator indicates the reduction in the energy consumption. It is calculated for each protocol by dividing the energy reduction by the energy consumption without a mediator. It is evidenced that the highest energy efficiency, at 26.67%, is achieved by the LoRa protocol when a mediator is added. The WSN protocol's efficiency reflects how well each protocol conserves energy for each method (with and without mediator). It is also exhibited that with a mediator, LoRa reaches the highest energy efficiency of 64.84%, while without a mediator, Zigbee achieves the highest efficiency at 62.61%. The overall efficiency considers both the WSN protocol and architecture (with or without a mediator). It is indicated that LoRa with a mediator achieves the highest overall energy efficiency of 67.93%.

TABLE III. WSN ENERGY CONSUMPTION OF THE FIXED TIME METHOD

Node	WSN energy consumption (Joule)					
	Zigbee		WiFi		LoRa	
	With mediator	Without mediator	With mediator	Without mediator	With mediator	Without mediator
S1	95.352	NA	247.604	NA	85.232	NA
S11	12.303	22.818	41.267	54.619	14.205	23.511
S12	12.303	22.747	41.267	54.619	14.205	23.511
S13	12.303	22.856	41.267	54.619	14.205	23.511
S14	12.303	22.968	41.267	54.619	14.205	23.511
S15	12.303	22.970	41.267	54.619	14.205	23.511
S2	95.398	NA	247.266	NA	85.232	NA
S21	12.303	22.639	41.267	54.619	14.205	23.511
S22	12.303	22.639	41.267	54.619	14.205	23.511
S23	12.228	22.575	41.267	54.619	14.205	23.511
S24	12.364	22.972	41.267	54.619	14.205	23.511
S25	12.347	23.038	41.065	54.619	14.205	23.496
S3	95.352	NA	246.391	NA	85.232	NA
S31	12.303	22.639	41.065	54.619	14.205	23.488
S32	12.303	22.639	41.065	54.619	14.205	23.488
S33	12.303	22.639	41.065	54.482	14.205	23.488
S34	12.303	22.639	41.065	54.416	14.205	23.488
S35	12.303	22.639	41.065	54.416	14.205	23.488
S4	89.732	271.506	123.554	818.836	42.679	352.646
Total	560.404	612.921	1482.613	1637.574	511.455	705.179

TABLE IV. WSN ENERGY CONSUMPTION OF THE OCCUPANCY-BASED CONTROL METHOD

Node	WSN energy consumption (Joule)					
	Zigbee		WiFi		LoRa	
	With mediator	Without mediator	With mediator	Without mediator	With mediator	Without mediator
S1	96.222	NA	254.887	NA	91.241	NA
S11	12.713	23.217	42.481	55.630	15.217	24.635
S12	11.530	22.684	42.481	55.630	15.217	24.619
S13	12.430	22.465	42.481	55.630	15.217	24.612
S14	12.476	22.548	42.481	55.428	15.194	24.612
S15	12.773	23.454	42.481	55.428	15.194	24.612
S2	97.865	NA	254.887	NA	91.166	NA
S21	12.702	23.246	42.481	55.428	15.194	24.612
S22	12.697	23.325	42.481	55.428	15.194	24.612
S23	12.554	23.050	42.481	55.428	15.194	24.612
S24	12.511	23.086	42.481	55.428	15.194	24.612
S25	12.536	22.408	42.481	55.428	15.194	24.612
S3	96.135	NA	254.548	NA	91.166	NA
S31	11.713	22.584	42.481	55.428	15.194	24.612
S32	12.723	23.094	42.481	55.428	15.194	24.612
S33	12.445	22.688	42.481	55.428	15.194	24.612
S34	12.534	23.002	42.481	55.428	15.194	24.612
S35	12.419	22.231	42.279	55.428	15.194	24.612
S4	90.847	278.620	127.398	832.051	45.666	369.329
Total	567.827	621.703	1528.735	1664.075	547.220	738.540

TABLE V. COMPARISON OF WSN ENERGY CONSUMPTION

Method	WSN energy consumption (Joule) and efficiency (%)					
	Zigbee		WiFi		LoRa	
	With mediator	Without mediator	With mediator	Without mediator	With mediator	Without mediator
Fixed-time	560.404	612.921	1482.613	1637.574	511.455	705.179
Occupancy-based	567.827	621.703	1528.735	1664.075	547.220	738.540
Average	564.115	617.312	1505.674	1650.824	529.3375	721.859
Efficiency of adding mediator	8.62%	0.00%	8.79%	0.00%	26.67%	0.00%
Efficiency of WSN protocol	62.53%	62.61%	0.00%	0.00%	64.84%	56.27%
Overall efficiency	65.83%	62.61%	8.79%	0.00%	67.93%	56.27%

Based on the above results, several recommendations are made:

- The energy consumption of WiFi is much higher compared to Zigbee and LoRa.
- Zigbee and LoRa clearly outperform the other options in energy efficiency, making them the top choices.
- The WSN configuration with the mediator is the best option, as it uses less energy than the configuration without the mediator.
- The LoRa with a mediator is the optimal solution for achieving the lowest WSN energy consumption.

B. *Evaluation of the Energy Management System*

Figure 10 displays the classroom (S11) power consumption over 5 days (Monday to Friday), with the red and green lines representing the fixed-time and occupancy-based methods, respectively. It is shown that the power profiles of the fixed-time method vary according to the AC power consumption, which is influenced by outdoor temperature. The power consumption decreases in the afternoon, caused by the lower temperatures in the afternoon compared to the morning and noon. Analyzing the occupancy-based method profile reveals fluctuations in switching on and off on Tuesday, Wednesday, and Thursday, due to the absence of classes (and consequently, no occupants) on these days. Turning off the lighting and AC when there are no occupants helps reduce the energy consumption, as illustrated in Figure 11. Figure 11 displays the energy consumption of classroom (S11) over 5 days (Monday to Friday), with the red and green lines representing the fixed time and occupancy-based methods, respectively. It is demonstrated that the occupancy-based control can significantly reduce the energy consumption.

Figure 12 depicts the total classroom power consumption over 5 days (Monday to Friday), with the red and green lines indicating the fixed-time and occupancy-based approaches, respectively. Since all classrooms follow identical lighting and AC schedules in the fixed-time method, the power profile in Figure 12 closely resembles that in Figure 10. In contrast, the occupancy-based method's power profile in Figure 12 differs from Figure 10 because it reflects the total power consumption across all classrooms, where the occupancy times differ for each room. It is demonstrated that the occupancy-based method consistently consumes less total power than the fixed-time approach. As a result, the overall classroom energy use with the occupancy-based method is notably lower than with the fixed-time method, as portrayed in Figure 13.

Table VI presents a comparison of the energy use in smart classrooms using fixed-time versus occupancy-based controls over a 5-day period. Classroom S31 exhibits the most significant energy savings at 66.50%, whereas classroom S15 shows the least at 31.87%. Overall, all classrooms experience a 51.55% reduction in the energy consumption. These findings confirm that the energy management in smart classrooms is effective, with occupancy-based control resulting in a significant decrease in the energy use.

TABLE VI. COMPARISON OF ENERGY CONSUMPTION OF SMART CLASSROOMS BETWEEN FIXED TIME AND OCCUPANCY-BASED METHODS

Room	**Energy consumption (W-h)**		**Energy consumption reduction**
	Fixed time	Occupancy-based	
S11	57925.855	36881.694	36.33%
S12	57925.855	22601.282	60.98%
S13	57925.855	20213.763	65.10%
S14	57925.855	20731.852	64.21%
S15	57925.855	39463.458	31.87%
S21	57925.855	31963.836	44.82%
S22	57925.855	36546.049	36.91%
S23	57925.855	27470.373	52.58%
S24	57925.855	26638.006	54.01%
S25	57925.855	21934.036	62.13%
S31	57925.855	19406.563	66.50%
S32	57925.855	30346.556	47.61%
S33	57925.855	23192.800	59.96%
S34	57925.855	33921.624	41.44%
S35	57925.855	29624.608	48.86%
Total	868887.828	420936.498	51.55%

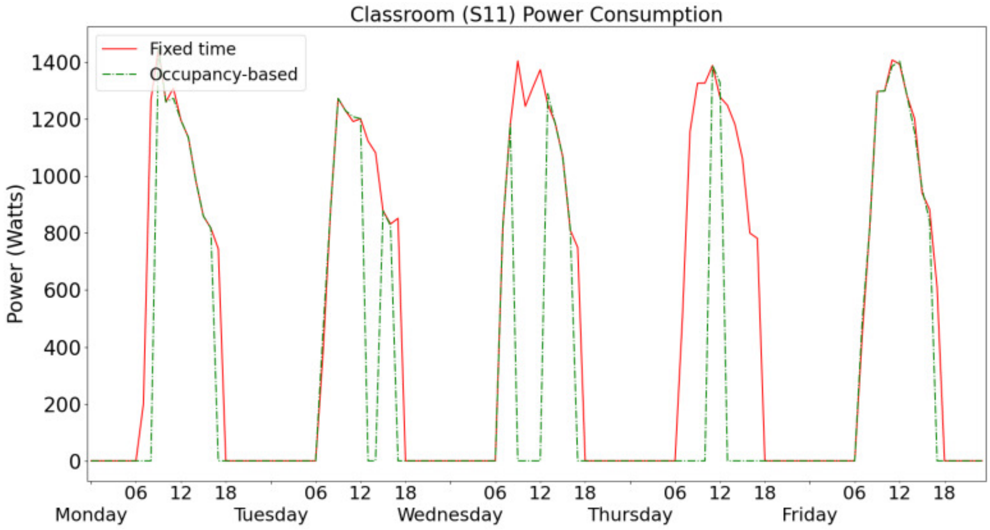

Fig. 10. Classroom (S11) power consumption.

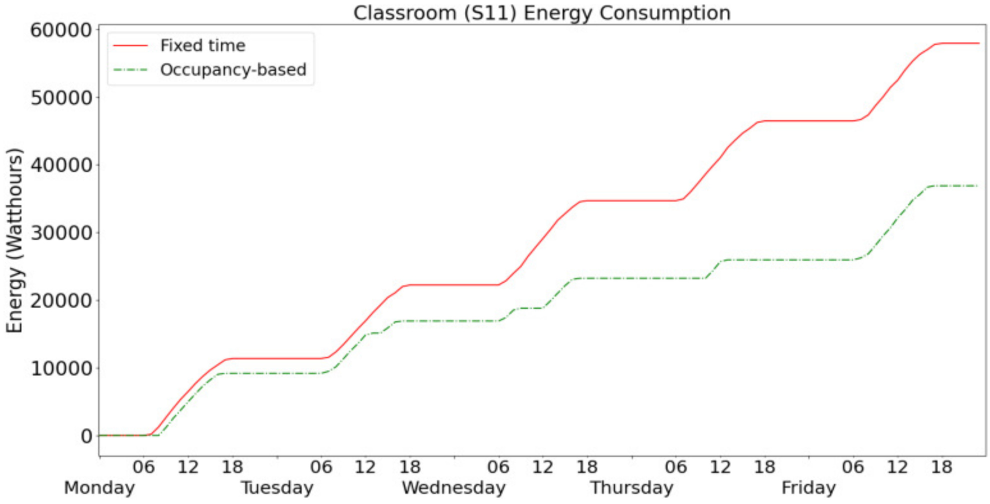

Fig. 11. Classroom (S11) energy consumption.

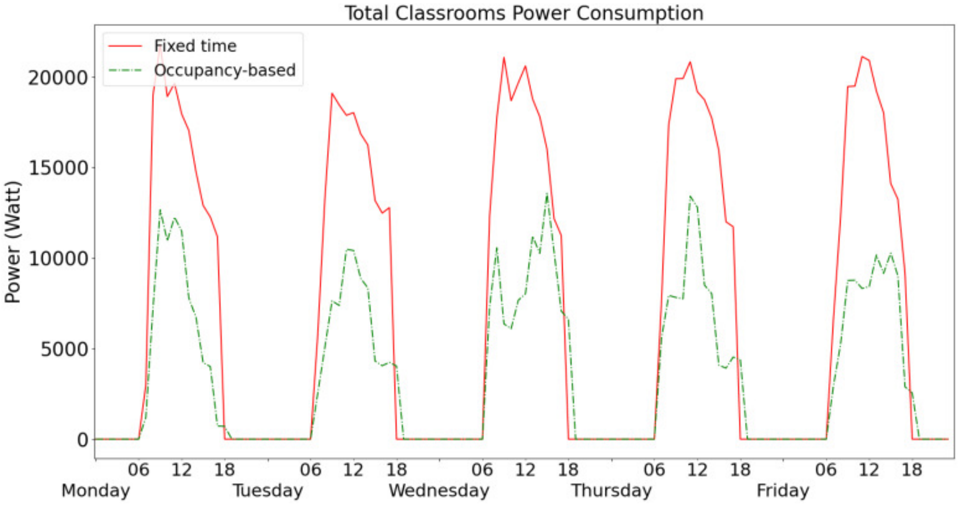

Fig. 12. Total classrooms power consumption.

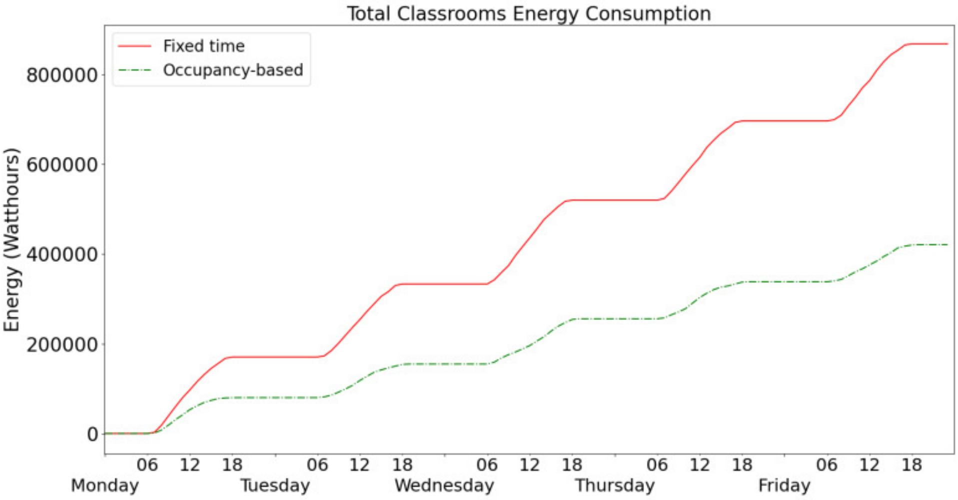

Fig. 13. Total classrooms energy consumption.

C. Practical Consideration

This section discusses the practical considerations for implementing the energy management system, focusing on three main issues: simulation modeling, sensor node limitations, and data communication constraints. For simulation modeling, two models are considered: the AC power model and the communication distance model of the WSN. The AC power model, shown by (1), is a simple linear model. In reality, the AC power is more complex, so the energy efficiency during actual implementation may differ from that in the simulation. However, the model incorporates both room and outdoor temperatures, offering a reasonable representation of the AC power, particularly in managing the ambient temperature variations. Regarding the WSN energy model in the simulator, it does not account for environmental factors, such as buildings and trees, which should be considered during real-world deployment. The actual implementation of the proposed approach requires installing sensors, actuators, and a communication module in each room, which increases the deployment costs. To reduce the costs, an optimization strategy could be used, such as grouping sensors and actuators on shared electrical power, combining sensor-based and scheduled-based room occupancy detection, choosing long-range communication modules (like LoRa or Zigbee) to minimize the number of nodes and mediators, using low-cost temperature and occupancy sensors, and integrating the system with the campus IT infrastructure. The data communication constraints to consider during implementation include the data reliability, latency, network congestion, sensor drift, and privacy issues.

One key advantage of the CupCarbon simulator is its ability to model the energy consumption of the communication nodes using WiFi, Zigbee, and LoRa. However, it does not model the data reliability, data loss, latency, or network congestion. Although these parameters are important in real-time applications, since the data transmission interval in the EMS is in min or h and involves a small number of data packets, the system's performance is not significantly impacted. The sensor drift, particularly when using low-cost sensors, can be mitigated with intelligent detection algorithms, such as those that employ machine learning techniques for prediction. Privacy concerns in the EMS may arise from sensor data collection that reveals the occupants' habits or room conditions, raising security issues. To address these concerns, measures, such as encrypting data during transmission and implementing access control for the master control can be applied.

D. Comparison to Existing Works

A comparison with the existing works is presented in Table VII, which compares the simulation platform, hardware implementation, EMS algorithm, and communication platform.

TABLE VII. IMULATION SCENARIOS USED FOR EVALUATION

Ref	Simulation platform	Hardware implementation	EMS algorithm	Communication platform
[9]	Simulink	Hardware testbed (LAMDA Microgrid)	Battery control; Power exchange minimization	Wired
[11]	Machine learning software	-	Energy consumption prediction	-
[12]	-	Embedded platform	Energy monitoring	WiFi
[13]	-	Embedded platform	Energy and environment monitoring	WiFi, LoRa
[15]	-	Embedded platform	Occupancy-based lamp control	-
[16]	-	Embedded platform	HVAC control	WiFi
[18]	-	Doppler sensor system	Motion detection-based lamp and AC control	Wired
[20]	Occupant model	Hardware testbed (Embedded platform)	Occupancy-based lamp, AC, plug control	WiFi
[25]	-	Embedded platform	Energy and environment monitoring	WiFi, LoRa, Zigbee
[32]	-	Hardware testbed (Embedded platform)	Energy optimization	WiFi
Proposed	CupCarbon	-	Occupancy-based lamp, AC control	WiFi, LoRa, Zigbee

According to Table VII, the proposed approach shows superiority in the following areas:

- Compared to existing simulation-based approaches [9, 11, 20], the proposed method models the actual geographical campus map for a realistic assessment of WSN networks' energy consumption using the CupCarbon simulator.
- Unlike previous works that focus on predicting and monitoring the energy consumption [11-13, 25] or on a basic control of the lamps and AC [15, 16, 18], the proposed method introduces a lightweight occupancy-based control algorithm that manages both the lighting and AC. This is similar to our earlier works [20, 32], but it is applied to a larger, real-world simulated area of the campus building.
- The current study provides a comprehensive comparison of the energy efficiency of three common WSN protocols (WiFi, Zigbee, and LoRa) across two network topologies, with and without mediators, addressing a gap not explored in previous research [25].
- The main limitations of the proposed approach are the absence of hardware implementation for the energy management system. However, the approach offers an EMS framework within the campus building for future actual implementation work.

IV. CONCLUSION

An Energy Management System (EMS) has been proposed to reduce the energy consumption in smart classrooms. It utilizes Wireless Sensor Network (WSN) technology to establish a communication system for exchanging data between the master, mediator, and nodes. The proposed system is implemented and evaluated using the CupCarbon simulator, a WSN simulator that simulates and visualizes the WiFi, Zigbee, and LoRa protocols. The WSN architecture using a mediator reduces the energy consumption in WSNs compared to one without a mediator. The LoRa protocol achieves the lowest energy consumption among the others. The proposed energy management system, utilizing an occupancy-based control method, significantly reduces the energy consumption of the lighting and the Air Conditioner (AC) in the classroom. In the future, the proposed approach will be expanded to include larger and more complex energy management systems in campus buildings. It will concentrate on developing advanced EMS algorithms to improve the system performance. Additionally, the reliability of the actual implementation will be examined.

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