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Occupancy-based Energy Management System in Campus Building: A Case Study in Electrical Engineering Department Building, ITN Malang

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ABSTRACT

Building energy management systems provide an effective method for energy saving. An occupancy-based energy management system considers the occupants' behavior that affects energy consumption. This paper presents the investigation of different scenarios based on the occupancy to control the energy consumption in the Electrical Engineering Department Building, ITN Malang. The results show that switching off the appliances when the occupants go home in the afternoon reduces the monthly energy consumption by 33.95%. The result indicates that the occupants' awareness regarding energy saving has recently been low. Thus, the occupancy sensor and automatic time scheduling for the appliance control are suggested to be installed.

1. INTRODUCTION

The building is a well-known infrastructure that consumes high electricity. Therefore, it needs to reduce its consumption for energy efficiency (Mir *et al.*, 2021). It is a part of the building energy management system (BEMS). (Numbi *et al.*, 2017; Gupta *et al.*, 2018; Soetedjo, Nakhoda and Saleh, 2019; Mahmud *et al.*, 2023). The identification and energy reduction in the campus building during working days, weekends, and holidays were conducted (Numbi *et al.*, 2017). The energy consumption at a university campus could be reduced by 10-20% by controlling the heating, ventilation, and air conditioning (HVAC) systems (Gupta *et al.*, 2018).

The optimization of the electricity cost and user comfort was achieved in the campus classrooms by developing the fuzzy logic controller for tuning the temperature set-point (Soetedjo, Nakhoda and Saleh, 2019). The particle swarm optimization technique was adopted for optimum energy management in the campus building with the demand response and solar power (Mahmud *et al.*, 2023).

The occupant is one factor that affects the energy consumption in the building (Delzendeh *et al.*, 2017). The literature survey showed that the word “occupant behavior” occurred along with “energy consumption” (Delzendeh *et al.*, 2017). Maintaining energy efficiency in the building without reducing user comfort was a challenge (Paone and Bacher, 2018). The awareness of the campus building regarding energy efficiency was investigated (Prafitasiwi, Rohman and Ongkowijoyo, 2022). The result showed that the lecturer achieved the best performance; the second was the staff, and the third was the student. The occupancy-based control of HVAC achieved an energy saving of 20%(Dong *et al.*, 2018).

Previous studies show the importance of the occupancy in the BEMS. Therefore, the occupancy models were developed to help researchers study its impact in the energy efficient in the building. The occupancy model can divided into four categories (Feng, Yan and Hong, 2015): a) The number of occupants in a building at a particular time; b) The occupancy status of a space at a particular time; c) The number of occupants in a space at a particular time; d) The detailed level that tracking the occupant.

Three different techniques of the occupancy prediction, namely the expectation maximization algorithm, a novel finite state automata (FSA), and a stochastic model, were introduced (Dong *et al.*, 2018). All the tree prediction techniques achieved the prediction accuracy more than 70%. The electricity consumption prediction based on the occupancy was developed (Ding *et al.*, 2019). In the prediction, the basic and variable influencing factors were considered, where the basic factor represents the building area, while the variable factor represents the building occupancy.

The occupancy model based on the Gaussian distribution was proposed for three different campus buildings: lecture, office, and dormitory (Tang *et al.*, 2021). Based on the model, the occupancy profiles in the lecture and dormitory buildings show three peaks, while the occupancy profile in the lecture building showed two peaks. The occupancy model in a campus building was implemented on the embedded platform and Internet of Things (IoT) technology (Soetedjo and Sotyohadi, 2021). Using this approach, the occupancy-based energy consumption can be simulated in real-time.

This paper presents the occupancy-based energy management system in the Electrical Engineering Department building, ITN Malang, Indonesia. The research aim is to investigate energy savings in the campus building by introducing different scenarios of occupancy-based electricity control. The occupancy is simulated according to the working time and lecture timetable. The electrical consumptions under consideration are the lighting, air conditioner, and computer located in the laboratory rooms, head laboratory rooms, administration rooms, corridor, restroom, and pantry.

The rest of paper is organized as follows. Section 2 presents the method. Section 3 presents the results and discussion. Conclusion is covered in Section 4.

2. METHOD

2.1. Case study building information

The case study building is located at the 2nd floor of the Electrical Engineering Department Building, ITN Malang, as illustrated in Figure 1. It consists of the laboratory room, head of laboratory room, the study program staff room, classroom, pantry, store room, and restroom. The electrical appliances in each room are the lighting, AC, and computer. The lighting in the room is controlled per room, except for the laboratory room and laboratory head room, which are controlled separately.

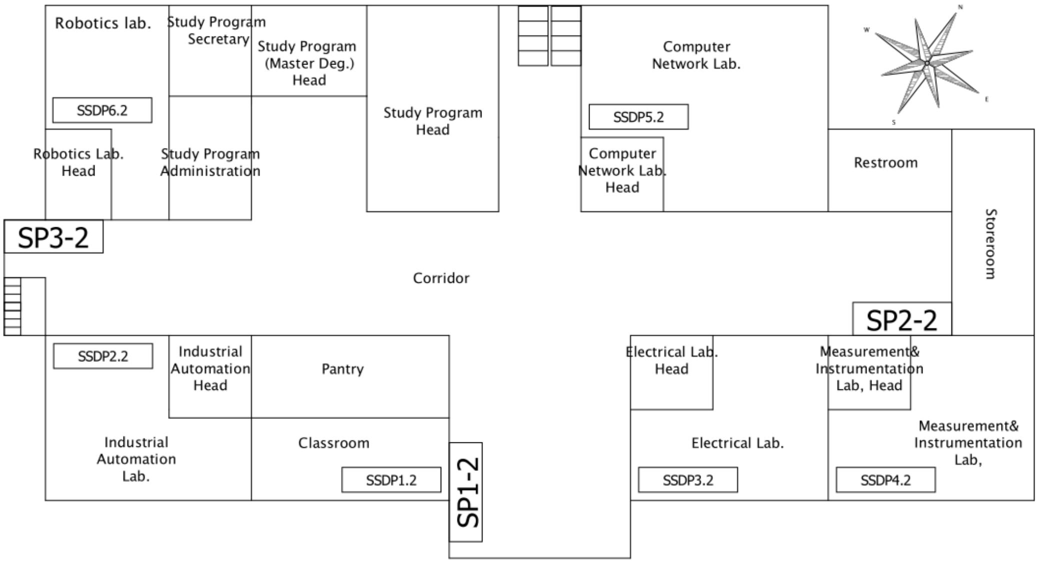

Figure 1. Room layout at Electrical Engineering Department building 2nd floor.

A Building Automation System (BAS) has been installed at this building that can be used to control the lighting and monitor the energy consumption (Budi Sulistiawati *et al.*, 2023; Sulistiawati *et al.*, 2023). Recently, the BAS only covers half of the rooms shown in Figure 1. The BAS provides the Human Machine Interface (HMI) dashboard as shown in Figure 2. In addition to control and monitoring, the BAS stores the electrical data in the memory for further data analysis.

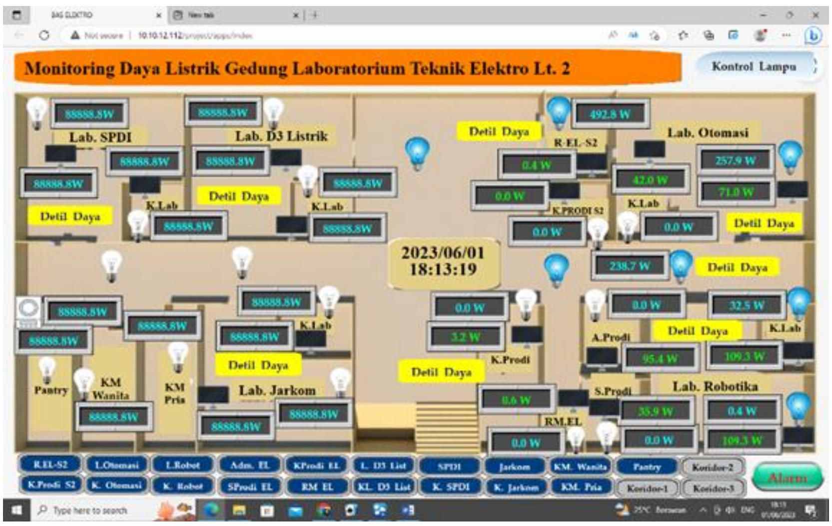

Figure 2. HMI dashboard of Building Automation System.

In this research, the data collected from the BAS is considered the existing energy consumption as shown in Table 1. The data is collected during a week, and the total energy consumption is calculated and given in the table. Meanwhile, the energy consumptions per day and month are calculated based on the weekly energy. It is noted here that since the BAS only covers a half portion of the rooms, namely the Program Study rooms, Robotics Laboratory rooms, Industrial Automation rooms, classroom, and pantry, the data for the other rooms are generated based on the manual observation and by referencing to the BAS data.

Table 1. Energy consumption of existing system.

Room	Energy consumption per day (kWh)	Energy consumption per week (kWh)	Energy consumption per month (kWh)
Industrial Automation Laboratory	5.29	37.10	148.38
Robotics Laboratory	12.49	87.42	349.68
Measurement and Instrumentation Laboratory	16.82	117.76	471.02
Electrical Laboratory	13.18	92.27	369.08
Computer Networks Laboratory	8.45	59.13	236.53
Classroom	4.59	32.16	128.63
Group of Study Program Rooms	10.75	75.28	301.12
Corridor	5.13	35.92	143.68
Restroom and Store room	1.96	13.75	55.00
Total	78.67	550.78	2203.12

2.2. Occupancy-based electricity control scenario

The energy consumption data in Table 1 is the existing system without the energy management. From the observations, the lighting and AC are sometimes switched on when there are no occupants in the room, or at night. In this work, several occupancy-based electricity control scenario are proposed and evaluated. There are four scenarios as follows:

1) Scenario-1
   In the first scenario, the appliances are switched on during working time, i.e., from 07:00 h to 16:00 h, depending on the occupants' activities in the room. The appliances are switched off from 16:00 h to 07:00 h.
2) Scenario-2
   In the second scenario, the appliances in the lecturer room (laboratory head room) are switched off when the occupant leaves the room. This scenario uses the lecturer's lecture timetable. It is assumed that the laboratory head room is empty when the lecturer goes to the class to teach.
3) Scenario-3
   In the third scenario, energy savings are achieved by switching off the lighting in the unused or rarely occupied rooms, or during off-hours.
4) Scenario-4
   In the fourth scenario, the working hours of the lecturer and students in the laboratory are different. For example, the laboratory head room will be unoccupied after 15:00 h, while the laboratory room will be unoccupied after 19:00 h.

3. RESULTS AND DISCUSSION

The energy consumption of Scenario-1 is given in Table 2. Comparing the table with the Table 1, it is clearly shown that switching off the appliances during off-hours reduces the total energy consumption. Table 2 shows that the energy consumptions in the most rooms are reduced. The Scenario-1 does not affect the group of Study Program rooms because the occupants work in regular working time and switch off the appliance properly when leaving the rooms. Since the corridor's lighting is switched on at the night, the energy consumption is not affected by the Scenario-1.

Table 3 shows the energy consumption of Scenario-2. Since this scenario deals with the laboratory head room's occupancy, the respective rooms' energy consumptions are affected or reduced. For instance, the daily energy consumption of the industrial automation laboratory reduces from 5.29 kWh to 5.16 kWh. The energy reduction is not significant since only the laboratory head room is affected, not a whole laboratory room.

Table 4 gives the energy consumption of Scenario-3. It shows the significant energy reduction achieved by the Measurement and Instrumentation Laboratory and Electrical Laboratory. This suggests that there are a few activities in these laboratories, or the lighting in these rooms is usually switched on when there are no occupants.

The energy consumption of Scenario-4 is given in Table 5. Comparing the table with Table 2 (Scenario-1), it is clearly shown that the Scenario-4 achieves a lower energy reduction than Scenario-1). It is caused by the different working time used in both scenarios, where in Scenario-4, the students at the laboratory room leaves lately (19:00 h) than Scenario-1 (16:00 h).

Table 2. Energy consumption of Scenario-1.

Room	Energy consumption per day (kWh)	Energy consumption per week (kWh)	Energy consumption per month (kWh)
Industrial Automation Laboratory	3.68	25.77	103.08
Robotics Laboratory	4.47	31.3	125.2
Measurement and Instrumentation Laboratory	14.49	101.4	405.6
Electrical Laboratory	5.75	40.28	161.12
Computer Networks Laboratory	3.49	24.44	97.76
Classroom	2.08	14.54	58.16
Group of Study Program Rooms	10.74	75.15	300.6
Corridor	5.13	35.92	143.68
Restroom and Store room	2.14	15	60
Total	51.97	363.8	1455.2

Table 3. Energy consumption of Scenario-2.

Room	Energy consumption per day (kWh)	Energy consumption per week (kWh)	Energy consumption per month (kWh)
Industrial Automation Laboratory	5.16	36.09	144.36
Robotics Laboratory	12.49	87.42	349.68
Measurement and Instrumentation Laboratory	17.11	119.79	479.16
Electrical Laboratory	3.06	21.39	85.56
Computer Networks Laboratory	8.45	59.13	236.52
Classroom	0.05	0.32	1.28
Group of Study Program Rooms	10.73	75.15	300.6
Corridor	5.13	35.92	143.68
Restroom and Store room	1.96	13.75	55
Total	64.13	448.96	1795.84

Table 4. Energy consumption of Scenario-3.

Room	Energy consumption per day (kWh)	Energy consumption per week (kWh)	Energy consumption per month (kWh)
Industrial Automation Laboratory	4.27	29.9	119.61
Robotics Laboratory	10.72	75.07	300.28
Measurement and Instrumentation Laboratory	16.82	117.76	471.02
Electrical Laboratory	8.38	58.69	234.75
Computer Networks Laboratory	4.95	34.67	138.66
Classroom	2.46	17.19	68.75
Group of Study Program Rooms	10.73	75.28	301.12
Corridor	5.13	35.92	143.68
Restroom and Store room	1.68	23.55	94.2
Total	65.15	468.02	1872.06

Table 5. Energy consumption of Scenario-4.

Room	Energy consumption per day (kWh)	Energy consumption per week (kWh)	Energy consumption per month (kWh)
Industrial Automation Laboratory	4.1	28.69	114.78
Robotics Laboratory	11.52	80.64	322.56
Measurement and Instrumentation Laboratory	17.735	124.15	496.6
Electrical Laboratory	8.384	58.69	234.76
Computer Networks Laboratory	4.978	34.85	139.4
Classroom	1.88	13.13	52.53
Group of Study Program Rooms	10.75	75.28	301.12
Corridor	4.65	32.53	130.12
Restroom and Store room	1.95	27.3	109.2
Total	65.94	475.27	1901.06

Table 6 gives the comparison of energy saving for four scenarios. The Scenario-1 achieves the highest monthly energy saving of 33.95%. It suggests that a scenario to switch off the appliance during off-hours work effectively. It also means that the existing system suffers from the occupant's awareness to switch off the appliance when leaving the rooms. Therefore the energy management system based on the occupancy sensor or time scheduling will give the solution for saving energy in the campus building.

Table 6. Comparison of energy saving for four scenarios.

Scenario	Energy consumption per day (kWh)	Energy saving per day	Energy consumption per week (kWh)	Energy saving per week	Energy consumption per month (kWh)	Energy saving per month
Existing	78.67	-	550.78	-	2203.12	-
Scenario-1	51.97	33.94%	363.80	33.95%	1455.20	33.95%
Scenario-2	64.13	18.48%	448.96	18,49%	1795.84	18,49%
Scenario-3	65.15	17.19%	468.02	15.03%	1872.06	15.03%
Scenario-4	65.94	16.18%	475.27	13.71%	1901.06	13.71%

4. CONCLUSION

The energy consumption in a campus building was investigated by collecting the energy consumption data using a Building Automation System (BAS) installed in the Electrical Engineering Department building, ITN Malang. Based on the BAS data and from the observation, the energy management system to reduce the energy consumption in the building is proposed by introducing four scenarios to control the appliances. The scenario to switch off the appliances after working time achieves the highest energy saving than the scenario for considering the lecture and laboratory timetable. This result gives a useful information about the occupant behaviour in the recent time. It yields a suggestion to improve the operation of appliances based on occupancy sensor and time scheduling.

In the future, the work will be extended to cover all floors in the building. Further, sophisticated energy management algorithms will be investigated to improve energy savings.

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