Reduction Of Air Conditioner Energy Consumption Through The Implementation Of A Non-Invasive Sensor Based Automatic Control System

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Abstract.

High energy consumption from air conditioning (AC) systems is a significant challenge to building energy efficiency, particularly in Indonesia's building sector where AC units can account for up to 70% of the total electrical load. This problem is often exacerbated by user negligence, such as leaving units on in unoccupied rooms. This research aims to design, build, and test a universal, non-invasive automatic control device to reduce such energy waste by automating its operation based on occupancy and temperature. The system integrates a Passive Infrared (PIR) sensor for occupancy detection and a DHT22 sensor for temperature monitoring, controlled by an Arduino Nano. Its primary innovation is a servo motor that mechanically presses the AC remote's button, ensuring universal compatibility. The control logic activates the AC only when presence is detected and the temperature exceeds 25°C, and deactivates it after a period of vacancy. The device's effectiveness was evaluated through comparative 8-hour tests on two different AC units. The results demonstrated highly significant energy savings. The use of the device reduced energy consumption by 2.716 kWh (44.85%) for AC 1 and 3.280 kWh (41.80%) for AC 2. With an average energy efficiency improvement exceeding 43%, the non-invasive automatic control device is proven to be a highly effective solution. Its universal, non-invasive design makes it a practical and widely applicable tool for energy conservation in various environments.

Keywords: *Energy Saving; Automatic Control; Air Conditioner; Non-Invasive and PIR Sensor.*

I. INTRODUCTION

Global energy consumption is rising exponentially with population growth and industrial development, raising serious concerns about resource sustainability and environmental impact [1]. In Indonesia, the building sector—particularly offices and residential homes—is a major contributor to national electricity consumption. The largest energy-consuming component is the Heating, Ventilation, and Air Conditioning (HVAC) system, often accounting for 40% to 70% of a building's total electrical load [2], [3]. Energy inefficiency in air conditioning (AC) systems stems not only from hardware but is also significantly influenced by user behavior. Studies indicate that occupant behavior can impact energy consumption by up to 30%, and savings of 10% to 40% can be achieved through behavioral interventions [4], [5]. A common issue is the continued operation of AC units in unoccupied rooms or after a comfortable temperature has been reached, often due to user negligence in turning them off [2].To address this challenge, innovative approaches in building energy management are required. The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) offers intelligent solutions for real-time monitoring and optimization of energy use. IoT-based systems can collect data from various sensors to automate device adjustments, thereby achieving optimal energy efficiency [6]. Numerous studies have explored the development of automatic AC control systems for energy conservation.

Some studies focus on IoT implementation across diverse environments [7], while others utilize sensor combinations such as Passive Infrared (PIR) for occupancy detection and DHT22 for temperature and humidity monitoring, integrated with microcontrollers [8], [9]. More advanced approaches have also been proposed, including the use of neural networks [10], cloud-based AI platforms [11], fuzzy logic [12], and GPS-based predictive control systems [13].However, most existing solutions require direct intervention with the AC unit itself, such as hardware modification or the programming of brand-specific infrared (IR) codes. This dependency limits the flexibility and scalability of implementation. To fill this gap, this research proposes a universal and non-invasive automatic AC control system. The primary innovation lies in a mechanical actuator capable of physically simulating the press of the power (ON/OFF) button on any brand of AC remote, thus eliminating the need for modifications to the unit or the remote itself.The proposed system integrates a PIR sensor for occupant detection and a DHT22 sensor for environmental monitoring, all managed by an Arduino Nano microcontroller. Therefore, this study aims to deliver a solution that is flexible, user-friendly, and broadly applicable to reduce energy waste caused by user behavior, thereby making a significant contribution to national energy conservation efforts.

II. METHODS

The initial step in this research was to design the hardware schematic and the software workflow. The hardware design phase included creating the electronic schematic and the physical casing design. The hardware consists of several commercially available components, including an Arduino Nano, a PIR (Passive Infrared) sensor, a DHT22 temperature and humidity sensor, and a servo motor, which functions as an actuator to press the power (ON/OFF) button on the AC remote. A more detailed electronic circuit diagram is presented in Figure 1.

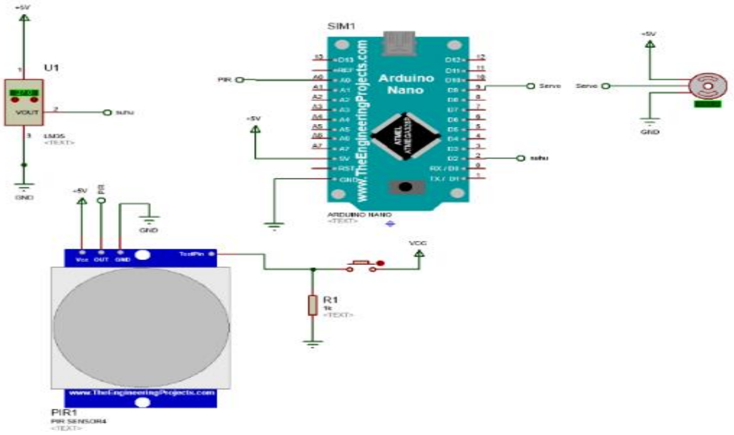

Fig 1. Schematic Diagram of the Automatic AC Remote Controller

Meanwhile, the device casing is designed to be highly adjustable and capable of being aimed in any direction. This allows the device to be placed in various positions within a room equipped with an air conditioner. The visual design of the casing is presented in Figure 2.

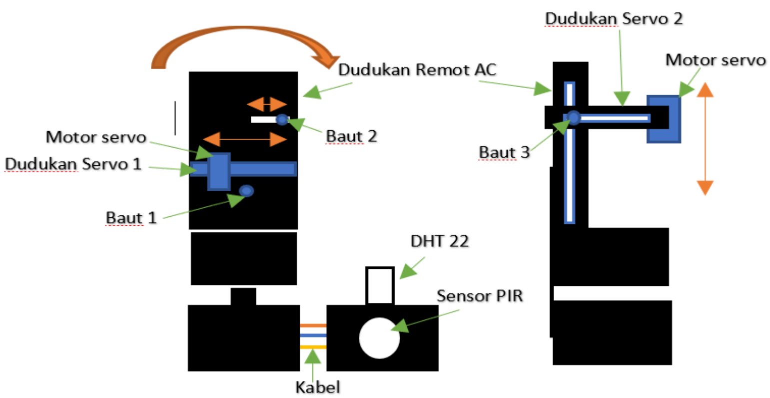

Fig 2. Casing Design

In this design, the mount for the PIR and DHT22 sensors is separate from the AC remote holder. This separation allows the sensor module to be aimed independently for optimal human motion detection. The servo motor mount is also specifically designed to facilitate its placement, ensuring precise access to the ON/OFF button on the remote. Furthermore, "Bolt 1" is included to rotate the remote holder, allowing it to be aimed accurately at the AC unit.The software for this automatic remote controller was designed according to its established operational principles. The detailed logic of the system is illustrated in the system flowchart shown in Figure 3.

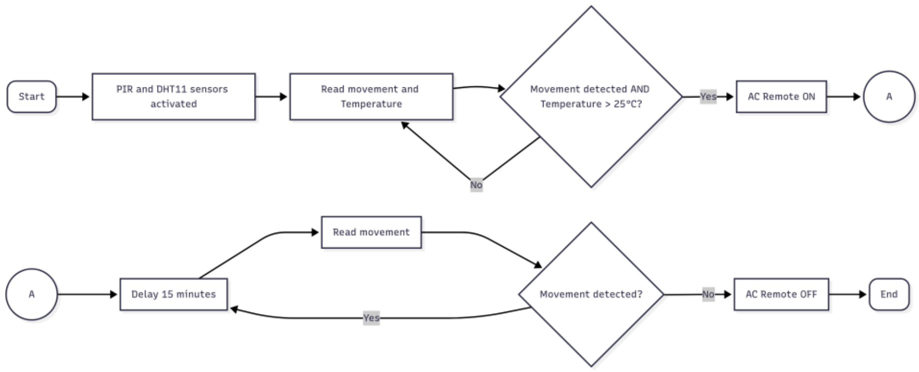

Fig 3. Automatic Remote Control Device Work Flow Diagram

This study involved several testing stages, including: a reliability test of the control hardware, a functionality test of the software, and an electrical energy consumption test on both the control device and the air conditioning (AC) units.The hardware reliability test aimed to evaluate the design's effectiveness in controlling the AC. In this test, the control device was placed at various coordinate points within the room, with a 1-meter distance between each point, to assess its performance from multiple positions. Furthermore, to verify the software's performance, testing was conducted by referencing the automatic control system's workflow diagram.

The energy consumption test was carried out through five different scenarios: (1) the power consumption of the automatic control device, (2) the power consumption of AC 1 without automatic control, (3) the power consumption of AC 2 without automatic control, (4) the power consumption of AC 1 with automatic control, and (5) the power consumption of AC 2 with automatic control.During the testing period, the air conditioner temperature was set to 18°C. A digital wattmeter was used to measure the electrical power consumption (kWh) of both AC units. The control device was programmed to operate at 15-minute intervals; consequently, power consumption data from the air conditioners were also recorded every 15 minutes.

III. RESULT AND DISCUSSION

The final developed device is presented in Figure 4. The mechanical and casing design was engineered to ensure effective operation from various points within a room, as illustrated in Figure 5. It is important to note that during mechanical testing, the servo motor was not aimed at the power (on/off) button but at the temperature control button. This setup was intended to ensure the AC unit remained active throughout the test.

Fig 4. Automatic AC Remote Control Device

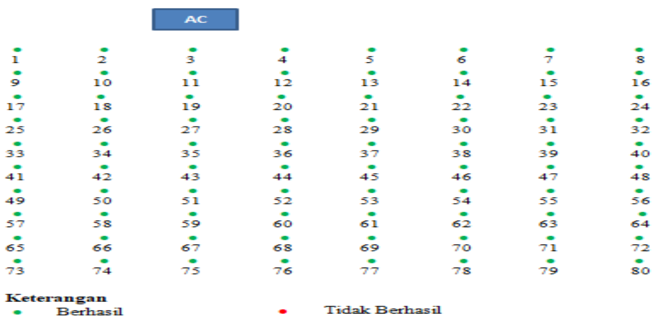

Fig 5. Placement points for automatic remote control devices

The results of the software functionality test are summarized in Table 1. This test covered eight main operational scenarios to verify the system's logic. The results demonstrate that the software successfully executed all tested scenarios, thereby achieving a 100% success rate.

Table 1. Software Functionality Test Results

No.	System Test Scenario	Result
1	Reading sensor inputs (Movement & Temperature)	Success
2	Condition: Movement & Temp > 25°C → AC Status: ON	Success
3	15-minute timer function (post-condition 2)	Success
4	Condition: Movement (temp irrelevant) & AC Status: ON	Success
5	15-minute timer function (post-condition 4)	Success
6	Condition: No movement → AC Status: OFF	Success
7	15-minute timer function (post-condition 6)	Success
8	Condition: Movement & Temp ≤ 25°C & AC Status: OFF	Success

The power consumption measurement results for the automatic control device, summarized in Table 2, show a gradual increase in energy usage over time. Power consumption was recorded starting at 0 kWh at the 0-minute mark and reached 0.0036 kWh by the 93rd minute, with a relatively consistent increase of approximately ±0.0006 kWh every 15 minutes, showing no significant power surges that would indicate a major load change.

Table 2. Power Consumption Measurement Results of the Automatic Control Device

Time (minutes)	Human Presence	Room Temperature (°C)	Power Consumption (kWh)
0	Present	33	0.0000
18	Present	31	0.0007
33	Absent	31	0.0013
48	Absent	32	0.0019
63	Present	33	0.0025
78	Present	31	0.0031
93	Absent	31	0.0036

Further analysis indicates that external factors such as human presence and room temperature fluctuations did not significantly influence the power consumption of the control device itself. Regarding human presence, the device's power consumption increased steadily regardless of whether the room was occupied. For instance, from the 33rd to the 48th minute, despite no human activity, consumption rose from 0.0013 kWh to 0.0019 kWh. Similarly, in terms of temperature, the data recorded fluctuations within the 31°C to 33°C range, yet no strong correlation was found between these changes and the device's power consumption. This proves that the baseline power consumption pattern of the control device is independent of these two variables.Subsequently, the power consumption test for the AC units was conducted for each simulation scenario. Each simulation was monitored for 8 hours (480 minutes), with data recorded at 15-minute intervals. The two primary parameters observed were room temperature (°C) and cumulative energy consumption (kWh). Figure 6 presents a graph illustrating the relationship between electrical energy consumption and room temperature over time for the 'AC 1 without automatic control' scenario. To facilitate easier interpretation, the data displayed in the graph begins from the 15-minute mark.

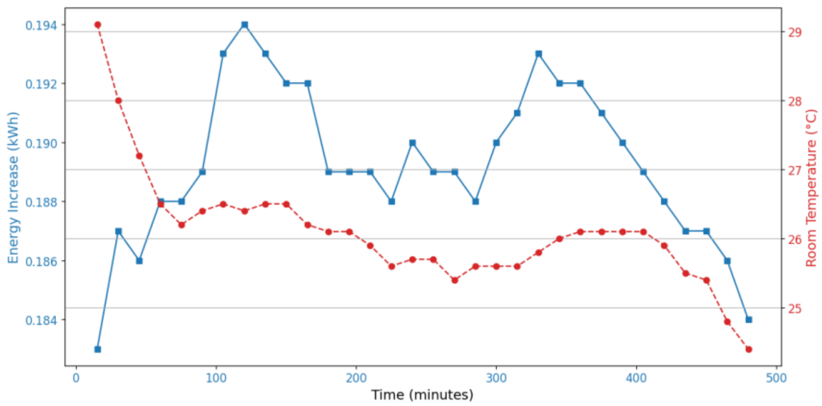

Fig 6. Graph of Energy Consumption and Room Temperature vs. Time for AC 1 Without Automatic Control

Based on Figure 6, the observation of room temperature began at the 15-minute mark, recorded at 29.1°C. The temperature subsequently exhibited a gradual downward trend. The most significant decrease occurred within the first two hours, with the temperature reaching 26.5°C by the 105th minute. Following this period, the temperature stabilized, fluctuating within the range of 25.4°C to 26.5°C. Towards the end of the observation period, the temperature again slowly decreased, reaching its lowest point of 24.4°C at the 480-minute mark. Overall, the data reveals a consistent pattern of temperature decline throughout the observation period.Conversely, the energy consumption data per 15 minutes shows a relatively stable pattern following the initial surge. The first data point displayed on the graph (at the 15-minute mark) registered a consumption of 0.183 kWh. Thereafter, energy consumption experienced only minor fluctuations within the narrow range of 0.183 kWh to 0.194 kWh. The highest consumption value (0.194 kWh) was recorded at the 120-minute mark.

These minimal fluctuations indicate the absence of extreme changes in the AC's workload during normal operation without automatic control.A combined analysis of these two parameters indicates that in this scenario, there is no direct correlation between the decrease in room temperature and the AC's energy consumption rate. The stable energy consumption pattern suggests that the AC compressor operated at a constant load, largely unaffected by the ambient temperature fluctuations that occurred during the test. A subsequent analysis was performed on AC 2 under the 'without automatic control' scenario, with the results presented in Figure 7. Unlike AC 1, the energy consumption pattern of AC 2 exhibited an earlier peak, reaching 0.259 kWh at the 30-minute mark. After peaking, the energy consumption tended to decrease and then stabilize, fluctuating within the range of 0.242 kWh to 0.249 kWh for the majority of the observation period. Despite minor fluctuations, such as a low point of 0.231 kWh at the 345-minute mark—which is likely an outlier—the overall trend indicates a relatively stable workload after the first 30 minutes.

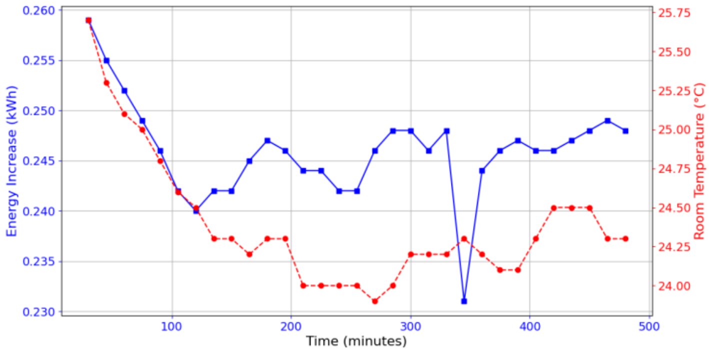

Fig 7. Graph of Energy Consumption and Room Temperature vs. Time for AC 2 Without Automatic Control

The correlation analysis between temperature and energy for AC 2 reinforces the findings from AC 1. There is a strong indication of no direct linear relationship between the decrease in temperature and energy consumption. The clearest evidence is observed within the first two hours of the test: while the room temperature was decreasing, the energy consumption paradoxically showed a significant increase, reaching its peak. Once the room temperature began to stabilize, the energy consumption also stabilized at a level lower than its peak. This phenomenon confirms that, under conditions without automatic control, the AC compressor's workload operates independently of changes in the ambient temperature.

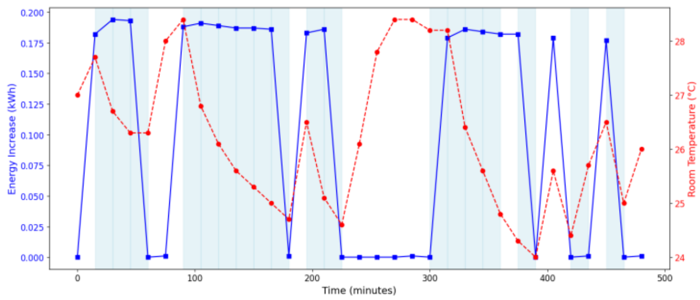

Fig 8. Graph of Energy Consumption and Room Temperature vs. Time for AC 1 Using the Automatic Remote Control Device

Figure 8 presents the analysis for the AC 1 scenario operated with the automatic control device. The graph reveals a clear correlation among the AC's operational status (on/off), energy consumption, and room temperature. It is observed that each time the AC is activated (indicated by the blue-shaded areas), there is a significant surge in energy consumption, with values ranging between 0.18 kWh and 0.20 kWh. Conversely, when the automatic control deactivates the AC, energy consumption immediately drops to near zero, confirming that the AC unit is the primary energy consumer. Concurrently, the room temperature responds inversely: the temperature decreases when the AC is on and rises again when the AC is off.This recurring cyclical pattern visually demonstrates the controller's intermittent operational strategy for the AC. The system actively cools the room until a certain temperature threshold is met, then deactivates the compressor to conserve energy, allowing the temperature to rise passively before the cooling cycle restarts. Therefore, Figure 8 effectively confirms that the automatic control device successfully manipulates the AC's state to influence fluctuations in both temperature and energy consumption, which is the key factor in achieving power efficiency.

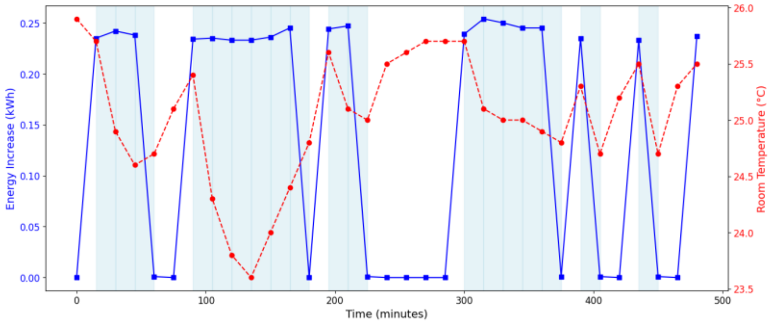

Fig 9. Graph of Energy Consumption and Room Temperature vs. Time for AC 2 Using the Automatic Remote Control Device

The analysis for AC 2, when operated with the automatic control device, is presented in Figure 9. The observed patterns are consistent with the results from AC 1, where energy consumption is highly dependent on the AC's operational status. Each time the AC is activated (blue-shaded areas), energy consumption surges to a range of 0.233 kWh to 0.254 kWh per 15 minutes, dropping to near-zero when the AC is deactivated. The room temperature (red line) also shows an inverse response: it gradually decreases when the AC is on and rises again when the AC is inactive. For instance, the temperature dropped from 25.4°C to 24.4°C between the 90th and 165th minutes (AC ON), and subsequently rose from 25.0°C to 25.7°C between the 225th and 285th minutes (AC OFF).Figure 10 presents a comparison of the cumulative energy consumption between the conditions with and without the control device for both AC units over a 480-minute period.

This graph visually highlights the difference in efficiency. Without the control device, the energy consumption curve shows a steep and uninterrupted rise. Conversely, when using the control device, the consumption curve is flatter and exhibits distinct plateau periods, representing the moments when the device effectively cuts off power to the AC when not needed.Quantitatively, the final test results demonstrate significant energy savings. The consumption of AC 1 was reduced from 6.056 kWh to 3.340 kWh with the device, resulting in savings of 2.716 kWh (44.85%). Meanwhile, AC 2's consumption decreased from 7.845 kWh to 4.565 kWh, saving 3.280 kWh (41.80%). Thus, the average efficiency improvement achieved by using the device on both AC units is over 43%. These findings conclusively prove that the developed automatic control device is highly effective in reducing electrical energy consumption and is viable for implementation to enhance the efficiency of air conditioner usage.

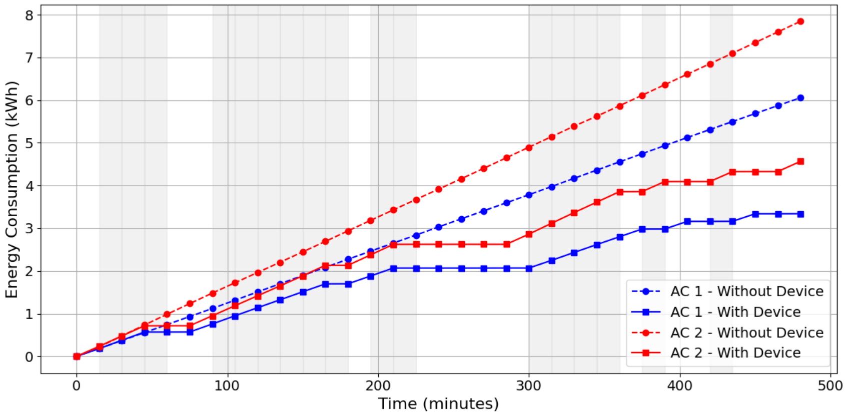

Fig 10. Comparison of Energy Consumption for AC 1 and AC 2 Under Conditions With and Without the Control Device.

IV. CONCLUSION

This research has successfully designed, built, and tested a universal and non-invasive automatic AC remote control system. Based on comparative testing, the system is proven to significantly reduce electrical energy consumption. For AC 1, a saving of 44.85% was recorded, while for AC 2, the saving reached 41.80%. These savings were achieved through an effective intermittent operational strategy, where the device intelligently deactivates the AC when the room is unoccupied or a comfortable temperature is reached, thereby eliminating energy waste caused by user negligence. With an average efficiency improvement of over 43%, these findings conclusively prove that the proposed control system is a highly effective, practical, and viable solution for energy conservation in air conditioners across various environments.

REFERENCES

[1] Z. Chen, R.-I. Chang, and Q. Wu, “Adaptive Smart System for Energy-Saving Campus,” *Eng. Proc.*, vol. 92, no. 1, p. 36, 2025.

[2] I. Rojek, D. Mikołajewski, A. Mroziński, M. Macko, T. Bednarek, and K. Tyburek, “Internet of Things Applications for Energy Management in Buildings Using Artificial Intelligence—A Case Study,” *Energies*, vol. 18, no. 7, p. 1706, 2025.

[3] S.Sirisumrannukul,T.Intaraumnauy,and N.Piamvilai,“Optimal control of cooling management system for energy conservation in smart home with ANNs-PSO data analytics microservice platform,”*Heliyon*,vol.10,no. 6, 2024.

[4] S. Nižetić, P. Šolić, D. López-de-Ipiña González-de-Artaza, and L. Patrono, “Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future,” ***J. Clean. Prod.***, vol. 274, p. 122877, 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122877.

[5] K. M. Al-Obaidi, M. Hossain, N. A. M. Alduais, H. S. Al-Duais, H. Omrany, and A. Ghaffarianhoseini, “A review of using IoT for energy efficient buildings and cities: A built environment perspective,” *Energies*, vol. 15, no. 16, p. 5991, 2022.

[6] Your Comms Group, “IoT and Energy Efficiency: Building a Sustainable Future,” Your Comms Group. Accessed: May 20, 2025. [Online]. Available: https://yourcommsgroup.com/case-study/iot-energy-efficiency-for-sustainable-future/

[7] F. Dinmohammadi, A. M. Farook, and M. Shafiee, “Improving energy efficiency in buildings with an IoT-based smart monitoring system,” *Energies*, vol. 18, no. 5, p. 1269, 2025.

[8] D. Afandi, “Rancang Bangun Sistem Kendali AC dengan Sensor DHT22 dan PIR Dalam Ruangan Menggunakan Mikrokontroller Arduino Nano,” ***J. Media Infotama*** *Vol*, vol. 21, no. 1, 2025.

[9] T. I. Nasution, S. H. Sinaga, and others, “Design of monitoring system temperature and humidity using DHT22 sensor and NRF24L01 based on Arduino,” in ***Journal of Physics: Conference Series*,** 2023, p. 12018.

[10] Y. Wang, X. Zhang, Y. Meng, and X. Wang, “Energy-saving optimization control method of commercial building double cold source air-conditioning units,” *Therm. Sci.*, vol. 26, no. 4 Part B, pp. 3545–3558, 2022.

[11] D. Lee and F.-P. Tsai, “Air conditioning energy saving from cloud-based artificial intelligence: Case study of a split-type air conditioner,” *Energies,* vol. 13, no. 8, p. 2001, 2020.

[12] Y. Zhang, “Design of air conditioning energy saving control system based on Niagara Internet of things technology and fuzzy algorithm,” in *IOP Conference Series: Earth and Environmental Science*, 2020, p. 12029.

[13] M. Çelik, M. Durgun, and L. Gökrem, “Gps Predictive Internet of Things (IoT) Based Air Conditioner Control System,” ***J. New Results Eng. Nat. Sci.,*** no. 17, pp. 9–20, 2022.