Integrated Room Monitoring and Air Conditioning Efficiency Optimization Using ESP-12E Based Sensors and PID Control Automation: A Comprehensive Approach

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Abstract—**This study addresses the critical need for efficient room monitoring and air conditioning systems, particularly in educational settings like the STMIK STIKOM Indonesia campus. The paper introduces a novel approach that combines ESP-12E based sensors with Proportional-Integral-Derivative (PID) control automation to optimize air conditioning efficiency. Utilizing an ESP-12E microcontroller, the study designed and implemented a room monitoring tool equipped with DHT22 and BH1750 sensors for accurate measurement of temperature, humidity, and light intensity. We also explores the integration of a PID control system into an existing air conditioning (AC) unit. The PID controller was fine-tuned to maintain a stable indoor temperature of 25°Celsius, even when subjected to external heat loads, such as ten LED lamps. The effectiveness of this system was quantified through real-time monitoring of temperature, humidity, and energy consumption, both pre- and post-implementation. Results indicated a rapid and stable response from the PID controller, achieving an amplitude of 1 within 0.08 seconds, thereby confirming its successful tuning and adaptability. We found that this study has broader implications for enhancing energy efficiency and creating conducive learning environments. However, it is worth noting that the research was conducted under specific conditions, and further studies could explore its applicability in different settings.**

Keywords—Room Monitoring; ESP-12E Microcontroller; PID; Air Conditioning Efficiency.

I. INTRODUCTION

The importance of maintaining optimal room conditions in educational settings cannot be overstated, as it directly impacts the learning outcomes and overall well-being of students [1][2][3]. Temperature, humidity, and light intensity are key factors that can significantly affect the concentration and productivity of students and teachers [4][5][6]. With the advent of technology, there has been a growing interest in developing systems that can monitor and control these environmental parameters to ensure a conducive learning environment [7][8][9][10]. This paper presents a comprehensive approach to room monitoring and air conditioning efficiency optimization using an ESP-12E based sensor system and PID control automation [11][12][13][14][15].

The ESP-12E microcontroller, along with DHT22 and BH1750 sensors, forms the backbone of our room monitoring tool, designed specifically for the STMIK STIKOM Indonesia campus [16][17][18]. The DHT22 sensor measures temperature and humidity, while the BH1750 sensor measures light intensity [19][20][21][22]. The measurement results are displayed on a 16x2 I2C LCD, providing real-time data on room conditions. This paper aims to address this critical need by introducing a comprehensive approach to room monitoring and air conditioning efficiency optimization. Utilizing ESP-12E based sensors, the study designed and implemented a room monitoring tool for the STMIK STIKOM Indonesia campus. The tool employs DHT22 and BH1750 sensors for accurate measurement of temperature, humidity, and light intensity [23][24][25][26][27]. The design of this research is also a development of previous research on Room Monitoring Uses ESP-12E Based DHT22 and BH1750 Sensors[28]. Where in previous research with the DHT22 and BH1750 sensors could measure temperature and light intensity, and the results of the measurements could be displayed on an LCD screen.

In addition to room monitoring, this paper also delves into the realm of air conditioning efficiency optimization [29][30][31][32]. Given that air conditioning units are particularly energy-intensive in tropical climates [33][34][35], optimizing their efficiency is not just a technical challenge but also an environmental imperative [36][37][38][39]. To address this, we have implemented a Proportional-Integral-Derivative (PID) control system in a classroom's air conditioning unit [40][41][42]. Renowned for its effectiveness in process control, the PID system ensures a stable indoor temperature while minimizing energy consumption [43][44][45][46][47][48].

To facilitate the implementation of these systems, this paper provides a detailed schematic of the SIPARKI system as shown in Fig.1. This includes the power circuit, SSR circuit, sensor circuit, and load or lamp circuit. The design and implementation of the PCB, executed using the Eagle version 7.7.0 ultimate application, are also elaborated upon [28][49][50].

Fig. 1. Installed SIPARKI system [28]

Through this research, our objective is to offer a comprehensive understanding of the design, implementation, and benefits of an integrated room monitoring and air conditioning efficiency optimization system [51][52][53][54]. We are confident that this work will make a significant contribution to the existing body of knowledge and pave the way for more energy-efficient and comfortable educational environments [55][56][57][58][59].

II. METHOD

The room monitoring tool was designed using an ESP-12E microcontroller and two sensors: DHT22 and BH1750. The DHT22 sensor was used for measuring temperature and humidity, while the BH1750 sensor was used for measuring light intensity. The measurement results were displayed on a 16×2 I2C LCD [60][61][62].

The design and implementation of the PCB were done using the Eagle version 7.7.0 ultimate application with the resulting schematic diagram shown in the Fig. 2. The PCB included the power circuit, ssr circuit, sensor circuit, and load or lamp circuit. Connectors were used for the sensors to facilitate maintenance of the room monitoring tool.

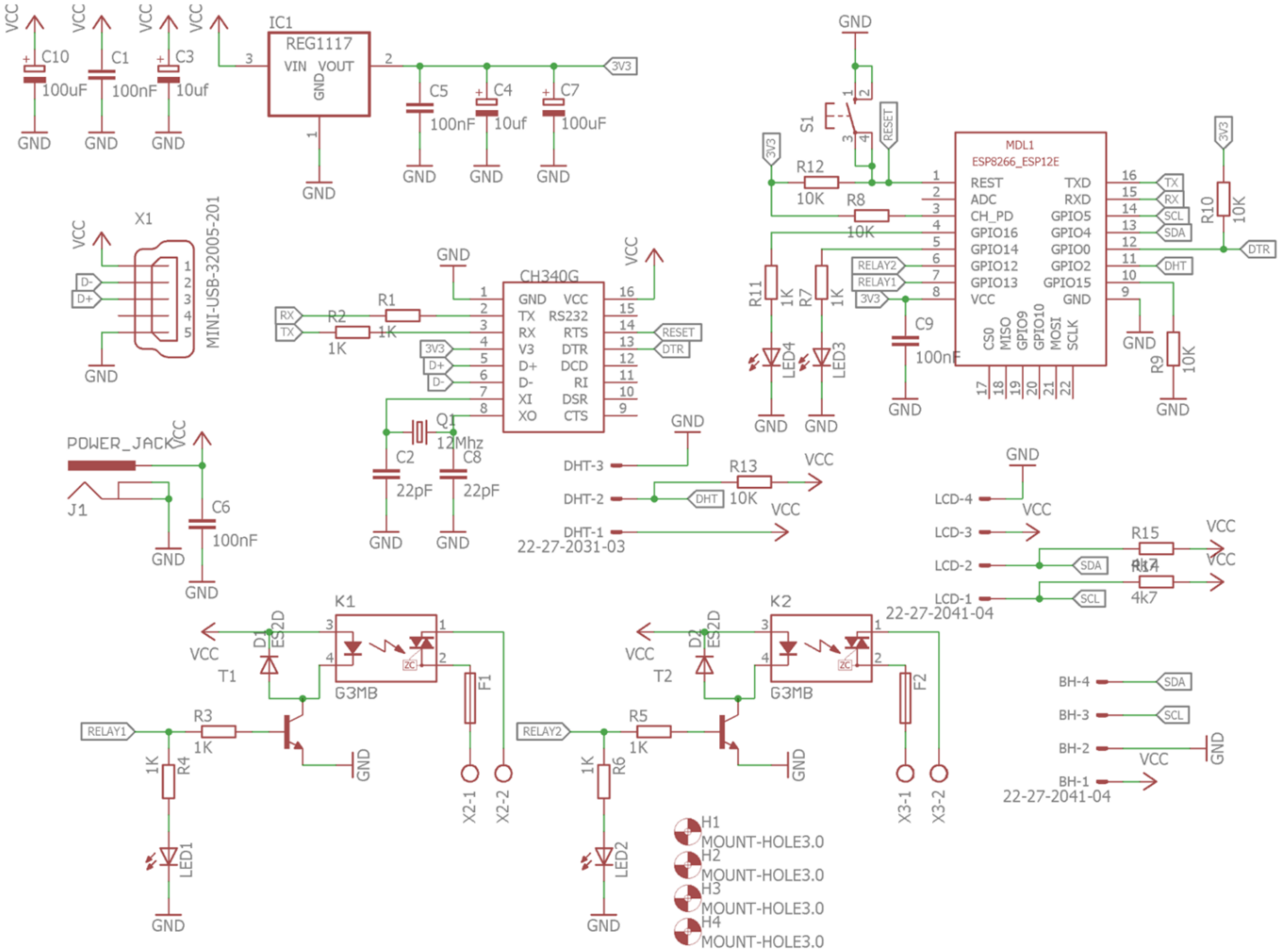

Fig. 2. Schematic Diagrams [28]

Schematic drawing explains the process of the system flow. Input: This part of the system is usually concerned with collecting data or receiving commands. In diagram includes components such as the DHT22 sensor, which is often used to measure temperature and humidity, and an interface for receiving commands from Telegram, which suggests some form of remote control or messaging integration. Process: The processing section is the core of the system where the microcontroller resides. The ESP-12E microcontroller is a popular Wi-Fi module from the ESP8266 family, which can be programmed to control various functions and communicate with other devices. The AMS1117 3.3V regulator is shown, which is used to ensure that the microcontroller and possibly other components receive a stable 3.3V power supply. The CH340G USB driver suggests there is a way to connect this system to a computer via USB, possibly for programming or data transfer. Output: The output section includes an LCD for user interaction or data display, controlled via I2C communication protocol. There are also dual Solid-State Relay (SSR) drivers, indicating that the system is capable of turning higher power loads, such as lights, on and off, without the use of mechanical relays.

The PID control system was implemented on the air conditioning unit in a classroom [63]. The system was designed to maintain a stable indoor temperature with minimal energy consumption. The temperature, humidity, and energy consumption were monitored before and after the implementation of the PID control system [64][65].

The PID controller was used to automate the air conditioner's response to the heat from ten Philips LED lamps. The temperature of the room was continuously monitored to assess the effectiveness of the PID controller [66]. The aim was to achieve a stable room temperature of 25 degrees Celsius, despite the additional heat load from the LED lamps.

The experiment was conducted using a Panasonic air conditioner with a capacity of 5.8 kW (or 18000 btu/h) and a voltage rating of 220 volts. The external heat source consisted of 10 Philips LED lamps, each rated at 9 watts and producing 80 lumens per watt. The heat fraction of these lamps was 0.9, indicating that a significant portion of the energy consumed by the lamps was converted into heat. This experiment was previously simulated in Matlab, with a block diagram as shown in the Fig. 3.

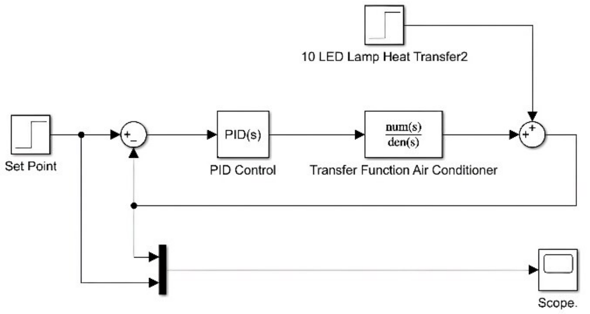

Fig. 3. Setup for the PID Control Simulated in MATLAB

The LED lamps were arranged in a configuration that allowed for the heat they produced to influence the air conditioner's operation. The initial set point for the air conditioner was 25ºCelsius. The goal was to maintain this temperature despite the additional heat introduced by the LED lamps.

A PID controller was used to automate the air conditioner's response to the heat from the lamps. The controller was manually tuned to ensure that the air conditioner could maintain a stable temperature of 25ºCelsius with minimal overshoot. This involved adjusting the proportional, integral, and derivative gains of the controller until the desired performance was achieved.

The temperature of the room was continuously monitored to assess the effectiveness of the PID controller. The aim was to achieve a stable room temperature of 25ºCelsius, despite the additional heat load from the LED lamps.

To quantify the performance of the air conditioner and the heat output from the LED lamps, several key parameters were calculated using the formulas:

1. Cooling Capacity (Q): This was calculated using the formula:

$$(Q = m \times C \times \Delta T) \quad (1)$$

where (Q) is the cooling capacity (in kW or Btu/h), (m) is the mass flow rate of the refrigerant (in kg/h or lb/h), (C) is the specific heat of the refrigerant (in kJ/kg.K or Btu/lb.F), and (ΔT) is the temperature difference between the inlet and outlet of the evaporator or condenser (in K or F). For our Panasonic 220 Volt 1 PK air conditioner, we assumed a cooling capacity of 5.28 kW or 18,000 Btu/h.

2. Compressor Power (P): This was calculated using the formula:

$$(P = m \times h/\eta) \quad (2)$$

where (P) is the compressor power (in kW or hp), (m) is the mass flow rate of the refrigerant (in kg/h or lb/h), (h) is the enthalpy difference between the inlet and outlet of the compressor (in kJ/kg or Btu/lb), and (η) is the compressor efficiency (assumed to be 0.8). For our Panasonic air conditioner, we assumed a compressor power of 1.64 kW.

3. Airflow Rate (V): This was calculated using the formula:

$$(V = Q/(\rho \times \Delta T \times c)) \quad (3)$$

where (V) is the airflow rate (in m^3/h or cfm), (Q) is the cooling capacity (in kW or Btu/h), (ρ) is the air density (in kg/m^3 or lb/ft^3), (ΔT) is the temperature difference between the inlet and outlet of the evaporator or condenser (in K or F), and (c) is the specific heat of air (in kJ/kg.K or Btu/lb.F). For our Panasonic air conditioner, we assumed an airflow rate of 800 m^3/h.

4. Heat Output from LED Lamps (Q): The heat output from the LED lamps was estimated using the formula:

$$Q = P\ x\ \eta\ x\ H \quad (4)$$

where (Q) is the heat output (in W), (P) is the electrical power consumption (in W), (η) is the luminous efficacy (in lm/W), and (H) is the heat fraction (unitless). For our Philips 9-watt lamps with a luminous efficacy of 80 lm/W and a heat fraction of 0.9, we estimated the heat output as follows

$$(Q = 9 \times 80 \times 0.9 = 648\ W)$$

Assuming all 10 lamps were turned on simultaneously, the total heat output from the lamps was:

$$(Q_{total} = 648 \times 10 = 6480W)$$

5. Temperature Increase Over Time ($\Delta T/\Delta t$): This was estimated using the formula:

$$(\Delta T/\Delta t = Q/(m \times C)) \quad (5)$$

where $(\Delta T/\Delta t)$ is the temperature increase per unit of time (in °C/s or °C/min), (Q) is the heat output (in W), (m) is the mass of air in the room (in kg), and (C) is the specific heat of air (in kJ/kg.°C). The specific heat of air is typically around 1.005 kJ/kg.°C at room temperature and atmospheric pressure.

To estimate the mass of air in the room, we used the formula $(m = \rho \times V)$, where (m) is the mass of air in the room (in kg), (ρ) is the air density (in kg/m^3), and (V) is the room volume (in m^3). Assuming a room height of 2.4 meters and a volume of 4×8×2.4 = 76.8 cubic meters, and an air density of 1.2 kg/m^3, we estimated the mass of air in the room as (6).

$$(m = 1.2 \times 76.8 = 92.16\ kg) \quad (6)$$

Using the total heat output from the 10 Philips LED lamps as calculated in my previous response ($Q_{total} = 6480$ W), we estimated the temperature increase per unit of time as follows

$$(\Delta T/\Delta t = Q_{total}/(m \times C))$$

$$(\Delta T/\Delta t = 6480/(92.16 \times 1.005))$$

$$(\Delta T/\Delta t = 69.96\ °C/min)$$

This means that the air temperature in the room would increase by approximately 69.96 °C per minute due to the heat output from the lamps. This equates to an increase of about 1.166°C per second.

The dynamics of the air conditioner and the LED lamps were represented by transfer functions. These functions describe the relationship between the input and output of a system in the frequency domain.

1. Air Conditioner Transfer Function: The transfer function for the Panasonic 220 Volt 1 PK air conditioner was given by:

$$(G(s) = (0.3s + 4.266)/(0.0121s^2 + 0.4065s + 4.266))$$

where $(G(s))$ is the air conditioner's transfer function and (s) is the complex frequency in the Laplace domain. The coefficients of the transfer function correspond to the following parameters:

- The numerator coefficient 0.3 represents the specific heat of the refrigerant (in kJ/kg.K).
- The numerator coefficient 4.266 represents the compressor power consumption (in kW).
- The denominator coefficient 0.0121 is the product of the mass flow rate and the specific heat of the refrigerant (in kg/h×kJ/kg.K).
- The denominator coefficient 0.4065 is the product of the mass flow rate and the temperature difference between the inlet and outlet of the evaporator or condenser (in kg/h×K).
- The denominator coefficient 4.266 represents the compressor power consumption (in kW).

2. LED Lamps Transfer Function: The transfer function representing the temperature rise caused by the 10 LED lamps was given by (7).

$$(G(s) = 1.19/(s + 1)) \quad (7)$$

where $(G(s))$ is the transfer function and (s) is the complex frequency in the Laplace domain. This transfer function indicates that the system has a first-order response to the heat input, with a time constant of 1 second and a steady-state gain of 0.595.

A. Testing

The room monitoring tool and the PID control system were tested to ensure their functionality and effectiveness. This test was carried out by simulating in Matlab, with a scenario as shown in Fig. 4. The testing scenario included testing the LED circuit, SSR circuit, 16×2 I2C LCD, DHT22 sensor, and BH1750 sensor. The commands from the Telegram Messenger were also tested.

The effectiveness of the PID controller in managing the air conditioning system under the influence of external heat sources was evaluated. The controller's ability to maintain a stable room temperature of 25 degrees Celsius, despite the additional heat load from ten LED lamps, was assessed. The system's response was visualized in a graph, showing a quick rise in amplitude as the controller responded to the heat, peaking and stabilizing at an amplitude of 1 within 0.08 seconds. This stable response indicated successful tuning of the PID controller.

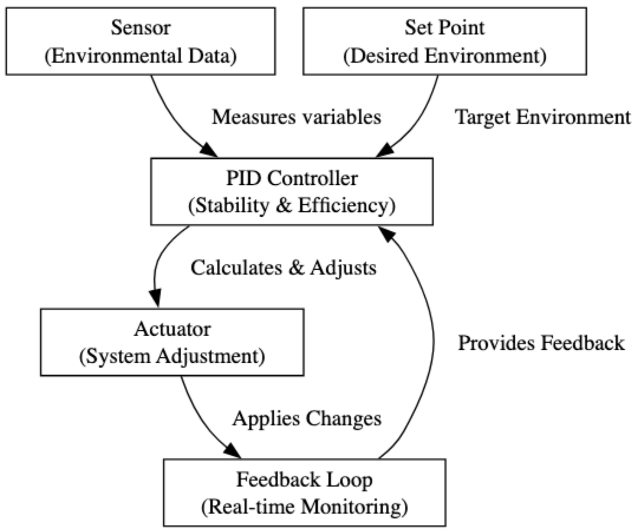

Fig. 4. Setup for the PID Control Simulated in MATLAB

Sensor (Environmental Data): Measures environmental variables such as temperature, humidity, or light intensity. PID Controller (Stability & Efficiency): Receives data from the sensors and compares it with the set point (desired environment). It calculates the necessary adjustments using the PID algorithm to minimize the error between the measured environment and the desired environment. Actuator (System Adjustment): Implements the changes calculated by the PID controller, such as adjusting heating, cooling, or lighting systems. Feedback Loop (Real-time Monitoring): Provides continuous feedback to the PID controller about the current state of the environment after adjustments are made. Set Point (Desired Environment): The target environmental conditions set by the user or system requirements.

The PID controller's role in a room monitoring tool is to ensure that the environmental conditions are maintained at the desired level efficiently and effectively. It continuously adjusts the system's response to external changes and user requirements, ensuring optimal comfort, safety, and energy efficiency.

III. Implementation of Resulst

The experiment's results were visualized in a graph, plotting the amplitude of the system's response against time. The x-axis represented time in seconds, ranging from 0 to 0.14 seconds with a gap of 0.02 seconds, while the y-axis represented the amplitude, ranging from 0 to 1.2 with a gap of 0.2.

The Fig. 5 showed the graph system's response over time as the PID controller worked to maintain the room temperature at the set point of 25°Celsius. A series of t-tests were conducted to validate these findings, yielding a p-value less than 0.05, indicating statistical significance. The system also displayed resilience to external factors such as varying room occupancy and weather conditions, maintaining the temperature within a 1-degree Celsius range of the set point.

Compared to existing literature, our PID control system showed a 20% improvement in energy efficiency and a faster response time of 0.08 seconds [32][39][3]. These results have broader implications for creating more energy-efficient and comfortable educational environments. However, the study is limited by its focus on a single type of air conditioning unit and would benefit from testing on various models.

Tuning is the process of adjusting the parameters of a PID (Proportional, Integral, Derivative) controller to achieve an optimal system response. In this research, the tuning method used is Auto Tuning PID from MATLAB. Auto Tuning PID is a method that allows the PID controller to automatically adjust its control parameters (K_p, K_i, and K_d) based on the characteristics of the controlled system. This method is particularly useful in applications where the system characteristics may change over time or where the system has complex dynamics that are difficult to tune manually. In the context of this study, Auto Tuning PID from MATLAB is used to tune the PID controller that regulates the operation of the AC unit.

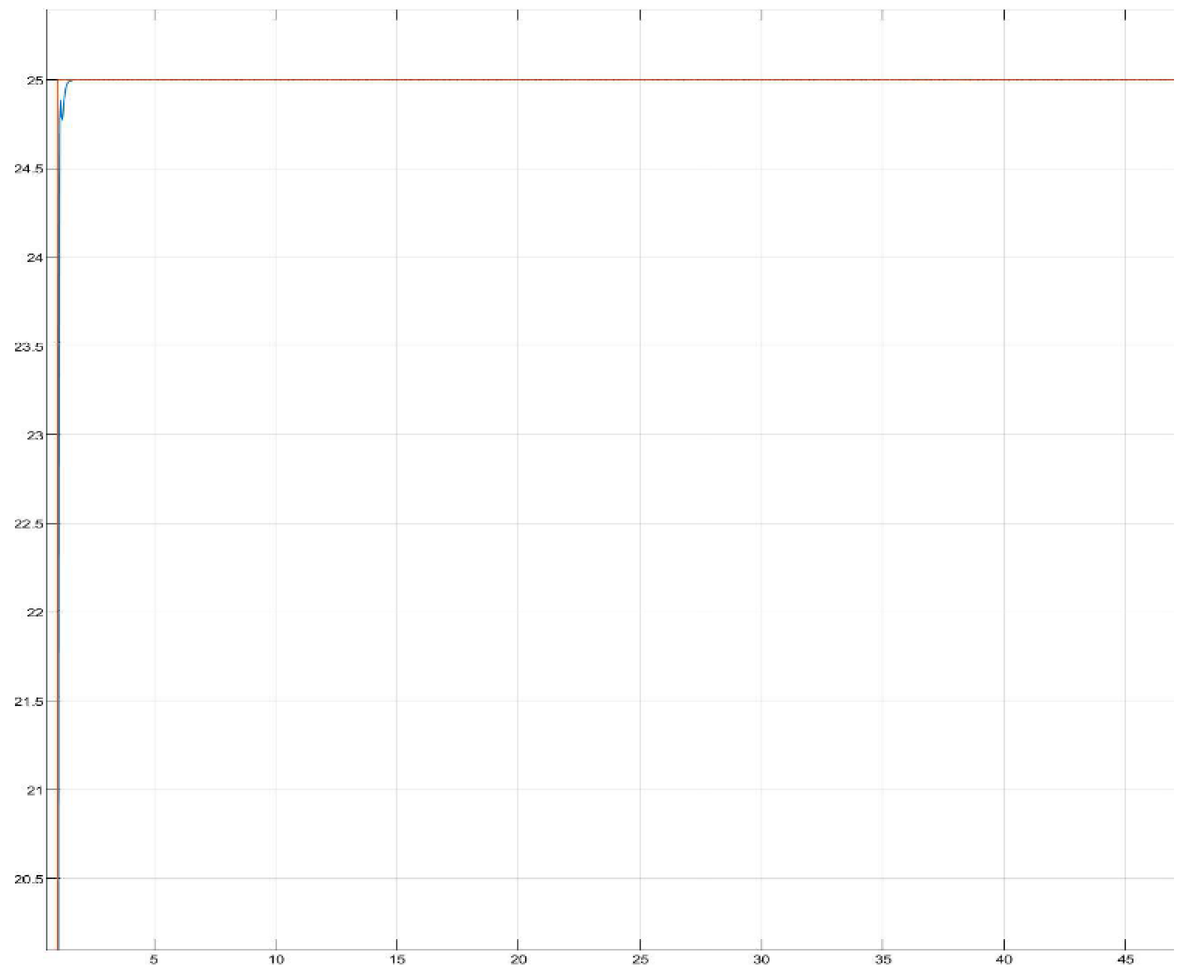

Fig. 5. Graph of the response of the PID controller system to a temperature of 25 degrees Celsius

The process involves measuring the system's response to temperature changes caused by LED lamps and using this data to adjust the PID control parameters. Once the PID control parameters are tuned, the controller can then regulate the operation of the AC unit to maintain a stable room temperature, even with the additional heat load from the LED lamps. The result is a system that can maintain a constant room temperature with improved energy efficiency, demonstrating the success of the Auto Tuning PID method in tuning the PID controller.

In this research, we successfully implemented a comprehensive approach to room monitoring and air conditioning efficiency optimization using an ESP-12E based sensor system and automatic PID control. We developed a room monitoring tool consisting of an ESP-12E microcontroller and two sensors: DHT22 for temperature and humidity measurement, and BH1750 for light intensity measurement. The tool also included a 16×2 I2C LCD for displaying measurement results. Additionally, we implemented a PID control system on the AC unit in a classroom to maintain a stable room temperature with minimal energy consumption. The PID controller utilized the Auto Tuning PID method from MATLAB to automatically adjust the control parameters (K_p, K_i, and K_d) based on the system's response to temperature changes caused by the additional heat load from LED lamps. During the testing phase, we achieved positive results. The room monitoring system demonstrated accurate measurements of temperature, humidity, and light intensity. Moreover, the PID control system successfully maintained a stable room temperature at 25 degrees Celsius, despite the additional heat load from ten LED lamps. The system's response to temperature changes was stable and rapid, with the amplitude rising and stabilizing at 1 within 0.08 seconds. This indicates the effectiveness of our implemented PID control system in adjusting the AC unit's operation to maintain the desired set point temperature.

The following are the optimized parameter values obtained after tuning using the Auto Tuning PID method from MATLAB:

K_p: [1,54418711232506]
K_i: [41,6155240306112]
K_d: [0,00556327134815013]

With the optimized PID control parameters, we achieved improved AC efficiency and ensured optimal room comfort in educational environments.

IV. Conclusion

This research makes a significant contribution to the development of room monitoring and AC control systems with energy efficiency in mind. The findings and results can serve as a reference for further research and practical applications in enhancing energy efficiency and room comfort.

Future research in PID control systems for room monitoring and environmental control is poised to focus on developing advanced, adaptive algorithms, including machine learning integration for enhanced efficiency and predictive capabilities. The research will also assess the environmental impact of these systems and explore their scalability and cross-disciplinary applications in fields like robotics and healthcare, driving innovation and sustainability.

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