BEST
Journal of Applied Electrical & Science Technology – University of PGRI Adi Buana Surabaya
p-ISSN 2715-2871
e-ISSN 2714-5247

Design and Build of Air Conditioners with Peltier Modules and PID Controls

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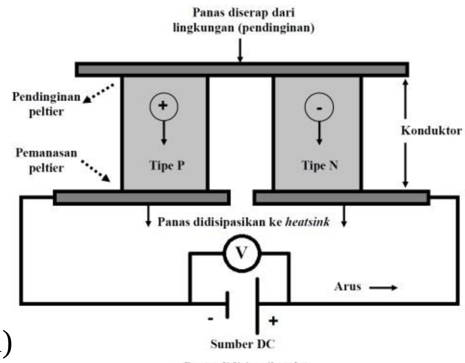
***Abstract*— Air conditioners are among the technologies that have been increasingly common, as time has gone on, from personal comfort to room comfort. A multi-story building is one location that requires air conditioning. This is because the structure's air pressure will rise until a certain level, making the temperature too low, so air conditioning is necessary to maintain a comfortable temperature. Similarly, in tropical areas where the temperature exceeds what is reasonably comfortable. However, the current air conditioner technology has the potential to harm the environment. Since Freon, which is used in it, can pass through the ozone layer. Eventually, global warming will happen and the world will get hotter. The SHT21 sensor is the kind of sensor that will be utilized in this final project since it has strong and steady chemical resistance over time and uses the I2C interface. This type of sensor is also capable of being utilized as a calibrated ambient temperature sensor, with a digital output form already comprised. This sensor will enable us to create a PID system with feedback that monitors the temperature produced by the Peltier module along with reacting to controlled PID by delivering PWM into the driver, then subsequently transmits the signal to the Peltier module for monitoring. When the duty cycle is 100 percent or the PWM value is set to 255, the Peltier module generates a 12-volt voltage at its best. When duty cycle 0 percent or PWM value 0 is selected, the module stops functioning. It is anticipated that this system will advance toward a Freon-free air conditioning system.**

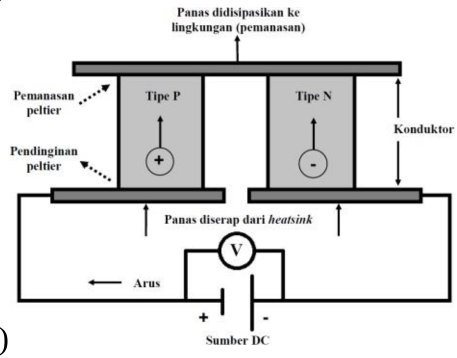
Keywords*— PID Control; Temperature Sensor; Thermoelectric Peltier

I. INTRODUCTION

Science and technology are advancing rapidly. This is done to facilitate everyday activities for society. The creation of devices that have never existed before. Technology and science have a significant impact on various fields around the world, including refrigration technology. Air conditioning (AC) is a device that cools the air to the necessary temperature and humidity, serving as a good air conditioner according to occupational health and safety regulations. This can help those who work indoors. The electrical current energy and heat energy in the connection of two types of metals are compared to create the Peltier effect. As a result, the two sides have a very sharp temperature difference, approximately 65 degrees Celsius. This Peltier effect causes one side to decrease in temperature while the other side increases in temperature. Generally, this unit can be used for heating or cooling.



a)



b)

Fig. 1. Peltier Module Schematics (a) cooling mode, (b) heating mode

II. THEORY

A. Module of Thermoelectric Peltier

Voltage and current regulation is a crossover adjustment in thermoelectric cooler (TEC) modules [1]. The optimal thickness of the component and optimal operating time are related to heat dissipation and external heat resistance [2]. The limitations of the TEC layout and technical constraints in building the TEC foundation use three indicators: foot distance, foot area, and foot quantity as optimization values. The lowest COP and highest material budget are determined, along with research on material structure as a determinant for measuring the best thermoelectric cooler foot [3].

Increasing the cross-section of the heating element or reducing its length will enhance the maximum heating capacity. The most important outcome achievable is the lack of correlation with high cooling capability while remaining stable against changes in location or length of the thermoelectric element [4].

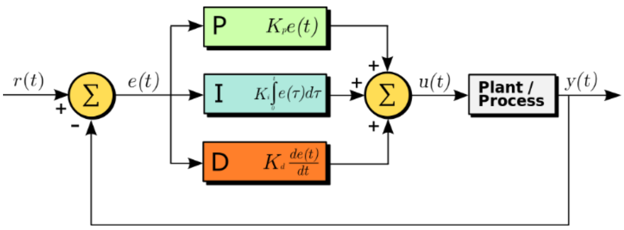


Fig. 2. Blok diagram of *PID control*

To enhance superior performance, better thermal materials are developed. This indicates that as the demand for electricity increases, the compatibility of materials for thermoelectric applications must be higher for super lattice materials [5]. The efficiency and cost of thermoelectric cooling systems depend on their dispersion system and absorption capacity [6].

B. PID Controller

There are three types of PID controllers: Proportional, Integral, and Derivative. These three types can be used in combination or separately, depending on the predetermined responsiveness of growth [7]. PID is a control method used in the design of control systems in factories to achieve the desired behavior [8].

The P component is responsible for the deviation variable at the initial stages. When the error level is high, the control output is also high. The I component is responsible for the error level afterward. If the output at this moment is not high enough, the error will continue to accumulate, prompting the controller to respond with increasingly higher outputs. The D component is responsible for the potential error level in the future based on the rate of improvement over a specific period [9]. The input-output controller (PID) is used to determine the accuracy of the hardware system and provide feedback to the system. A PID controller can produce a signal proportional to the error signal (Proportional), equal to the total error signal (Integral), or similar to the change in the current error signal compared to the previous signal (Derivative) [10].

PID control combines proportional, integral, and derivative control [11], as illustrated in Figure 2.

$$C_{PID}(s) = K_p \times (k + \frac{K_i}{s} + K_d \times s) \quad (1)$$

$$C_{PID}(s) = K_s \times (1 + (I_s/s))(1 + \frac{D_s s}{\gamma_s D_s s+1}) \quad (2)$$

$$C_{PID}(s) = K_p + \frac{I_p}{s} + \frac{D_p s}{\gamma_p D_p s+1} \quad (3)$$

Kp is the gain of the PID controller, Kp is the smoothness constant, Ki is the integral gain, and Kd is the derivative gain or decay. The values of Kp, Ki, and Kd are determined in this study using manual calibration. The control signal generated is PWM [12]. PWM is a technique for generating analog signals using a digital signal source. This signal has two main factors: frequency and duty cycle [13].

Fig. 3. Board of UNO type Arduino

C. .Temperature Sensor (SHT21)

The SHT21 is a state-of-the-art humidity and temperature sensor created by Sensirion, setting a new benchmark for accuracy and sensitivity. This module is packaged in two boards and is commercially available in a 3x3mm package with a height of 1.1mm, providing calibrated and linearized signals in a digital I2C format. Due to its unique CMOS circuit design, the capacitive humidity and temperature sensors have been developed with higher performance than previous generations.

D. UNO Type Arduino

The Uno type Arduino, is a microcontroller board based on the ATmega328, as shown in Figure 3. The Uno features 14 digital input/output pins, 6 of which can output PWM, and 6 analog input pins, along with a 16 MHz crystal oscillator, USB serial connection, power connector, ICSP header, and a reset button. To power the microcontroller, simply connect the Arduino Uno board to a laptop or PC with a USB cable or use a battery during operation.

The name 'Uno' translates to 'one' in Italian, marking the introduction of Arduino version 1.0. The Arduino Uno with version 1.0 is the version that will be used. This version of the Arduino board uses a USB serial connection and serves as the reference model for Arduino devices to be compared with earlier versions.

E. H-Bridge Driver

The H-Bridge is a configuration made up of transistors that forms the letter 'H,' as shown in Figure 4. These transistors are used as switches to enable the motor to rotate in both clockwise and counterclockwise directions. The driver circuit typically uses TIP 31 and TIP 32 transistors, which can be explained in more detail below:

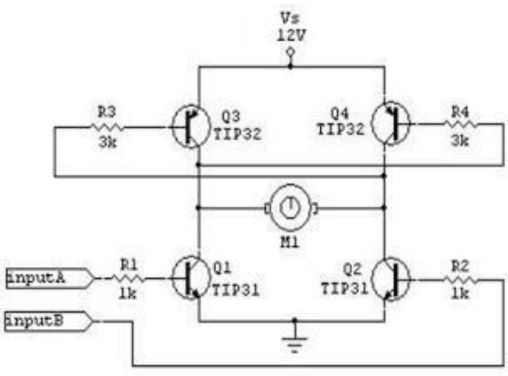


Fig. 4. Operating Principle of the H-Bridge Driver

- If A and B are both 0

Since both inputs A and B are equal to '0' or 0V, the TIP31 inverters Q1 and Q2 do not receive a trigger at their bases to turn on the transistors, resulting in them functioning as open switches. As seen in the circuit above, the two TIP32 transistors, Q3 and Q4, are connected to TIP31, with the base of TIP32 connected to the collector of TIP31. Therefore, when current does not pass through TIP31 at the collector, the base of TIP32 remains off, causing the motor to stop.

- If A is 0; B is 1

When input A is given a value of 0 or 0V and input B is given a value of 1 or 5V, Q2 becomes active while Q1 is turned off. Since Q2 is saturated or closed like a switch, the base of Q3 receives a trigger to turn on Q3. This results in current flowing in the following sequence: Vs to Q3, then to the motor, then to Q1, and finally to ground, causing the motor to rotate clockwise.

- If A is 1; B is 0

When input A is given a value of 1 or 5V and input B is given a value of 0 or 0V, Q1 is energized while Q2 is turned off. As a result, Q4 is activated because Q1 sends a trigger to the base of Q4. The current flows in this sequence: Vs to Q4, then to the motor, then to Q1, and then to ground, resulting in the motor rotating counterclockwise.

- If A and B are both 1

When both inputs are simultaneously given a value of 1, all cells are in a saturated state. Logically, the motor does not rotate because there is no potential difference at the junction. However, heat energy will accumulate in the transistors, potentially causing issues. Therefore, this condition should be avoided.

III. System Design

A. System Diagram

Generally, process control involves software as the interface and hardware that includes a master unit and a slave unit. The master device contains the Arduino UNO module for controlling the temperature sensor and PID, as well as processing the transmission of temperature data to the slave unit. The slave device uses the SHT21 as the temperature sensor. The system block diagram is shown in Figure 5. The components in this system include the Peltier thermoelectric device, cooler, power supply (PSU), Arduino UNO microcontroller, and SHT21 sensor.

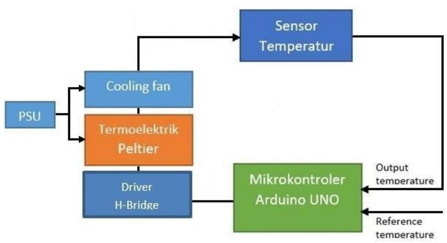


Fig. 5. Block Diagram of the System

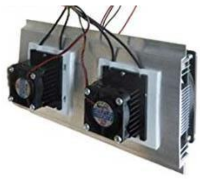


Fig. 6. Two TEC1-12706

In the Peltier thermoelectric block circuit, cold temperatures are generated and transferred. The cold air from the cooling fan is distributed outward. The PSU block is used to power the thermoelectric Peltier and the cooling fan. The Arduino UNO microcontroller acts as the PID controller for the Peltier device, communicating serially with the computer and the temperature sensor. In the slave unit, the SHT21 sensor functions as a thermometer, providing feedback for the PID control.

The software in this system runs on the microcontroller. In the microcontroller, the software functions as both the PID control processor and for serial communication. This block is used for serial communication via I2C with the temperature sensor.

B. Design of the Peltier Thermoelectric

In this study, two Peltier thermoelectric devices of type TEC1-12706 are used, as shown in Figure 6.

The first assumption is that the temperature on the hot side is 50°C, while the ambient temperature in Indonesia ranges from 30 to 35 degrees Celsius. Therefore, it is very challenging to maintain a high temperature at the TEC below room temperature. It is then assumed that the temperature on the cold side is approximately 20 degrees Celsius, as the surrounding temperature is around 24-26°C, meaning the cold side temperature must be lower than that.

From the above conditions, the temperature difference between the two sides is about 30 degrees Celsius. If the room is calculated, the heating load is 185 British Thermal Units (Btu) per hour. Since one Btu per hour is equivalent to 0.293W, the required heating capacity is 54.205W. Compared to the heating capability of a TEC, which is 30W, the required capacity of 54.205W indicates that approximately two TEC units are needed to meet the demand.

Table 1. Air Changes on Several Places

Place	Air Changes per Hour
Laundry	0 to 15
Library	3 to 4
Guest Area	4 to 6
Workspace	4 to 6
Café	10 to 15
Retail Area	8 to 15
Restroom	6 to 10
Storage	3 to 6
Bedroom	2 to 4
Machine Room	15 to 30
Industry	8 to 10
Garage	6 to 10
Kitchen	10 to 15

p-ISSN 2715-2871
e-ISSN 2714-5247

Fig. 7. Power Supply Unit 12VDC 15A

C. *Design of the Cooling Fan*

The cooling fan is designed to distribute the low-temperature output from the Peltier element through the air. To calculate the power of the cooling fan unit, the following formula can be used:

$$N = (P \times Q)/R \quad (4)$$

N is the number of fans, P is the volume of the room in cubic meters, Q is the air change rate per hour, and R is the air flow rate per hour (m^3/hour), which can be found in the specifications of the fan. If the dimensions of the area are 0.6m x 0.6m x 0.6m, the volume P is 0.216m^3, then the required air circulation per hour is twice that (assuming the test space is a bedroom as per Table 1) (Q), and the total volume of air needed is 0.216 x 2, or 0.432 cubic meters/hour.

The airflow rate for the cooling fan used is approximately 76.8 Cubic Feet per Minute (CFM), which converts to about 130.484029 cubic meters per hour (CMH) or R. Therefore, the value of N is equal to 0.0033107500075737. Thus, the required number of cooling fan units is approximately 1 unit.

D. *Design of the Power Supply Unit*

In this study, a 12 VDC 15A power supply is used, as shown in Figure 7. The Peltier unit draws 12.8A, two thermoelectric fans use a total of 0.6A, and there are two cooling fans. Therefore, the total current is 14A. Thus, a PSU with an output of 15 Amperes will be used to meet these requirements.

E. *Design of the Temperature Sensor*

The SHT21 temperature sensor will be used in the study, as shown in Figure 8. The SHT21 is a detector used for measuring temperature and relative humidity. The output from the SHT21 temperature sensor is digital I2C. The SHT21 requires a power supply of 3.2 µW. The relative humidity (RH) range for the SHT21 is between 0-100% RH, and its operating temperature range is -40 to 125 degrees Celsius.

Fig. 8. Temperature Sensor SHT21

Fig. 9. IBT 2 Module

F. *Design of the Temperature Sensor*

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G. *Design of the H-Bridge Driver*

The controller and regulator for the power supply to each fan used in this study are shown in Figure 9, which is the IBT-2. The IBT-2 motor driver requires an input voltage of 5.5 to 27 V, with a driver start voltage of 3.3 to 5 V, and a current rating of 43 Amperes.

H. *Design of the Experimental Room*

The experimental room is made of a cubic wooden cabinet, measuring 1m x 1m x 1m, with the SHT21 temperature sensor positioned in the center. The Peltier thermoelectric module is positioned at the back of the cabinet, with its cold side extending into the cabinet and its hot side outside. The experimental room is shown in Figure 10.

a)
b)


Fig. 10. Experimental Room (a) Front View, and (b) Back View

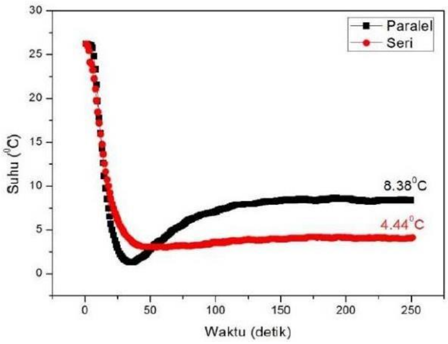

Fig. 11. Temperature in Parallel and Series

IV. Test and Analysis

A. *Testing of the Peltier Thermoelectric*

The testing was conducted by connecting the Peltier unit to the power supply, as well as when two thermoelectric units are connected in parallel and in series. Figure 11 shows the temperature diagram in parallel mode and series mode.

Then, the Peltier component testing was conducted using a 12-volt power supply. The results of the testing in parallel configuration reached 1.3°C, but only lasted for 4 seconds, and then stabilized at a temperature of 8.3°C. In contrast, during the series mode testing, the minimum temperature achieved was 3.0°C and stabilized at 4.4°C.

B. *Testing of the Power Supply Unit*

Measuring the power supply is essential because it provides the electrical power necessary for the devices to operate. The sensor and microcontroller require power to function properly. Electrical energy is measured by assessing the input, processing, and output. The purpose of this test is to determine the voltage required for the sensor and microcontroller. The power supply was measured using a digital multimeter. Table 2 shows the results of the power supply testing.

C. *Testing of Peltier Control*

In this test, data was collected when the sensor was placed in the experimental area, using PWM with duty cycles of zero, ten, twenty, thirty, and up to one hundred percent. This signal was applied for approximately 180 seconds while the room temperature was around 26.9 degrees Celsius. Figure 12 shows the results of the experiment.

Table 2 Power Supply Measurement with LM7805

No	Vin Terukur		Catu daya		Kesalahan %
	Tidak Dengan beban	Berbeban	Vout (Original)	Vout (Terukur)	
1	12	12	5	4,954	1
2	12	12	5	4,953	1
3	12	12	5	4,954	1
4	12	12	5	4,955	1

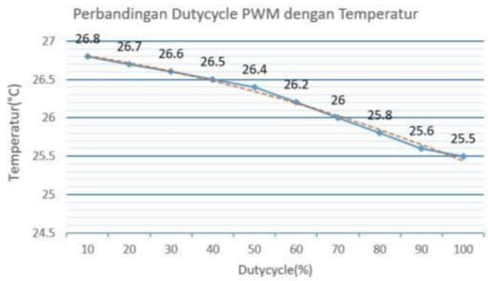

Fig. 12. Comparison Graph of PWM Duty Cycle and Temperature

a)
b)

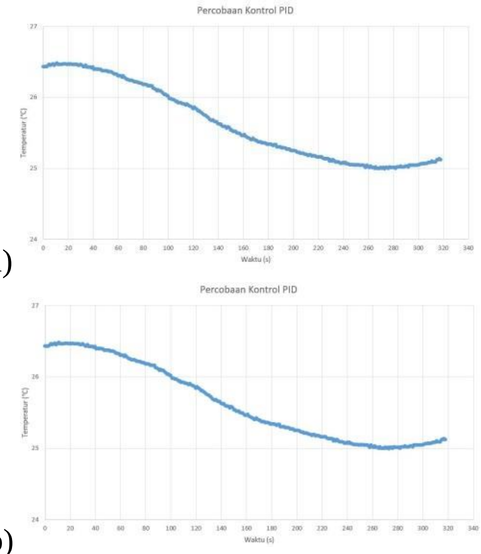

Fig. 13. PID Control Graph (a) Kp Value 15000, and (b) Ki Value 4

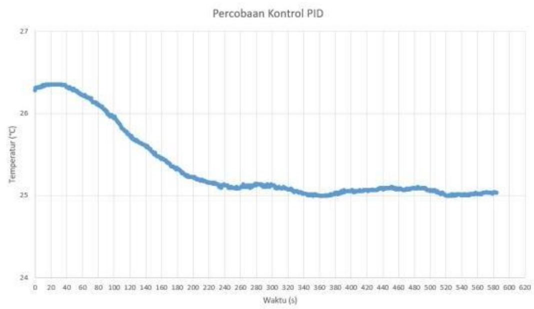

Fig. 14. PID Control Graph with Kd 0.4

The experiment continued by collecting data through the adjustment of PID variable values to achieve an output temperature close to the predetermined set point of 25 degrees Celsius. After determining the appropriate Kp value of 15000, the Ki value was then adjusted. Once Ki was established, the Kd constant was calculated to obtain the derivative value. The output data from the experiments are shown in Figures 13 and 14.

V. Conclusion

In this study, an air cooler was designed and built using Peltier Thermoelectric control and PID. The system is based on an Arduino Uno microcontroller, which sends PWM digital signals to the IBT 2 H-Bridge, then to the thermoelectric unit that outputs low temperature. The SHT21 sensor measures the temperature values, and these values are sent back to the microcontroller as feedback.

The Peltier unit can be adjusted through the PID program in the microcontroller. The cooling fan effectively distributes the low-temperature air as expected. The PID control program in the microcontroller processes the feedback from the SHT21 temperature sensor. The airflow can effectively disperse heat. Overall, the designed system is capable of processing feedback to achieve optimal results, with the processed temperature approaching the specified set points of 20°C, 25°C, and 26°C.

ACKNOWLEDGMENT

The author would like to express heartfelt gratitude to everyone who has supported me both academically and emotionally during the writing of this study.

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