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Study on the application of green energy in a mini-AC cooling system utilizing Peltiermodule and heat pipe technology

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Abstract

The climate in tropical countries is characterized by high levels of humidity and heat, necessitating the use of environmentally friendly cooling equipment and air humidity regulations. The conventional Peltier method, which uses a heatsink to release heat from the hot side, is not optimally effective due to the limited area of thermal resistance. To enhance the heat release and maximize the heat transfer from the hot side of the Peltier to the surrounding air, heat pipes can be employed as passive heat exchangers. This study aims to determine the rate of heat transfer when utilizing a Peltier module and heat pipe, to investigate the influence of Relative Humidity (RH) in the room, and to examine the installation of a temperature and RH control system. Experimental methods involving the design of mini-AC equipment were employed. The findings of this research reveal that the Peltier module is capable of efficiently transferring heat. Specifically, the Peltier module used in the study achieved a heat transfer rate of 22.7 W per second with three operating fans, consuming 136.1 W of power. The total energy released amounted to 114.7 W, which is still considered suitable for cooling a room.

Keywords:
TEC, heat pipe, air conditioning, heat balance.

1 Introduction

The climate in tropical countries is characterized by high humidity and heat, which necessitates the use of cooling systems and humidity regulation. According to SNI and ASHRAE standards, the ideal comfort zone falls within a temperature range of 20-24 degrees Celsius, with an average humidity level below 60%[1], [2]. However, the conventional tools currently available on the market are not environmentally friendly. For instance, traditional air conditioning units typically employ CFC refrigerants or materials derived from hydrocarbons.

As a member of the 2015 Paris Agreement, also known as COP 21, Indonesia has committed to reducing and ultimately ceasing carbon emissions in daily life by 2040[3], [4]. Naturally, this has significant implications for the use of conventional air conditioning systems that rely on hydrocarbon refrigerants[5]–[9].

An alternative option to conventional AC systems is the utilization of Thermoelectric Coolers (TEC). TECs function by employing dissimilar materials on the positive and negative sides, resulting in a Peltier effect that transfers heat from the input side to the output side. This effect can be likened to that of a heat pump and has found widespread application in various fields[10]–[18].Numerous studies have focused on designing TEC applications that utilize water, fan air, and heat sinks to enhance temperature transfer on the hot side or reduce temperature on the cold side [19]–[22]. As the result of those designs, the cold air produced in ranges above 10°C.

Heat pipes are employed as passive heat exchange devices to optimize the cold air output of the TECs. These heat pipes facilitate the maximum heat transfer from the hot side of the Peltierto the surrounding air. The objective of this research is to determine the rate of heat transfer and assess whether it can be influenced by the Relative Humidity (RH) in the room. Additionally, the research aims to evaluate whether the installation of a temperature and RH control system can effectively cool the room.

2 ResearchMethods

Experimental methods were employed in this research. The ambient temperature was monitored for a period of 3400 seconds under stable conditions. Temperature measurements were taken using a Lutron BTM-4208SD data logger and recorded automatically at one-second intervals. The measurements were stored on an SD card. The STC 3028 control panel was utilized to regulate both temperature and humidity by controlling the operation of the fan and Thermoelectric Cooler (TEC). The temperature range was set between 13°C and 30°C, and the humidity range was maintained between 55% and 55.6%.

The air velocity of the fan was manually measured at 10-minute intervals using a Lutron AM-4204 device. The cold air outlet (located on the cold side of the TEC module) exhibited three distinct air speeds, each corresponding to Fan 1, Fan 2, and Fan 3, with a speed of 3 m/s for each fan. On the other hand, the hot side air of the TEC module, aided by heat pipes and fans, had an air velocity of 4.5 m/s.

The Mini AC mapping experimental setup is depicted in Fig. 1, the tools which were used such as 2 TEC, 2 heatsink, 2 heatpipe with fan to suction hot air, 1-3 fan discharge cool air. The voltage and current were taken manually by using Kyoritsu 2300R at interval 10-minute. The electric power is expressed as Eq. 1.

$$P = V \cdot I \tag{1}$$

For the forced convection can be expressed as Eq. 2 and Eq. 3.

$$Q_{cool} = \dot{m} \cdot c_p \cdot \left(T_{air,ambient} - T_{air,cool}\right) \tag{2}$$

$$Q_{hot} = \dot{m} \cdot c_p \cdot \left(T_{air,hot} - T_{air,ambient}\right) \tag{3}$$

from the Eq. 2 and Eq. 3, the energy balance can be described as Eq. 4 – Eq. 6.

$$Q_{in} = Q_{out} \tag{4}$$

$$P_{TEC,below} + P_{TEC,above} + P_{Fan,cool} + P_{Fan,hot} = Q_{cool} + Q_{hot} \tag{5}$$

$$P_{Total} = Q_{Total} \tag{6}$$

The fan cool air position was placed on the inside wall, and the fan hot air was attached to a heat sink or placed on the outside wall. , and the fan hot air is attached to a heatsink or placed on the outside wall. To determine the effectiveness of the mini-AC design, the comparison result of total power P_{Total} and total energy Q_{Total} will be calculated using variations in the number of fan cool turned on from 1, 2 and 3.

3 Results and Discussion

Based on the analysis of experimental data in this study, it was found that the difference in heatsink temperature on the cold side of the TEC module was higher when using a heat pipe configuration for heat dissipation on the hot side of the TEC module (28°C) compared to that without a heat pipe (20°C), as explained in a previous study [17].

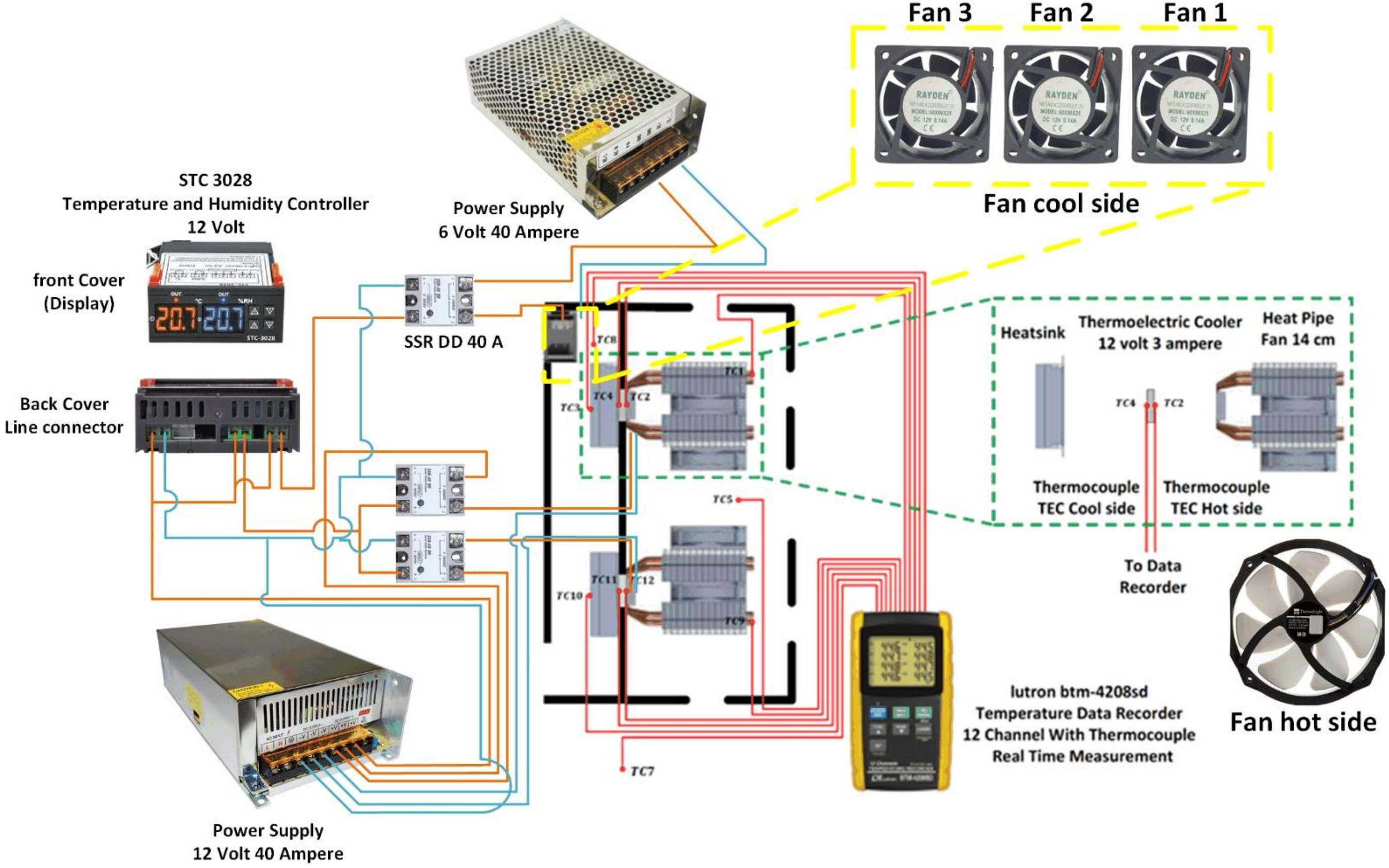

Fig. 1. The setup system controlsthe temperature and relative humidity pointmeasurements.

Fig. 2 shows that the temperature of TC11 was lower than that of TC12 because TC11 was at the top level, while TC12 was at the bottom level. The steady state data with one cold fan section showed abnormal data due to a small mass flow rate, and the number of cold fans resulted in a significant temperature decrease.The design with one cold fan showed that the TEC at the bottom was already cold, so the TEC at the top was also cooler than the bottom, as proven by the installation results with twofans and threefans.

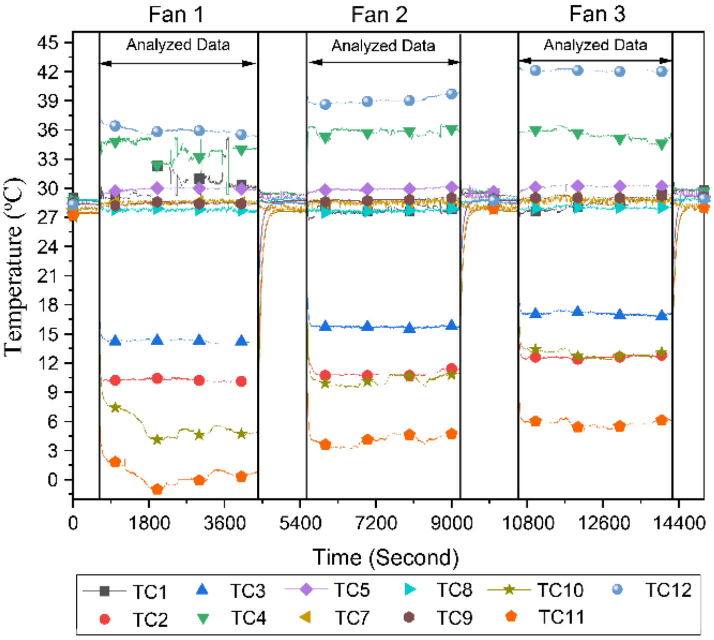

Fig. 2. Data temperature.

In Fig. 3, the voltage (V) is shown in red, current (A) is shown in black, and power (W) is shown in blue. Furthermore, there was a decrease in voltage (V) on the TEC module at the bottom and top of the mini-AC owing to heat absorption by the cold side of the TEC module, which was dissipated through the hot side of the TEC module with the help of a heat pipe system with variations in Fan 1, Fan 2, and Fan 3. The decrease in voltage resulted in an increase in current (A) when using fan 2 and fan 3 compared to using fan 1.

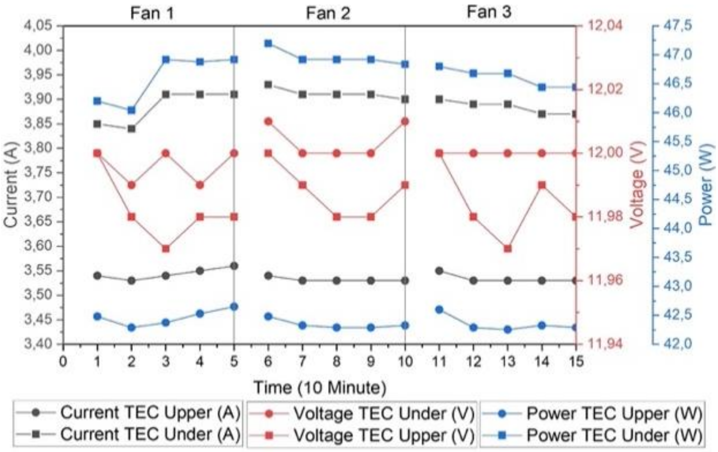

Fig. 3. Data power, voltage, and current.

An anomaly occured in fan number 1 due to a decrease in temperature, resulting in a surge in current and power and stagnation if thermal equilibrium occurs at the TEC position.

In Fig. 4, the ambient temperature experiences a constant decrease in RH at fan number 1 due to the TEC absorbing room heat. RH begins to stabilize at fan numbers 2 and 3 due to the energy balance in the room is achieved. The speed of fans 1, 2, and 3, as well as the amount of mass flow in the outgoing HOT air, was kept constant bycomparingthe total current energy of the TEC system.

The comparison of TEC retrieval using acquisition data and manual data are shown in Fig. 5. As a result, the average difference between the two data was 1.42°C. The results of the data differences were used to calibrate the air data. The recorded air data are entered into a psychrometric diagram with the assumption that no condensation occurs in the cold and hot air coming out. The analyzed air data are presented in Table 1.

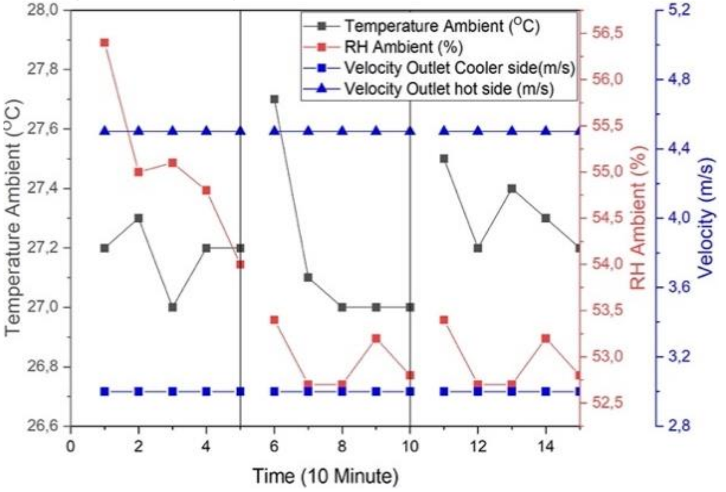

Fig. 4. Data velocity hot air outlet, velocity cold air inlet, ambient temperature, and RH.

As shown in Table 1 on variation Fan 1 the air ambient data shows an enthalpy of 59.3 kJ/kg, and the cold exit air is 58.4 kJ/kg; an enthalpy reduction of 0.9 kJ/kg. In the finished air, the enthalpy is 60.6 kJ/kg, and an addition of 1.3 kJ/kg.

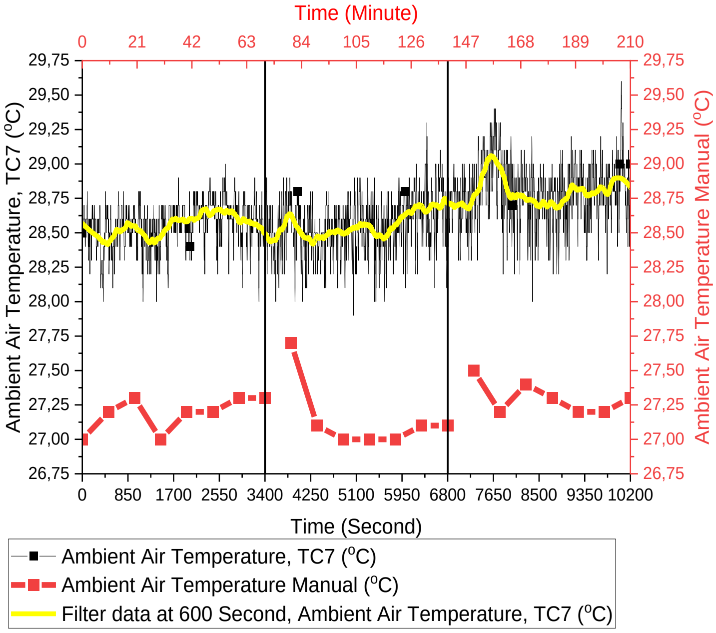

Fig. 5. The comparison data of ambient temperature used manual and data logger.

Table 1. Enthalpy and absolute humidity data on Fan 1, Fan2, and Fan 3

Fan variation	Position	Dry bulb temperature (T_{db})(°C)	Wet bulb temperature (T_{wb})(°C)	Dew point (T_{DP})(°C)	Relative humidity $(\emptyset)$(%)	Absolute humidity $(\omega)(kg/kg)$	Enthalpy (kJ/kg)	Pressure $(P)(Pa)$
Fan 1	Ambient	27.2	20.6	17.5	55.10	0.0125	59.3	101325
	Cool	26.4	20.4	17.5	58.00	0.0125	58.4	101325
	Hot	28.5	21.0	17.5	51.30	0.0125	60.6	101325
Fan 2	Ambient	27.2	20.2	16.9	53.00	0.0120	58.0	101325
	Cool	26.3	20.0	16.9	56.00	0.0120	57.1	101325
	Hot	28.5	20.6	16.9	49.30	0.0120	59.3	101325
Fan 3	Ambient	27.3	20.3	16.9	53.00	0.0120	58.1	101325
	Cool	26.6	20.1	16.9	55.00	0.0120	57.4	101325
	Hot	28.8	20.7	16.9	48.40	0.0120	59.6	101325

Variation Fan 2, the air ambient data shows an enthalpy of 58.0 kJ/kg and cold exit air of 57.1 kJ/kg, a reduction in enthalpy of 0.9 kJ/kg. In the finished air, the enthalpy is 59.3 kJ/kg, and an addition of 1.3 kJ/kg.

Furthermore, variation Fan 3, the air ambient the air data shows an enthalpy of 58.1 kJ/kg, and the cold exit air is 57.4 kJ/kg, a reduction in enthalpy of 0.7 kJ/kg, and this is a decrease compared to the two number of fans, due to the presence of too large a mass inside as shown on variation Fan 3. The cooling system results in a reduction of 0.7 kJ/kg. In the finished air, the enthalpy is 59.6 kJ/kg, and an addition of 1.5 kJ/kg. In other words, the mini-AC reduces the enthalpy of the output air from the system being designed.

The comparison between conventional AC and mini-AC with a TEC module shows that conventional AC has a large COP and uses refrigerants, compressor devices, evaporator, condenser, and expansion valve. Meanwhile, compared with AC-mini with a TEC module, it is more compact, but the COP value is still low. Further studies are needed to create semiconductor materials that have the potential to increase COP.

The comparison energy ratio results in Fig. 6, the ratio of cooling and heat output shows that the energy output on the hot side tends to be constant at ± 90 J/s, and the cold side absorbs heat from 7 J/s at Fan 1, increasing to 16.4 J/s at Fan 2, and number of Fans 3 22.7 J/s. This is due to the increase in mass flow in Eq. 2 and Eq. 3.

The comparison between the incoming power and the outgoing energy from the cooling system from Fan 1 shows 122.7 W and the energy output can be 97.5 J/s, resulting in a difference of 25W as shown in Fig. 7. With fan number 2, the input power was 127.3 W, and the output energy was 106.2 J/s, resulting in a difference of 21.1 W. With the number of fans 3, the incoming power results are 136.1 W, and the output energy is 114.7 J/s, resulting in a difference of 21.5 W.

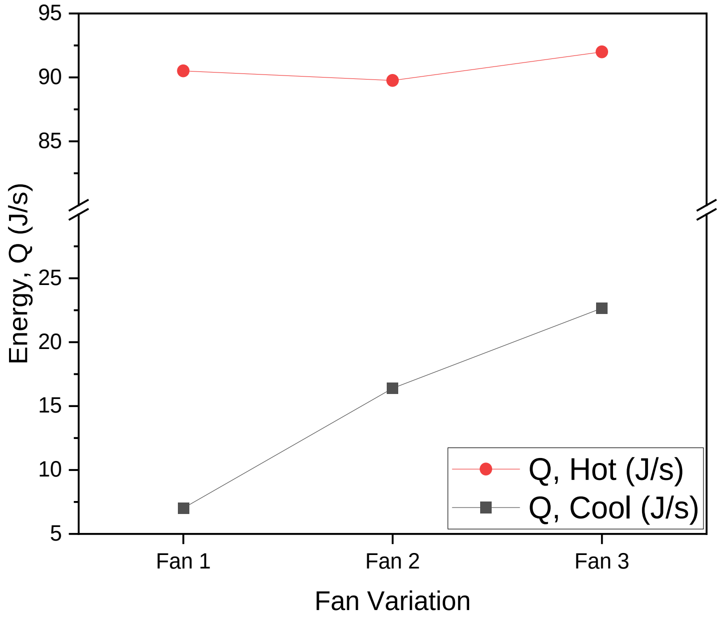

Fig. 6. The ratio of cooling energy to heat energy.

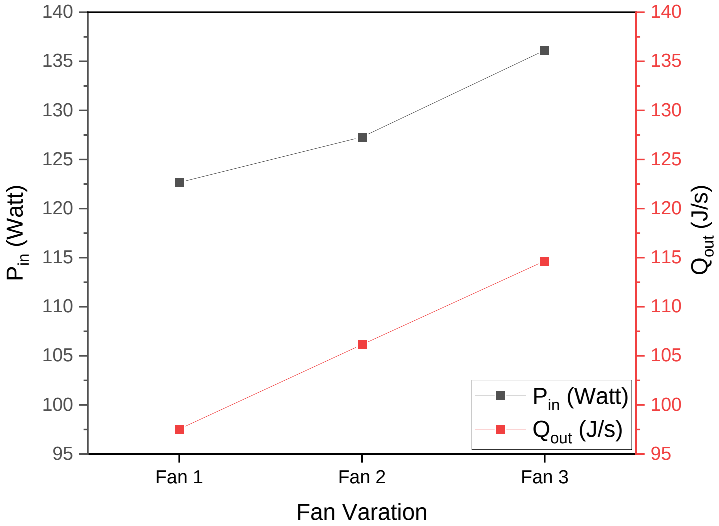

Fig. 7. Comparison of total in power to total out energy.

4 Conclusion

This research concludes that TEC Cooler can transfer heat to a maximum. TEC can transfer heat at 22.7 J/s per second with 3 running fans.

Heat pipes were used to remove heat from the hot side of the TEC module to increase the COP of the mini-AC with the TEC module. In addition, using a heat pipe is also better than using a heat sinkfor heat dissipation on the hot side of the TEC module with an increase of 7°C.

At a power consumption of 136.1 W. The total energy release is 114.7 J/s, and this energy is still considered suitable for use in cooling a room.

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Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirm that the paper is free of plagiarism.

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