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Mini air conditioning design with two levels of thermoelectric cooler module: cooling heat pipe

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Abstract
As the tropical country, the use of air conditioning (AC) in Indonesia is still high. This will affect energy consumption and global warming issue. This study aims to make solution of the AC issue with a design of the mini-AC using thermoelectrical cooler (TEC) technology and determine the output temperature result of the design, then to find out the Coefficient of Performance (COP) of the TEC cooler. The mini-AC design or method uses two TEC with additional heat sink, heat pipe, and fan to help release temperature to environment. The temperature measuring uses an 11-point thermocouple with real-time data collection using BTM-4208sd logger. *The results of the study concluded that the mini-AC could work well even though one of the TECs was below its best performance. The use of heat pipes can help reduce heat quickly from TEC heat side. The best COP of TEC with ideal heat reduction is 0.69 from the upper position (72 W), and the highest at lower position (48 W) with 2.19.*

Keywords:
Air Conditioning;
Coefficient of Performance;
Heat Pipe;
TEC Cooler;

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INTRODUCTION

Indonesia's population growth rate and energy consumption are still high. As a tropical country, the use of air conditioning (AC) is one of the most significant contributors to reduce heat temperature of the room. The use of AC will consume much energy, then if a leak occurs on the AC's refrigerant, the chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) will affect to global warming [1][2].

To reduce greenhouse gas emissions, United Nations and European Union make regulations to start the transition from HFC refrigeration systems to natural refrigerants, which is expected can reduce 71 % of the annual carbon emissions at the end of 2030 [3][4].

Therefore, the thermoelectric Cooler (TEC) module technology is one of the solutions to overcome these carbon emissions in AC's refrigerant which is stated by the several researchers [5][6]. The TEC module is powered by electricity which generates a temperature difference by absorbing Peltier heat on the TEC cool side and releasing it on the hot side [7].

TEC modules made two dissimilar materials with electrically compatible properties in series-parallel, where they are connected in parallel by thermally. The TEC module also consists of legs made by two different materials that are placed between the ceramic surfaces of the cover. The research focus on the TEC dissimilar material has been applicated in zero-emission buildings, including the role of air conditioners [8, 9, 10, 11, 12].

The research by using the heat pipe as a passive coolant on the hot side of the TEC to increase the temperature difference in the TEC has been investigated, where the heat pipe will discharge the heat temperature into environment with addition help by the heatsinks and fans [13]–[20]. This study aims to design a mini-AC with a TEC module with addition several number of the heat pipes and heat sinks, where the purpose to find out the outlet air temperatures and the

Coefficient of Performance (COP) of the design mini-AC with low energy consumption.

METHOD

This experimental design of the mini-AC uses the environment friendly material of TEC modules. As shown in Figure 1, the method using balance energy prediction, where the inside thermal energy (Q_{in}) will be absorbed by TEC energy Q_1 and Q_2, the heat will be released to outside wall (environment) assisted by heat pipe and fan. Where the result of the value out thermal energy Q_{out} is equal to:

$$Q_{in} = Q_{out} + (Q_1 + Q_2) \quad (1)$$

The mini-AC chases are made from acrylic material with thickness 5 mm, then 190 mm wide, 320 mm long and 478 mm high in inside wall with length 138 mm and outside wall length with 170 mm. The air coming out of the inside wall has three fans with the same diameter of 6 cm.

Heat pipe used eight pieces with 6 mm diameter heat pipe, the total weight of heat pipe and fins; 750 grams heat pipe, and heat sink materials; C1100 Pure copper nickel plated, overall dimensions of the heat pipe and fins; 154 mm long x 103 mm wide x 163 mm high. The heat pipe cooling fan has dimensions of 14 cm, with two fans.

In the TEC position on the cold side, heat is absorbed using a heatsink with dimensions of length 90 mm x width 72 mm x height 32 mm with a fin thickness of 1 mm and fins of 17 pieces. Cold air is exhaled using three fans with a diameter of 6 cm. Temperature data with an interval of 1 second for 1 hour. 12 Volt 40-ampere power supply is used as the power source for the TEC fans and coolers.

The temperature data collection tool uses the Lutron BTM-4208sd logger at 11 measurement points. The flow velocity measurement was done manually using a Lutron AM-4204. Two types of TEC 12706 are placed in the upper position (level 2) and the lower position (level 1). TEC hot side cooling with heat pipe.

According to Figure 2, the temperature data will be measured on the steady state condition from inside and outside mini-AC. Data collection uses a type K thermocouple. TC1 is used to measure the heat pipe at level 2, TC2 is for the hot surface of TEC, TC3 is for measuring the heatsink, and TC4 is for measuring the cold surface of TEC.

Measurement of air temperature using TC5, TC7, and TC8. TC5 measures the air at the outlet of the heat pipe, TC7 measures the ambient air temperature, and TC8 measures the air exiting the heat sink.

Heat pipe measurement level 1 uses TC9, TC10 measures the heatsink, TC11 measures the cold side of the TEC surface, and TC12 measures the hot surface of the TEC. Channel 6 is not used in recording data but as a separator between TEC level 1 and TEC level 2.

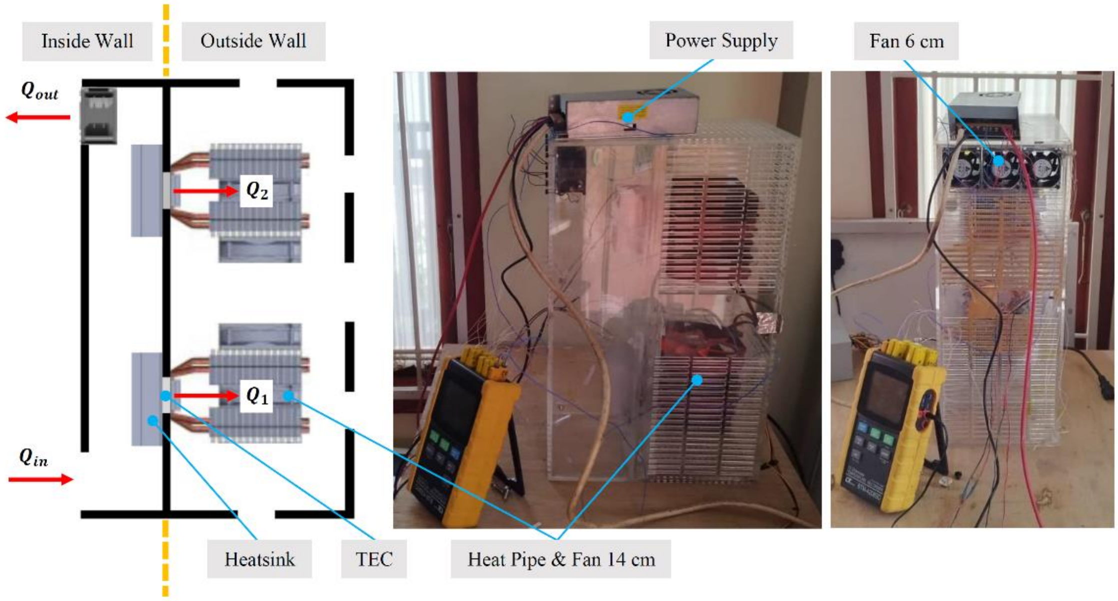

Figure 1. Research method and tool setup for mini-AC design

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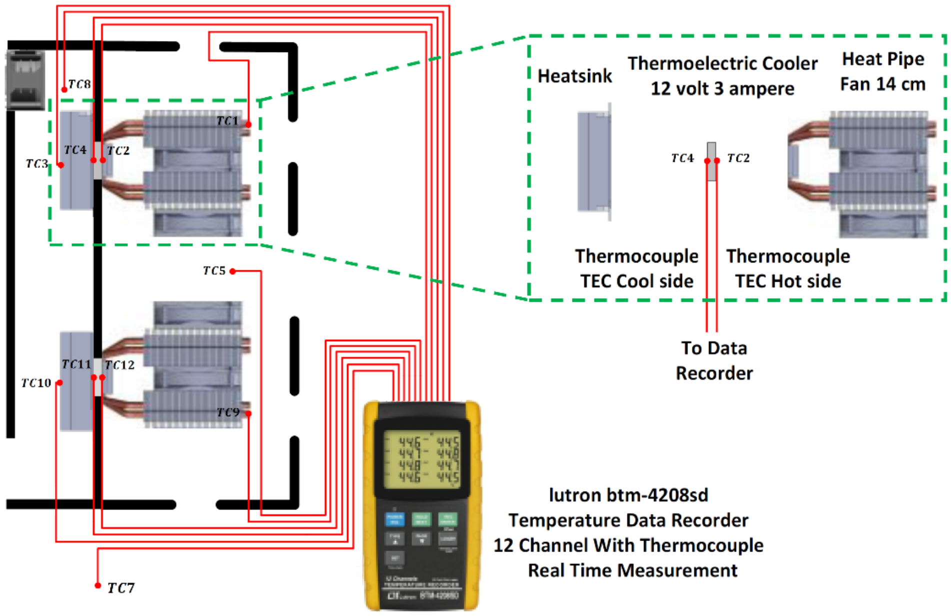

Figure 2. Temperature measurement setup using 11-point channels of thermocouple

RESULTS AND DISCUSSION

In Figure 3, temperature measurement data with 3 variations in the number of fans, all data measurements are compiled into one data and then made into a figure to determine the measurement data's characterization. From the initial measurements, the two TEC values were 6 A, and 4 A. TEC 6 A was installed in the upper position (level 2 / Upper Position), and TEC 4 A was installed in the lower position (level 1 / Under Position). However, there is still a temperature difference on the hot side of the TEC and the cold side of the TEC.

The lowest temperature data collection is on the cold side of the upper position (level 2) TEC averages 18.8 degrees Celsius. Conversely, the upper position (level 2) of the hot side TEC has an average temperature of 48.5 degrees Celsius, while the average ambient temperature is 31.5 degrees Celsius.

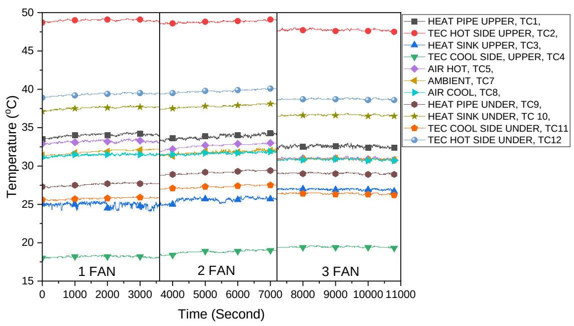

Figure 3. Temperature Measurement Data with 3 variations of the number of fans

In Figure 4, changes in the temperature of the hot air coming out are affected by the ambient air temperature. The ambient temperature is directly proportional to the decrease in hot air. At speed 3, there is a significant decrease in the temperature of the hot air coming out of the heat pipe which is almost the same as the temperature of the ambient hot air coming out.

Figure 5 shows the decrease in the delta temperature between hot and cold air; This is also due to the greater mass flow rate of the cold air fan, which affects the exit temperature of the hot air.

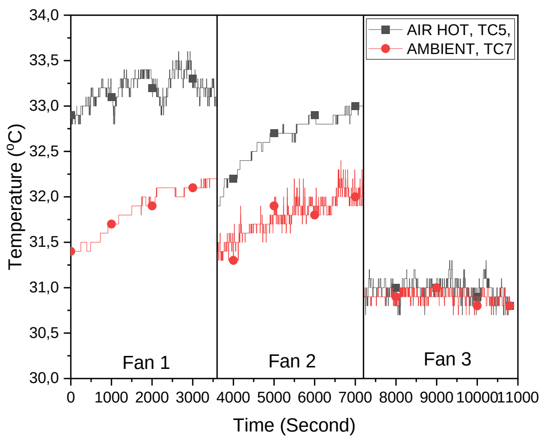

Figure 4. The air is hot out with air ambient.

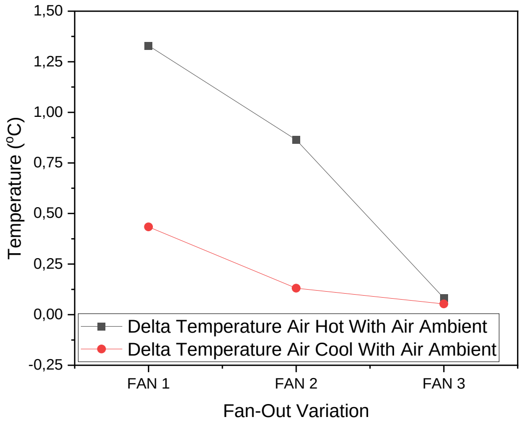

Figure 5. Delta Temperature Air Hot Out and Cool Air Out with air ambient.

The delta temperature of cold and ambient air gets smaller due to the influence of the mass flow rate of the fan; the more the number of fans used increases, the greater the incoming air mass, resulting in a delay in heat exchange between the air and the cooling side fins.

Figure 6 shows the difference between the hot side of the TEC and the heat pipe with the cold side of the TEC and the heatsink. There is a constant increase in temperature between the heatsink and the heat pipe due to the additional amount of mass flowing out of the heatsink.

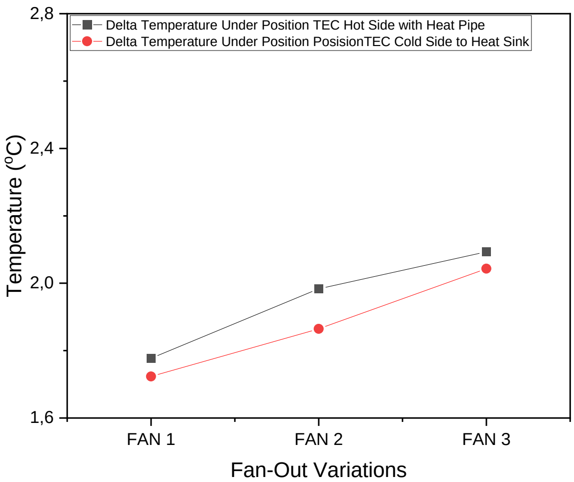

Figure 6. Delta Temperature TEC hot side with heat pipe and Delta Temperature TEC Cold side with heat sink in TEC under position.

Figure 7 shows a consistent but not significant increase in the temperature delta due to the greater mass flow rate of the cold side TEC fan, which affects the performance of the high position TEC. Utilization of heat pipes is evidenced by the large temperature delta between the hot side of the TEC and the end of the heat pipe condenser (average 15.05 degrees Celsius). It is expected that the life of the TEC will be longer.

Figure 8 shows that the COP of the two TEC modules has a significant difference because the two TEC modules have different power supplies. The TEC module at the top has a power of 72 W. The TEC module at the bottom has a capacity of 48 W. As has also been studied by J. Zhang et al. [21], and F. Yuanli also studied the increase in the hot side of the TEC with the increase in the COP [22].

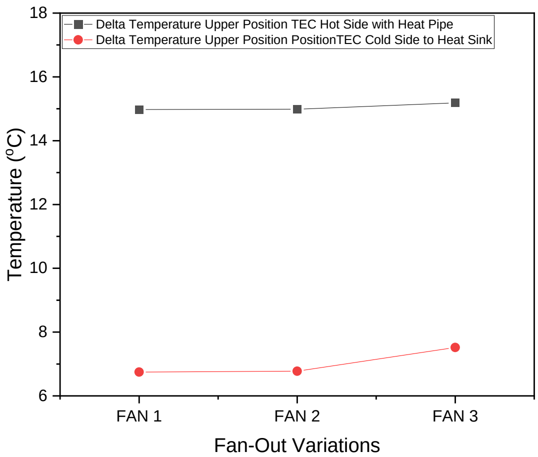

Figure 7. Delta Temperature TEC hot side with heat pipe and Delta Temperature TEC Cold side with the heat sink in the upper position

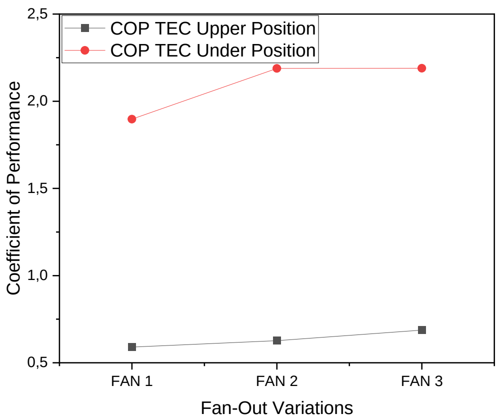

Figure 8. Coefficient of performance (COP) TEC Upper position and Under Position

The Coefficient of Performance (COP) results from the temperature difference on the two sides of the thermoelectric element. Carnot's definition of COP (ideal), here is represented as COP_c, T_h is described by hot side TEC, and is described by cold side TEC [23, 24, 25, 26, 27, 28].

$$COP_c = \frac{1}{(T_h/T_C)-1} = \frac{T_c}{T_h - T_C} \qquad (2)$$

CONCLUSION

The results of the study concluded that the designed module TEC mini air conditioner can work well as expected. The use of heat sinks and heat pipes can dissipate heat quickly into the environment (the average temperature difference is 0.76 degrees Celsius). The COP TEC value is 0.69 in the Upper position or level 2 for TEC with 72 W power. Meanwhile, the COP TEC value is 2.19 in the lower position or level 1 for TEC with 48 W power.

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