The experimental study of thermoelectric cooler performance in Medan city

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Abstract. The research purpose is to determine the performance of thermoelectric cooler boxes driven by solar power through photovoltaic devices. The research method was conducted experimentally. The designed thermoelectric cooler has dimensions of 1032 x 676 x 25 mm. The cooler box testing is carried out for several days, starting at 09.30-16.00 WIB with varying weather conditions in June 2020 in the Medan city. The installation of solar panel modules is carried out in locations not obstructed by buildings or other objects. The cooling load in the form of fruit and beverage cans is put in the box cooler. The test results showed that the minimum temperature of fruits and the minimum canned drinks obtained in the test were 25.63°C and 26.58°C, with an environmental temperature of 33.21°C. The values of the coefficient of performance obtained during testing ranged from 0.051 to 0.101.

1. Introduction

The cooling process becomes essential when human needs and technological progress increase. Refrigeration is needed to distribute medicines, food, and drinks to keep the refrigerated products of good quality. These conditions, of course, require a practical and easy to carry cooling process, especially when working in a room that does not have a refrigerator. One solution to overcome this problem is to use a thermoelectric cooler box that is simple and inexpensive. The source of electrical energy used to drive the device can be sourced from solar energy utilization through solar panels. Based on research that has been done so far, most regions in Indonesia will always be exposed to solar radiation for 10-12 hours every day. The estimated amount of average solar radiation reaching Indonesia is around 4.8 kWh/m²/day [1,2]. The research purpose of determining the performance of thermoelectric cooler boxes driven by solar energy through photovoltaic cells. Thermoelectric cooling is very environmentally friendly because it does not use a refrigerant as other refrigeration devices.

Thermoelectric is a phenomenon of conversion from temperature differences into electrical energy or vice versa [3]. The phenomenon has been developed into a module to be used as a power plant or cooling/heating device. The cold side can be used as a cooler, and the hot side can be used as a heater. Peltier element is an electrical component that can produce cold temperatures on one side and heat temperatures on the other side and be electrified. This element is also called the Thermo-Electric Cooler, which was discovered by Jean Peltier in 1834 and then developed by Emil Lenz in 1838 [4,5]. After conducting several experiments, Lenz concluded that the heat produced or absorbed depends on the direction of the electric current flow. The working principle of thermoelectric coolers based on the Peltier effect, when a DC flows to a Peltier element consisting of several pairs of p-type semiconductor cells (semiconductors that have lower energy levels) and type n (semiconductors with higher energy levels). It will result from one side of the Peltier element becomes cold (heat absorbed),
and the other side becomes hot (heat is released). The thing that causes the cold side of the Peltier element to cool down is the flow of electrons from p-type to n-type semiconductors [6]. So that p-type electron with lower energy levels can flow, the atoms absorb heat, which causes the side to cool down. At the same time, the release of heat into the environment occurs at the hot side connection, where electrons flow from higher energy levels to lower energy levels.

By definition, the energy efficiency of a photovoltaic system is expressed as the maximum output power from the solar panel to the power intensity of solar radiation reaching the surface of the photovoltaic. The efficiency of photovoltaic energy can be calculated using the equation [7,8]:

\[ \eta = \frac{P_{\text{out}}}{S_{\text{RT}}} \]  

where \( P_{\text{out}} \) is maximum output power of PV (W) and \( S_{\text{RT}} \) is solar radiation (Standard Test Conditions) is 1000 W/m².

Meanwhile, the coefficient of performance (COP) is the ratio of temperature decreasing from the maximum cooling load in the cooler box (Qin) to the power supplied to the cooler box from the solar panel (Pin) which can be calculated by the equation [9, 10]:

\[ \text{COP} = \frac{Q_{\text{in}}}{P_{\text{in}}} \]  

2. Methodology

Research methods conducted experimentally. The cooling box uses a thermoelectric cooling element of type TEC1-12706. The cooler has four peltiers, four fans, two heat sinks, and four cold sinks. The box material on the outside is made of plywood, and the inside is made of polyurethane foam. The parameters observed were time, solar radiation, and temperature changes in the cooler. The testing process was carried out in June 2020 in Medan city. The test is carried out for several days, starting from 09.30-16.00 WIB. The cooling load used is one orange fruit kilogram and one liter of beverage. Seven thermocouple cables are installed at several points on the cooler. When testing, the cooler is tightly closed so that there is no air infiltration from outside into the box and vice versa.

HOOBO weather meters are used to measure weather conditions. Solar panels are used to provide power supply to batteries that have 12 V and 70 Ah specifications. The solar panels used amounted to two modules with the SA100-72M model, which have a power of 100 W each and measuring 1032 x 676 x 25 mm. The voltage regulator (SCC) is used to regulate the charging current from the solar panel to the battery to avoid excess voltage. The SCC used has PWM type specifications and EPHC10-EC type (10A, 12V). Figure 1 shows the thermoelectric cooler box tested and figure 2 shows the experimental scheme carried out.
3. Results and Discussions
In this experiment, measurements are made on air temperature, solar radiation, and temperature changes in the thermoelectric cooler. During the test, the measurement results showed that the maximum air temperature was 33.88°C at the time of testing on the fourth day. Based on the measurement results obtained, solar radiation during testing tends to have fluctuations at any time. Solar radiation starts to increase after 07.00 WIB and, on average, reaches its peak at 11.00-13.00 WIB. The maximum radiation occurred on the second day testing of 701.9 W/m².

3.1. The first day testing
The test on the first day was to measure the cooler temperature without using the cooling load, as shown in Figure 3. It appears that the temperature outside the box has a maximum temperature of 33.4°C, among other measurement points that occurred at 12.30 WIB. At the same time, the minimum temperature occurs at the bottom of the cooling box at 25.09°C. The temperature inside the cooler is fluctuating every time. Several factors cause an increase in the cooler box temperature: first, the increase in the temperature of the air outside the cooler box, which has a significant effect on the temperature inside the cooler box. Secondly, the reduced electrical power entering the Peltier so that the Peltier does not work optimally.

3.2. The second day testing
On the second day, it was tested with cooling load a one liter of canned drinks. Figure 4 shows that the beverage temperature can fluctuate during the test due to the influence of solar radiation and quite high ambient temperature. It appears that all measurement temperature points in the cooler also increased during the test. The increasing temperature is due to the ambient temperature outside the box being high enough during the test and causing the temperature inside the cooler to increase.
3.3. The third day testing

On the third day, it was tested with a cooling load of one kilogram of citrus fruit. The test results show that the minimum fruit temperature is 25.88°C. The minimum temperature on the bottom side of the cooler is 25°C. Figure 5 shows that the cooler temperature fluctuations are also affected by ambient temperature. The maximum temperature of the cooling load occurs at around noon. The minimum temperature occurs in the bottom side of the cooler because it is slightly affected by the ambient temperature and solar radiation.
3.4. The fourth day testing

The cooling box performance test on the fourth day was carried out using a cooling load of one kilogram of oranges and one liter of canned drink. The test results show the lowest temperature occurs on the bottom side of the cooler. The minimum temperature of the fruit is 26.44°C, and the minimum temperature of the beverage can is 27.02°C. Figure 6 shows that the lowest temperature occurs at the bottom of the cooler because it is not directly affected by solar radiation. It also appears that when the ambient temperature rises, the temperature in the cooler also increases, and vice versa. This condition can be caused by the Peltier work, which is less than optimal because the electrical current supplied by photovoltaic is not optimal. Meanwhile, the power needed by the Peltier components and the cooling load is quite large, as well as infiltration from the cooler that causes heat to enter through the cooler small gaps.
3.5. The coefficient of performance (COP)
The COP value of the thermoelectric cooler is the ratio of temperature reduction from the maximum cooling load in the cooler to the cooler's power from the solar panel. The coefficient of performance value obtained during the testing process can be seen in table 1. The maximum COP obtained on the second day was 0.1796. The conditions also influenced by weather conditions and the cooling load in the cooler.

| Testing  | Minimum | Maximum | Average |
|----------|---------|---------|---------|
| Second   | 0.0070  | 0.1796  | 0.057   |
| Third    | 0.0061  | 0.1590  | 0.051   |
| Fourth   | 0.0052  | 0.1743  | 0.101   |

4. Conclusions
Research on the performance of thermoelectric cooler boxes has been carried out in the city of Medan. The thermoelectric solar cooler is an environmentally friendly cooling system because it does not use refrigerant that cause pollution. The test results showed that the minimum temperature of fruits and the minimum canned drinks obtained in the test were 25.63°C and 26.58°C, with an environmental temperature of 33.21°C. The coefficient of performance values obtained during testing ranged from 0.051 to 0.101.

Acknowledgments
The author thanks the DRPM DIKTI project for the PTUPT research provided in the year 2020.

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