Utilization of peltier cooling systems driven by solar power for storing vegetables and fruits

T. B. Sitorus[1,2], Z. Lubis[1], F. Sembiring[1], B. Christopel[1], J. A., R. Siagian

[1]Mechanical Engineering, Universitas Sumatera Utara, Medan - Indonesia
[2]PUI Energi Berkelanjutan dan Biomaterial, USU, Medan - Indonesia
e-mail: zulkiflilubis123@yahoo.com

Abstract. This article aimed to determine the performance of the Peltier cooler box system that utilizes solar power for storing vegetables and fruit. The advantage of the Peltier cooling system is that it does not consume electricity and environmentally friendly. The thermoelectric component is coupled with a heat sink where a small fan is placed on the outside, and another fan is set inside the cooler. Data is obtained from the measurement system and then analyzed so that the performance of the cooling system can be determined. The experiment is carried out in a location that is exposed to solar radiation. The process of measuring weather conditions is carried out by using a weather instrument. To record the temperature distribution on each component of the Peltier cooling system are used thermocouples which are connected to the data acquisition. Experimental results show that the minimum temperature that can be achieved on vegetables and fruits ranging from 17.324°C. The average temperature of vegetables and fruits during the experiments varies from 22°C. The results of this experiment indicate that the Peltier cooler box tested can be used to maintain the freshness of vegetables and fruits. The maximum COP value of the Peltier cooling system tested is 0.670, and the minimum COP value is 0.428.

1. Introduction

Based on the research that has been done so far that most regions in Indonesia will always be exposed to the solar radiation for 10-12 hours every day and it is estimated that the average of solar radiation reaching the Indonesian earth ranges from 4.8 kWh/m^2/day [1, 2, 3]. One of the equipments used to utilize solar radiation is photovoltaic cells or solar panels. In general, photovoltaic cell technology has the advantage of low operating and maintenance costs [4]. The PV cells are equipment that converts solar energy into electrical energy. In their use, photovoltaic cells are arranged interconnected to produce more energy and enormous power, known as photovoltaic cell panels or modules. The current generated from photovoltaic cells, in general, is direct current (DC), but by using a converter, this current can be made into alternating current (AC). The demand for photovoltaic cells such as for energy generation is increasing every time around the world due to the consideration of growing awareness about global warming and the comparative price of solar energy with conventional thermal power plants [5].

One of the cooling systems that can utilize solar radiation through photovoltaic cells is the Peltier cooling system. Peltier cooling driven by solar power is a cooling system that uses solar energy as a substitute for conventional energy to operate Peltier equipment so that it can be used to cool a room or object [6, 7]. In general, the main components of the solar Peltier cooler include Peltier modules, photovoltaic cells, coolers, insulators, heat sinks, and cooling fans. The electrical energy produced by PV cells is supplied to the Peltier cooling system through photovoltaic effects. This study is purposed to determine the performance of the working system of Peltier cooler driven by solar power for storing vegetables and fruits.

2. Literature Study

Peltier cooling system or thermoelectric cooler is a solid state electric cooling component that can function as a heat pump to carry out the cooling process. The principle is to use a Peltier effect where the cold side is used for cooling, and the hot side is used to remove heat from the cold side into the environment by utilizing the heat sink and cooling fan [8, 9]. On the side of the Peltier cooling system that absorbs heat, a cooling effect occurs, and this is used for various cooling processes. It said Peltier cooling system because this system utilizes the Peltier effect, which was first discovered by Jean Charles Antanase Peltier in 1834. Briefly, it can be noted that the Peltier effect was an effect of heat on one side and cold on the other when the direct current passed to a series of two different types of material that are connected [10, 11]. The material is a thermoelectric element material made from semiconductor material.

In general, the advantages of Peltier cooling systems are practical because of their small shape, easy installation, do not involve large and complex mechanical supporters, can be applied to portable cooling devices, are not easily damaged, and are predicted to be able to use around 100,000 hours. The disadvantages are the limited cooling and low efficiency. As a note that the efficiency of the Peltier cooling system ranges from 10-15% [12, 13]. Applications that are often used by Peltier cooling systems are by utilizing the temperature of the cold parts produced, namely as processor coolers, mini air conditioners, refrigerators in dispensers, beverage coolers, and aquarium temperature regulators. While the temperature of the heat can be removed by attaching the heat sink and fan. The coefficient of performance (COP) of the Peltier system is the ratio between the heat produced by Peltier and the energy supplied. The COP value of the Peltier system can be determined from the equation [14, 15]:

$$\mathrm{COP} = \frac{Q_{cooling}}{W_{in}} \tag{1}$$

The equation can determine cooling capacity (W).

$$Q_{\ cooling} = m.\ C_p.\ \Delta t \tag{2}$$

Where W_{in} is the energy used to move Peltier components (W).

3. Methodology

In this study, the cooler box assembled using four Peltier cooling elements with types of TEC1-12706 with a voltage of 12 V and a current of 6 A. Two batteries is used to provide electrical power to the Peltier components contained in the cooler. To supply power to cells with solar energy sources, two solar panel modules are used. A solar charge controller (SCC) voltage regulator is used to adjust the current for charging from solar panels to batteries to avoid overcharging/overvoltage and monitor battery temperature. The SCC used was one with a voltage of 12 V and a current of 10 A. The vegetables and fruits were used as cooled objects. To minimize the influence of air infiltration, the Peltier system cooler is isolated with

10 mm thick plywood on the outside, 40 mm thick Styrofoam in the middle, stainless steel plate 1 mm thick and coated with aluminum foil on the inside.

The experiment process is carried out starting at 09.00 WIB up to 17.00 WIB, and the power supply from the battery begins to be activated. Data acquisition is connected with J type thermocouples with an accuracy of ±0.4% used to measure the temperature distribution that occurs in the cooler. Data acquisition works automatically and records measurement results for every minute. To record weather conditions is used weather measuring device consisting of a pyranometer to measure solar radiation (accuracy of ±5%), temperature smart sensor to measure ambient temperature (accuracy ±0.2^{o}C) and RH smart sensor for measure air humidity (accuracy ± 2.5%). The cooler and battery are deactivated at 17.00 WIB. The battery was again activated at 09.00 WIB the next day, and the experiment was carried out again with the same procedure. The experiments are carried out for three consecutive days in June 2018 in Medan city. Table 1 shows the specifications of the Peltier cooling box system tested.

Table 1.Specifications of the Peltier cooling box system tested

No	Data	Information
1	Cooler box dimension	length 36 cm, width 28 cm, high 26 cm
2	Type/number of Peltier	TECl-12706 / 4 pieces @ 72 watt
3	Number of heat sink/cold sink	Each four pieces
4	Number of fans	4 piece @ 1,8 watt
5	Number of photovoltaic cells	2 piece @ 100 watt
6	Cooled objects	vegetables and fruits
7	Cooler box material	plywood, styrofoam, stainless steel, aluminum foil

Figure 1 shows the section of the outside, and inside parts of the Peltier cooling system tested. Figure 2 shows the experimental scheme carried out.

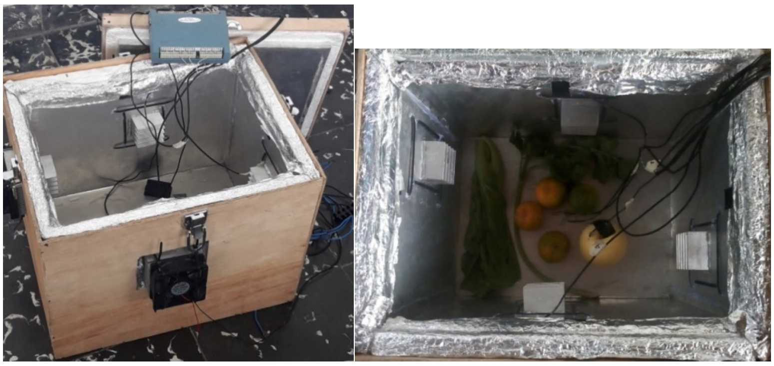

Figure 1. The outside and inside of the Peltier cooling box system

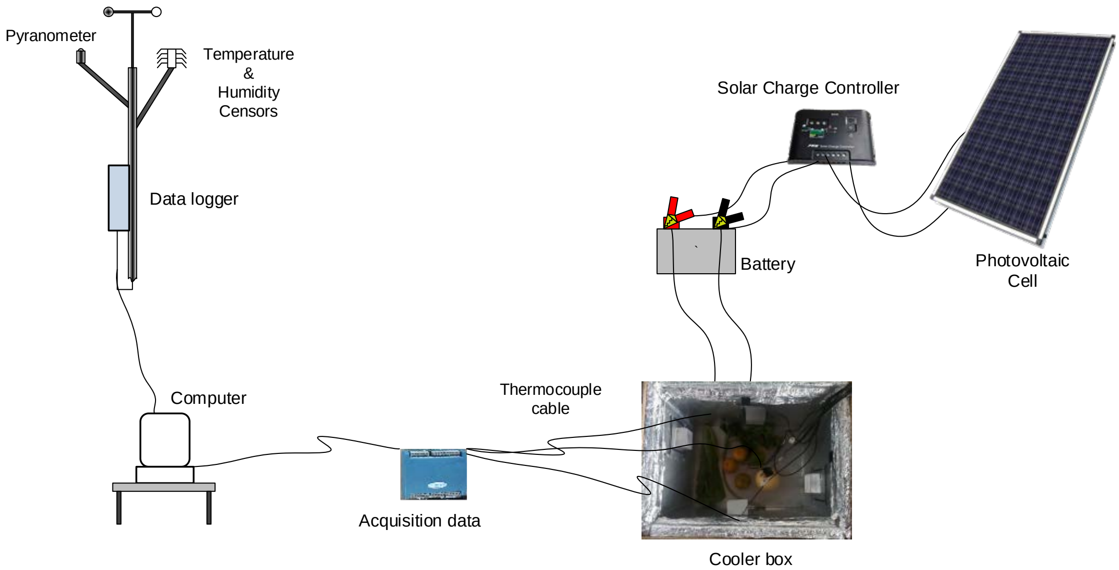

Figure 2. Experimental scheme

4. Results and Discussions

4.1. Weather Conditions

The experimental process is carried out in an open location that experiences direct solar radiation. The weather conditions need to be known because they are related to the performance of the photovoltaic cells used. Photovoltaic cells are used to absorb solar radiation energy and are stored in batteries. The battery component is used as an energy source to drive the Peltier component in the cooling process.

The process of measuring weather conditions was carried out for three days of experiments. The measurement time range is done every minute. Table 2 shows the condition of the average weather parameters during the experiment process. In this study, the measured weather parameters are ambient temperature, air humidity, and the intensity of solar radiation.

Table 2. Weather condition during the experiments

Experiment Time	Average ambient temperature (ºC)	Average relative humidity (%)	Average solar radiation (W/m^2)
5/06/2018	31,593	61,23	190,65
6/06/2018	30,586	77,45	182,43
7/06/2018	30,229	79,11	167,88

4.2. Photovoltaic Performance

The experiment of the Peltier cooler box uses solar panels cell to absorb solar radiation to produce electrical energy. To calculate the estimated number and power of a PV module that is needed, it is necessary to know the power required by the cooling system every day. In this study, four small fans and four Peltier components of type TEC1-12706 were used. The average electricity usage for 8 hours in one day is 2311.2 watts.

As a note that for the calculation of total and power estimates, it is assumed that the weather conditions are sunny with the intensity of solar radiation averaging 8 hours per day. Because the efficiency of the Peltier cooling system around 96% so that the number of PV cells needed is two pieces. Based on the PV specifications used, the maximum power for one PV cell is 108.60 watts, and PV efficiency is 15.60%. This experiment used a battery that serves to store electrical energy that has been produced by PV cells to drive fan equipment and Peltier components. The battery power specification used has a 12V and 70 Ah. The solar panels have 18.9 V and 5.3 A which is then regulated by SCC to 12 Volt and 10 A so that it can charge the battery of 70 Ah.

4.3. Performance of Peltier Cooling System

The performance of the Peltier cooling system is tested by placing a thermocouple sensor at several points in the cooler box. The thermocouple sensor is positioned on the outside of the cooler box, the top cover wall, the left wall, the right wall, the lower wall, and the vegetables and fruits. The experiments are carried out starting at 09.00 WIB until 17.00 WIB for three days with different weather conditions. Figures 3 up to 5 show that the temperature distribution in the cooling box system and the air temperature for three days. Measurements are made on the Peltier cooler box and outside air conditions. On the inside of the cooler, the temperature distribution is measured on the left wall, right wall, the bottom wall, top cover wall, vegetables, and fruits.

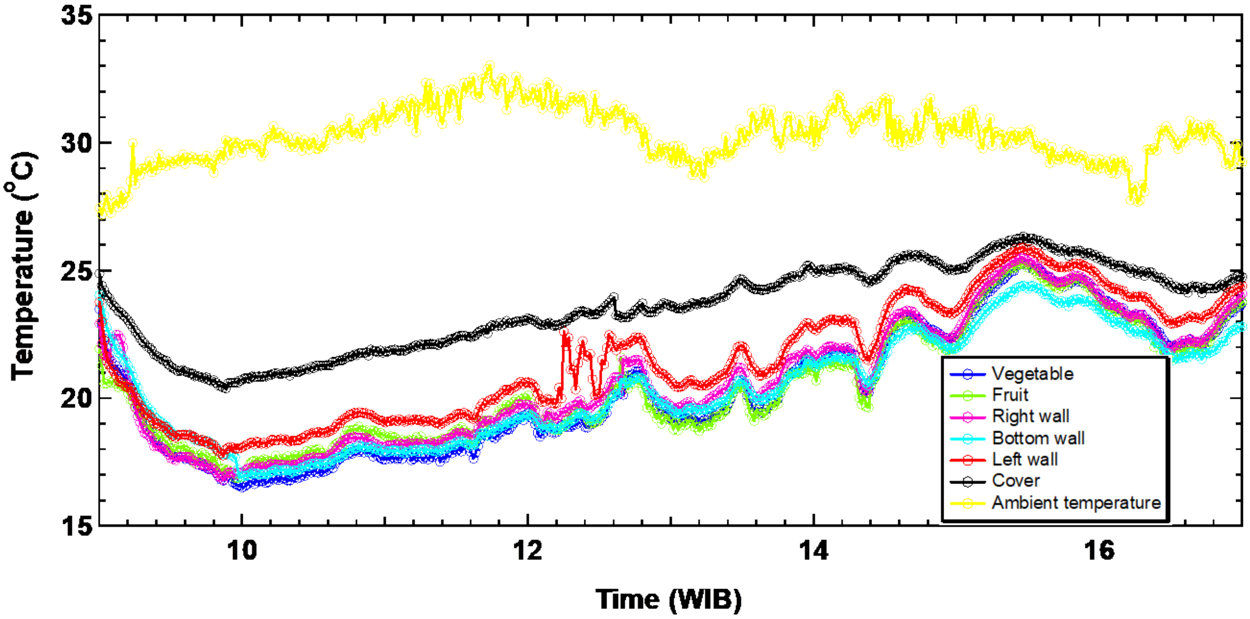

Figure 3. The temperature distribution of the Peltier cooling box system on the first day

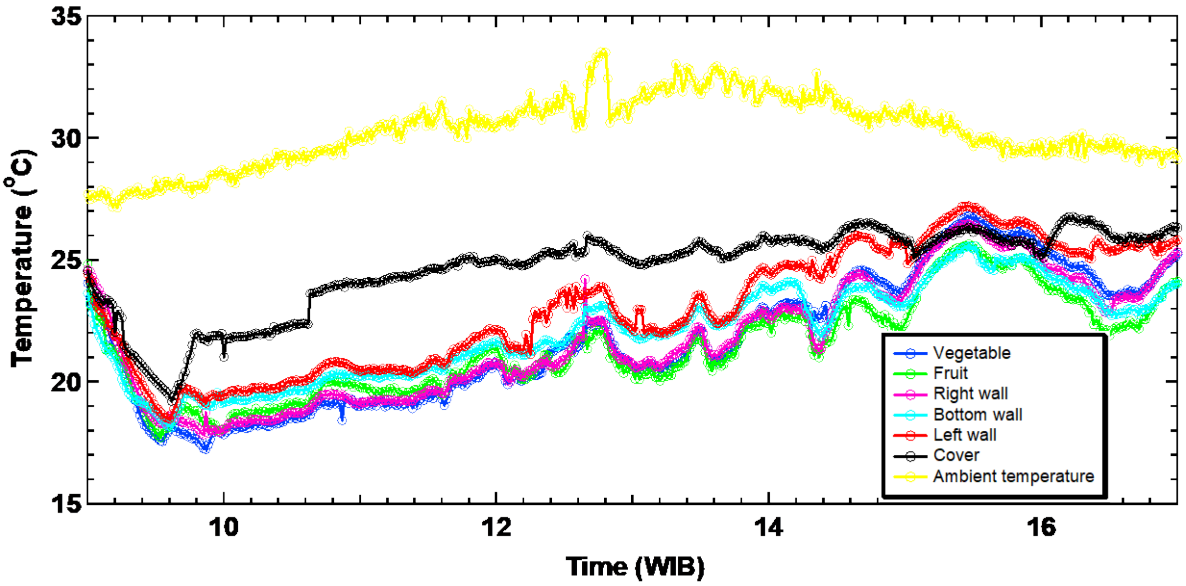

Figure 4. The temperature distribution of the Peltier cooling box system on the second day

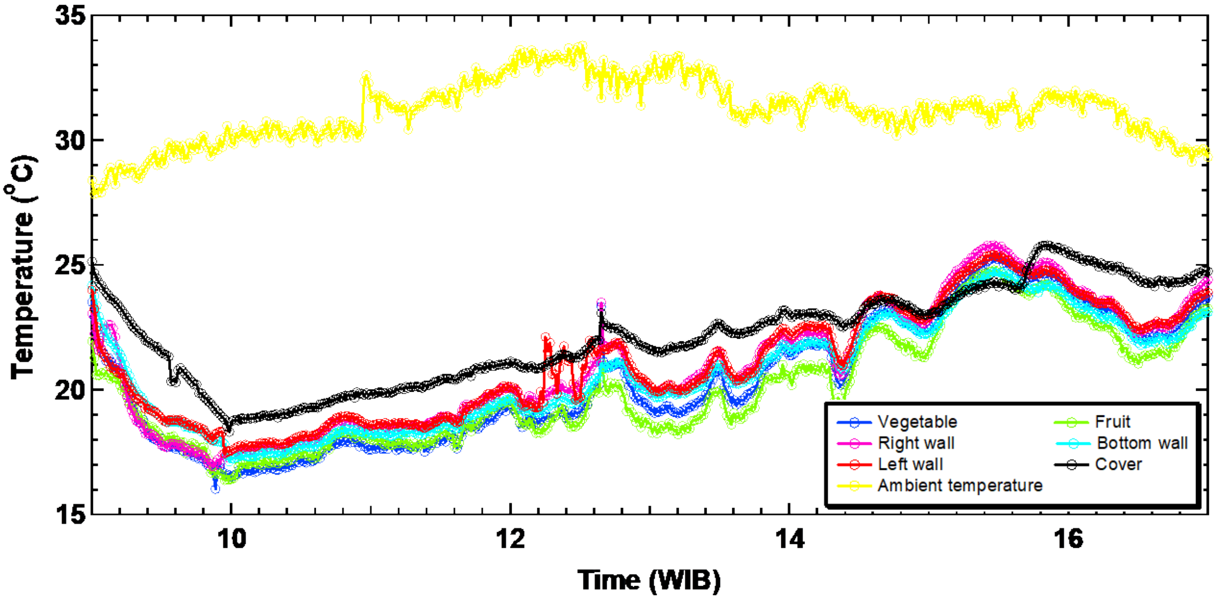

Figure 5. The temperature distribution of the Peltier cooling box system on the third day

During the experiments in three days, the minimum temperatures of vegetables are 17.324°C, 17.876°C, and 18.102°C, respectively. The minimum temperature of fruits is 17.688°C, 17.923°C, and 18.328°C. The minimum temperature of vegetables and fruits is obtained on the first day with an average environmental temperature of 31.593°C. Generally, the minimum temperature of vegetables and fruits is obtained at 09.00-10.00 WIB. The average temperature of vegetables and fruits is 22°C, and the average temperature of the inner wall of the cooler box is around 23°C. The measurement results showed that the average temperature of the outside air on the first day up to the third day was 30.803°C. The experimental data also showed that the maximum environmental air temperature that had been reached was 34.566^{o}C, which occurred on the first day. Based on the measurement results obtained that although small there is a temperature difference in the vegetables and fruits. This is influenced by the water content in the fruits and vegetables. In general, there is a difference in temperature distribution that occurs at the measured component point. Figures3 up to5 show that the temperature distribution on the top cover is higher than on the left, right, and bottom walls. This is also influenced by the distance of the heat sink components that are closer to the left, right and bottom walls and direct solar radiation towards the top cover. Experimental measurement data shows that the temperature on the outer wall is the highest compared to other measurement points. This is caused by the influence of ambient temperature and the effect of heat discharged by the fan from the heat sink attached to the surrounding environment. Research data indicate that the temperature distribution in the cooler box is quite evenly distributed to all sides of the cooler. The temperature difference in the cooler with the ambient temperature is around 14-17°C. This condition indicates the occurrence of heat removal processes contained in the cooler into the ambient so that there is a cooling effect on the vegetables and fruits. The measurement results also show there were fluctuations in the temperature distribution of the components measured in the cooler box during the experiments. Several factors can cause an analysis of the variation of the temperature distribution in the cooler. First, changes in the ambient temperature also influence the temperature distribution in the cooler. Second, the performance of a fan that is used for a long time can result in heat in the cooler system. Third, the reduced supply of energy from the battery to drive the fan and Peltier components that make the cooling system is not optimal. It was found from the experimental results that the maximum COP value was 0.670 on the first day with the cooling time of 41 minutes. The COP value obtained is influenced by the cooling time for each experiment and the energy supply from the battery to the Peltier component. Based on the analysis carried out that battery capacity correlates with solar radiation received by solar cells. The intensity of solar radiation is strongly influenced by fluctuating weather experiencing sunny and cloudy conditions.

Table 3. The COP value obtained

Day	Initial temperature (^{o}C)	Minimum temperature (^{o}C)	Cooling time (minute)	Average ambient temperature (^{o}C)	COP
1	25,561	17,324	41	31,593	0,670
2	25,654	17,876	45	30,586	0,525
3	26,819	18,102	49	30,229	0,428

5. Conclusions

The Peltier cooler box has been successfully assembled and tested its performance. The advantage of the Peltier cooling system driven by solar power is without using electrical energy and chemical refractors so that it is environmentally friendly. In testing for three days, the minimum temperature was obtained for vegetables and fruits of 17.324°C. The average temperature of vegetables and fruits during the experiments ranges from 22^{o}C. This condition is enough to keep vegetables and fruits fresh because based on the literature that the average temperature for fresh vegetables and fruits is smaller than the room temperature of 25°C.

The results of the experiments indicate that the Peltier cooling system tested can be used to maintain the freshness of vegetables and fruits. The maximum COP value of the Peltier cooling system tested is 0.670, and the minimum COP value is 0.428. For further research, it is necessary to consider the capacity of batteries to store energy from photovoltaic cells because this also affects the performance of the Peltier cooling system.

References

[1] Yan-Wei Gao, Hao L, Xiao-Dong Wang, Wei-Mon Yan. 2017. Enhanced Peltier cooling of two-stage thermoelectric cooler via pulse Currents. *International Journal of Heat and Mass Transfer*vol 114 pp. 656-663.

[2] T.B. Sitorus et al., 2018 IOP Conf. Ser.: Mater. Sci. Eng. 420 012025

[3] T.U.H.S. Ginting Manik et al., 2018 IOP Conf. Ser.: Mater. Sci. Eng. 420 012026

[4] Rumbayan M., Nagasaka K. 2012. Solar Irradiation Estimation With Neural Network Method Using Meteorological Data In Indonesia. *International Journal of Technology*vol 2, pp.110-120.

[5] Irvan et al. 2017, IOP Conf. Ser.: Mater. Sci. Eng. 206 012028

[6] F. Ariani et al. 2017, IOP Conf. Ser.: Mater. Sci. Eng. 277 012045

[7] T.B. Sitorus et al., 2018 IOP Conf. Ser.: Mater. Sci. Eng. 309 012089

[8] J Arjuna et al. 2018 IOP Conf. Ser.: Mater. Sci. Eng. 309012088

[9] Sabah A. Abdul-Wahab, Ali Elkamel, Ali M. Al-Damkhi, Ishaq A. Al-Habsi, Hilal S. Al-Rubai'ey. 2009. Design and Experimental Investigation of Portable Solar Thermoelectric Refrigerator. *Renewable Energy*vol 34 pp. 30-34.

[10] Xi H, Luo L, Fraisse G. 2007. Development and applications of solar-based thermoelectric technologies. *Renew Sustain Energy Rev*vol 11 pp. 923-36.

[11] Bosen Qian, Fei Ren. 2016. Cooling performance of transverse thermoelectric devices. *InternationalJournal of Heat and Mass Transfer*vol 95 pp. 787–794

[12] T. B. Sitorus, F. H. Napitupulu, H. Ambarita, T. G. Manik. TAE 2016 - Proceedings of 6th International Conference on Trends in Agricultural Engineering 2016.

[13] Christian J.L. Hermes, Jader R. Barbosa Jr. 2012. Thermodynamic comparison of Peltier, Stirling, and vapor compression portable coolers. *Applied Energy* vol 91 pp. 51-58

[14] T. B. Sitorus, F.H. Napitupulu, H. Ambarita. 2016. Experimental Study of Solar Refrigerator System Using Activated Alumina and Methanol Adsorption Pair. *International Journal of Technology*. IJTech Journal, Vol. 7, Issue 5, pp. 910-922.

[15] Martinez, D. Astrain, A. Rodriguez, P. Aranguren. 2016. An advanced computational model for Peltier effect based refrigerators. *Applied Thermal Engineering*vol 95 pp. 339-347.