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Car Cabin Cooling System Using Solar Energy

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Abstract. Recent Car cabin cooling system works while the car is running or the engine is started. When the car stops or the car park is turned off, the cooling system automatically does not work and the cabin space becomes hot. In principle, the cooling system works by absorbing heat from the cooling room, as the cooling system that uses solar energy. In this study, solar energy is used to be converted into electrical energy which is then used in the car cabin cooling system. This study aims to obtain the maximum heat absorption where the minimum temperature in the car cabin is obtained. This research was a combination of three systems, namely the solar cell system, the thermoelectric system, and the cooling system itself. Solar and thermoelectric cells were placed on top of the car's cabin, which is a cool chamber. On the upper side of the inside of the cooling chamber, a heatsink was used to get as much heat absorption as possible. The heatsink was attached to the cold side of the thermoelectric, while the hot side of the thermoelectric was closed so that the temperature can be controlled. Solar cells that face direct sunlight throughout the day (measurement time from morning to evening) would convert solar energy into electrical energy. Through a thermoelectric cooling system that is supplied with electrical energy from solar cells, the cooling system underneath would absorb the surrounding heat where the temperature of the cooling room would decrease in turn. The results showed that the cooling room conditions were as follows, namely the coefficient of performance (CoP) obtained by the cold room was 0.042 and the lowest temperature that could be reached was 25.60 oC.

1. Introduction

The car cooling system only works when the car is started or is running. When the car is stopped or parked, the car engine automatically stops the cooling system. The cabin space of the car becomes hot [1]. This condition makes it unsafe and uncomfortable to be inside of the car cabin, as it is detrimental to health.

Solar energy is a renewable and environmentally friendly energy source [2]. However, the great potential of this energy has not been optimally used, especially in the field of transportation and indoor air conditioning systems. Through solar cells, solar energy can be converted into electrical energy. This electric energy can be utilized by the thermoelectric cooler to cool a room, by holding the temperature on the hot side so that the cold side can absorb heat and reduce the surrounding temperature. Meeting the needs of air conditioning requires the availability of a cooling machine that is powered thermally and electrically. Conventional cooling technology is dominated by compression cooling systems [3].

The existence of thermoelectric technology contributes to the development of cooling technology, especially for room coolers [4]. Solar thermal energy can be used for cooling [2]. The integration of solar energy into the 'cold' production process is carried out using a source of heat energy supplied from the solar collector or electricity supplied from the solar cell system [5].

The solar cell system converts on average less than 20% of solar radiation to electricity, while the remaining 80% is converted to heat [6]. Solar radiation in the form of heat is part of the solar spectrum that emits photon energy. Solar cell technology uses adaptations from semiconductors [7]. This technology generates electricity from the energy transfer contained in the photons [7] with an energy level higher than the gap band energy level of the absorbent material. Photons with an energy level lower than the slit band energy level are not absorbed by the solar cell and can contribute to heating the solar cell when absorbed by metal back contacts [8]. The energy generation of the electron-hole pair, is depicted in Figure 1 below [9].

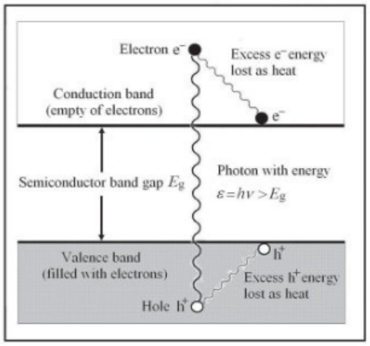

Figure 1. Energizing the electron-hole pair [9]

The solar cell system produces performance that is influenced by material parameters, temperature, light intensity, and light spectrum. The input electric power that comes from the intensity of sunlight is measured and calculated in the area of the solar cell module, with equation [1]:

$$P_{in(pv)} = E_{ph}A \tag{1}$$

Solar cells produce output electric power obtained from measurements of electric voltage and electric current, which are calculated by Equation [1]:

$$P_{out(pv)} = VI \tag{2}$$

The electric power given to the thermoelectric cooling system is supplied from the solar cell generator. Therefore, the output power from the solar cell becomes the input power for the thermoelectric cooling system, whereby [10]:

$$\dot{W} = P_{out(pv)} \tag{3}$$

The electric power that goes into the thermoelectric cooling system makes a temperature difference in the thermoelectric module which takes advantage of the Peltier effect on the thermoelectric module [10]. The cooling due to the Peltier effect is depicted in Figure 2 below, which is different from the Seebeck effect [5].

$$P_{in(pv)} = E_{ph}A \tag{4}$$

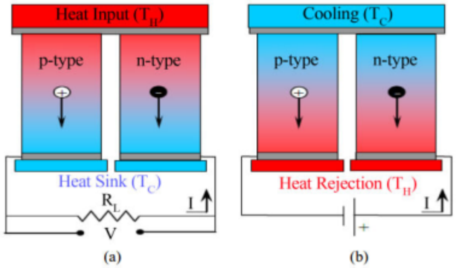

Figure 2. Arrangement of the thermoelectric module for power generation by the Seebeck effect and (b) cooling by the Peltier effect [5]

The heat absorbed by the cold side of the Peltier cooler is [11]:

$$\dot{Q}_c = \propto T_c I - \frac{1}{2} I^2 R - K \Delta T \qquad (5)$$

While the heat released by the hot side is [11]:

$$\dot{Q}_h = \propto T_h I + \frac{1}{2} I^2 R - K \Delta T \qquad (6)$$

The first law of Thermodynamics which applies across a pair of sides of a thermoelectric module is [11]:

$$\dot{W} = \dot{Q}_h - \dot{Q}_c \qquad (7)$$

The cabin of the car on all four sides has glass with a heating source from the engine, which is sensitive to thermal loads due to slight insulation. Therefore, the car cabin space cooling system is influenced by material factors, geometry, the number of people inside the car, weather conditions (air temperature, inner and outer surface temperatures, wind speed, relative humidity, and sunlight intensity), and heat transfer that occurs (inside and outside convection, conduction, and radiation). The transfer of heat in a car cabin is influenced by several mechanisms, including [1]:

1. Heat transmission through the windshield.
2. Conduction through the car body.
3. Air convection in the car cabin.
4. Radiation emitted by car interiors.
5. Air vents in the car.

In the cooling room, there is a mechanism of heat transfer for conduction and convection. Conduction occurs on the walls of the cooling chamber and the heatsink fins. Meanwhile, convection heat transfer occurs from the heatsink fins to the cooling chamber.

Conduction heat transfer is the transfer of heat to the material which is not followed by particle transfer. Conduction occurs due to differences in temperature between one side of a material. The equation used in conduction heat transfer was introduced by Fourier as follows [12]:

$$q = -k.A.\frac{T_1 - T_0}{\Delta x} \qquad (8)$$

Meanwhile, the transfer of heat from the conduction fin is [13]:

$$q_{fin} = \left[\sqrt{hPkA_c}\tanh\left(\sqrt{\frac{hP}{kA_c}}L\right)\right](T_b - T_\infty) \qquad (9)$$

Convection heat transfer occurs in the fluid due to the movement of the fluid particles. The convection process is accompanied by mass movement of particles, where convection involves thermal transfer and mass transfer. The equation used comes from Newton's Law of Cooling, namely [12]:

$$q = h.A.(T_s - T_\infty) \tag{10}$$

In a car cabin cooling system, heat transfer convection occurs by natural convection or free convection. In this type of convection, a buoyancy force movement occurs due to the reduced density of fluid near the surface of heat transfer due to the heating process [12]. In this natural convection heat transfer, there are four dimensionless numbers, namely Prandtl number (Pr), Nusselt number (Nu), Grashof number (Gr), and Rayleigh number (Ra). For the Nusselt number it is calculated by Equation [12]:

$$Nu_x = \frac{hx}{k} \tag{11}$$

For free convection analysis, it is free convection from vertical plates, both for the transmission heat load between the walls in the cooling chamber and the transmission heat load between the inner walls and the outside environment. In free convection, the following three equations apply, namely Equations (11), (12), and (13) [12]:

$$Gr_x = \frac{g.\beta.(T_w - T_\infty).x^3}{v^2}\, Gr_x = \frac{g.\beta.(T_w - T_\infty).x^3}{v^2}\, Gr_x = \frac{g.\beta.(T_w - T_\infty).x^3}{v^2} \tag{12}$$

$$T_f = \frac{T_w + T_\infty}{2} \tag{13}$$

$$Ra = GrPr \tag{14}$$

Meanwhile, free convection on the vertical plate is determined with the following two equations, namely equations (14) and (15) with their use the range of Ra values is determined [12]:

$$\underline{Nu} = 0{,}68 + \frac{0{,}670 Ra^{1/4}}{[1+\left(\frac{0{,}492}{Pr}\right)^{\frac{9}{16}}]^{4/9}}\ untuk\ Ra_L < 10^9 \underline{Nu} = 0{,}68 + \frac{0{,}670 Ra^{1/4}}{[1+\left(\frac{0{,}492}{Pr}\right)^{\frac{9}{16}}]^{4/9}}\ untuk\ Ra_L < 10^9 \tag{15}$$

$$\underline{Nu^{1/2}} = 0{,}825 + \frac{0{,}387 Ra^{1/6}}{[1+(\frac{0{,}492}{Pr})^{9/16}]^{8/27}}\ untuk 10^{-1} < Ra_L < 10^{12} \underline{Nu^{1/2}} = 0{,}825 +$$

$$\frac{0{,}387 Ra^{1/6}}{[1+(\frac{0{,}492}{Pr})^{9/16}]^{8/27}}\ untuk 10^{-1} < Ra_L < 10^{12} \quad \underline{Nu^{\frac{1}{2}}} = 0{,}825 + \frac{0{,}387 Ra^{\frac{1}{6}}}{\left[1+\left(\frac{0{,}492}{Pr}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}$$

$$\underline{Nu^{1/2}} = 0{,}825 + \frac{0{,}387 Ra^{1/6}}{[1+(\frac{0{,}492}{Pr})^{9/16}]^{8/27}}\ untuk 10^{-1} < Ra_L < 10^{12}\ \ untuk 10^{-1} < Ra_L < 10^{12} \tag{16}$$

The heat loss can be calculated using the equation of heat transfer on a flat wall with the following equation [10]:

$$q = \frac{T_{luar} - T_{kabin}}{\left(\frac{\Delta x}{k.A}\right)_{logam} + \left(\frac{\Delta x}{k.A}\right)_{insulasi}} \tag{17}$$

The cooling chamber performance is calculated by equation [1]:

$$CoP = \frac{Q_c}{W} \tag{18}$$

The heat load absorbed by the cooling chamber is calculated as the sum of the heat loss, transmission heat load, and heat absorbed by the heatsink.

2. Methodology

The research was not carried out on actual cars. Rather, by making a space cooler model in the form of a cold room. The solar cell is placed on an inclination of 30o facing North (the optimal position to get sunlight for this part of the earth in south latitude). The solar cell used was the 100 Wp *Polycrystalline Solar Cell Module* 1005 mm x 665 mm x 30 mm. Thermoelectric coolers were used as thermoelectric type TEC 1-12706 with BiSn material measuring 40 mm x 40 mm x 3.8 mm. The heatsink was made of aluminum which has a size of 350 mm x 78 mm x 40 mm and has 10 fins. The *thermoelectric-heatsink* pairs are arranged in a parallel arrangement for the thermal system, whereas the electrical system is pre-tested with batteries for each series, series-parallel, and parallel connection that was then installed in the system.

In the cooling chamber, a thermoelectric-heatsink arrangement was placed at the top. All the walls in the cold room and the bottom were covered with aluminum metal, while the outer layer was covered by *Styrofoam* insulation material. Metal layers and insulation represent the composition of the material in the actual car cabin space. Measurement of sunlight radiation intensity was carried out throughout the day by paying attention to data on air temperature, air humidity, and wind speed at each measurement time. The temperature of the upper and lower sides of the solar cell was also measured to monitor the decrease in the performance of the solar cell due to the increase in temperature. The solar energy received by the solar cell module was converted into electrical energy and was then flowed to the *Solar Charge Controller*. Afterwards, it was then stored in the battery (*energy storage*) and from the Solar Charge Controller, electrical energy was also given to the load (cooling system).

The system device was tested by observing the temperature of the cold room. If the temperature obtained was still far from the target temperature, then this data was said to be invalid and the system was checked or replaced by the temperature device and the cooling space (volume) was checked in relation to the insulation system. If the resulting temperature was within the target temperature tolerance, data was said to be valid and the system would be analyzed.

3. Result and Discussion

In this car cabin cooling system, solar cells were used as a converter of solar energy into electrical energy. Energy input and energy output in solar cells and environmental conditions that influence them were described below. Figure 3 below explains the magnitude of the solar radiation intensity received by solar cells per one square meter and the resulting output.

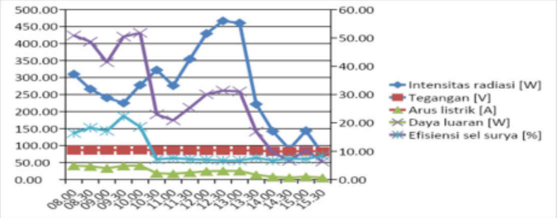

Figure 3. Input, output, and performance of solar cells

The magnitude of the intensity of solar radiation received by the surface of solar cells fluctuate due to weather conditions, which were environmental temperature, air humidity, and wind speed, as well as sunny or cloudy cloud conditions [10]. The output of a solar cell was an electric current that tends to decrease, while the voltage was stable over the span of the measurement time. This output was influenced by changes in radiation intensity and temperature of solar cells [1]. The environmental temperature was high enough, so that it has a heating effect on solar cells. The temperature of the solar cell was quite high both on the top and the bottom side. The temperature difference between the two sides relied on the composition of the solar cell panels and the level of solar radiation [14]. The cell temperature increased and the output electric power tended to decrease.

The supply of electrical energy from the solar cell was used by the thermoelectric module to convert them into the temperature difference between the two sides. The cold side would absorb heat, while the hot side would release heat. Figure 4 below describes the temperature distribution in the cooling system, namely the thermoelectric cooler temperature and the cooling room temperature as well as the ambient temperature and outside-cooling temperature.

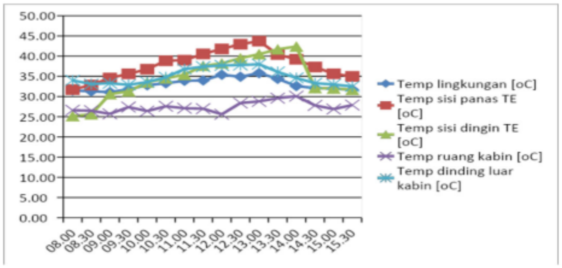

Figure 4 Distribution of cold room temperature

In Figure 4 above, the graph of the hot side temperature increased through the ambient temperature, because the hot side of the thermoelectric not only received heat from the sun but also released heat from the thermoelectric system [10]. When the environmental temperature decreased due to changes in air humidity, wind speed increased, the outer wall temperature was still high due to heat absorption in the wall material. The cabin room temperature that can be achieved ranged from 25° C [1] to 30° C.

The CoP cooling system calculation is:

$$CoP = \frac{q_c}{P_{in}}$$

$$CoP = \frac{2{,}5011675\ W}{60{,}09\ W} = 0{,}042$$

4. Conclusion

Solar cells in this study can convert the average solar radiation energy of 268.84 W with an output power performance of 28.43 W, while the efficiency obtained was 10.79%. The cold room has a performance coefficient; the largest CoP is 0.042. The lowest cold room temperature that this cooling system can produce is 25.60oC. With the achievement of the lowest temperature, research on the model of a car cabin cooling room can be carried out in the actual location and conditions. Performance improvements can be obtained with accurate construction that can prevent heat loss to a minimum.

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