EXPERIMENTAL ANALYSIS OF A COOLING SYSTEM FOR PARKED AUTOMOBILE CABIN EMPLOYING THERMOELECTRIC REFRIGERATION

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ABSTRACT

This work is aimed at the solution to a real-life problem. It mainly aims in providing cooling to an automobile cabin when it is parked steadily in hot sun. It has been observed that the temperatures inside a closed car cabin get too high and in-turn they are spreading harmful gases like carcinogen which causes cancer in addition to that benzene gas is also released which is injurious to health. In order to resolve this, a cooling and ventilation system that uses conservative energylike solar energy as a power source and a thermo-electric refrigeration module using a Peltier cooler. All these systems are coupled with a microcontroller and temperature sensor and the entire system is made to run automatic without the usage of engine power forming a mechatronics system. With the help of this system, cabin temperature can be reduced to an extent where the environment inside the cabin becomes safe and comfortable.

Keywords: *Automobile air-conditioning, Cooling system, Mechatronics, Parked car cooling, Thermoelectric refrigeration.*

1. Introduction

This work mainly aims in cooling of an automobile cabin when it is parked steadily in hot sun. It has been observed that the temperatures inside a closed car cabin are getting too high and in-turn they are spreading harmful gases like carcinogen which causes cancer in addition to that benzene gas is also released which are poisonous. The thermoelectric effect represents direct conversion of the temperature difference into voltage and vice versa and refers to phenomena with which the current flows through the ends of a thermoelectric module. The thermoelectric effect is formed due to free motion of the charge carriers (free electrons $e-$ considered as negative charge carriers and holes $h+$ considered as positive charge carriers) in metals and semiconductors while carrying energy and electric charge. The thermoelectric effects are Peltier effect, Thomson effect and SeeBeck effect. This effect was discovered in 1834 by the French physicist Jean-Charles-Athanase Peltier. It is the phenomenon that converts current to temperature and occurs when an electric current flows through a thermoelectric device. The Peltier effect is a reversible phenomenon, because the Peltier heat depends directly on the direction of the carrier flow or electrical current. There is interdependence between the sense of the electric current and the temperature difference at the hot and cold ends of a thermoelectric device. In other words, if the current flow is changed, the temperature at the hot and cold ends is changed as well.

The heat flow rate is given by

$$Q_{Peltier} = \pi\ AB.I.T = (\pi B - \pi A).\ I\ .T \quad (1)$$

Where QPeltier is the absorbed or dissipated heat flow rate, in W; I is the electric current that flows through the junctions, in A; **π AB**, **πA** and **πB** are the Peltier coefficients of the thermocouple and conductors A and B, in $W{\cdot}A^{-1}$; and T is the absolute temperature, in K. The Peltier coefficient π is defined as the amount of heat developed or absorbed at a junction of a thermocouple when a current of one ampere passes through this junction for one second. The Peltier coefficient π is positive for heat absorbed and negative for heat dissipated. The Peltier coefficient determines a cooling effect when the current flows from the N-type semiconductor material to a P-type semiconductor material and a heating effect when the current flows from the P-type semiconductor material to an N-type semiconductor material. This effect was discovered by a German physicist Thomas Johann SeeBeck in 1821. It is the production of an electromotive force (emf) and consequently an electric current in a loop of material consisting of at least two dissimilar conductors when two junctions are maintained at different temperatures. The conductors are commonly metals, though they need not even be solids. The voltages produced by SeeBeck effect are small, usually only a few microvolts (millionths of a volt) per kelvin of temperature difference at the junction. If the temperature difference is large enough, some SeeBeck-effect devices can produce a few millivolts (thousandths of a volt). Numerous such devices can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current. Large arrays of SeeBeck-effect devices can provide useful, small-scale electrical power if a large temperature difference is maintained across the junctions. The Seebeck effect is responsible for the behavior of thermocouples, which are used to approximately measure temperature differences or to actuate electronic switches that can turn large systems on and off. This capability is employed in thermoelectric cooling technology. Commonly used thermocouple metal combinations include constantan/copper, constantan/iron, constantan/chromel and constantan/alumel. The SeeBeck coefficient is defined as the ratio of the voltage difference to the temperature gradient. If the temperature difference δT between two ends of a material is small, then the SeeBeck coefficient of a material is defined as:

$$\alpha_{ab} = \frac{\delta V}{\Delta T} \quad (2)$$

$$\alpha_{ab} = \alpha_a - \alpha_b \quad (3)$$

α_a and α_b are the SeeBeck coefficients with the units of volts per Kelvin for metals p. This effect was discovered (1854) by the British physicist Kelvin. It is the evolution or absorption of heat when electric current passes through a circuit composed of a single material that has a temperature difference along its length. If a copper wire carrying a steady electric current is subjected to external heating at a short section while the rest remains cooler, heat is absorbed from the copper as the conventional current approaches the hot point, and heat is transferred to the copper just beyond the hot point. It has two effects positive and negative. When the hot end has high voltage and the cold end has low voltage, the heat is generated when the current flows from hotter junction to colder junction, the heat is absorbed when the current flows from colder junction to hotter junction. Vice versa for the negative effect. Thermoelectric refrigeration is the process of pumping heat energy out of an insulated chamber in order to reduce the temperature of the chamber below that of the surrounding air. Thermoelectric refrigeration uses a principle called the 'Peltier' effect to pump heat electronically. Applying a DC voltage difference across the thermoelectric module, an electric current will pass through the module and heat will be absorbed from one side and released at the opposite side. One module face, therefore, will be cooled while the opposite face simultaneously is heated. This device is called Peltier device, it is a solid state active heat pump which transfers heat from one side of the device to the other, with the consumption of electrical energy and the direction of current. It is also called as Thermoelectric cooler (TEC). It can either be used for cooling application or heating application.

2. Literature review

The vast review of literature will help to understand the concepts, theory and different factors affecting the performance of machine: -

John H Miller et al [1] studied about a solar energy cell system is used as an electric supply source to operate an air conditioner or a fan ventilation system contained within the interior chamber of an automobile. The electrical circuit comprises a series circuit consisting of: the solar energy cells, a voltage regulator, a storage battery, a thermostatic temperature control and a ventilation fan or an automobile air conditioner. Shu Shum et al [1] studied about an automobile cooling system where electrical energy derived from solar cells are used to drive the pump and fan of a vehicle mounted evaporative cooling system. Automatic control of the system is provided by a thermostatic switch located within the vehicle. Lon E. Bell, Robert W. Diller [3] investigated that in certain embodiments, a thermoelectric heat pump includes a heat transfer region having an array of thermoelectric modules, a waste channel in substantial thermal communication with a high temperature portion of the heat transfer region, and a main channel in substantial thermal communication with a low temperature portion of the heat transfer region. Rudolf Joseph Franz et al [4] studied the performance of ambient or recirculated air is passed through a housing containing an evaporator core and a heating core by means of a blower The control system comprises an automatic temperature control sensor which provides a modulated vacuum control signal for a vacuum motor which has an output which adjusts a biasing element in a pressure operated electrical switch, resulting in on/off duty cycling of an electrically energizable clutch which transmits power from the vehicle engine to the cooling unit compressor. Sham P Sundhar et al [5] investigated an air conditioning unit is provided for a parked automotive vehicle having a cooling unit comprising a

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cooling chamber with at least one insulated wall having on opposite sides thereof a heat sink and a cooling block having there between a thermoelectric chip. Lakhi Nandlal Goenka et al [6] examined a heating, ventilating and air conditioning (HVAC) system for a hybrid vehicle is disclosed, the HVAC system including at least one thermoelectric device for providing supplemental heating and cooling for air supplied to a passenger compartment of the vehicle. S.B. Riffat, Xiaoli Ma [7] presents the results of tests carried out to investigate the potential application of heat pipes and phase change materials for thermoelectric refrigeration. The work involved the design and construction of a thermoelectric refrigeration prototype. Yuanyuan Zhou, Jianlin Yu [8] presents a generalized theoretical model for the optimization of thermoelectric cooling (TEC) system, in which the thermal conductance from the hot and cold sides of the system are taken into account. Detailed analyses of the optimal allocation of the finite thermal conductance between the cold- side and hot-side heat exchangers of the TEC system are conducted by considering the constraint of the total thermal conductance.

3. Construction of Peltier device

Each Peltier features an array of alternating n type and p type semiconductors. The array of elements is soldered between two ceramic plates, electrically in series and thermally in parallel. Solid solutions of bismuth telluride, antimony telluride, and bismuth selenide are the preferred materials for Peltier effect devices because they provide the best performance from 180 to 400 K and can be made both n-type and p-type. The cooling effect of any unit using thermoelectric coolers is proportional to the number of coolers used. Typically multiple thermoelectric coolers are connected side by side and then placed between two metal plates.

3.1 Solar panel and Solar charge controller

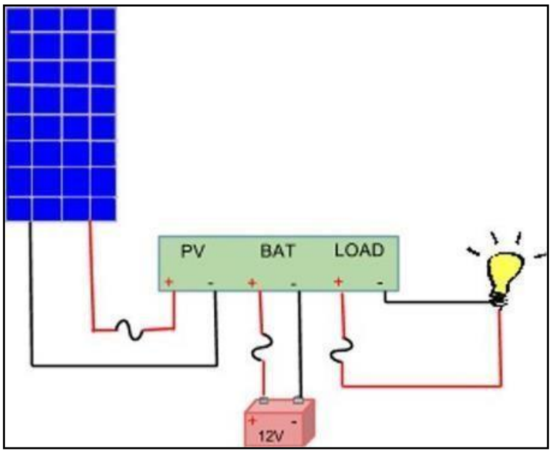

Figure 1 implementation of solar charge controller

Two solar panels with a solar rating at standard test conditions 1000 W/m^2, 1.5 A.M^2, 25 °C which can output 8.5V and a max voltage of 10V individually, were used in the apparatus. Both were connected in series to produce 17V with 6 watts power outp

Three Peltier's (TEC12706) with rating of 12V and 5A are used in making this cooling kit.

To extract heat from the hot side of the peltier's, 3 large aluminium sinks with fans are attached to it.

3.3 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328. It has 20 digital input/output pins (of which 6 can be used as PWM outputs and 6 can be used as analog inputs), a 16 MHz resonator, a USB connection, a power jack, an in- circuit system programming (ICSP) header, and a reset button.

Figure 2 peltier module (TEC1-12706)

Figure 3 cool side aluminium sink

3.4 Power

The Uno R3 can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from

an

Figure 4 hot side sink with fan

AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm centre-positive plug into the board's power jack. Leads from a battery can be inserted in the Ground and input voltage pin headers of the power connector. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the

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board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

3.5 Memory

The ATmega328 has 32 KB (with 0.5 KB used for the boot loader) is used. It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

3.6 Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pin Mode, digital Write, and digital Read functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 KOhms. The Uno R3 has 6 analog inputs, labelled A0 through A5, each of which provides 10 bits of resolution. There are a couple of other pins on the board: AREF. A reference voltage for the analog inputs is used with analog reference. Reset brings this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board

3.7 Relay switches

Relays are most commonly used switching devices in electronics. We are using a 12V dual channel relay switch, so that we can send the power for cooling unit only when the temperature sensor crosses

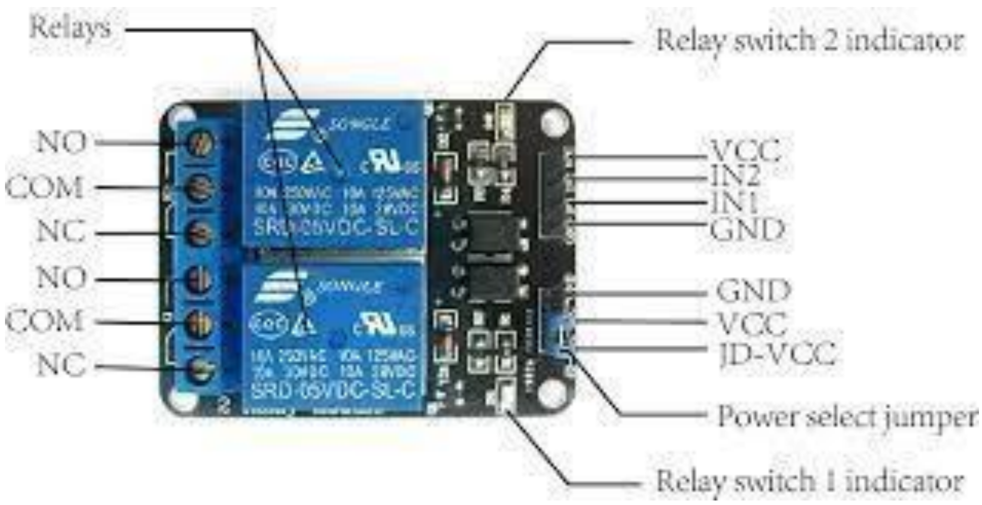

Figure 5 12V dual channel relay switch

the target temperature and also to cut off the power when the required temperature is achieved. The usage of relay switch along with the temperature system makes the cooling unit to run automatically without the intervention of human operation.Com (Common) is connected to the end of the load that is to be controlled. Normally close (NC) is the other end of the load is either connected to NO or NC. If connected to NC the load remains connected before trigger. Normally open (NO) is the other end of the load is either connected to NO or NC. If connected to NO the load remains disconnected before trigger.

Figure 6 ports of relay switch

3.8 Battery

A rechargeable lead acid battery of capacity 30Ah is used. they are the technology of choice for automotive SLI (Starting, Lighting and Ignition) applications because they are robust, tolerant to abuse, tried and tested and because of their low cost.

3.9 TEC Cooling Box

Three Peltier modules are connected in series in order to cool the air. A thermoelectric cooling is chosen because in this system there are no moving parts and it occupies less space. It can be easily fit in an automobile without altering its design. The cooling of the air is done inside a thermocol box. The heat sinks are attached to the hot junction of the Peltier module using a thermal paste, and CPU fans are connected to the heat sinks in order to remove the heat from the heat sinks. The three Peltier modules and the three fans are connected in series. The Peltier modules are connected in series because when connected in series the modules give more cooling effect than when connected in parallel. All the three modules are placed on a board of 16mm thickness. Since the hot junction attains higher temperatures, the heat sinks used to remove heat are heavier. In order to support all the weights high thickness board is used.

3.10 Power consumption

4 Peltier modules 12V 5A	→	12*5=60W*4 peltier's = 240W (4)
4 Big fans	12V 0.3A →	12*0.3 = 3.6W*4 fans = 14.4W (5)
4 Small fans	12V 0.7A →	12*0.7 = 8.4 W*4 fans=33.6W (6)

3.11 Connections

The COM port of relay 1 is connected with the common positive terminal of the peltier kit and the negative terminal of the peltier kit is connected to the NC port of relay1. On the input side IN1 pin is connected to Arduino's analog pin 13 and the VCC pin is connected to the supply and the ground pin

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of relay is connected to the ground pin of Arduino. The positive of the exhaust fan is connected to the analog 4th pin of the Arduino and the negative of the exhaust fan is connected to the Arduino ground pin.

4. Result and discussions

Peltier surface temperatures were shown in the table below after running a certain period of time. The above results are recorded at the start of making the peltier cooling kit so that we could actually know how much temperatures we are getting on the peltier cold surface. Then the temperature of air is recorded after making the entire cabin with fans and sinks and the cold side is completely insulated with a thermocol box. The below readings were taken on a hot sunny day, the cabin is placed under hot sun and then final readings were taken. Periodic readings were taken to check various reality scenarios like if the car is parked for 10 min how much amount of cooling is needed, similarly for 20min like particular intervals and readings of the inside temperature were taken.As already mentioned in previous chapter, the readings were taken with and electronic thermometer, the probe is placed near the fan of the cooling kit, temperature difference obtained with this equipment can be observed. A temperature difference of nearly 20°C was obtained when compared with the ambient conditions. A temperature of 72.1^{o}C is noted without cooling system after one hour where as with cooling system a temperature of 51^{o}C.

Table 4.1 Peltier Module Temperature Readings

Ambient temperature	Peltier run time	Cool side surface temperature	Hot side temperature
28°C	01 min	8°C	35°C
28°C	02 min	12°C	33°C
28°C	05 min	15°C	31ºC
28°C	30 min	18°C	30°C
28°C	45 min	19°C	31°C
28°C	60 min	19°C	32°C

Table 4.2 Cabin Temperature Readings

Run time of Peltier cooling kit in minutes	Ambient temperature	Cabin temperature before turning ON	Cabin temperature after turning ON
10 min	30.9°C	46.3°C	40.7°C

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20 min	31.0°C	48.0°C	42.6°C
30 min	31.7°C	57.7°C	45.9°C
45 min	32.0°C	63.0°C	48.2°C
60 min	32.6°C	72.1°C	51.0°C

5. Conclusion

A real-life problem of heating up of car cabin parked under Sun due to green house effects can be controlled by providing ventilation and some cooling system. A solar assisted parked car cooling system is proposed and experimentally investigated. All these systems are coupled with a microcontroller and temperature sensor and the entire system is made to run automatic without the usage of engine power forming a mechatronics system. It is observed that with the help of this system, cabin temperatures can be controlled effectively to an extent where the environment inside the cabin becomes safe and comfortable and this system does not lay additional load on the engine because it relies on solar energy.

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