Smart Peltier Thermoelectric Cooling System

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ABSTRACT

It generally say 'Energy can neither be created nor be destroyed', only it can be transformed from one form to another form. This is the Universal Truth and in concern with that many scientists given their laws. The existing air conditioning system works on the compressor and these depends on refrigerant gases like Freon, Ammonia, CFCs etc. One of the major disadvantages for these refrigerant gases are global warming and harmful gas emission which contributes in environmental problems. So, to reduce the intensity of the discharge gases eco-friendly alternative had found. Research shows that thermoelectric cooler is the best option for this problem. Motive of this project is to analyse the working of the TEC and to design the system. The system uses TEM which works on Peltier effect. On this phenomenon this project had developed, a new air conditioning system which works on Peltier effect of thermoelectric module (TEM) which is completely eco-friendly air condition and portable, no vibration, small in size unlike the existing cooling system.

Keywords: *Air conditioning, eco-friendly, peltier effect, thermoelectric module (tem), thermoelectric cooler (TEC).*

INTRODUCTION

Refrigeration, including air conditioning and other conventional cooling systems are necessary in life and will continue to expand worldwide. But its impact on environment is huge as compare to its cooling purpose. In fact, one kilogram of the refrigerant has the same greenhouse impact as two tons of carbon dioxide, which is the equivalent of running your car for six months. Many efforts have already been made. However, reduction in CO2 emissions and fluorinated gas emissions are challenges to be addressed on an ongoing basis.

As heat carrier fluids in conventional refrigeration systems has become a subject of great concern and resulted in extensive research into development of refrigeration technologies. It is found by some researchers that Thermoelectric operated devices can be the best alternative in refrigeration technology due to their distinct advantages. Meanwhile, due to the semiconductor temperature control system using the Peltier element, so compared with the traditional temperature control method, it also has the advantages of small volume, light weight, long service life, no noise, no mechanical movement, rapid refrigeration, high precision temperature control, no need of refrigerant, no pollution to the environment.

LITERATURE SURVEY

Mohammad Majid M. ALKhalidy, this paper shows the strong side of using Peltier (TEC) module in Air cooling systems and it shows that the TEC is small in size, operate silently, has free vibration and it work as cooler in the summer and heater in the winter. And by considering the environmental problems this system does not emit harmful or toxic gases like

HCFCs and CFCs etc. This system works with the latest technology like the Internet of Things IOT, in which it uses a smartphone app to make the air-conditioner very convenient.[1]. Akram N M, Nirmani H R This paper analyzes the cooling performance of thermoelectric air conditioner. The researcher has conducted an experiment on the TEM and concluded on the investigation of the thermal study of the thermoelectric module. TEC1-12708 type thermoelectric module has used by the researcher for heating and cooling application experiments.

Major results have been identified, such as relation between voltage and temperature / temperature gradient of two surfaces and current flow in TEC and efficiency and impact of different cooling methods. By using Active and passive cooling can increase the efficiency of the system [2]. Marc Hodes in this paper the analysis is generalized by using flux-based quantities where applicable and it accounts for the electrical contact resistance at the interconnects in a TEM. Implementation of the optimization procedures are illustrated and the ramifications of the results are discussed [3].

Kaloyan IVANOV, Ivaylo BELOVSKI has design a Small Portable size Thermoelectric Refrigerator for Vaccines. In this paper the researcher has find the way to design a lightweight, efficient and compact system. The system has calibrated to draw less current and work on low electric energy about 60 W. The system can maintain and reach up-to negative temperature within the compartment [4].Radek Guráš, Miroslav Mahdal has used TEM for liquid cooling purpose and from mathematical calculation and simulation its shows that the design of this system is not appropriate as COP of the device is very less as compare to compressor refrigeration device. The calculated efficiency of the device is approximately 12.6%, which is a low value as compared to compressor refrigeration devices, which normally show an efficiency of about 50-60%. Researcher had highlighted some of the TEM advantages over conventional cooling devices such as in the field of noise and vibration, where the use of thermoelectric elements has no competition [5].

In the above papers design the low COP of TEM is concern, so this paper has come-up with a solution to increase the COP of the system. Here 3-stage (multistage) thermoelectric module has considered and mathematical analysis shows that COP is increased to 3times than the normal single stage TEM. Researchers are Jatin Patel, Matik Patel, Himanshu Modi [6]. Niketan Patil had a study that Peltier devices are very reliable because they contain no moving parts providing silent operations and vibration-free [7].

Yan SUN and Zhen-Fei WEN both researched tells is TEM made of two different semiconductors. When DC voltage is supplied to the surface of TEC, its one side releases heat and make it cold while opposite side gets heated [8]. Ning Wang Shown that the cross-section area of the Semiconductor pellets in a Thermoelectric Module (TEM) operating in refrigeration mode does not affects its performance or efficiency, but may size to tune its operating current and voltage. Next it is shown that a range of pellets heights accommodates a specified performance below the maximum one and a procedure is provided to compute the corresponding maximum efficiency [9].

Mr. Swapnil B. Patond gave the advantage that the important thing is to be note that it the one-time investment & is free from maintenance. A similar model was made in Oman which was totally helpful to that people in 1996[10]. According to C.A.

Gould, N.Y.A. Shammas Thermoelectric module has a relatively low conversion efficiency and figure-of-merit (ZT) compared with other technologies. Also some researches are going on to synthesizing new materials and fabricating material structures with improved thermoelectric performance, in an attempt to improve the thermoelectric figure-of-merit by reducing the lattice thermal conductivity[11].

BASIC PRINCIPLE

Thermoelectric Effect

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

The Seebeck Effect

The German physicist Thomas Johann Seebeck discovered this effect in 1821. The Seebeck effect is used to measure temperature with more sensitivity, accuracy and to generate electric power for special applications. It is named for the Baltic German physicist Thomas Johann Seebeck. Basically in thermocouple measurement; thermocouple A is used as a reference and maintained at a cool temperature, T_L. While thermocouple B is used to measure the temperature that is need, in this case T_H.

Normally the temperature, T_L is greater than temperature, T_H. When heat is applied to thermocouple B, a voltage will appear between terminal T_1 and T_2. This voltage known as Seebeck EMF shown in figure 1.

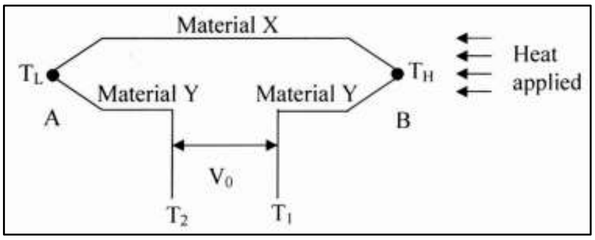

Fig. 1: *Circuit to illustrate Seebeck Effect[12].*

The Peltier Effect

The Peltier effect is the inverse to the Seebeck effect. Figure 2 indicates that an electrical current, I will flow in the circuit if a voltage, Vin is applied to terminals T_I and T_2. Because of the current flow, a slight cooling effect, Q_L will occur at junction A where heat is absorbed while a heating effect, Q_H will occur at junction B where heat is expelled. Note that this effect may be reversed whereby if the direction of the electric current flow is changed, it will reverse the direction of heat flow.

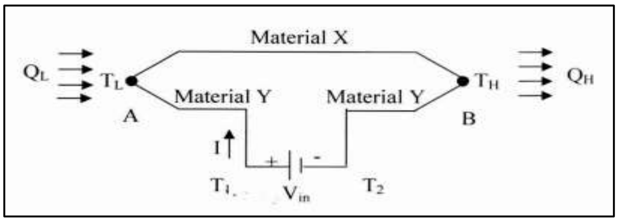

Fig. 2: *Circuit to illustrate Peltier Effect [12].*

The Thomson Effect

This effect was discovered in 1854 by the British physicist William Thomson (Lord Kelvin). For Thomson effect the heat is evolved or absorbed when current flows in a thermoelectric element with a temperature gradient. But the Thomson effect is not important in the operation of practical thermoelectric modules.

BLOCK DIAGRAM

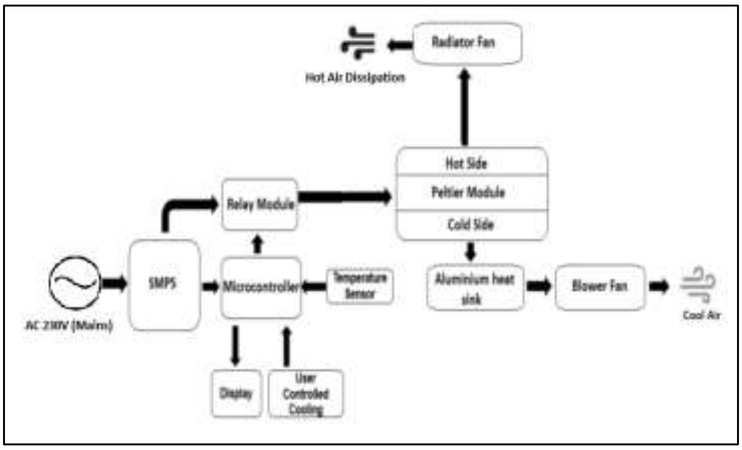

Fig. 3: *Block Diagram of the System.*

Figure 3 shows Block Diagram of the system. A single phase 230V, 50Hz AC supply which is easily available in our houses is given to the SMPS (Switch Mode Power Supply). SMPS converts 230V AC supply into 12V DC supply which is requirement of us. The Same supply given to the Arduino UNO R3 (A Microcontroller used here). With Arduino UNO R3, various devices are connected like Temperature sensor (DS18B20 Thermal probe sensor) and 16×2 LCD Display.

Simultaneously 12V DC output of SMPS is given to the Relay Module as an input Relay module is connected parallel to the Arduino. Here relay module work as a switch. Further the output from the relay module (12V DC) is given to the Thermoelectric Module. 12 V DC input creates the Temperature difference between P-N junctions with the help of Peltier effect. The electrons from the P side moves towards the N side making the density of electrons towards P side is less compared to N side. That creates Temperature difference making one side as a Heat absorbing (Cooling Side) while other is Heat releasing (Hotter side). Thermoelectric Module contains 2 heat sinks for improve the performance efficiency. Heat sink on hot side called Hot side heat sink while heat sink on cold side called cold side sink. On both hot and cold surface fan is placed, blows the cool air from the cool side and heat dissipation occurs from the heat sink.

The Temperature is set by the user through user controllable device which is connected to the Micro-controller. The cold side temperature is sensed by the Thermal Probe Sensor, placed on the cold side sink. If the temperature of the cooling (cool side) gets decrease below the temperature set by the user, the feedback signal is given to microcontroller (Arduino UNO). It automatically sends signal to relay module which switch off the supply, given to Peltier module. The temperature of the cooling is shown on the 16×2 LCD display.

METHODOLOGY

An experiment was conducted by the researcher in one of the paper which identify the behaviour of TEC under availability of different cooling mechanisms at the hot surface. The researcher has conducted test in 3 different cases and results were obtained.

case1: TEM is used alone,
case2: Heat sink is placed on the TEM and
case3: Heat sink and fan is placed on the TEM

Figure 4. Shows Behaviour of TEC with different cooling methods illustrates below: For case 1 result is observed that while using the TEM alone the cold surface temperature was not able to maintain the constant temperature and the desired value. After some time the temperature is drastically increased.For case 2 results shows that there was slight improvement in the system, by using heat sink the hot surface dissipate heat more efficiently. Cold surface has reduce its temperature to 20°C within 30 seconds. But after some time the cool surface temperature has started increasing. For case 3 results shows better improvement in the results when the heat sink and fan has used. The cool side temperature has reduce till 17°C and that temperature is maintain constant. According to results, it is prove that a TEC cannot be used alone without a proper cooling mechanism at the hot surface. And using only a passive cooling would not be sufficient for the system to maintain the cold side temperature. The heat should be removed efficiently by combining both active and passive cooling. This project is created by combining three main circuits namely Microcontroller, Peltier Module, and Power supply unit. This project required a lot of procedures from getting information about how each part functions, what are previous researches has been done based on this, software learning, constructing the circuit and combining all the three circuits with other parts like Temperature Sensor, LCD Display, Draught fans etc.

The Peltier Module and all the components using each circuit is important in order to understand the process and details on how this circuits operates in individual and when it is combined. While making hardware model of this, it is important to know various graphs like voltage v/s Temperature. By considering their variation active cooling technique (Heat sink+Draught fan) is used. Based on all information gathered all three circuits have different functions but receiving the same power supply from the SMPS. The function of each circuit is explained with the help of block diagram (Fig.2.5) to clearly illustrate how all circuits flow. After once the hardware model has been done it get tested and optimization of it can be done. Later optimization final submission has been done.

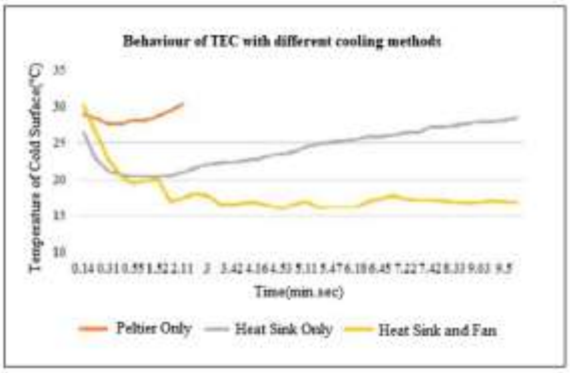

Fig. 4: *Behaviour of TEC with different cooling methods [2].*

Components Specifications

1. Arduino UNO: Operating Voltage: 5 Volts, Input Voltage: 7 to 20 Volts, Digital I/O Pins: 14 (of which 6 can provide PWM output), Analog Input Pins: 6, Weight: 25 g, Power Sources: DC Power Jack & USB Port.
2. Thermoelectric Module (Peltier module) TEC1 12706 Bismuth Tin: Imax= 6A, Vmax=14V, Module Resistance=1.98ohm, Dimensions (mm) = 40*40*3.8, Max. operating temperature = 138 degree Celsius , Life Expectancy= 200000 hours, Failure rate= 0.2%. No. of modules= 2
3. Thermal Paste: ARCTIC MX-4 Thermal Paste.
4. Thermocol: thermal conductivity is 0.025
5. SMPS (Switch Mode Power supply): Input Voltage 100 – 270V AC , Output Voltage 24 V DC , Output Current 5A.
6. Relay Module: Supply voltage – 12V Single channel.
7. Display: LCD Display 2*16.
8. Temperature Sensor (DS18B20): Thermal Probe Temperature Sensor.
9. Radiator fan=12V (For Active Cooling) No. of Fans= 2
10. Aluminium Heat Sink
11. Bluetooth Module: hc-05

MATHEMATICAL CALCULATION

A. COP**:** COP is the ration of the thermal output power and electrical input power of the TEC. It is a unit-less parameter and used to measure the performance of cooling system. The coefficient of performance which is the thermal efficiency must be considered for a TE system. It depends upon the material which is used in TEM. The materials used are semiconductors. Bismuth-Tin semiconductors TEM is used. It is very reliable having widely used which having failure rate 0.2%.

Peltier Module Dimensions: length = 40mm, width = 40mm, height = 3.9mm
Mass = 25g
Supply Current (I) = 3 A
Supply Voltage (V) = 12 V
Resistance (R) = 4 Ω
Temperature of Hot Side (T_1) = 60 degree Celsius
Temperature of Cold Side (T_2) = 20 degree Celsius
Seebeck coefficient (α) = 5.72 x 10^-4 V/K
q_h = Heat Rejection W
q_c = Heat Absorption W
W= Energy Supplied W

Effective Thermal Conductance (U) = 0.06 W/K

COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power.

$$COP = \frac{Q_c}{W} = \frac{Q_c}{Energy\ supplied} = \frac{Q_c}{(Q_c - Q_h)}$$

Thermoelectric heating(Q_h), while the heat transferred out of the hot side into heat sink is given by,

$$Q_h = \alpha T_1 I - U(T_1 - T_2) + \tfrac{1}{2} I^2 R$$

Thermoelectric cooling (Q_c), the amount of heat to be absorbed at the cold surface is given by,

$Q_c = -[\alpha T_2 I - U(T_1 - T_2) - ½ I^2 R]\ I^2 R]$
(–) sign for heat rejection.

Energy supplied,
$W = -Q_h + Q_c$
$= -[\alpha T_1 I - U(T_1 - T_2) + ½ I^2 R] + [\alpha T_2 I - U(T_1 - T_2) - ½ I^2 R]$
$= -[\alpha (T_1 - T_2) I + I^2 R]$

Where negative sign indicated that energy has to be supplied to the system.
Coefficient of Performance can be calculated as,

$$COP = \frac{\alpha T_2 I - U(T_1 - T_2) - ½ I^2 R}{[\alpha (T_1 - T_2) I + I^2 R]}$$

Heat absorption is calculated as below,

$Q_c = -[(5.72 \text{ x}10^{-4}) \times (293) \times 3 - 0.06 \times (313) - \frac{1}{2} \times 9 \times 4]$
$= -[-36.277]\text{ W} = 36.277\text{ W}$
$W = -Q_h + Q_c$
$= -[\alpha (T_1 - T_2) I + I^2 R]$
$= -(5.72 \text{ x } 10^{-4}) \text{ x } (273+40) \text{ x } 3 + (3^2 \text{ x } 4)$
$= 36.5371\text{ W}$

$$\therefore COP = \frac{Q_c}{W}$$

$$= \frac{\alpha T_2 I - U(T_1 - T_2) - ½ I^2 R}{[\alpha (T_1 - T_2) I + I^2 R]}$$
$$= \frac{36.277}{36.519} = 0.9928$$

Total Internal Heat Energy and Time required for cooling:
Let’s consider following assumptions: -
Q_c = Cooling capacity of TEM (J/s)
C_p = specific heat capacity (Air: 1005 J/Kg°C)
ρ = density of air (1.165 kg/m^3)
ΔT= Temperature difference

Mass of the air in room (M) = Vρ (ρ=density of air)

$$\text{Time} = \frac{Q}{Q_c}$$

Q = Total internal heat energy inside the room (Joules)
$Q = MC_p \Delta T$

Now let’s consider three different volumes of room required to cool and consequently calculate the time taken for cooling.

1) Considering 30cm x 30cm x 30cm of cube.
Volume of cube(V) = l × b × h

= 0.3m × 0.3m × 0.3m
= $0.027m^3$
Mass of Air(M) = Vρ
= 0.027 x 1.165
= 0.03145 Kg
Total internal heat energy $(Q) = MC_p\Delta T$
= 0.03145 x1005 x 10
= 316 J
Time required to cool that volume = $\frac{Q}{Q_c} = \frac{316}{36}$
= 8.77sec

2) Considering 45cm x 45cm x45cm of cube.
Volume of cube(V) = l × b × h
= 0.45m × 0.45m × 0.45m
= $0.091m^3$
Total internal heat energy (Q) = 1066 J
Time required to cool that volume = $\frac{Q}{Q_c}$ = 29.61 sec
3) Considering 60cm x 60cm x 60cm side of cube.
Volume of cube (V) = l × b × h
= 0.6m × 0.6m x 0.6m
= $0.216m^3$
Mass of Air (M) = 0.2516 Kg
Total internal heat energy $(Q) = MC_p\Delta T$
= 2528.98 J
Time required to cool that volume = $\frac{Q}{Q_c}$ = 70.25 sec

It is seen that as the volume is increased, the time required for cooling is also increases. Simultaneously the number of TEM also goes on increasing to cool the same volume of room. Heat generated from cold side heat sink fan is 12 volt × 0.12 Amp = 1.44 Watts. So, 1.44 Watts or 1.44 Joules per second heat is produce by the cool side heat sink fan.
Now let us consider one practical example.
Finding time taken to cool the 3m×3m×3m room by the cooling module.
3 meter = 9.8425 feet (approx 10 feet) .
Volume of cube(V) = l × b × h = $27m^3$
Mass of Air in room(M) = Vρ = 31.455 Kg
Total internal heat energy $(Q) = MC_p\Delta T$ = 316122 J
Time required to cool that volume = $\frac{Q}{Q_c}$ = 8781 sec
Time taken by the cooling module to cool the room is 8781 sec = 146 min
= 2 hour and 30 min (Approx.)
Consider, that system should cool the room in 10 min.
10min = 600sec
$Qc = \frac{Q}{Time} = \frac{316122}{600}$
= 526.87 W
No of Peltier module (TEM) required = $\frac{526.87}{36}$
= 14.63

= 15 (Approx.)

Hence, 15 peltier modules is required to obtain 20°C temperature in 10min.

The calculations have done considering TEM alone, hence the COP is less as compare to its desired performance. Approach is to optimize its COP above 1. From the free and forced convection calculation, conclusion is that the force convection increases performance of the system. Heat load calculation clearly shows that to cool the 3m x 3m x 3m room it take 2 hrs and 30 min, which makes it difficult to analysed the performance of the peltier module. And by using 15 peltier module the power consumption and cost increase. Hence to tackle this problem, 30cm × 30cm × 30cm container is used and from the above calculation time require to analyze the performance is less as compare to considering actual room size.

HARDWARE AND SOFTWARE WORKING

Fig. 5: *With acrylic sheet.*

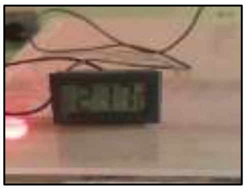

Fig. 6: *With acrylic + Styrofoam.*

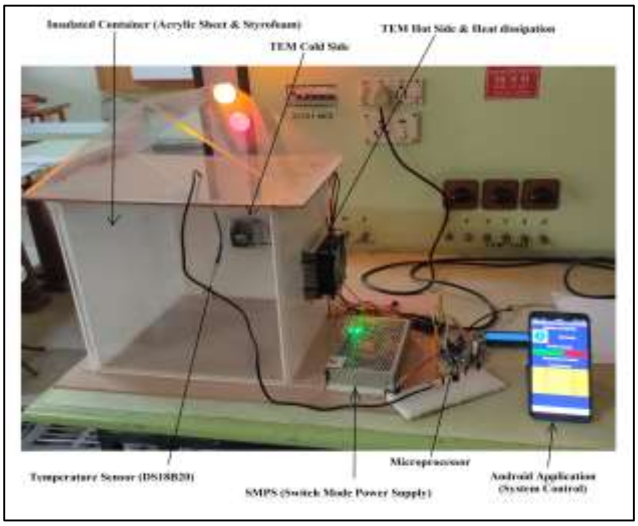

Fig. 7:.*Actual Overall System.*

Fig. 8: *Android Application for System Control.*

To implement the methodology a 30cm × 30cm × 30cm container is used, made up of acrylic sheet which has less thermal conductivity and thermocol (Styrofoam) is used as an insulation from the inner side of the wall. Initially the ambient temperature is 31℃, so the internal temperature of the block will be same. The cooling system has run for about 35 min with insulation and without insulation, and the following results shows the performance of the system.

Case 1: Without insulation provided to walls (only acrylic sheet), the internal temperature of the block is cooled down to 23.9 ℃. Figure 5. Shows the same.
Case 2: With insulation provided to walls (acrylic sheet + styrofoam), the temperature of the block is cooled down to 21.7 ℃. Figure 6. Shows the same.

CONCLUSION

The project idea is very clear that to make an alternative on cooling system. Not only this but in addition on that system should be portable, not complex, Environment friendly, compact in sized and maintenance free. The objective is to cool the particular volume of room. Making the collection of data and various sheets according that made our choice very clear. Understanding the dependency of COP on various parameters and cooling methods is also taken into considerations. In this project both mathematical as well as practical outcomes has done and from the results it is clear that TEM (Thermoelectric Module) cooling system performance is less as come to conventional cooling system. Time required to cool up to that temperature is quite high as compare to conventional cooling system. The main thing got here is that various methods to analyse the working of Thermoelectric Module. The social relevance for the project is that it does no discharge harmful gases, hence it as an Eco friendly system. But, as per observations there is a huge scope of research in this field about thermoelectric materials, its fabrication (multistage TEM module), heat sink design.

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