A PROJECT REPORT
ON
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SUBMITTED BY

VIBHU PANDA	**19GPTC4010064**
RAJAN DUBAY	**19GPTC4010055**
ATUL BAJPAYEE	**19GPTC4010040**
DEEPAK TIWARI	**19GPTC4010054**
PRINCE YADAV	**19GPTC4010071**

GALGOTIAS UNIVERSITY

Plot No.2, Sector 17-A Yamuna Expressway, Greater Noida, Gautam Buddh Nagar,

Uttar Pradesh, India, Session (2019-2022)

CERTIFICATE

This is to Certify that the project report entitled "PORTABLE AIR COOLER"Was Successfully completed by Student of sixth semester Diploma in mechanical engineering).

VIBHU PANDA	**19GPTC4010064**
RAJAN DUBAY	**19GPTC4010055**
ATUL BAJPAYEE	**19GPTC4010040**
DEEPAK TIWARI	**19GPTC4010054**
PRINCE YADAV	**19GPTC4010071**

In partial fulfillment of the requirements for the award of the Diploma in (Mechanical Engineering) and submitted to the Department of (Mechanical Engineering) of Galgotias University, University Polytechnic, work carried out during a period for the academic year 2019-2020 as per curriculum

Mr. Rashid Khan
Name of Program Chair

Mr. Rashid khan
Name of Guide

External Examiner

Mr. Mohit Gaharwar
(Principal)

GALGOTIAS UNIVERSITY

Plot No.2, Sector 17-A Yamuna Expressway, Greater Noida, Gautam Buddh Nagar,
Uttar Pradesh, India, Session (2019-2022)

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ABSTRACT

Refrigerator and air conditioners are the most energy consuming home appliances and for this reason many researchers had performed work to enhance performance of the refrigeration systems. Most of the research work done so far deals with an objective of low energy consumption and refrigeration effect enhancement. Thermoelectric refrigeration is one of the techniques used for producing refrigeration effect. Thermoelectric devices are developed based on Peltier and Seeback effect which has experienced a major advances and developments in recent years. The coefficient of performance of the thermoelectric refrigeration is less when it is used alone, hence thermoelectric refrigeration is often used with other methods of refrigeration. This paper presents a review of some work been done on the thermoelectric refrigeration over the years. Some of the research and development work carried out by different researchers on TER system has been thoroughly reviewed in this paper. The study envelopes the various applications of TER system and development of devices. This paper summarizes the advancement in thermoelectric refrigeration, thermoelectric materials, design methodologies, application in domestic appliances and performance enhancement techniques based on the literature.

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1. Introduction

Refrigeration is the process of heat-removal from a space in order to bring it to a lower temperature than surrounding temperature. In this context, my seminar topic, **“Peltier cooling module”** which works on thermoelectric refrigeration, aims to provide cooling by using thermoelectric effects rather than the more prevalent conventional methods like ‘vapour compression cycle’ or the ‘vapour absorption cycle’.

There are three types of thermoelectric effect: The Seebeck effect, the Peltier effect, the Thomson effect. From these three effects, Peltier cooler works on the Peltier effect; which states that when voltage is applied across two junctions of dissimilar electrical conductors, heat is absorbed from one junction and heat is rejected at another junction.

Peltier coolers are basically used as a cooling element in laser diodes, CCD cameras (charge coupled device), blood analyzers, portable picnic coolers laser diodes, microprocessors, blood analyzers and portable picnic coolers.

History

Thermoelectricity was discovered and developed in 1820-1920 in Western Europe, with much of work centered in Berlin. The first important discovery related to thermoelectricity occurred in 1823. German scientist Thomas Seebeck found that a circuit made from two dissimilar metals and junctions of the same kept at two different temperatures, produces thermoelectric force which is responsible for flow of the current through module. Now this invention is known as Seebeck effect. In 1834, a French watchmaker and physicist, Jean Charles Athanase Peltier invented thermoelectric cooling effect also known as Peltier effect. Peltier stated that electric current flows through two dissimilar metals would produce heating and cooling at the junctions. The true nature of Peltier effect was made clear by Emil Lenz in 1838, Lenz demonstrated that water could be frozen when placed on a bismuth-antimony junction by passage of an electric current through the junction. He also observed that if the current was reversed the ice could be melted. In 1909 and 1911 Altenkirch [6] give the basic theory of thermoelectric. His work explained that thermoelectric cooling materials needed to have high Seebeck coefficients, good electrical conductivity to minimize Joule heating, and low thermal conductivity to reduce heat transfer from junctions to junctions. In 1949 Loffe developed theory of semiconductors thermo-elements and in 1954 Goldsmid and Douglas demonstrated that cooling from ordinary ambient temperatures down to below 0°C was possible. Rowe, shortly after the development of practical semiconductors in 1950's, Bismuth Telluride began to be the primary material used in the thermoelectric cooling.

1.1 Objective of work

The objective of this seminar work is to analyze the working of Peltier cooler. Scope of this work includes:

- Study of the principles and working of Peltier refrigerator; working parameters; performance parameters of the same.
- Exploring methods to improve the efficiency of the Peltier cooling systems and study the advancement in the field of thermoelectrics.
- Studying new heat sink designs, which improves the performance of the Peltier cooler.

2. Theory

2.1 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.

2.1.1 The Seebeck effect

The Seebeck effect is the conversion of heat directly into electricity at the junction of dissimilar electrical conductors. It is named for the Baltic German physicist Thomas Johann Seebeck. [9]

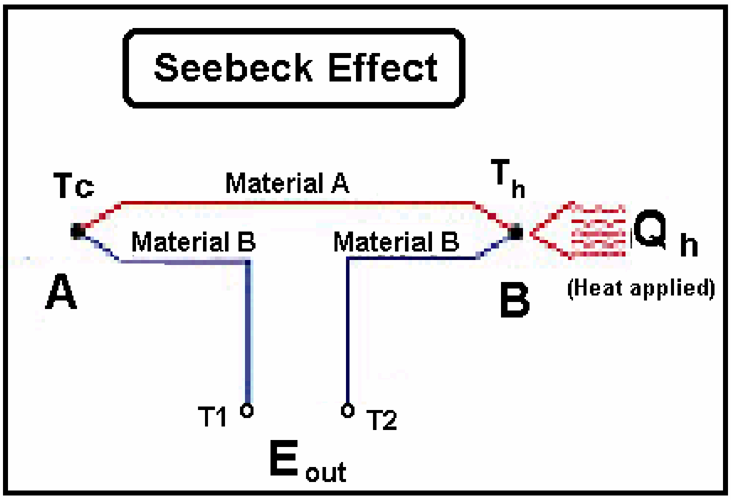


Figure 1 : The Seebeck effect

As shown in Figure 1, the conductors are two dissimilar metals denoted as material A and material B. The junction temperature at A is used as a reference and is maintained at a relatively cool temperature (TC). The junction temperature at B is used as temperature higher than temperature TC. With heat applied to junction B, a voltage (E_{out}) will appear across terminals T1 and T2 and hence an electric current would flow continuously in this closed circuit. This voltage is known as the Seebeck EMF, can be expressed as

$$E_{out} = \alpha(T_H - T_C)$$

Where:

- $\alpha = dE / dT = \alpha_A - \alpha_B$
- α is the differential Seebeck coefficient or (thermo electric power coefficient) between the two materials, A and B, positive when the direction of electric current is same as the direction of thermal current, unit is V/K.
- E_{out} is the output voltage in volts.
- T_H and T_C are the hot and cold junction temperatures, respectively, in Kelvin.

2.1.2 The Peltier effect

Peltier found there was an opposite phenomenon to the Seebeck Effect, whereby thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flowed within the closed circuit. [9]

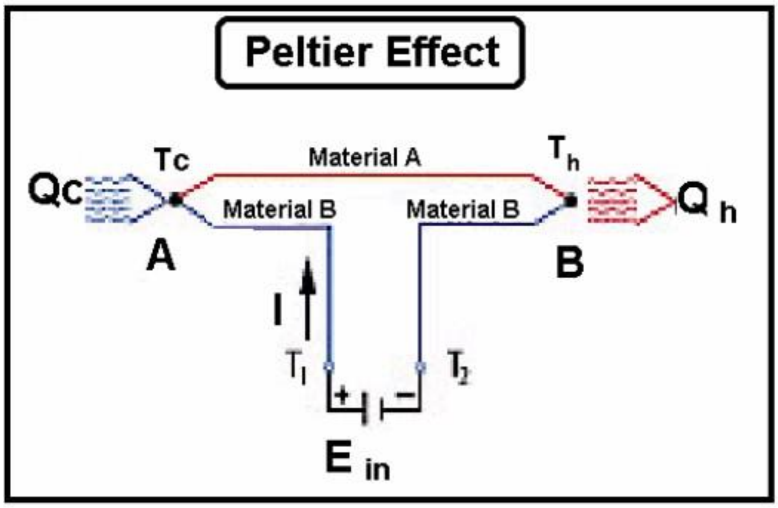


Figure 2 : Peltier effect

In Figure 2, the circuit is modified to obtain a different configuration that illustrates the Peltier Effect, a phenomenon opposite that of the Seebeck Effect. If a voltage (E_{in}) is applied to terminals T1 and T2, an electrical current (I) will flow in the circuit. As a result of the current flow, a slight cooling effect (Q_C) will occur at thermocouple junction A (where heat is absorbed), and a heating effect (Q_H) will occur at junction B (where heat is expelled). Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow.

Joule heating, having a magnitude of $I^2 \times R$ (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This Joule heating effect acts in opposition to the Peltier Effect and causes a net reduction of the available cooling. The Peltiereffect can be expressed mathematically as

$$Q_c \text{ or } Q_H = \beta \times I = (\alpha T) \times I$$

Where:

- β is the differential Peltier coefficient between the two materials A and B in volts.
- I is the electric current flow in amperes.
- Q_C and Q_H are the rates of cooling and heating, respectively, in watts.

2.1.3 The Thomson effect

As per the Thomson effect, when an electric current is passed through a conductor having a temperature gradient over its length, heat will be either absorbed by or expelled from the conductor. Whether heat is absorbed or expelled depends on the direction of both the electric current and temperature gradient. This phenomenon is known as the Thomson Effect.

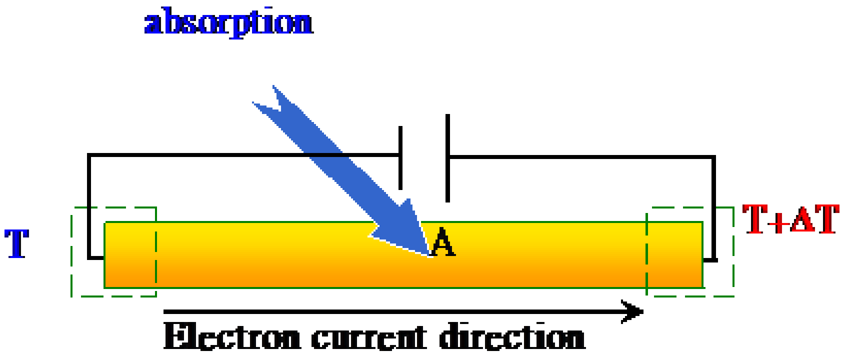


Figure 3 : The Thomson effect

2.2 Transport properties

The thermoelectric phenomena are reversible in the sense that they do not of themselves give rise to thermodynamic losses. However, they are always, in practice, accompanied by the irreversible effects of electrical resistance and thermal conduction. It turns out that the performance of any thermocouple as an energy convertor can be expressed in terms of the differential Seebeck coefficient and the thermal and electrical resistances of the two branches. These resistances depend on the thermal and electrical resistivities and the ratios of length to cross-sectional area.

The electrical resistivity ρ is the reciprocal of the electrical conductivity σ, which is defined by the relation,

$$I = \frac{\sigma V A}{L}$$

Where, 'I' is the electric current through a specimen of constant cross-sectional area A and length L when a voltage V is applied. Likewise, the thermal conductivity, K is defined by the equation,

$$q = -\frac{K A \Delta T}{L}$$

Where, q is the rate of heat flow through a similar specimen that has a temperature difference T between its two ends. We shall refer to the thermoelectric coefficients and the electrical and thermal conductivities of a given material as its transport properties. All these properties will generally be temperature-dependent.

3. Working and fabrication

3.1 Working of Peltier cooler

The Peltier effect occurs whenever electrical current flows through two **dissimilar conductors**; depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. In the world of thermoelectric technology, **semiconductors** (usually Bismuth Telluride) are the material of choice for producing the Peltier effect because they can be more easily optimized for pumping heat. Using this type of material, a Peltier device (i.e., thermoelectric module) can be constructed in its simplest form around a single semiconductor "pellet" which is soldered to electrically-conductive material on each end (usually plated copper). In this configuration, the second dissimilar material required for the Peltier effect, is actually the copper connection paths to the power supply. [10]

It is important to note that the heat will be moved in the direction of charge carrier movement throughout the circuit (actually, it is the charge carriers that transfer the heat).

3.1.1 Peltier cooling with N-type semiconductor

In Figure 5, "N-type" semiconductor material is used to fabricate the pellet so that electrons (with a **negative** charge) will be the charge carrier employed to create the bulk of the Peltier effect.

As shown in **Error! Reference source not found.**, N-type semi-conductor has a extra electron in its Fermi level (higher energy level).

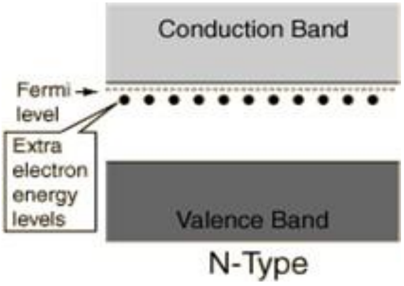


Figure 4 : N-type semiconductor Energy band diagram [11]

With a DC voltage source connected as shown, electrons will be repelled by the negative pole and attracted by the positive pole of the supply; due to this attraction, electrons at Fermi level move towards positive terminal by releasing heat and creating the holes in the Fermi level. Now, due to continuous supply of current, electrons move from valance band (lower energy band) to Fermi level by absorbing energy from the junction. With the electrons flowing through the N-type material from bottom to top, heat is absorbed at the bottom junction and actively transferred to the top junction. [10]

So we can say that, in Peltier cooler using N-type of semiconductor, heat is absorbedat the junction near negative terminal and heat is rejected at the junction near positiveterminal.

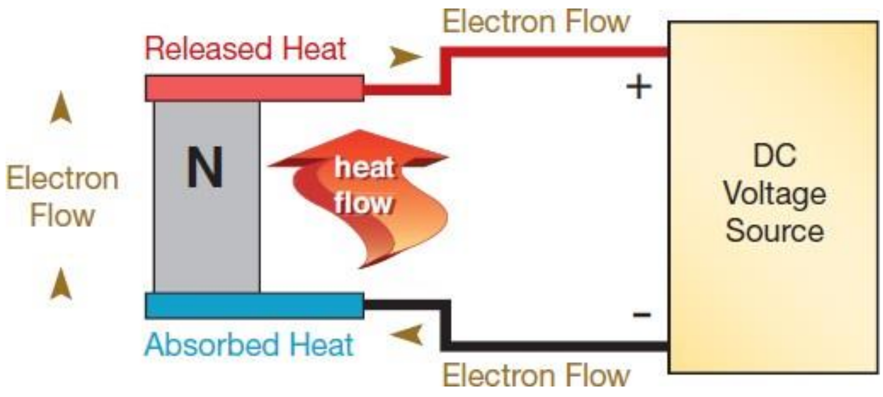


Figure 5 : Peltier cooling with N-type semiconductor [10]

3.1.2 Peltier cooling with N-type semiconductor

In the thermoelectric industry, “P-type” semiconductor pellets are also employed. Figure 6 shows the energy band diagram of P-type semiconductor. In this, holes are at the Fermi level (higher energy level).

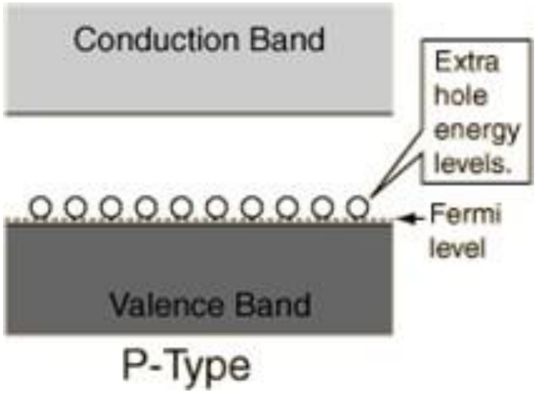


Figure 6 : P-type semiconductor Energy band diagram [11]

Now, when DC current is applied through the circuit as shown in Figure 7; holes get attracted towards negative terminal of source. By this attraction, holes move to negative terminal by releasing heat. Due to continuous supply of current, holes from conduction band moves to Fermi level by absorbing heat from the junction.

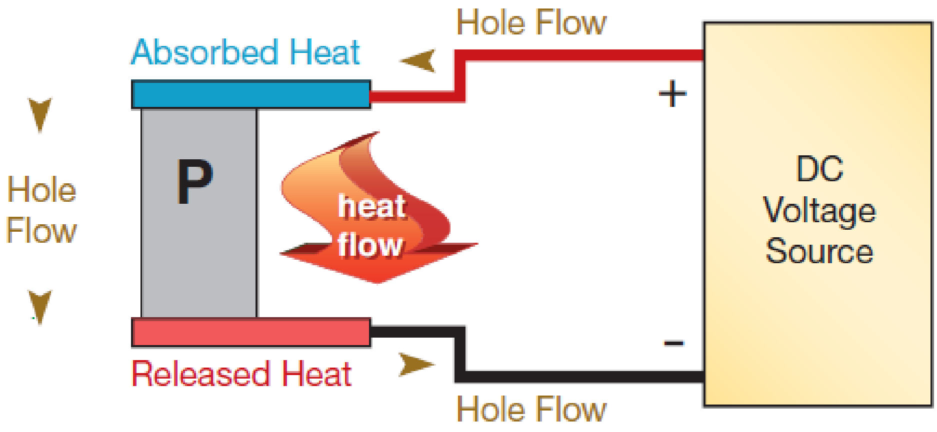


Figure 7 : Peltier cooling with P-type semiconductor [10]

So we can say that, in Peltier cooler using P-type of semiconductor, heat is absorbed at the junction near positive terminal and heat is rejected at the junction near negative terminal.

3.1.3 Peltier cooling with P & N type of semiconductors

By arranging N and P-type pellets in a “couple” (see Figure 8) and forming a junction between them with a plated copper tab, it is possible to configure a series circuit which can keep all of the heat moving in the same direction. As shown in the illustration, with the free (bottom) end of the P-type pellet connected to the positive voltage potential and the free (bottom) end of the N-type pellet similarly connected to the negative side of the voltage.

As we have seen in previous section, for N-type of semiconductor, heat is absorbed from the junction near to the negative terminal and heat is releases at the junction near to the positive terminal. For P-type of semiconductor, heat is absorbed from the junction near to positive terminal and released at the junction near to negative terminal.

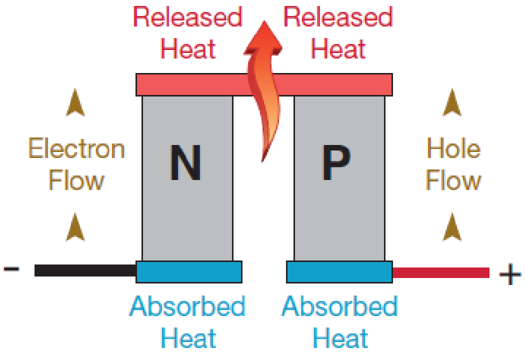


Figure 8 : Peltier cooling by couple of N&P [10]

By arranging the circuit as like in Figure 8, it is possible to release heat to the one side and absorb from another side. Using these special properties of the TE “couple”, it is possible to team many pellets together in rectangular arrays to create practical thermoelectric modules as in Figure 9.

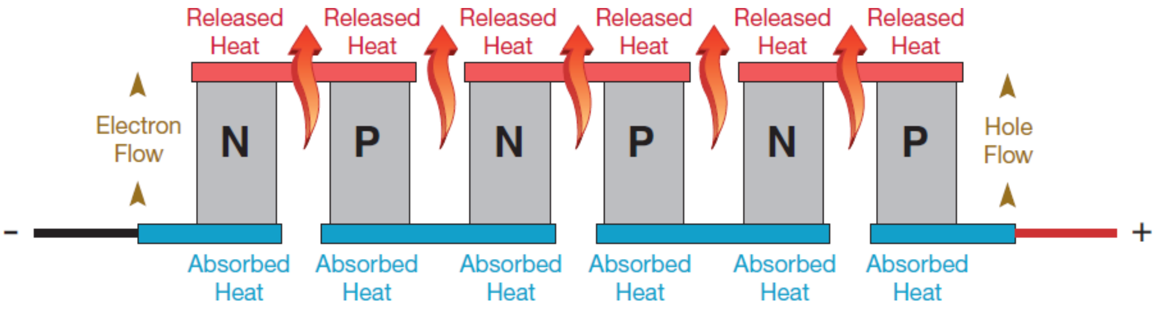
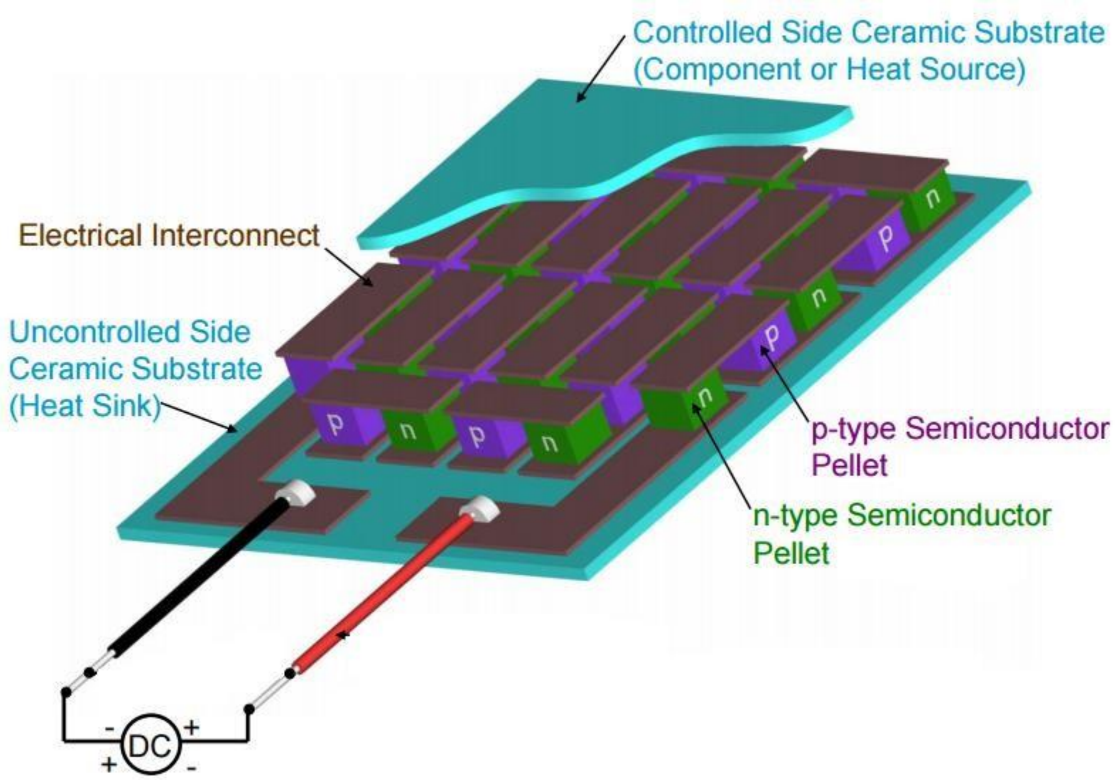


Figure 9 : Peltier cooling by multiple pallets [10]

3.2 Fabrication of Peltier cooler

As we have seen in previous section, for producing thermoelectric effect couples of P and N type semiconductors are connected in series by metal plates. By doing this it absorbs the heat from one side and releases the heat to another side.

So, when solid state P-N materials are connected electrically in series and thermally in parallel it makes one thermoelectric unit as shown in Figure 10.



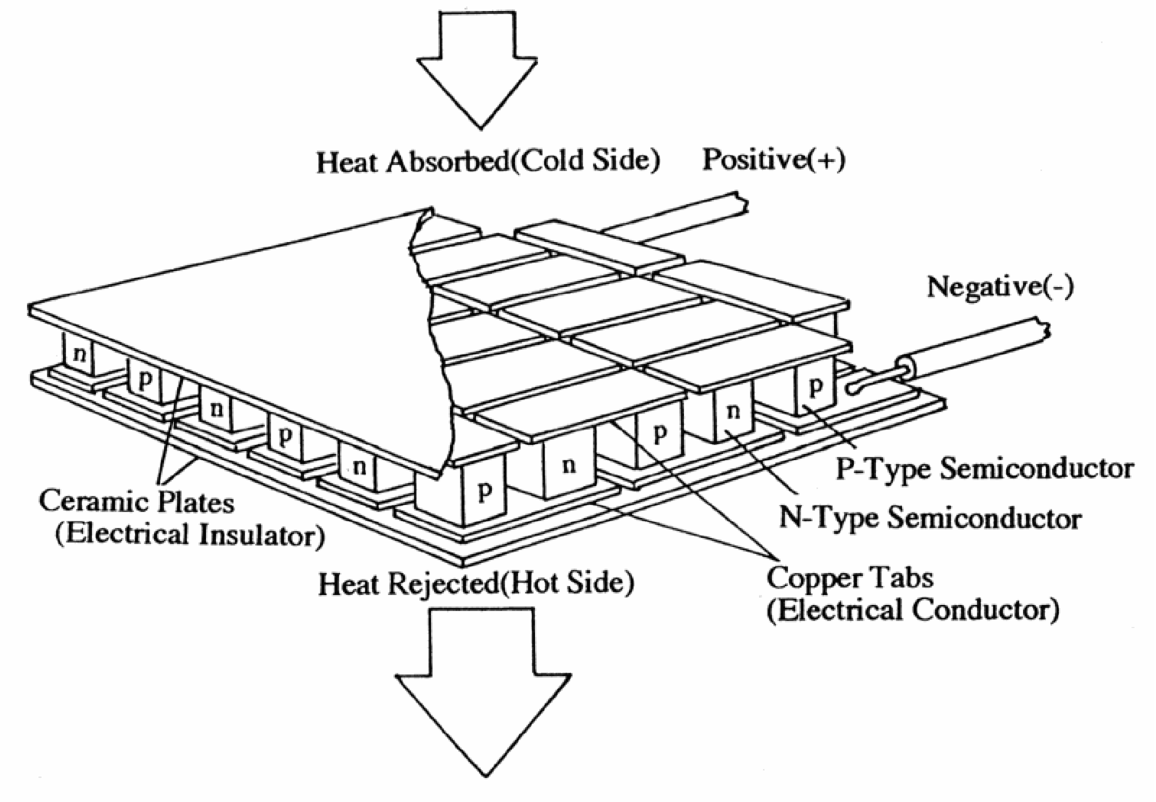


Figure 10 : Fabrication of Peltier module [12]

A typical TEC module comprises of two highly thermally conductive substrates ($A1_2O_3$, AlN, BeO) that serve as Hot/Cold plates. An array of p-type and n-type semiconductor ($B_{i2}Te_3$, Sb_2Te_3, Bi_2Se_3, PbTe, Si-Ge) pellets are connected electrically in series sandwiched between the substrates. The device is normally attached to the cold side of the TEC module, and a heat sink which is required for enhanced heat dissipation is attached to the hot side. Solder is normally used to connect the TEC elements onto the conducting pads of the substrates. The construction of a single stage thermoelectric module is shown in Figure 10. [12]

Considering a typical thermoelectric system designed to cool air in an enclosure (e.g., picnic box, equipment enclosure, etc.) as in Figure 11; this is probably the most common type of TE application. Here the challenge is to "gather" heat from the inside of the box, pump it to a heat exchanger on the outside of the box, and release the collected heat into the ambient air. Usually, this is done by employing two heat sink/fan combinations in conjunction with one or more Peltier devices. One of the heat sinks is used on the inside of the enclosure; cooled to a temperature below that of the air in the box, the sink picks up heat as the air circulates between the fins. In the simplest case, the Peltier device is mounted between this "cold side" sink and a "hot side" sink. As direct current passes through the thermoelectric device, it actively pumps heat from the cold side sink to the one on the hot side. The fan on the hot side then circulates ambient air between the sink's fins to absorb some of the collected heat. Note that the heat dissipated on the hot side not only includes what is pumped from the box, but also the heat produced within the Peltier device itself (V x I). [10]

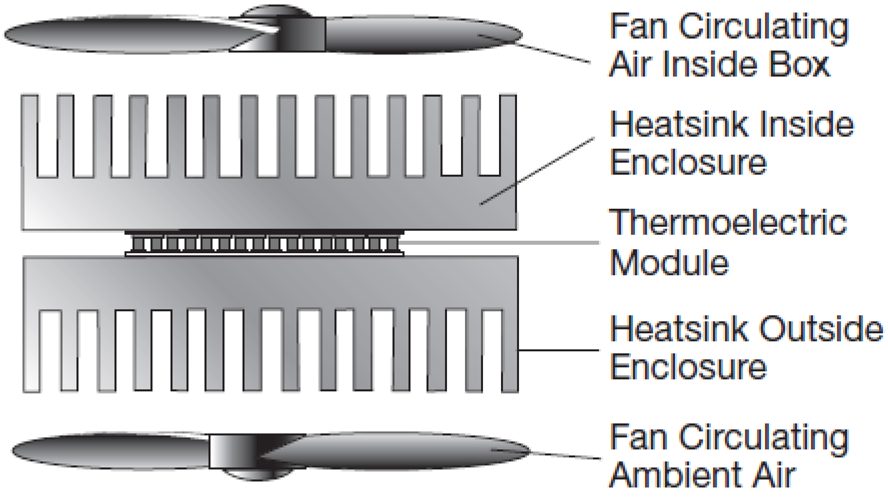


Figure 11 : Configuration of air-to-air thermoelectric cooler [10]

Let's look at this in terms of real numbers. Imagine that we have to pump 25 watts from a box to bring its temperature to 3 ^{o}C from 20 ^{o}C (ambient). To accomplish this, we might well have to take the temperature of the cold side sink down to 0° C. Using a Peltier device which draws 4.1 amps at 10.4 V, the hot side of the system will have to dissipate the25 watts from the thermal load plus the 42.6 watts it takes to power the TE module (for a totalof 67.6 watts). Employing a hot side sink and fan with an effective thermal resistance of 0.148C°/W. The temperature of the hot side sink will rise approximately 10°C above ambient. It should be noted that, to achieve the 17° C drop between the box temperature and ambient, wehad to create a 30° c (45°F) temperature difference across the peltier device.

4. Governing Equations and performance parameters

4.1 Cooling power

The cooling capacity Q_1 results from the energy balance at the cold side of the thermoelectric refrigerator.

When a current, I , is passed through the couple, there is Peltier cooling at the source equal to, $(\alpha_p - \alpha_n)IT_1$. α_p and α_n are the Seebeck coefficients of the two branches which, of course, should have opposite signs.

This cooling effect is opposed by heat conduction at the rate $(T_2 - T_1) * (K_p + K_n)$, where K_p and K_n are the thermal conductance of the branches. The cooling is also opposed by Joule heating within the thermo elements. It is easily shown that half of the Joule heating passes to the sink and half to the source, each half being equal to $\frac{I^2(R_p+R_n)}{2}$, where R_p and R_n are the thermal resistances of the branches. [14,15]

So, the expression for cooling power is,

$$Q_1 = (\alpha_p - \alpha_n)_1 - (T_2 - T_1) * (K_p + K_n) - \frac{I^2(R_p +}{R_n)2}$$

4.2 Power consumed

The electrical power consumption W in the thermo element is the Joule resistance heating plus the power used to create the temperature difference ΔT by applying Peltier voltage. [14,15]

$W = (\alpha_p - \alpha_n). I. (T_2 - T_1) + I^2. (R_p + R_n)$First

term is the power used to create the temperature difference ΔT. Second

term is power used in joule heating

4.3 Coefficient of performance (COP)

The quantity of greatest importance for a refrigerator is the coefficient of performance (COP), which is defined as the ratio of the heat extracted from the source to the expenditureof electrical energy. If the thermocouple were free of losses associated with heat conduction and electrical resistance, the COP would reach the ideal value; that is, the value for a Carnot cycle. The ideal COP can be much greater than unity as it is given by $T_1/(T_2 - T_1)$, where T1and T2 are the absolute temperatures of the source and sink, respectively.[15]

The coefficient of performance COP is the ratio between the cooling capacity Q_1 and the electrical power consumption W,

$$COP = \frac{Q_1}{W}$$

$$\therefore COP = \frac{((\alpha_p - \alpha_n)IT_1 - (T_2 - T_1) * (K_p + K_n) - \frac{I^2(R_p + R_n)}{2})}{((\alpha_p - \alpha_n).I.(T_2 - T_1) + I^2.(R_p + R_n))}$$

4.4 Maximum cooling power

Referring equation for cooling power from section 4.1,

$$Q_1 = (\alpha_p - \alpha_n)_1 - (T_2 - T_1) * (K_p + K_n) - \frac{I^2(R_p +}{R_n)2}$$

As the current is increased, the Peltier cooling rises linearly but the Joule heating depends on I^2. Thus, a plot of cooling power against current has the parabolic form shown in Figure 12. The cooling power is negative until the Peltier effect is great enough to counteract both heat conduction and Joule heating. As the current increased, Peltier effect increases and after some value Peltier effect will be more that sum of heat conduction and joule heating. So, cooling power will become positive at a certain value of the current. However, as the currentis increased further, there will come a point at which the difference between the Peltier cooling and the Joule heating begins to diminish. In other words, there is a particular currentat which the cooling power reaches its maximum value. [15]

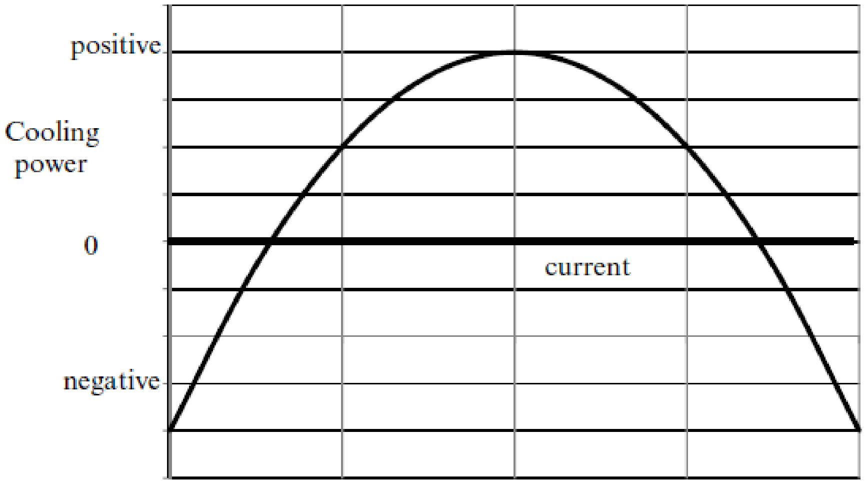


Figure 12 : Schematic plot of cooling power against current for a thermoelectric cooler [15]

it to 0, To find the maximum cooling power, differentiating Q_1, with respect to I and equating

$$\frac{dQ_1}{dI} = 0$$

By, solving above equation, we can get current required for maximum cooling power,

$$I_{max} = \frac{(\alpha_p - \alpha_n) * T_1}{R_p + R_n}$$

Value of maximum cooling power, corresponding to I_{max},

$$Q_{\max} = \frac{\alpha^2 * T_1^2}{2 * R} - K * (T_2 - T_1)$$

$$Here, \quad \alpha = \alpha_p - \alpha_n$$

$$K = K_p + K_n$$

$$R = R_p + R_n$$

Now, let's take $z = \frac{\alpha^2}{R.K}$ and substituting in Q_{max}

$$Q_{max} = \left[\frac{Z.T_1^2}{2} - (T_2 - T_1)\right].K$$

Here, the term Z is known as the figure of merit, which is explained in upcoming section.

Value of COP at maximum cooling power,

$$COP_{max} = \frac{\frac{Z.T_1^2}{2} - (T_2 - T_1)}{Z.T_2.T_1}$$

4.5 Figure of merit

We can see from the above equations of Q_{max} and COP_{max} that, it solely depend on Z and the temperatures of the source and sink. So, Z is known as the figure of merit for thermocouple. Z has the dimensions of inverse temperature and it is more usual nowadays to specify the dimensionless figure of merit, which is equal to ZT_m at a mean temperature T_m. [13]

$$z = \frac{\alpha^2}{R.K} \quad and \quad zT_m = \frac{\alpha^2.T_m}{R.K}$$

Here, R is the electrical resistance, which is equal to $\frac{\rho.l}{A}$ or $\frac{l}{\sigma.A}$.

Since, length l and area A are not material properties, one can write figure of merit as,

$$Z = \frac{\alpha^2 * \sigma}{K}$$

In practice, ZT represents the efficiency of the N-type and P-type materials which compose a thermoelement. A thermoelectric material having a higher figure of merit ZT is more convenient, as it can carry out higher cooling power.

5. Literature review

5.1 Thermoelectrics material

Material used in thermoelectrics is largely dependent on Figure of merit. It is advisable to use the material which has higher value of figure of merit because it leads to higher cooling power of a module. As we have seen figure of merit in previous section, it depends on seebeck coefficient, thermal conductivity and electrical conductivity. So, the properties which are considered for selection of thermoelectric material are:

Electrical conductivity

For figure of merit to be high, electrical conductivity must be high. Metals are typically good electrical conductors, but the higher the temperature, the lower the conductivity. This tendency can be explained in terms of the Drude conductivity formula: [16]

$$\sigma = \frac{n.\,e^{2}.\,r}{m}$$

- n is charge carrier density
- e is charge per carrier (elementary charge)
- τ is carrier mean free time between scattering events
- m is carrier mass

For, metals as temperature increases, τ decreases while the other numbers stay constant, thereby decreasing σ.

In contrast, the electrical conductivity of semiconductors generally increases with temperature. In semiconductors, carrier mean free time decreases with increasing temperature, however carrier density increases faster with increasing temperature, resulting in increasing σ.

Thermal conductivity

For figure of merit to be high, thermal conductivity must be low. Thermal conductivityof any material is the sum of conductivities of electron and phonon. [16]

$$K = K_{phonon} + K_{electron}$$

According to the Wiedemann–Franz law, the higher the electrical conductivity, the higher $K_{electron}$ becomes. Therefore, it is necessary to minimize K_{phonon}. In semiconductors, $K_{phonon} > K_{electron}$ so it is easier to decouple K and σ in a semiconductor and K can be improved by working on K_{phonon}.

Power factor

In order to determine the usefulness of a material in a thermoelectric generator or a thermoelectric cooler the power factor is calculated by its Seebeck coefficient and its electrical conductivity under a given temperature difference: [16]

$$Power\ factor = \sigma * \alpha^2$$

Where α is the Seebeck coefficient and σ is the electrical conductivity.

5.1.2 Bismuth- Telluride based material[1]

The best thermoelectric materials currently available, compounds of doped Bi_2Te_3, have ZT ≅ 1 at room temperature and attain maximum temperature differential of ≅ 82K. Some of the commonly used conventional thermoelectric materials are as follows:

- Bi_2Te_3, Bi_2Se_3 and Sb_2Te_3 ; ZnSb, PbTe and PbSe

Bi_2Te_3, this compound has been extensively used in the construction of thermoelectric modules. The performance of these modules has steadily improved, since the original observations, due to a number of factors. The thermoelectric figure of merit has increased from the order of 0.5 to values significantly greater than one.

To increase the ZT value for this material, research is going to decrease thermal conductivity without affecting electrical conductivity.

As we have seen, The thermal conductivity of the material can be decomposed into two principle components.[2] The first is the lattice contribution, related to thermal conduction by phonons (lattice vibrations). The second is the radiative contribution related to thermal conduction by photons (electromagnetic radiation). Now, decrease in thermal conductivity can be achieved about through a reduction in the lattice component of the thermal conductivity. Researchers have developed some techniques for doing so, includes : [16]

1. Superlattices
2. Phonon-glass electron crystal materials
3. phonon-liquid electron-crystal

5.2 Heat sink

Performance of thermoelectric cooler can be improved by working on thermal side. By properly designing the heat sink on hot side and cold side can improve this system. To obtain the best performance, a Peltier cooler must be designed with heat sink thermal resistance as small as possible. The conventional heat sink unit utilized at the TEC hot side is composed of fins and a fan. The fins are employed to increase heat transfer area. The fan conducts heat transfer through convection. Although the thermal resistance of such a unit can be as low as 0.1 K/W [3], it is usually larger in size. The conventional heat sink can only be employed in situations where space is not restricted. Various researchers are working on designing proper heat sinks that can be applied to TEC, which includes

1. Phase change materials
2. Thermo-syphonic heat exchanger
3. Micro-channels

Each of this three are described below:

5.2.1 Phase change materials

A Paper by S. Riffat, S.A. Omer and Xiaoli Ma on “A novel thermoelectric refrigeration system employing heat pipes and a phase change”. **[4]**

The heat sink should be designed to minimize the thermal resistance. Alternatively, the heat sink could be designed to have a large heat storage capacity, which would help to keep the sink temperature low relative to the junction temperature. This latter solution could be achieved using a phase change material (PCM).

PCMs have long been identified as candidates for thermal storage systems, due to the high energy densities (MJ/m^3). A further advantage of PCMs is that heat transfer normally takes place at a constant temperature (the transition temperature). The principle of this technique is that as the temperature rises due to dissipated heat energy, the PCM absorbs energy, first as sensible heat, and then as latent heat when the phase change temperature is reached. At this stage, the temperature remains constant until the phase change is complete.

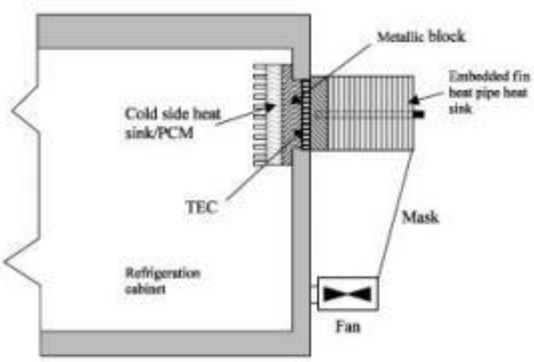


Figure 13 : TEC with PCM as a heat sink [6]

PCMs are available with a large range of phase change temperatures, and thus may be utilized on both the cold and hot junctions of a TEC and for a range of applications and environments. By selecting a PCM with suitable transient temperature and large storage capacity, the temperature difference across the thermoelectric module may be maintained at a low value, thus improving the performance of the device.

When a conventional heat sink is used on the cold side, the temperature of the cold junction drops rapidly until the maximum possible temperature difference across TEC is reached. When the PCM is used, most of the cooling energy is absorbed by the PCM, and therefore the cold side temperature drops more slowly than when PCM is not used; this is shown in Figure 14. With PCM, the temperature drops slowly at the beginning until the transient temperature is reached. During the phase change process, the temperature of the refrigeration system is almost constant until the phase change process is complete. This helps to keep the temperature difference across the TEC to a minimum, thus improving its performance.

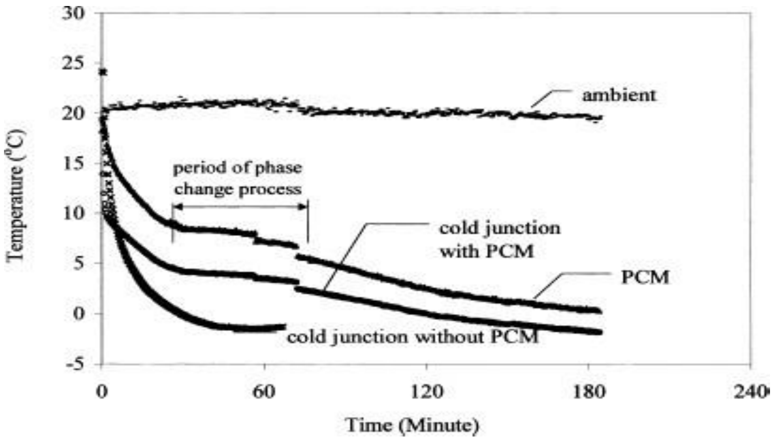


Figure 14 : Variation of cold junction and PCM temperatures during the cooling process for the tests with, andwithout, PCM material

Use of a PCM provides a storage capacity, which helps to overcome peak loads and cooling losses during periods of door opening. If the electrical power is turned off for any reason, the refrigeration system employing PCM would have a storage capacity capable of meeting the cooling load for a longer period. For example, as shown in Figure 15, after the electrical power was turned off, it took twice as long for the temperature in the cabinet with PCM to rise to the same value as in the cabinet with no PCM.

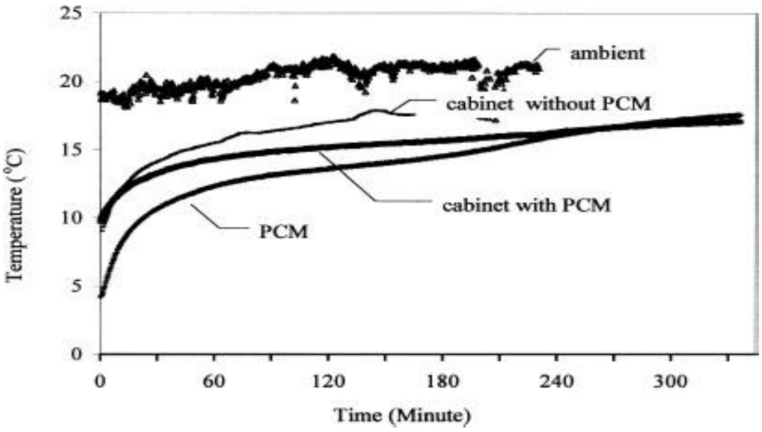


Figure 15 : Variation of cold cabinet and PCM temperatures for the tests with, and without, PCM material, after thepower was turned off.

In general, use of a PCM improves the performance of the thermoelectric refrigeration system, as shown in Figure 16. As can be seen, because the cold junction temperature remains constant during the phase change process, the rate of cooling is also constant, as is the COP of the refrigeration system. This is a major advantage of using a PCM compared with a conventional heat sink.

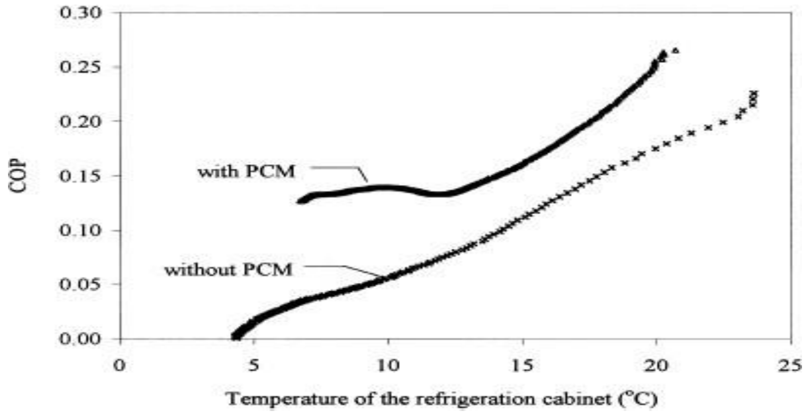


Figure 16 : Comparison between performance of thermoelectric refrigeration system, with and without, PCM material

5.2.2 Thermosyphonic heat exchanger in cold side

A paper by J.G. Vian, D. Astrain, “Development of a heat exchanger for the cold side of a thermoelectric module”. [8]

Authors have developed a heat exchanger for the cold side of Peltier pellets in thermoelectric refrigeration, based on the principle of a thermosyphon with phase change and capillary action. This device improved the thermal resistance between the cold side of a Peltier pellet and the refrigerated ambient by 37% (from 0.513 of the finned heat sink, to 0.323 K/W). It also has been experimentally proved that the COP of thermoelectric refrigerators can be improved up to 32% (from 0.297 to 0.393) by incorporating the developed device.

The device they have used is called TPM (thermosyphon porous media). This device (TPM) consists a hermetically closed volume which contains a fluid and a porous material adhered to its internal surface, as shown in . When absorbing the heat from the room, the liquid evaporates. The liquid ascends by capillarity due to the porous medium adhered to the surface of the TPM, achieving this way the evaporation of the fluid in the whole surface of the TPM. This steam ascends by natural convection reaching the cold side of the TPM, which is in contact with the cold side of the Peltier pellet where it condenses. The condensed liquid returns to the lower part of the thermosyphon by gravity, creating a closed, self-feeding cycle.

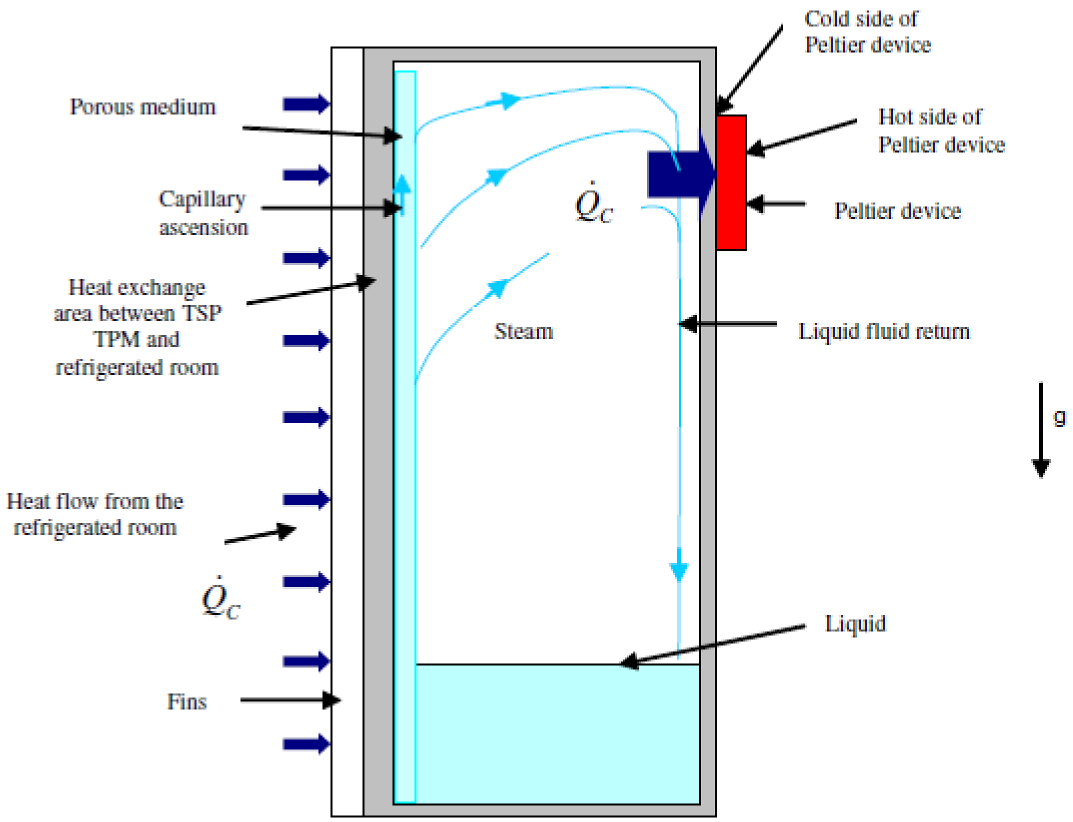


Figure 17 : Operation scheme of TPM device

Authors performed experimental study of the COP increase obtained in a thermoelectric refrigerator if TPM is used. Two configurations were tested: one corresponds to the scheme shown in Figure 17, where the heat exchanger for the cold side of the Peltier pellet is the TPM device; the other configuration consists on replacing the TPM by a finned heat sink.

These results are shown in Table 1. From result of COP of both refrigerators, TPM and finned heat sink, It can be appreciated that when introducing the TPM device in a hermoelectric refrigerator, the COP increases by 32%

Table 1 : Result of experiment for TPM and Finned sink

	TPM	Finned heat sink
Tamb - Tint	11.2	8.43
Qc (W)	19.47	14.67
We (W)	49.6	49.4
Rthermal	0.323	0.513
COP	0.393	0.297

5.2.3 Micro-channels

Paper by R. Chein, Y. Chen, "Performances of thermoelectric cooler integrated with microchannel heat sinks", International Journal of Refrigeration 28 (2005) 828–839. [5]

In this study, experimental and theoretical studies on thermoelectric cooler (TEC) performance for cooling a refrigerated object (water in a tank) were performed. Microchannel heat sinks fabricated with etched silicon wafers were employed on the TEC hot side to dissipate the heat.

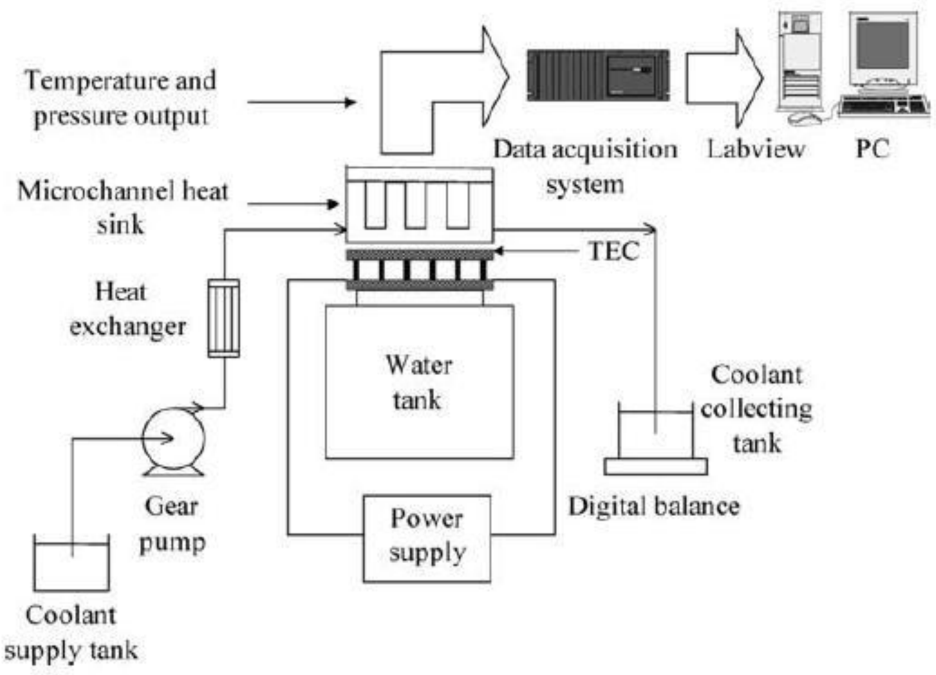


Figure 18 : Experimental setup of TEC with micro channels as a heat sink

Figure 18 shows the experimental setup used in this experiment. The TEC used in this study is a commercially-available unit, Model cp 1.4-127-06L, which has a published maximum, cooling rate of 51.4W and maximum temperature difference of 67.8 C.

The microchannels of the heat sink used in this study were fabricated using standard etching process on the orientation silicon wafers. The thickness of the silicon wafer is 500 mm. A 500 mm-thick glass plate was covered on the top surface of the microchannels to form the flow passages. Figure 19 shows a typical cross section of a microchannel etched on the silicon wafer. The channel has a trapezoidal shape with the top width, bottom width and depth denoted as Wt, Wb, and H, respectively. Figure 20 illustrates the top view of a typical microchannel heat sink. In addition to the parallel channels, inlet and outlet ports are also required for distributing the coolant into the microchannels and collecting coolant at the channel exits.

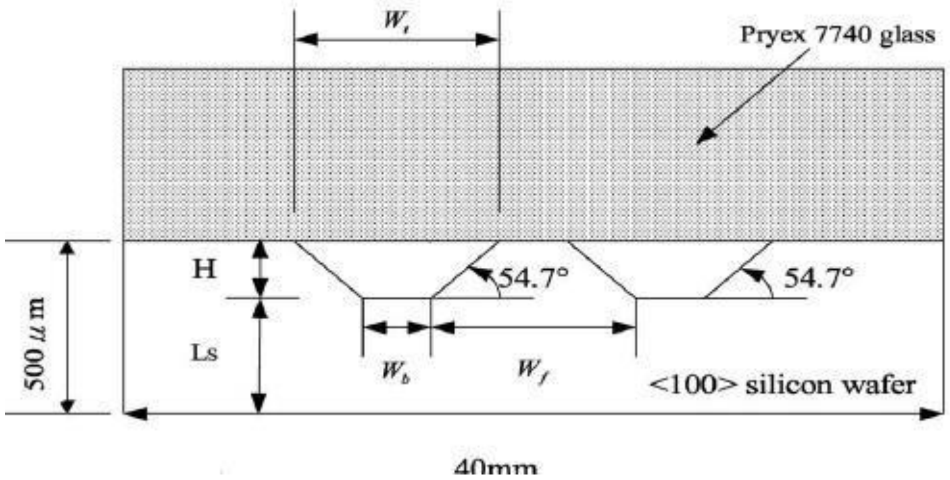


Figure 19 : Microchannel geometry

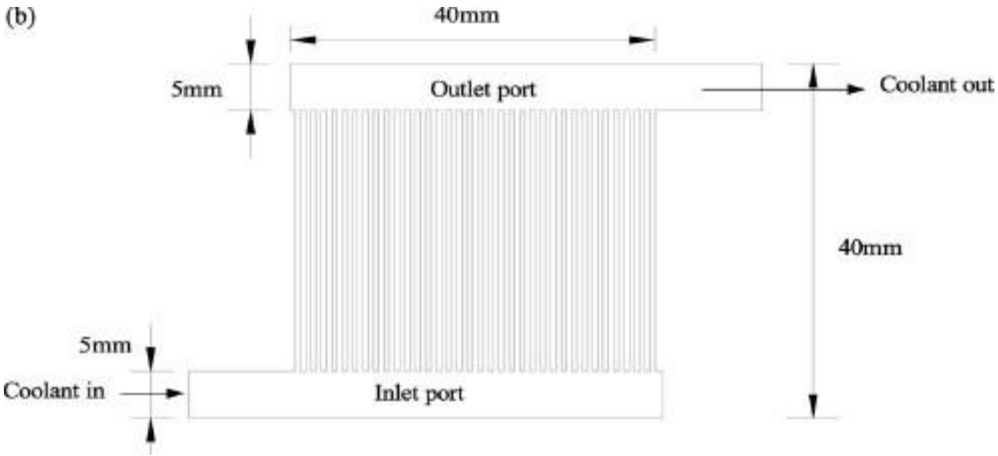


Figure 20 : Microchannel heat sink configuration

Water was used as the coolant. The water was pumped into the microchannel heat sink with a gear pump. The coolant temperature was kept at 25.8C before it was entered into the heat sink with a heat exchanger unit. The coolant flowrate was measured via a digital balance with the time recorded.

They did experiment on this model by varying coolant flow rates in range of 289-10702 *ml/h*. The result of this experiment is shown in Figure 21.

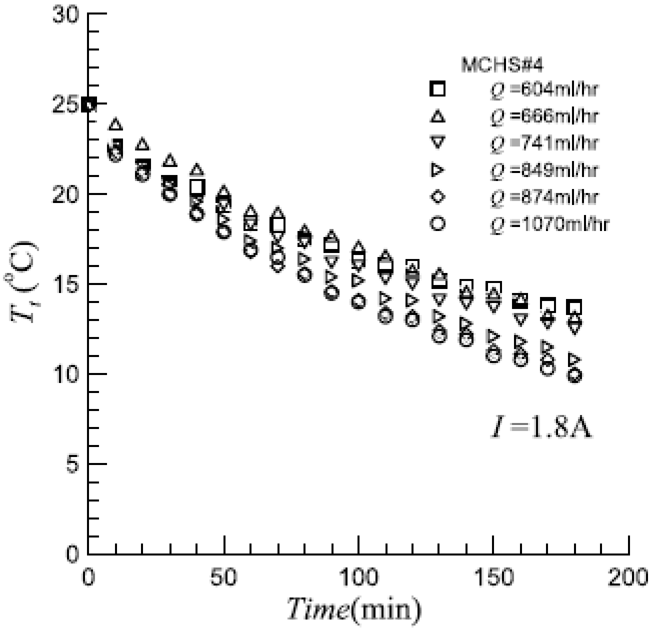


Figure 21 : Variations of refrigerated object temperature Tt as functions of time and coolant flow rate

Figure shows the temperature of refrigerated space decreases with respect to time. Wecan also see that, the temperature reduces if the flow rate of water is increased. Figure 22 shows the comparison of the microchannels heat sink with fin type heat sink. As we can see, the difference in temperatures of refrigerated space in both the cases are not much, but herethe advantage is the size of heat sink. Conventional heat sink is not applicable where space is the restriction, while microchannel require a space in micrometers.

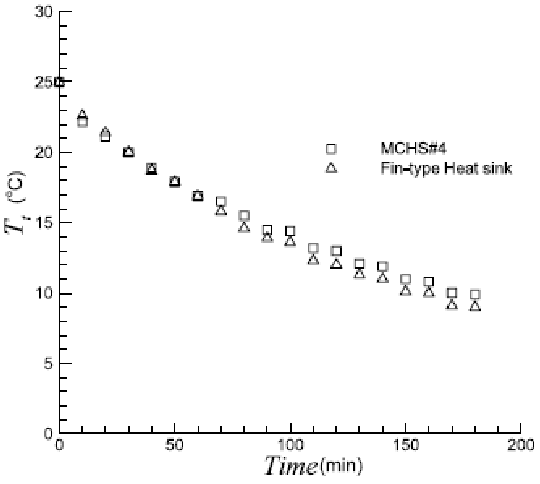


Figure 22 : Comparison of TEC performances using conventional heat sink and microchannel heat sink.

5.3 Comparison of Peltier, Sterling and vapour compressionportable cooler

A paper by C. Hermes, J. Barbosa, “Thermodynamic comparison of Peltier, Stirling, and vapor compression portable coolers” [7]

This paper compares the thermodynamic performance of four small-capacity portable coolers that employ different cooling technologies: thermoelectric, Stirling, and vapor compression using two different compressors (reciprocating and linear). The refrigeration systems were experimentally evaluated in a climatized chamber with controlled temperature and humidity. Tests were carried out at two different ambient temperatures (21 and 32 °C) in order to obtain key performance parameters of the systems (e.g., power consumption, cooling capacity, internal air temperature, and the hot end and cold end temperatures).

In this work, author compared performance parameters using a thermodynamic approach that splits the overall 2nd law efficiency into two terms, namely, the internal and external efficiencies. In doing so, the internal irreversibilities (e.g., friction in the working fluid in the Stirling and vapor compression machines, Joule heating and heat conduction in the thermoelectric devices of the Peltier cooler) were separated from the heat exchanger losses (external irreversibilities), allowing the comparison between different refrigeration technologies with respect to the same thermodynamic baseline.

Cooling systems used for analysis are as given in Table 1.

Table 2 : Cooling systems

Characteristics	**Thermoelectric**	**Stirling**	**Recip. compressor**	**Linear compressor**
Cabinetvolume (l)	56	26	31	34
Refrigerant	Electrons	Helium	HFC-134a	HFC-134a
Cold end heat exchanger	Air source ,forced	Thermosyphon	Roll-bond, natural	Roll-bond, natural
Hot end heat exchanger	Air source ,forced	Air source ,forced	Air source ,forced	Air source ,forced
Voltage supply	120 VAC	12 VDC	24 VDC	12 VDC
Temperature control	Continuous	Continuous	On–off	On–off

Results of this experiment are shown below. Figure 23 shows the comparison of COP for ambient temperature at 21 C and 32 C. As we can see, carnot COP of TEC is highest, but due to electrical irreversibility its actual COP is much lower that other system.

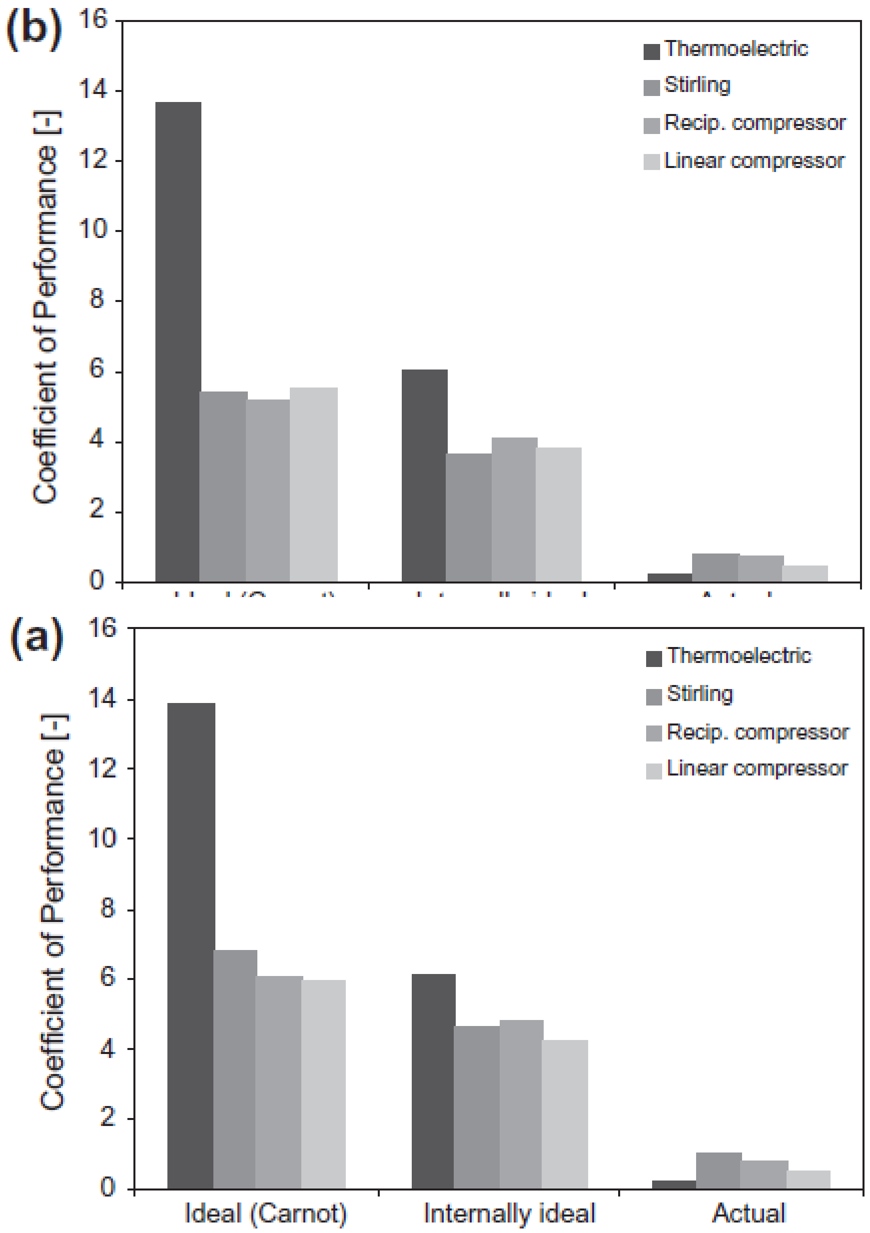


Figure 23 : Coefficient of performance: ambient air at (a) 21 C and (b) 32 C.

Figure 24 shows the comparison of second law efficiency of all the refrigerators, which indicates internal efficiency of thermoelectric cooler is very less, means that the internal irreversibilities in the thermoelectric module can be quite high. Indeed, this combined with the comparatively large value of its internally ideal coefficient of performance confirms the need for improvement of the thermoelectric properties of the thermoelectric cooler.

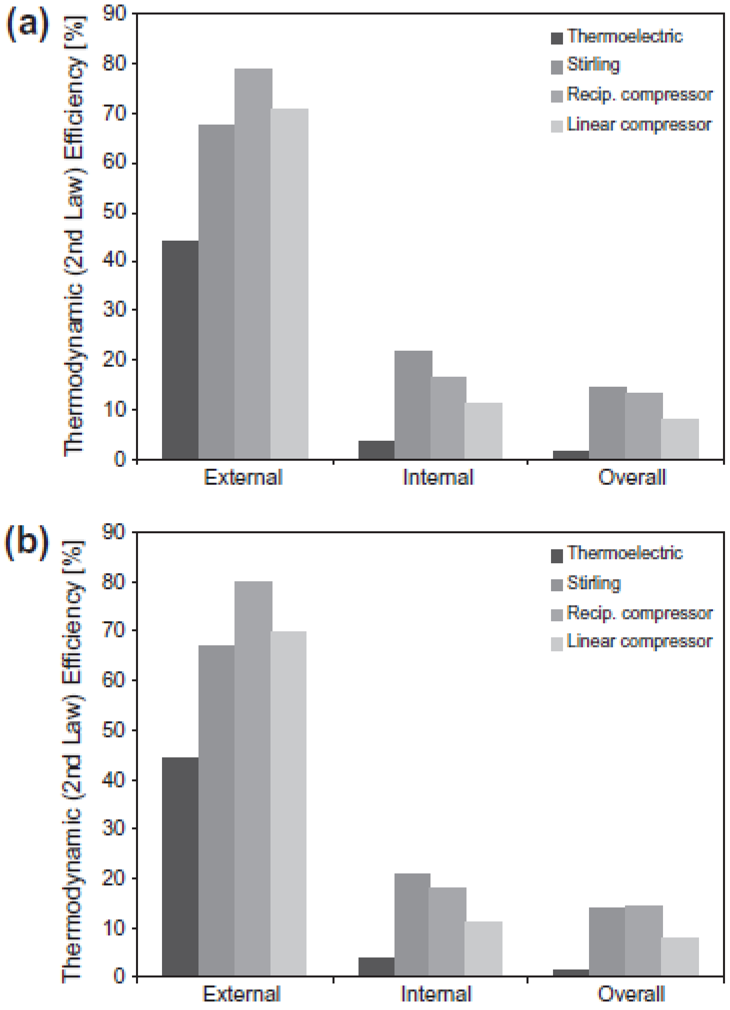


Figure 24 : Second law efficiency: ambient air at (a) 21 C and (b) 32 C.

6. Applications of Peltier cooler

- Thermoelectric cooling is used in medical and pharmaceutical equipment, spectroscopy systems, various types of detectors, electronic equipment, portable refrigerators, chilled food and beverage dispensers, and drinking water coolers.
- Requiring cooling devices with high reliability that fit into small spaces, powerful integrated circuits in today's personal computers also employ thermoelectric coolers.
- Using solid state heat pumps that utilize the Peltier effect, thermoelectric cooling devices are also under scrutiny for larger spaces such as passenger compartments of idling aircraft parked at the gate.

Some of the other potential and current uses of thermoelectric cooling are:

Military/Aerospace

- Inertial Guidance Systems, Night Vision Equipment, Electronic Equipment Cooling, Cooled Personal Garments, Portable Refrigerators**.**

Consumer Products

- Recreational Vehicle Refrigerators, Mobile Home Refrigerators, Portable Picnic Coolers, Wine and Beer Keg Coolers, Residential Water Coolers/Purifiers.

Laboratory and Scientific Equipment

- Infrared Detectors, Integrated Circuit Coolers, Laboratory Cold Plates, Cold Chambers, Ice Point Reference Baths, Dewpoint Hygrometers, Constant Temperature Baths, Thermostat Calibrating Baths, Laser Collimators.

Industrial Equipments

- C Computer Microprocessors, Microprocessors and PC's in Numerical Control and Robotics, Medical Instruments, Hypothermia Blankets, Pharmaceutical Refrigerators - Portable and Stationary, Blood Analyzers, Tissue Preparation and Storage, Restaurant Equipment, Cream and Butter Dispensers.

Miscellaneous

- Hotel Room Refrigerators, Automobile Mini – Refrigerators, Automobile Seat Cooler, Aircraft Drinking Water Coolers.

6.1 Commercial thermoelectric cooling products:

A varied variety of products based on thermoelectric cooling are now currently available in the market. These are important because they can be bought off the shelf as per the requirements. Some of the important listings are as follows:

- **PowerChill™ Plus 40-qt Vertical/Horizontal Thermoelectric Cooler (Gray/White) : Model No. 5642A807 (Company - Coleman)**

  - Capacity: 45.5 L
  - Price: Rs. 7000
  - Voltage Requirement : 110 volts

- **16 Quart Gray/Blue Personal Thermoelectric Cooler : Model No. 5615-807 (Company – Coleman)**

  - Capacity : 18.2 L
  - Price : Rs. 4000

- Voltage Requirement : 110 volts

- **Liquid Chiller Model No. TLC-700 (Company - Thermoelectric cooling America Corporation)**

- Reservoir capacity : .5 L
- Price : Rs. 2000
- Voltage Requirement : 120 volts ; Power Requirement : 500 W

7. Conclusion

Since Peltier cooling is not efficient comparatively and due to its small size applications, it is not widely used. It found its application only in electronics cooling etc. But, we have seen that there is a huge scope of research in this field about thermoelectric materials, its fabrication, heat sink design etc. Researcher are working on reducing irreversibilities in the systems, because Peltier cooler has more potential which we can see from the vast difference between value of first law efficiency and second law efficiency.

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