IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 18, Issue 6, Ver. VI (Nov.-Dec.. 2016), PP 99-107
www.iosrjournals.org

Thermoelectric Air Conditioning System: Applications and Technology

Namrata mishra[1], Himanshu Sekhar Moharana[2]
1(Department of Mechanical engineering,Gandhi Engineering College,India)
2(Department of Mechanical engineering,Gandhi Engineering College,India)

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 Seebeck 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. The present air-conditioning system produces cooling effect by refrigerants like Freon, Ammonia, etc.Using these refrigerants can get maximum output but one of the major disadvantages is harmful gas emission and global warming. These problem can be overcome by using thermoelectric modules (Peltier effect) air conditioner and their by protecting the environment. The present paper deals with the study of thermoelectric air conditioner using different modules are discussed. Thermoelectric cooling systems have advantages over conventional cooling devices, such as compact in size, light in weight, high reliability, no mechanical moving parts and no working fluid.

Key Word*: Thermoelectric module; Peltier effect*; Figure of Merit; Device Design Parameter; Seebeck Coefficient; Coefficient of performance.

I. Introduction

Refrigeration means removal of heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. Thermoelectric cooling is a way to remove thermal energy from a medium, device or component by applying a voltage of constant polarity to a junction between dissimilar electrical conductors or semiconductors. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect i.e. Peltier effect rather than the more prevalent conventional methods like those using the „vaporcompressioncycle"orthe„gascompressioncycle".[14]

Thermoelectric Refrigeration finds applications in electronic systems and computers to cool sensitive components such as power amplifiers and microprocessors. TER can also be used in a satellite or space application to control the extreme temperatures that occur in components on the sunlit side and to warm the components on the dark side. In scientific applications like digital cameras and charge coupled devices (CCDs) TER is used to minimize thermal noise, thereby optimizing the sensitivity and image contrast.

The coefficient of performance (COP) of compression refrigerators decreases with the decrease in its capacity. Therefore, when it is necessary to design a low capacity refrigerator, TER is always preferable. Also, better control over the space temperature is the major advantage of the TER. Hence, TER is good option for food preservation applications & cooling of pharmaceutical products.[15]

In thermoelectric materials, electrical energy can be directly converted into thermal energy and thermal energy into electrical energy. Direct conversion between electrical and thermal energy is possible because of two important thermoelectric effects: the Seebeck effect and the Peltier effect. The Seebeck effect refers to the effect refers to the absorption of heat into one end of a thermoelectric material and the release of heat from the opposite end due to a current flow through the material.

Thermoelectric cooling, commonly referred to as cooling technology using thermoelectric coolers (TECs), has advantages of high reliability, no mechanical moving parts, compact in size and light in weight, and no working fluid. In addition, it possesses advantage that it can be powered by direct current (DC) electric sources, When a voltage or DC current is applied to two dissimilar conductors, a circuit can be created that allowsforcontinuousheattransportbetweentheconductors"sjunctionsthisistheprincipleofthermoelectricaircondition. Air conditioning is a process of removing heat from a room or other applications. Many ways of producing a cooling effect by like vapour compression and vapour absorption air condition. These air conditioners are producing cooling effect by using refrigerants like Freon and ammonia etc. It gives maximum output but, one of the disadvantages is producing harmful gases to the atmosphere. The harmful gases are cluro fluro carbon and some other gases are present.

These types of air conditioners have wide range of applications. An air conditioner is a major home appliance, system, or mechanism designed to change the air temperature and humidity within an area. The cooling is typically done using a simple refrigeration cycle, but sometimes evaporation is used, commonly for comfort cooling in buildings and motor vehicles. Normally we are used in the vapour compression air-condition system, it has many moving parts and as well as produce harmful gases to the environment. By using thermoelectric modules air-conditioners we can overcome the existing air-conditioning system by modifying it to protect the environment.

A conventional cooling system contains three fundamental parts - the evaporator, compressor and condenser. The evaporator or cold section is the part where the pressurized refrigerant is allowed to expand, boil and evaporate. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor acts as the refrigerant pump and recompresses the gas to a liquid. The condenser expels the heat absorbed in the evaporator plus the heat produced during compression, into the environment or ambient. A thermoelectric has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element(p-type).

II. Literature Review

This Matthieu Cosnier et al**1** presented an experimental and numerical study of a thermoelectric air-cooling and air-heating system. They have reached a cooling power of 50W per module, with a COP between

1.5 and 2, by supplying an electrical intensity of 4A and maintaining the 5°C temperature difference betweenthe hot and cold sides.

Suwit Jugsujinda et al**2** conducted a study on analyzing thermoelectric refrigerator performance. The refrigeration system of thermoelectric refrigerator (TER; 25 × 25 × 35 cm3) was fabricated by using a thermoelectric cooler (TEC; 4 × 4 cm2) and applied electrical power of 40 W. The TER was decreased from 30 ºC to 20 ºC for 1 hr and slowly decreasing temperature for 24 hrs. The maximum COP of TEC and TER were 3.0 and0.65.

Wei He et al**3** conducted did Numerical study of Theoretical and experimental investigation of a thermoelectric cooling and heating system driven by solar. In summer, the thermoelectric device works as a Peltier cooler when electrical power supplied by PV/T modules is applied on it. The minimum temperature 17 degree C is achieved, with COP of the thermoelectric device higher than 0.45.Then comparing simulation result and experimental data.

Riff and Guoquan**4** conducted an experimental study of comparative investigation of thermoelectric air conditioners versus vapour compression and absorption air conditioners. Three types of domestic air conditioners are compared and compact air conditioner wasfabricated.

Riffat and Qiu**5** compared performances of thermoelectric and conventional vapor compression air-conditioners. Results show that the actual COPs of vapor compression and thermoelectric air-conditioners are in the range of 2.6-3.0 and 0.38-0.45, respectively. However, thermoelectric air conditioners have several advantageous features compared to their vapor-compression counterparts.

Astrain, Vian & Domınguez**6** conducted an experimental investigation of the COP in the thermoelectric refrigeration by the optimization of heat dissipation. In thermoelectric refrigeration based on the principle of a thermo syphon with phase change is presented. In the experimental optimization phase, a prototype of thermo syphon with a thermal resistance of 0.110 K/W has been developed ,dissipating the heat of a Peltier pellet with the size of 40*40*3.9 cm , Experimentally proved that the use of thermo syphon with phase change increases the coefficient of performance up to32%.

Shen, Xiao et al**7** investigated a novel thermoelectric radiant air-conditioning system (TE-RAC). The system employs thermoelectric modules as radiant panels for indoor cooling, as well as for space heating by easily reversing the input current. Based on the analysis of a commercial thermoelectric module they have obtained a maximum cooling COP of 1.77 when applying an electric current of 1.2 A and maintaining cold side temperature at 20°C.

Virjoghe, Diana et al**8** conducted an numerical investigation of thermoelectric System. The thermoelectric systems have attracted renewed interest as concerns with the efficient use of energy resources, and the minimization of environmental damage, have become important current issues. This paper presents of numerical simulation for several the thermoelectric materials. Numerical simulation is carried out by using a finite element package ANSYS.

Maneewan et al**9** conducted an experimental investigation of thermal comfort study of compact thermoelectric air conditioner. In this paper analyze the cooling performance of compact thermoelectric air-conditioner. TEC1-12708 type thermoelectric modules used for heating and cooling application. The compact TE air conditioners COP was calculated to its optimum parameters. Then analyze the cop with respect to time and calculated cop at variousconsiderations.

Manoj and Walke**10**conducted an experimental study of thermoelectric air cooling for cars. They are trying to overcome these demerits by replacing the existing HVAC system with newly emerging thermoelectric couple or cooler which works on peltier and seebeck effect.

Yadav and Mehta**11** presented combined experimental and theoretical study of thermoelectric materials and application. The present study develops and optimization design method for thermoelectric refrigerator. This device is fabricated by combining the standard n- and p-channel solid-state thermoelectric cooler with a two-element device inserted into each of the two channels to eliminate the solid-state thermalconductivity

Manoj Kumar et al**12** presented an experimental study of noval potential green refrigeration and air-conditioning technology. They are analyzing the cause and effect of an existing air-conditions system. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. The available literature shows that thermoelectric cooling systems are generally only around 5–15% as efficient compared to 40–60% achieved by the conventional compression cooling system.

Huang. B et al**13** conducted an experimental study of design method of thermoelectric cooler. They are fabricated the thermoelectric cooler and analyze various considerations. The system simulation shows that there exists a cheapest heat sink for the design of a thermoelectric cooler. It is also shown that the system simulation coincides with experimental data of a thermoelectric cooler.

III. Material Review

Thermoelectric module is made of two different semiconducting materials, which generate thermoelectric cooling effect (Peltier effect) when a voltage of similar polarity & in appropriate direction applied through the connected junction. Two heat sinks & fans are attached to hot and cold sides of thermoelectric module in order to enhance heat transfer and system performance. There exists an optimum current & optimum voltage for maximum coefficient of performance (COP) for a specific module and fixed hot/cold side temperatures.

Accordingtotheprimarycriterionoffigureofmerit(□=□2□□),agoodthermoelectricmaterialshould have high Seebeck coefficient, high electrical conductivity, and low thermal conductivity. Commonly used thermoelectric materials are Bismuth Telluride (Bi2Te3), Lead Telluride (PbTe), Silicon Germanium (SiGe) and Cobalt Antimony (CoSb3), among which Bi2Te3 is the most commonly used one. These materials usually process a ZT value (figure of merit at temperature) less than one. From 1960s to 1990s, developments in materials in the view of increasing ZT value were modest, but after the mid-1990s, by using nano structural engineering thermoelectric material efficiency is greatly improved. Thermoelectric materials such as primary bulk thermoelectric materials like skutterudites, clathrates and half-Heusler alloys, which are principally produced through doping method are developed but not exploited for commercial use.[16]

The best commercial thermoelectric materials currently have ZT values around 1.0. The highest ZT value in research is about 3. Other best reported thermoelectric materials have figure-of-merit values of 1.2-2.2 at temperature range of 320-5200C. It is estimated that thermoelectric coolers with ZT value of 1.0 operate at only 10% of Carnot efficiency. Some 30% of Carnot efficiency could be reached by a device with a ZT valueof 4. However, increasing ZT to 4 has remained a formidable challenge. Bell also mentioned that if the average ZT reaches 2, domestic and commercial solid-state heating, ventilating and air-cooling systems using thermoelectric material would become practical. [16]

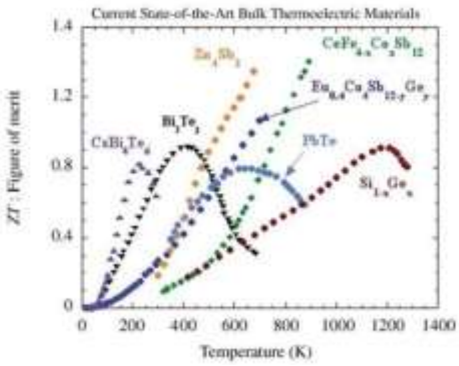


Figure No. 1: ZT Characteristics of different TE Materials

IV. Design Consideration ForTER

A system design method of thermoelectric cooler is developed in the present study. The design calculation utilizes the performance curve of the thermoelectric module that is determined experimentally. An automatic test apparatus was designed and built to illustrate the testing method.

The performance test results of the module are used to determine the physical properties and derive an empirical relation for the performance of thermoelectric module. The thermal resistance of heat sink is chosen as one of the key parameters in the design of a thermoelectric cooler. An optimal design of thermoelectric cooler at the conditions of optimal COP is also studied. The optimal design can be made either on the basis of the maximum value of the optimal cooling capacity, or on the basis of the best heat sink technology available. [17]

Methodology-

The theoretical equations for the thermoelectric module performance include:

The voltage equation,

□= (□□−□□) + □□ (1)

The input power equation,

□= □(□□−□□) + □2□ (2)

The cooling capacity equation,

□□= □□□□− (□□−□□) − 0.5□2□ (3)

The total heat rejection equation,

□□□□−(□□−□□)+0.5□2□ (4)

And COP is given by,

□□□= □□/ □ (5)

An important physical property for the thermoelectric module is the figure of merit Z which is given by,

□= □^{2}/□□ (6)

The thermoelectric cooler can be designed at maximum COP or at maximum cooling capacity. In many applications, the thermal efficiency is more important. Thus, the design based on the maximum COP is adopted in the present study. [18]

Goktun [14] showed that heat transfer at a finite rate and electrical resistive losses are necessarily irreversible processes and unavoidable in a thermoelectric device. It is shown that the internal and external irreversibility in a thermoelectric refrigerator may be characterized by a single parameter, named the device-design parameter. The presence of this parameter in the equations for the refrigeration effect and the maximum input power shows that a real refrigerator has a smaller cooling capacity and needs more input power than an ideal refrigerator. [14]

The thermoelectric refrigerator circuit is shown in Figure 2 [14] for steady state conditions, the heat flow rate from the low temperature reservoir at $T_L$to the cold junction at $T_c$can be written as:

□□=*h*□□□(□□−□□) (7)

Similarly, on the high temperature side, the heat flow rate is:

□□= *h*□□(□□−□□) (8)

Where h is the heat transfer coefficient, A is the heat exchanger surface area; T_w and $T_H$is the hot junction and sink temperatures respectively. Assuming all material properties, including the Seebeck coefficient (α), of the thermoelectric element is independent of temperature. A one-dimensional heat conduction analysis in the direction of current (I) flow yields the net rates of heat input and heat rejection as:

From the first law of thermodynamics, the input power □ is:

□=□□−□□=□(□□−□□)+□²□ (9)

According to second law,

□□/□□=□(□□/□□)□□ℎ□<1 (10)

Substituting equations (7) & (8) into (10), S becomes,

□=(□□−□□)□□/(□□−□□)□□ (11)

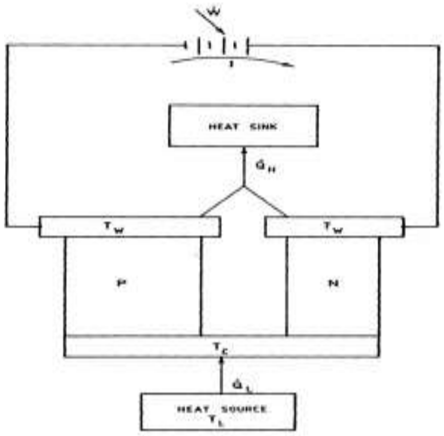


Figure No. 2: A Thermoelectric Refrigerator

Using equation (9) and dimensionless temperature ratio specified above, the cold junction ratio can be written as:

□□=□□□ (12)

Where,

□=□□/□+□(1−□/□)with□<□<1 (13)

Prime requirement of a TER is the optimum refrigeration effect, therefore optimizing □□with respect to I yields:

(□)□□□=□□□□/□ (14)

□=(□□)□□□/(□□□²)/2□=□2+2(□□−□□)/(□□□²)(15)

□□□□=□(□□□)²/2□=2□ (16)

- For β=0 and S=1, X approaches to ψ, then equation (15) reduces to the maximum refrigeration effect of TE refrigerator.
- Thermoelectric devices can be characterized by single parameter X, named device-designparameter.
- This parameter appears in both the equation for optimum refrigeration effect and maximum inputpower.
- In order to get high values of X, S must be decreased for the values of β within the range ofinterest.
- In order to get better the refrigeration effect, X must be increased.[19]

V. Thermoelectric Cooler

Development of TE Devices

The thermoelectric cooler is a cooling device based on TER principle which has been widely used in military, aerospace, instrument, and industrial or commercial products, as a cooling device for specific purposes. The schematic of the thermoelectric cooler is shown in Figure 3 [13]. Huang et.al. [20] Developed a system design method of TE cooler in their study which utilizes the performance curve of the TE module.

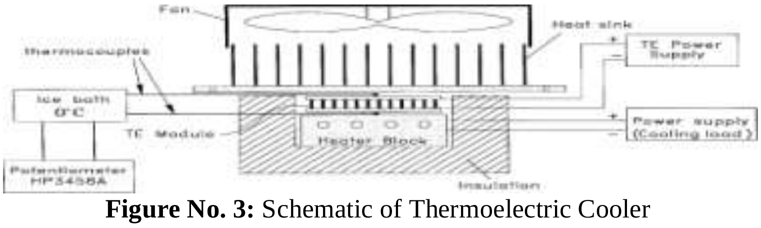


Figure No. 3: Schematic of Thermoelectric Cooler

Jiajitsawat [15] investigated theoretically & experimentally the effect of combination of TER system & DEAC system. For this he had fabricate a portable hybrid thermoelectric-direct evaporative air cooling system and tested. The schematic of the prototype is shown in Figure 4. [15] The operating principle of the prototype is the conversion of sensible heat of the hot air to the latent heat of water vaporization. Installation of thermoelectric refrigeration system is to remove the sensible heat from the water in the container for further improvement of the air cooling capacity.

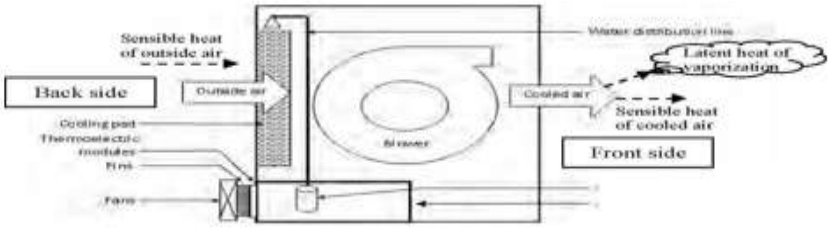


Figure No. 4: The Combined TE-Direct Evaporative Air Cooler

Experiment was carried out in three ways: Fan operation, direct evaporative air cooling operation & TER-DEAC operation. When DEAC system is in active, the cooling performance of the prototype increases by 20% & is up to 30% with higher fan speed. The results of TE installation can improve the cooling performance of the DEAC system by 10% and is up to 20% with higher fan speed. Therefore the implementation of TE to DEAC seems to be reliable and possible for commercial application. [21]

A. Thermoelectric Refrigerator

TE modules are also used for constructing thermoelectric refrigerator. Although the COP of a TE module is lower than that of conventional VCR system, efforts have been made to develop thermoelectric domestic refrigerators to exploit the advantages associated with this solid-state energy conversion technology. The basic configuration of a thermoelectric refrigerator is shown schematically in Figure 5. [22] It consists of a refrigerated cabinet, a Peltier module sandwiched by two heat exchangers, a D.C. power supply and a temperature controller. Although the basic structure of a thermoelectric refrigerator is essentially the same, their configurations may differ significantly depending on the heat exchangers employed. [22]

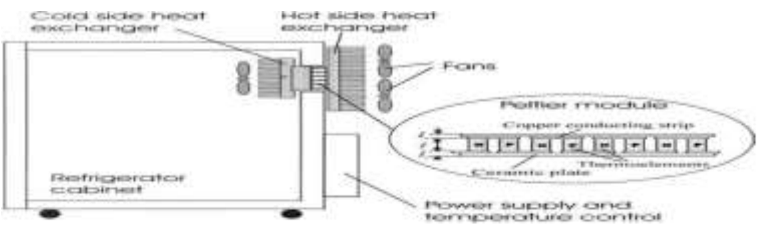


Figure No. 5: The Combined TE-Direct Evaporative Air Cooler

The thermoelectric refrigeration system is feasible for outdoor purpose in cooperation with solar cells. Dai et.al [26] conducted experimental investigation & performance analysis on prototype of a thermoelectric refrigerator driven by solar cells, which is mainly configured by the array of solar cells, controller, storage battery, rectifier and thermoelectric refrigerator, is shown in Figure 6. [26]

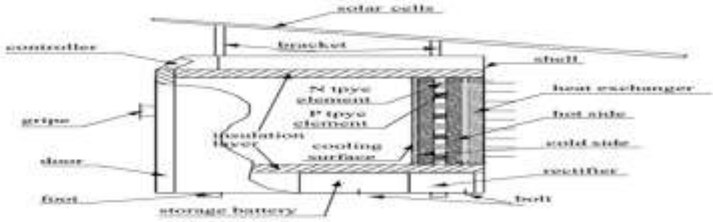


Figure No. 6: Schematic of Solar Cells driven Thermoelectric Refrigerator

In daytime, solar cells receive solar energy and turn it into electric power supplied to thermoelectric refrigerator by means of photovoltaic effect. If the amount of electric power production is large enough, the power surplus can be accumulated in storage battery besides driving the refrigerator. If the solar cells cannot produce enough electric power, for example, in cloudy or rainy days, the storage battery may offer a makeup. [26]

Experimental results shows that the performance of solar cells driven thermoelectric refrigerator is strongly dependent on the intensity of solar insulation and the temperature difference of hot and cold sides between the thermoelectric module, etc. The studied refrigerator can maintain the temperature in refrigerated space at 5-100C, and has a COP about 0.3 under given conditions. [26]

B. Heat exchanger for the cold side of TE module

Vian et.al [33] shows the development of a thermo-siphon with phase change (TSF) which improves the thermal resistance of the heat exchanger of the hot side of the Peltier pellet by 36%, what produces an increase in the COP of a domestic thermoelectric refrigerator of 26% at an ambient temperature of 200 C, and 36.5% at 300 C. Along this line, Riffat et.al [34] apply the thermo-siphon system, in a thermoelectric heat pump system that works as cooling and heatingmode.

The aim is to design and experimentally optimize a heat exchanger which improves the thermal resistance between the cold side of a Peltier pellet and the refrigerated room by the application of the principles of capillarity against gravity, phase change and thermo-siphon. A new device TPM (thermos-siphon porous media) to interchange heat between the cold side of a Peltier pellet and the inner room of a thermoelectric refrigerator has been designed and built. [34]

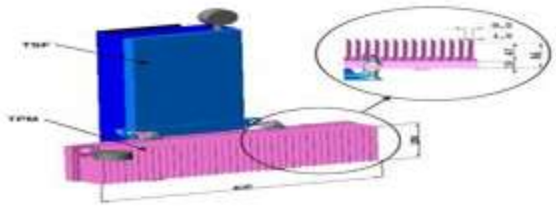


Figure No. 6: TPM & TSF

VI. COP Improvement

In Due to the fact that TE modules have very low value of COP, many researchers have taken efforts with prime objective of COP improvement. With this objective they have developed TE modules, used different modeling approaches and so on.

A. Optimization of heatdissipation

In this context, D. Astrain et al. [35] developed one device that dissipates heat from hot side of Peltier module. This device works on the principle of thermo-siphon with the phase change. Two thermoelectric domestic refrigerators are used for the experimentation, one of them with the device developed and other with the conventional fins dissipater. It is proved with the help of experiments that the use of thermo-siphon with phase change increases the COP up to 32%. It has been proved in that for each Celsius degree that we achieve to decrease the temperature drop between the hot side of Peltier and the ambience, we manage to increase the COP of a thermoelectric refrigerator in more than a 2.3%.That is exactly the focus of study: the optimization of heat dissipation from the hot side of the Peltier pellet, in order to increase the COP of the thermoelectric refrigerators.[35]

With the aim of succeeding in spreading uniformly the heat flow through the whole base of the fin dissipater,Theyhavedesigneda„„TSF"devicebasedonthermo-siphonandphasechange,whichprovidesa minor thermal resistance and in consequence a minor temperature drop between the hot side of the Peltier pellet and the ambience, which will result in an increase of the COP of the thermoelectric refrigerator. [20]

B. Increment in effectiveness of heatexchangers

The results of the work carried out by Min et al. [36] Showed that an increase in COP of the thermoelectric domestic-refrigerator is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers. A number of prototype thermoelectric refrigerators are investigated and their cooling performances evaluated in terms of the coefficient-of performance, heat-pumping capacity and cooling-down rate.

Min et al. [36] Studied following 3 prototypes for COP improvement:

TER-1 (Heat exchangers with forced convection)

TER-2 (Forced convection at the cold side and liquid circulation at the hot side) TER-3 (Liquid circulation heat-exchangers)

This study of the exchangers for the TE module is taken further by again Vian et al [33] by developing HEX for the Cold side of the TE Module. The objective is to design and experimentally optimize a heat exchanger which improves the thermal resistance between the cold side of a Peltier pellet and the refrigerated room by the application of the principles of capillarity against gravity, phase change and thermo-siphon.

Their study envelopes the development of a thermo-siphon with phase change (TSF) which improves the thermal resistance of the heat exchanger of the hot side of the Peltier pellet by 36% as elaborated above. During this research they have developed a thermo-siphon with phase change and capillary action (TPM) for the cold side of the Peltier pellet which allows decreasing the thermal resistance and, as a consequence, to improve the COP of thermoelectric refrigerators. [33]

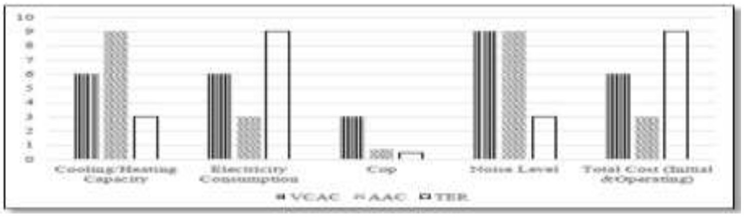
VII. Comparative Analysis

It is necessary to provide a comparative analysis of thermoelectric refrigeration system at this stage with the other parameters. The aim of this study is to provide information to the researchers to select appropriate refrigeration system suitable for the application. Hence one should compare TER system on various parameters with the other refrigeration systems. In a commercial point of view, Riffat et al. [38] Compares TER system with Vapor compression and absorption system, as these two systems are mainly used commercially in the market.

This study compares the performance of three types of domestic air conditioning systems and presents methods of COP calculations. The study includes distinct description of three systems, performance contrast among them, economic analysis and COP analysis & comparison. The conclusions are mentioned parameter wise in Table 1 & Graph 1.

Table No. 1: Comparison of Three types of AirConditioners

Parameter	**VCAC**	**AAC**	**TER**
Cooling/Heating Capacity	Medium	High	Less
Electricity Consumption	Medium	Low	High
Cop	2.6-3.0	0.6-0.7	0.38-0.45
Noise Level	Noisy	Noisy	Quiet
Total Cost (Initial &Operating)	Medium	Lowest	Highest



Graph No. 1: Comparison of Three types of AirConditioners

Effect of Number of Stages-

The simplest mode of thermoelectric refrigeration is to use a single-stage thermoelectric device. However, due to the performance limits of thermoelectric materials, a single-stage thermoelectric refrigerator can only be operated over a small temperature range. If the temperature ratio between the heat sink and the cooled space is large, a single-stage thermoelectric refrigerator will lose its effectiveness. Thus, the application of two- or multi-stage combined thermoelectric refrigerators is an important method of improving the performance of thermoelectricrefrigerators.

Chen et al. [37] compared the performance of single stage and two stage thermoelectric refrigeration system. For this they established cycle model of single and two stage TER system and derived general expressions of three important performance parameters such as COP, Rate of refrigeration and powerinput.

It states maximum COP of two stage is larger than that of single stage but maximum rate of refrigeration is smaller. In general, it is more convenient to use directly a single-stage thermoelectric refrigeration system when the temperature ratio of the heat sink to the cooled space is small. However, when the temperature ratio of the heat sink to the cooled space is larger, both the maximum COP and the maximum rate of refrigeration of a two-stage thermoelectric refrigeration system are larger than those of a single-stage thermoelectric refrigeration system. The study of Chen et al. [37] provides some theoretical bases for the optimal design and operation of a two-stage thermoelectric refrigeration system.[37]

Karimi et al. [35] Analyzed and fabricated a new device with multistage or stack of single stage TE module. Multi-stage thermoelectric coolers offer larger temperature differences between heat source and heat sink than single or two stage thermoelectric coolers. In this study, a pyramid type multi-stage cooler is analyzed, focusing on the importance of maximum attainable target heat flux and overall COP. Having considered the COP and the thermal resistance of a heat sink as key parameters in the design of a multi-stage thermoelectric cooler, analytical formulas for COP and heat sink thermal resistance versus working electrical current are derived. The study concludes that multistage TER system allows use of heat sink with higher thermal resistance which helps in improvement of COP.[35]

VIII. Conclusion

This paper reviews the developments in TER system over the years. This study on the thermoelectric refrigeration emphasize that the TER system is a novel refrigeration system which will be a better alternative for conventional refrigeration system. The research and development work carried out by different researchers on TER system has been thoroughly reviewed in this paper. The study of this seminar spreads over the application of TER system and various technologies used with the same. This seminar summarizes the advancement in thermoelectric refrigeration, thermoelectric materials, recent modeling approaches, application in domestic appliances and various technologies.

This paper also concludes that, to achieve better COP & temperature control we can combine TER with other refrigeration systems. For example combining VCR & TER systems reduces the energy consumption, gives high COP & good temperature control within the refrigerated area. Hence it is better to have such hybrid systems & devices to reduce total energy consumption.

References

[1]. ElCosnierW.,GillesM.,Lingai.,Anexperimentalandnumericalstudyofathermoelectricair-coolingand air-heating system. international journal of refrigeration, **31**,1051 –1062,**(2008).**

[2]. Sujin., Vora and Seetawan., Analyzing of Thermoelectric Refrigerator Performance. Proceedings of the 2ndInternational Science, Social-Science, Engineering and Energy Conference, **25**,154–159,**(2000)**.

[3]. Wei., Jinzhi., Jingxin & Chen.,Theoretical and experimental investigation on a thermoelectric cooling and heating system driven by solar. Applied Energy, **107**, 89–97,**(2013).**

[4]. Riffat and Guoquan., Comparitive investigation of thermoelectric air- conditioners versus vapour compression and absorption air-conditioners. Journal of Applied Thermal Engineering, **24**,1979-1993,**(2004).**

[5]. Riffat and Qiu., Design and characterization of a cylindrical water cooled heat sink for thermoelectric air conditioners. International journal of energy research, **30** , 67-80,**(2005)**.

[6]. Astrain D., Vian J.G., & Domınguez M., Increase of COP in the thermoelectric refrigeration by the optimization of heatdissipation. Applied Thermal Engineering, **23**, 2183–2200,**(2003).**

[7]. Shen., Xiao., Chen & Wang., Investigation of a novel thermoelectric radiant air-conditioning system. Journal of Energy and Buildings, **59**,123–132,**(2012).**

[8]. Virjoghe., Diana., Marcel & Florin., Numerical simulation of Thermoelectric System. latest trends on systems,**15**(2) , 630-635,**(2009).**

[9]. Maneewan., Tipsaenpromand Lertsatitthanakorn., Thermal comfort study of a compact thermoelectric air conditioner. Journal of electronic materials, **39(9)**, 1659-1664,**(2010).**

[10]. Manoj S., & Walke., Thermoelectric Air Cooling For Cars. International Journal of Engineering Science and Technology, **40(5)**, 2381-2394,**(2011).**

[11]. Yadav and Nirves., Review on Thermoelectric materials and applications. International Journal for Scientific Research & Development,**1**,413-417,**(2013).**

[12]. Manoj Kumar., Chattopadhyay and Neogi., A review on developments of thermoelectric refrigeration and air conditioning systems: a novel potential green refrigeration and air conditioning technology. International Journal of Emerging Technology and Advanced Engineering, **38**,362-367,**(2013).**

[13]. Huang B., Chin C.J., and Duang C.L., A design method of thermoelectric cooler. International Journal of Refrigeration, **23**,208-218,**(1999).**

[14]. "Thermoelectric cooling," [Online]. Available: www.wikipedia.org.

[15]. "RAC LECTURE 10 PDF," in Version 1, ME, IIT Kharagpur.

[16]. D.ZhaoandG.Tan,"Areviewofthermoelectriccooling:Materials,modelingandapplications,"AppliedThermalEngineering, vol. 66, no. 1–2, pp. 15-24, May 2014.

[17]. T. M. Tritt, "Thermoelectric Materials: Principles,Structure, Properties, and Applications," Encyclopedia of Materials: Science and Technology, pp. 1-11,2002.

[18]. T. J. Seebeck , "Magnetische Polarisation der Metalle und Erze durch Temperatur-Differenz. Abh. Akad. Wiss.," pp. 1820–21, 1822,289–346.

[19]. J.C.A.Peltier,"NouvellesexpériencessurlacaloricitédescourantsélectriqueAnnalesdeChimieetdePhysique,"vol.56,pp.371-386, 1834.

[20]. H. E. Lenz, "Ueber einige Versuche im Gebiete des Galvanismus," St. Pétersb. Acaf. Sci. Bull, vol. III, pp. 321 326, 1838.

[21]. E. Altenkirch, "Uber den nutzeffekt der thermosaule physikalische zeitschrift," vol. 10, p. 560,1909.

[22]. A. F. Loffe, "Semiconductor thermoelements & thermoelectric cooling," Infosearch,1957.

[23]. H.J.GoldsmidandR.W.Douglas,"Theuseofsemiconductorsinthermoelectricrefrogeration,"Br.J.Appliedphysics,vol.5,no.11, p. 386, 1954.

[24]. D. M. Rowe and C. M. Bhandari, "Modern Thermoelectrics," Hot Technology, 1983.

[25]. M. K. Rawat, H. Chattopadhyay and S. Neogi, "A review on developments of thermoelectric refrigeration and air conditioning systems: a novel potential green refrigeration and air conditioning technology," International Journal of Emerging Technology and Advanced Engineering, vol. 3, no. 3, pp. 362-367, Feb2013.

[26]. D. Zhao and G. Tan, "A review of thermoelectric cooling: Materials, modeling and applications," Applied Thermal Engineering,vol. 66, no. 1–2, pp. 15-24, May 2014.

[27]. T. M. Tritt, "Thermoelectric Materials: Principles,Structure, Properties, and Applications," Encyclopedia of Materials: Science and Technology, pp. 1-11, 2002.

[28]. B. Huang, C. Chin and C. Duang, "A design method of thermoelectric cooler," International Journal of Refrigeration, vol. 23, no.3, pp. 208-218, May 2000.

[29]. S. Göktun, "Design considerations for a thermoelectric refrigerator," Energy Conversion and Management, vol. 36, no. 12, pp.1197-1200, December 1995.