REVIEW ON THERMOELECTRIC COOLING APPLICATIONS

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Abstract: This study reviews the recent advances of thermoelectric materials, modeling approaches and applications. Thermoelectric cooling systems have advantages over conventional cooling devices, including compact in size, light in weight, high reliability, no mechanical moving parts, no working fluid, being powered by direct current, and easily switching between cooling and heating modes.

The study begins with the introduction and fundamentals of thermoelectric technology. A brief of thermoelectric generation is given. Some models have been presented which shows how the efficiency of the system can be increased and the materials which can be used for better cooling and various range of temperature. Further, applications of thermoelectric cooling in various areas like electronics cooling, cooling of buildings and thermoelectric refrigerators are described. The study helps to identify various applications of thermoelectric cooling which can be expanded further and also various methods to increase the efficiency of thermoelectric cooling using various methods and materials.

Index Terms – **Thermoelectric Cooling, Peltier cooling, Applications.**

1 INTRODUCTION

Increase in energy consumption has lead mankind to find various alternative ways to reduce the energy usage. Refrigeration is one of the processes which consume more energy. Various methods are adopted to reduce the energy consumption of the normal refrigeration cycle as well as to increase the efficiency of given cycle. Solar energy is one of the alternatives to use renewable energy source and it is currently in rapid progress. Moreover, different refrigerants are used to decrease the harmful effects on environment. Alternative processes are experimented in place of Vapour Compression Refrigeration System for cost as well as power reduction. One of the methods found for cooling is Thermo-electric Cooling. The process having lower energy consumption is currently studied for implementing it in day to day life.

1.1 Thermo-electric Principles:-

In 1834, Jean Peltier, a French watchmaker and amateur scientist discovered that the passage of electric current through a junction between two dissimilar conductors in a certain direction produces a cooling effect. There is a heating effect when the current is passed in opposite direction. Peltier's experiment followed those of Thomas Seeback, who in 1821 discovered that an electromotive force could be produced by heating a junction between two metals. As we see, Peltier and Seeback effect are closely related. The Thomson effect is the extension of the Peltier-Seeback model created by William Thomson in 1854[1]. Thomson showed that there will be evolution of heat when electric current passes through a circuit composed of a single material that has a temperature difference along its length. This effect is also known as thermo-electric effect. The three effects known as Peltier effect, Seeback effect and Thomson effect are inter-related and leads to a new method of conversion of heat into electricity and vice-versa.

As per Peltier effect, if a voltage difference is created between two dissimilar metals, a hot and cold junction is created. This cold junction created, can be used for cooling purpose and this utilization is known as Thermo-electric Refrigeration.

1.2 Thermo-electric Refrigeration:-

Thermo-electric devices can convert electric energy into a temperature gradient (Peltier Effect). With more research in semi-conductor materials came the capability for a wide variety of practical thermo-electric refrigeration applications.

Thermo-electric refrigeration is achieved when a direct current is passed through one or more pairs of n- and p-type semiconductor materials. Fig.1 shows a single pair consisting of n- and p-type semiconductor materials. In cooling mode , direct current passes from n- to p-type semiconductor material. The temperature of interconnecting conductor decreases and heat is absorbed from the environment. This heat absorption occurs when electrons pass from low-energy level in the p-type material through the interconnecting conductor to a higher energy level in n-type material. This phenomenon is known as Peltier effect.

Seeback effect is also important in Thermo-electric Refrigeration. The Seeback voltage is directly proportional to the temperature difference. The constant of proportionality is known as Seeback co-efficient. Similarly the Peltier effect is controlled by the Peltier co-efficient which is defined as the product of Seeback co-efficient of the semiconductor material and the absolute temperature. The Peltier effect relates to a cooling effect as current passes from n-type material to p-type material and a heating effect when current passes from p-type material to n-type material. Reversing the direction of current reverses the temperarure of the hot and cold ends[2].

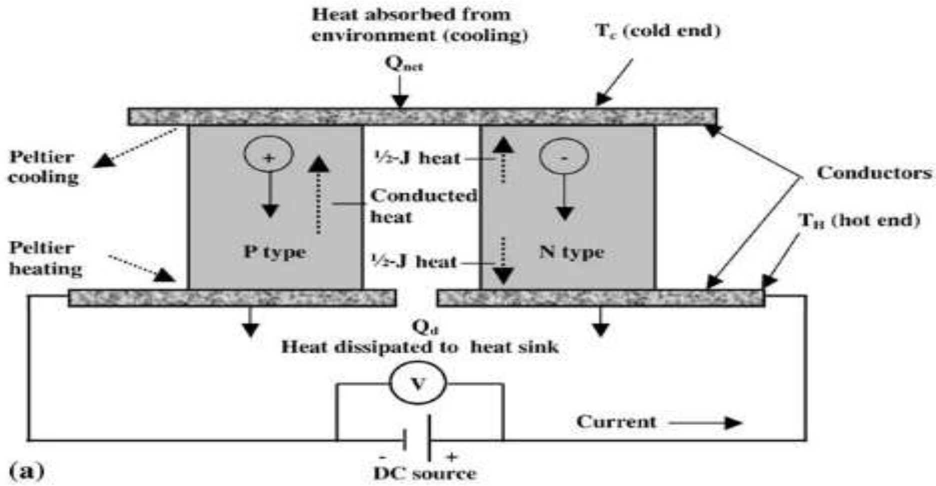

Fig.1:-Cooling mode of p-n junction [2]

1.3 Materials for Thermo-electric Refrigeration and Figure of Merit:-

The effect of heating and cooling due to thermo-couples remained minimal until the development of semi-conductor materials. N-type semiconductors and P-type semiconductors are used in thermo-couples. A good thermo-electric material should have high Seeback coefficient, high electrical conductivity and low thermal conductivity. The recent researches are based to maximize ZT (Figure of Merit) of the thermocouple materials. Conventional thermo-electric materials used are Bismuth telluride (Bi_2Te_3), Lead telluride (PbTe), Silicon germanium (SiGe) and $CoSb_3$, among which Bi_2Te_3 is most commonly used one. These materials usually possess a ZT value less than one [3]. After 1990's, theoretical predictions suggested that thermoelectric material efficiency could be greatly enhanced through nanostructural engineering.

1.3.1 Figure of Merit (Z):-

From the experimental results it was seen that the Peltier cooling term varies linearly with the electric current, where as the Joule's heating term varies as the square of the current. This means that there must be a a particular value of current at which the cooling power reaches it maximum value. It was found that positive cooling effect cannot be achieved if the temperature difference achieved is too great [4]. Thus the figure of merit for a thermo-couple was defined.

The thermo-electric figure of merit indicates whether a material is good thermo-electric cooler or not. It depends on three material parameters:- electrical resistivity ρ (or electrical conductivity, σ=1/ρ), Seeback coeffiecient α, and total thermal conductivity *k* between the cold and hot sides.

$Z = \alpha^2/\rho k = \alpha^2\sigma/k$

Considering the absolute temperature T (which represents the mean temperature between cold side and hot side of the thermocouple module), a widely used parameter is the dimensionless product ZT [5].

An alternative expression of Z takes into consideration electrical resistance R of thermo elements in series and thermal conductance *K* of thermo elements in parallel [6].

In practice, *ZT* represents the efficiency of N-type and P-type materials which compose a thermo element. A thermo-electric material having higher figure of merit is more convenient, as it can carry higher cooling power or temperature drop.

Riffat and Ma [7] showed in their review that

- Bismuth telluride (Bi_2Te_3) is the best low temperature thermo-electric material and has a maximum value of $ZT = 1$.
- If *ZT* is increased to 2 or 3, the thermo-electric cooling device would be competitive with vapour compression refrigeration systems.
- If *ZT* is increased to 6, then thermo electric devices would be able to cool to cryogenic temperature (77 K) from room temperature.

1.4 Photo-voltaic Technology:-

Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The power from sun intercepted by the earth is about 1.8 $\times 10^{11}$ MW, which is many times larger than the present rate of all the energy consumption. Photovoltaic technology is one of the finest ways to harness the solar power. Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere. Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts [8].

A photovoltaic cell is a specialized semiconductor diode that converts visible light into direct current. Each cell consists of two wafers of doped silicon (n-type and p-type), in contact to form a junction with each wafer having an electrical connection. Typically each cell is very thin, measures approximately 100mm across. One of these cell may be capable of producing upto 0.7 V with maximum power being produced around 0.4 V. Several solar cell are wired together as a module to create a panel. A 24 V panel may have 72 solar cells within it, wired in series, giving its maximum power at a voltage of approximately: 0.4*72 = 28.8 V [9].

The materials commonly used for photo-voltaic cell are Monocrystalline silicon. Epitaxial silicon development, Polycrystalline silicon, Ribbon silicon, Mono-like-multi silicon (MLM), Cadmium telluride, Copper indium gallium selenide, Silicon thin film, etc.

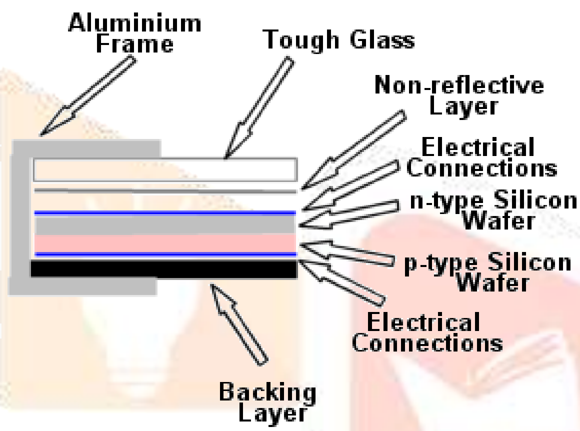

Fig.2:- Construction of PV cell [9]

1.5 Solar based Thermoelectric Technology:-

Riffat et al. [10] reasoned that thermoelectric frameworks have an extensive potential market for little fenced in areas where the power utilization would be low, or wellbeing and unwavering quality would be vital. The International of Refrigeration in Parishas assessed that around 15% of all power on the planet is utilized for different sort of refrigeration and kinds of aerating and cooling, and the vitality utilization for air-conditioining frameworks has been evaluated to 45%of the entire family and business structures [11].

The thermoelectric gadgets can change over sunlight based vitality into a temperature distinction to go about as coolers or radiator with the assistance of PV exhibits, and furthermore the thermoelectric gadgets can change over sun based warm vitality from temperature contrast into electric vitality to go about as power generators. Utilizing sun oriented vitality to control the thermoelectric gadgets is believed to be an alluring method to serve the requirements for refrigeration, cooling applications and power age, and all the while take care of demand for vitality preservation and condition assurance.

PV innovation is generally used to give the ability to the sun based driven thermoelectric refrigeration frameworks. A commonplace configuration of a sun powered driven thermoelectric refrigeration framework is appeared in Fig.3. The sun based PV/battery thermoelectric refrigeration is first created. The fundamental parts of the framework are the PV cell(including the PV cluster, the capacity battery, the controller), the thermoelectric refrigeration framework, and the cooled question (e.g., a cooling box).

The PV cluster, which produces DC power when presented to daylight, is the most costly part in the framework. It is introduced outside far from shadows, more often than not in the house rooftop and tilted towards the equator by an edge equivalent to the scope of the area. The capacity battery stores the abundance power delivered amid daylight periods. This put away vitality is utilized for running the icebox amid evenings, overcast and stormy days. There are exceptionally planned lead-corrosive batteries appropriate for profound release cycles happening in PV frameworks. The controller is an electronic gadget, which controls the framework operation as indicated by the condition of charge of the battery. Its principle obligation is to ensure the battery against exorbitant charging or releasing [11].

In this way the mix of sun oriented and thermoelectric innovation can be an approach to create cooling or warming and in addition for control age however can likewise take care of demand for vitality preservation and condition security.

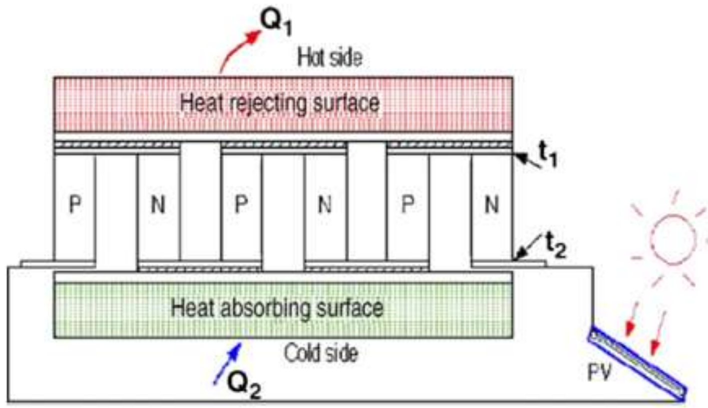

Fig.3:- Schematic of solar-driven thermoelectric refrigeration system [11]

2 Thermoelectric Generation:-

Thermoelectricity has vast applications in heating, cooling and electricity generation. When voltage is applied across junctions of different materials then temperature difference is generated and hot and cold junctions are formed (Peltier effect) and thus heating and cooling are done. Whereas, the reverse process shows that when a junction is kept at high temperature and other junction at low then voltage will be generated across the junctions (Seebeck effect) and power is produced, thus the name generator.

2.1 Thermo electric Generator:-

Thermoelectric generator directly converts heat energy into electricity using solid state and thus it has vast applications in space, automobiles, buildings and many other areas. Various heat sources are available from solar, biomass and earth. It should be noted that the TEG efficiency is rather small compared to other generating systems but with the enhancement of material properties its efficiency can be increased. Various techniques are implemented to increase the figure of merit of materials which in turn will increase the system efficiency.

Hsiao et al. [12] performed a simulation of thermoelectric module for a purpose to enhance the efficiency of an internal combustion engine. The results show that the maximum power of 51.13 mW/cm^2 is produced from the module when the temperature difference is 290 ˚C and moreover the module presents better performance on the exhaust pipe than on the radiator.

Zheng et al. [13] examined the local thermoelectric cogeneration framework for warming of structures. The framework utilizes accessible warmth source in residential condition to create preheated water for home utilize and produce power. So the framework which is coordinated the thermoelectric cogeneration to the current household kettle utilizing a warm cycle can use the unconverted warmth (more than 95% of the aggregate assimilated warm) to preheat sustain water for local heater.

One of the noticeable points of interest of TEG is its adaptability and in this manner it can successfully rummage poor quality waste warmth to supply the power for little gadgets, for example, wearable hardware, remote correspondence units and sensors. Choi et al. [14] have examined the tellurium nano-wire films hybridized with single walled carbon nanotube as an adaptable thermoelectric material. The outcomes demonstrate that amazing mechanical security and electrical conductivity assumes a noteworthy part in improving the adaptability of the material. Weber et al. [15] researched the looped up thermo-electric smaller scale control generator with the metal movies sputtered on a thin polyimide thwart, which expects to increase high voltages at a little generator zone. The outcomes appear at the structure is sufficiently adequate for low power hardware like a wrist watch.

Thus many other applications exist for thermoelectric generator, but in this review the main concern is to show the applications of thermoelectric cooling or heating which is explained in next section.

3 Thermoelectric Cooling:-

Research work is going on in the field of thermoelectric cooling for it has many advantages over conventional systems like it is solid-state, no vibration, simplicity and environment friendly. The main disadvantage of TEC is its low-efficiency for which it is not recommended in commercial applications. Various models are developed to increase the COP of TEC systems by optimizing the system.

3.1 Thermoelectric Models:-

Astrain et al. [16] developed an experimental model for dissipating the heat from hot side of Peltier pellets in thermo-electrical refrigeration based on the principle of thermosyphon with phase change in order to optimize the heat dissipation to increase the COP of thermo-electric refrigeration. The device design was established by analytical calculations and simulations with computational fluid dynamics. Fig.4 shows the schematic diagram of the model developed. The inner fluid in the thermosyphon is in contact of the hot side of peltier module which leads to its boiling. The generated vapour rises by natural convection towards the high part of thermosyphon.

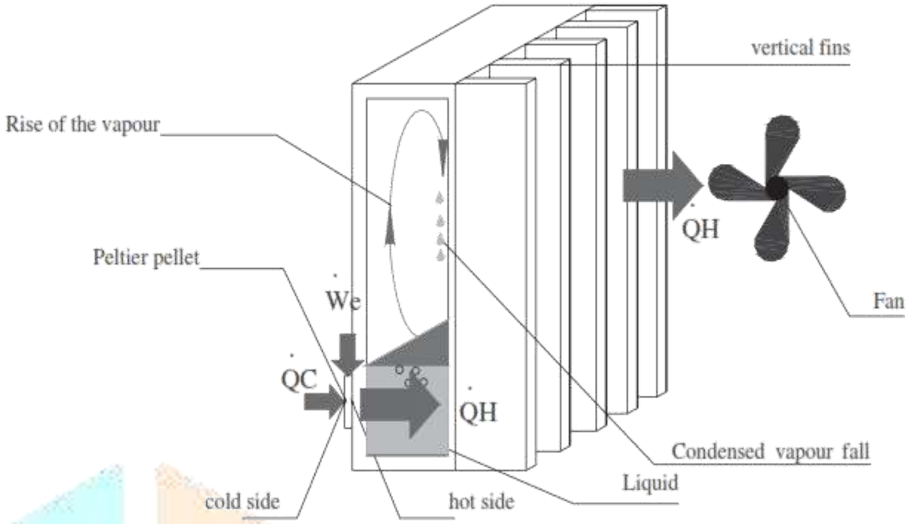

Fig.4:- Thermal diagram of TSF [16]

The experimental results showed that TSF has higher COP. The COP for TSF varies from 23.8% to 51.4% as compared to commercial finned heat sink which has COP in range of 13.8% to 45% depending on the ambient temperature.

Jeong et al. [17] have researched one dimensional explanatory mode to improve the Thermo-electric cooling module. Ideal current is acquired to boost the COP of the framework and in addition the conclusion demonstrates what parameters will influence the COP. The outcomes demonstrate that the ideal current expanding the COP is controlled by the cooling limit of a thermoelement, the hot and chilly side temperatures, the properties of thermoelectric material and the warm and electrical contact protections however not by the length of thermo-component. The outcomes likewise demonstrates that greatest protection diminishes as the contact protection increments and the protection diminishes as the cooling limit increments.

Wang et al. [18] studied optimum configuration of a thermoelectric cooling system by applying entropy generation analysis method. The effects of total thermal conductance and the heat capacity rate of cooling fluid on the irreversibility under the condition of maximum COP and cooling capacity are investigated in detail. Fig.5 shows a graph plotted of N_s v/s COP as a function of $m_f c_{pf}$ with various UA/K_m where I and x both are set to maximize Q_c. The results showed that in case of highest cooling capacity condition, increasing both thermal conductance and heat capacity rate of the capacity of the cooling fluid will lead in the improvement of corresponding COP.

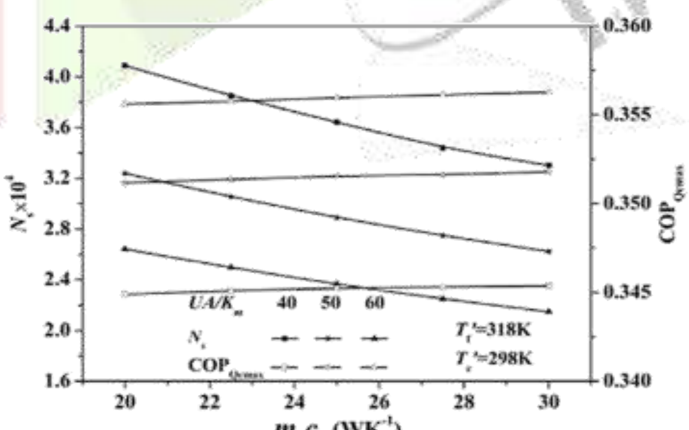

Fig.5:- N_s and COP plotted as a function of $m_f c_{pf}$ with various UA/K_m [18]

Through working condition administration of the thermoelectric modules (TEM) and outline advancement of the warmth exchangers connected to the TEM, David et al. [19] have presented an advancement technique for enhancing thermoelectric warmth pump execution. Two business thermoelectric modules was constructed and looked at. The outcomes demonstrate that comparable outcomes are gotten by minimization of the entropy age in the gadget. The hot warm power request is incorporated into the improvement factors for finish streamlining of the gadget.

The performance of thermoelectric systems largely depends on the type of semiconductor used in peltier pellets. The properties of semiconductors have led to the development of materials with a large enough thermoelectric power to permit the construction of thermo elements with much higher efficiencies than was possible with metals. Bismuth Telluride is the most common semiconductor used in thermoelectric systems. Preliminary experiments have led to the production of a thermocouple consisting of bismuth telluride, Bi_2Te_3, and bismuth, capable of maintaining 26 ˚C of cooling. Rosi et al. [20] measured electrical conductivity, thermoelectric power and thermal conductivity on Bi_2Te_3 and the alloy systems $(BiSb)_2Te_3$, $Bi_2(TeSb)_3$ and $(BiSb)_2(TeSb)_3$. The results showed that the thermocouples made of above materials have yielded maximum cooling corresponding to a temperature difference of 65 ˚C between hot and cold junction, with the hot junction kept at 300 K.

Pei et al. [21] has found that the transport properties of PbTe alloyed with MnTe results in a ZT as high as 1.6 at 700 K. The best commercial thermoelectric materials currently have value of ZT around 1. The highest ZT value in research is about 3. Research is going on to increase the ZT, so as to make thermoelectric systems more efficient.

Chung et al. [22] has studied the properties of a material $CsBi_4Te_6$. The material has been synthesized and the results show that the material will act as an excellent thermo cooler. When doped appropriately, it exhibits a high thermoelectric figure of merit below room temperature (ZT=0.8 at 225 K).

3.2 Thermoelectric Cooling Applications:-

Thermoelectric Cooling can be applied in many areas. This overview mainly focuses on three fields. The most common application of thermoelectric cooling is for cooling electronic devices which is explained in the first subsection. The other applications include cooling in buildings and refrigerating equipments. The applications also include solar assisted cooling which is used to reduce the energy consumption for thermoelectric cooling.

3.2.1 Thermoelectric Cooling in Electronic Device:-

With steady expanding of microchip control dispersal and the extent of chip, the warmth motion of chip is bit by bit expanding. In addition, the quick increment of data innovation causes an expansion popular for chip that has a high figuring capacity. A CPU has around 1.17 billion transistor unit planted in it, which implies that a lot of warmth is created. The aggregate warmth scattering from a top of the line CPU is around 110-140 W, and it will increment if the CPU voltage and recurrence increments. Along these lines thermoelectric coolers are utilized as a part of cooling of CPU units [23].

Liu et al. [24] proposed a thermoelectric mini cooler coupling with a micro thermosyphon cooling system for the purpose of CPU cooling. A mathematical model was established as well as full scale experiments were conducted to know the effect of thermoelectric operating voltage, power input of heat source on the performance of cooling system. The cold side of thermocouple was attached to the CPU whereas the hot junction to the thermosyphon was coupled with the sink. He concluded that (i) Heat source surface temperature increases with the increase in power input of heat source. (ii) Cooling capacity of thermoelectric cooler doesn't increase with the increase in power input. (iii) Blindly increasing thermoelectric module numbers could deteriorate the performance of cooling system. (iv) If total dimension of thermoelectric module matches well with the dimension of CPU then maximum results can be on obtained. (v) According to 84 W power input, the maximal surface temperature is 70˚C under steady state operation.

Chein et al. [25] have tended to the warmth sink warm protection for TEC execution in the electronic cooling. The outcomes demonstrate that the cooling limit could be expanded with the expansion of Tc (temperature of frosty intersection) and decreasing of ΔT and the greatest cooling limit and chip intersection temperature got were 207 W and 88˚C, separately. The outcomes additionally show that when the TEC was worked in the authorized administrations ($\Delta T < 0$), bigger cooling limit and higher COP could be gotten and the limitation of the TEC execution are Tc esteems and warmth sink warm protection at the TEC hot side.

Cai et al. [26] presented a multiple-objective optimization based on thermoelectric heat exchanger module (TEHEM) for application in CPU cooler. The thermoelectric heat exchanger module coupling multi-parameters is used as a novel method to solve the heat dissipation. By combining the surface temperature of CPU and input power with the weight factor as the multi-objective function, optimization is implemented. The variables of single-objective and multi-objective functions are compared and optimal conditions are concluded. Fig.6 shows the relation of power input (P) and current (I) with total resistance (R_t) and surface temperature (T_j) of heat source for a single-objective optimization. The results shows that it is necessary to control and I and R_t in order to get optimal operating conditions. The multi-objective optimization is implemented with aim to decrease T_j and P. Fig.7 shows variation of current (I) with hot side thermal resistance (R_t) on multi-objective function (J) at different weight factor (f). It is concluded that the optimal current for minimum T_j is 18 ˚C, I=9.8 A at R_t=0.02 Ω, 36.6 ˚C, I=8.3 A, R_t=0.05 Ω, respectively.

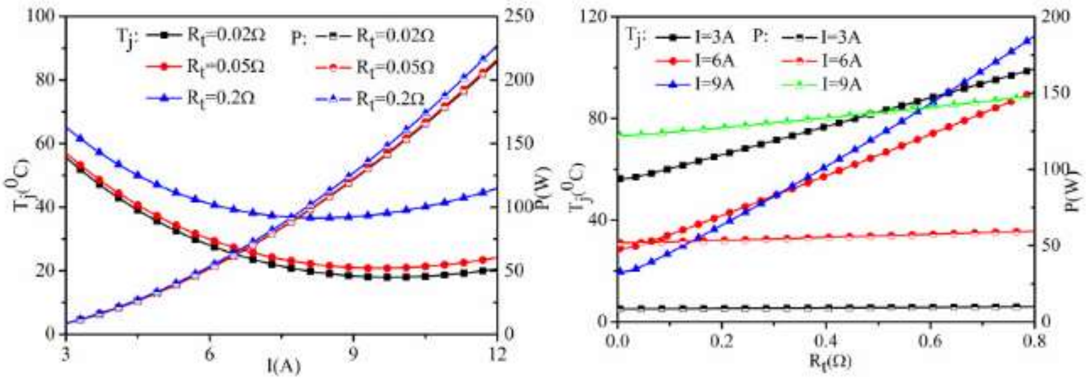

Fig.6:- Variation of current (I) and hot-side thermal resistance (R_t) with surface temperature (T_j) and input power (P) [26]

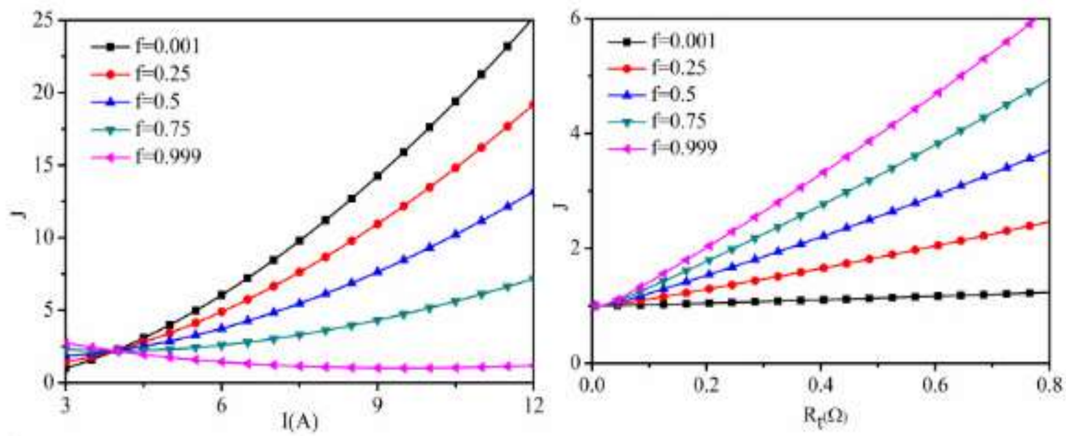

Fig.7:- Variation of current (I) and hot-side thermal resistance (R_t) with multi-objective function (J) at different weight factor (f) [26]

Zhu et al. [27] have investigated the impacts of the load current, the geometric size, the ratio of length to cross-sectional area and the substrate's thermal resistance on the cooling performance and response time of the miniature thermoelectric coolers via finite element methods. The results show that reducing TEC's size and ratio of length to cross-sectional area can improve the TEC's performance. For the given condition, maximum cooling temperature difference of 88 ˚C, a cooling power density of 1000 W/cm^2 and a short response time on the order of milliseconds can be achieved.

3.2.2 Thermoelectric Cooling in Buildings:-

He et al. [28] have studied the buildings composited with thermoelectric cooling and heating systems using solar energy to cool rooms in summer and heat rooms in winter via thermoelectric devices and photovoltaic/thermal (PV/T) dual function modules. Fig.8 shows the system's working structure.

The bottom of a heat pipe (1) is welded on the back of solar cells, while the top is inserted in the heat exchanger. The bottom of thermoelectric device in the experimental room is connected to radiator whose material is aluminum, and the top is connected to the evaporator end of heat pipe (2) whose condenser end is inserted into the outside heat exchanger. On one hand, the photovoltaic/thermal (PV/T) system transports the heat gotten from the sunlight into the heat exchanger through heat pipes (1); on the other hand, when the thermoelectric device is powered by PV/T system, its cold side absorbs heat and the hot side releases a lot of heat which will be transported into the heat exchanger by heat pipe (2). And the heat exchanger is linked to a storage tank through a circulating pump which can transport heat between them.

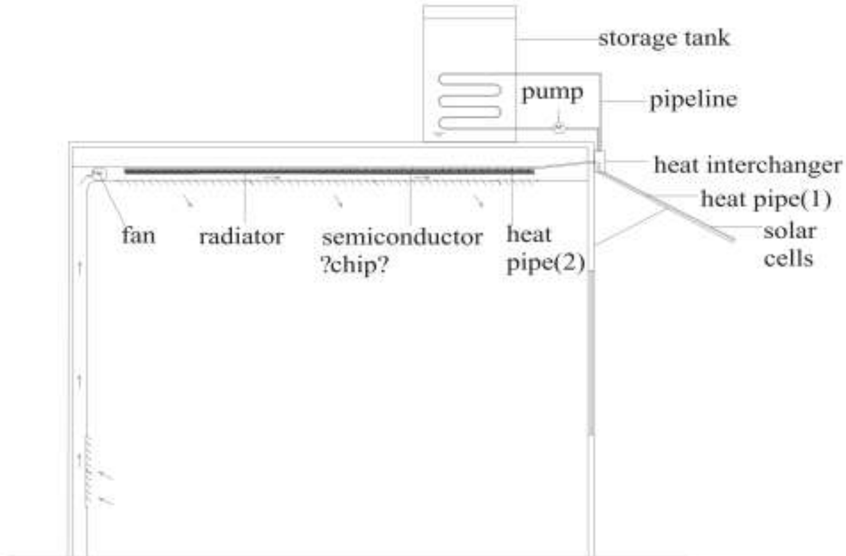

Fig.8:- Working Principle of Thermoelectric Room Cooling [28]

The fan and radiator which are tied to the cold side will discharge cold more efficiently, which causes the temperature of experimental room drop quickly.

Thus, in summer the TE device works as a cooler, utilizing the electric power generated by PV/T modules. In winter the voltage applied to the thermoelectric device is reversed. Hence, the thermoelectric device could release heat to increase the temperature of the room. It was concluded that minimum temperature of 17 ˚C is achieved, with COP of thermoelectric device higher than 0.45 and the temperature of water in the storage tank with a volume of 18.5 L has risen about 9 ˚C. The result also shows that the thermal efficiency of system is 12.06%.

Khire et al. [29] have investigated the Active Building Envelope (ABE) systems which use solar energy to compensate for the passive heat losses or gains in building envelopes or other enclosures. In ABE systems, solar radiation energy is converted into electrical energy by means of a photovoltaic unit (PV unit). Subsequently, this electrical energy is used to power a thermoelectric heat pump unit (TE unit), which is a collection of thermoelectric coolers (heaters in winter). The TE unit allows the transport of heat through the ABE wall. The PV and TE units are integrated within the ABE system enclosure.

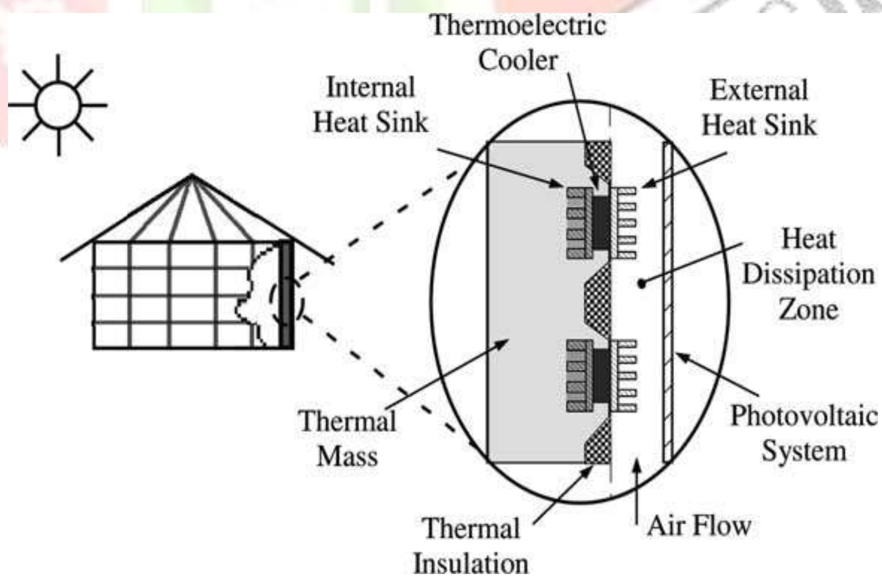

Fig.9:- Active Building Envelope System [29]

The TE unit can operate in a heating or a cooling mode, depending on the direction of the current supplied by the PV unit. This feature allows for the ABE system to be used for heating as well as cooling applications. As shown in Fig.9, the PV unit forms an envelope surrounding the external wall such that a gap is maintained between the wall and the PV unit. This gap acts as an external heat dissipation zone for the TE unit. The investigation focuses on the design and analysis of a key component of the TE unit which becomes an integral part of the generic enclosure. The result shows that for the given design a TE unit configuration using 20 TE coolers are required.

A solar-driven thermoelectric cooling module with a waste heat regeneration unit designed for green building applications is investigated by Cheng et.al. [30]. The waste heat regeneration unit consisting of two parallel copper plates and a water channel with staggered fins is installed between the solar cells and the thermoelectric cooler. The useless solar energy from the solar cells and the heat dissipated from the thermoelectric cooler can both be removed by the cooling water such that the performance of the cooling module is elevated. The tested combined module is divided into four major components: namely, solar cells, thermoelectric cooler, waste heat regeneration unit, and the measurement system, which are shown in Fig.10.

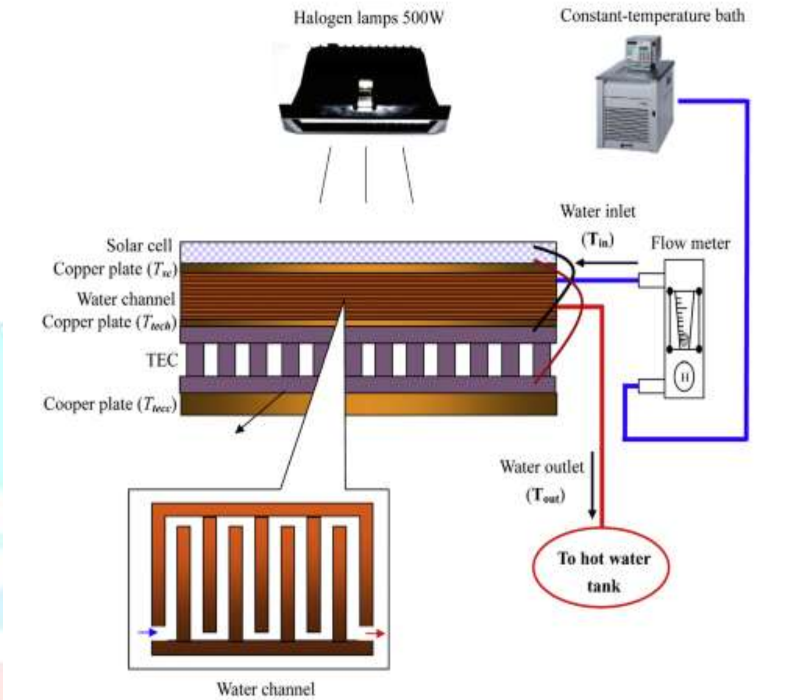

Fig.10:- Schematic Diagram of Experimental Setup [17]

The combined module is tested in the applications in a model house. It is found that the present approach is able to produce a 16.2 ˚C temperature difference between the ambient temperature and the air temperature in the model house.

Manikandan et. al. [31] presented a modified pulse operation of the thermoelectric cooler (TEC) for building space cooling application. In the modified pulse operation, along with the pulse current, the hot side heat transfer coefficient is also pulsed. A numerical model for the thermoelectric cooling system is developed and the system is studied with variable pulse current ratio, cooling load, variable pulse width and with dissimilar pulse shapes. The result shows that, for a typical operating condition with the modified pulse operation, the thermoelectric cooling system can provide an average cooling power of 600 W with the COP of 1.01, which are 23.3% and 2.12% higher than the normal mode of operation (i.e. without current pulse) respectively. This study also found that the rectangular-shaped pulse can provide higher average cooling power and COP when compared with the ramp and exponential pulse.

Investigation on thermoelectric cooling for small-scale space conditions applications is presented by Gillott et al. [32] theoretically and experimentally. Eight pieces of Ultra TEC were shown to generate up to 220 W of cooling with a COP of 0.46 under the input current of 4.8 A for each module. Thermo-economical analysis was carried out and results showed that a system with PV panel can compete with an equivalent system without a PV panel when PV costs fall down per Watt. For the cases without a PV panel, the system with a high level of TEC power input delivered a better performance in terms of the average cooling energy price than that system with a low level of TEC power input after critical interest rate (approximately 4%).

3.2.3 Thermoelectric Cooling in Refrigerators:-

Y.J. Dai [33] developed a small PV/battery thermoelectric refrigerator to meet the need for outdoor use (2-3 persons). Two panels of solar cells are used in this experiment. Fig.11 shows the prototype of solar cell driven, thermoelectric refrigerator which is mainly configured by the array of solar cells, controller, storage battery, rectifier and 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.

Fig.2.4 shows the prototype of solar cell driven, thermoelectric refrigerator which is mainly configured by the array of solar cells, controller, storage battery, rectifier and 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. The controller, also an auto switcher, plays a role to maintain the energy conversion process in most optimized way. In nighttime, the storage battery, as well as a backup AC rectifier is used to power the refrigerator.

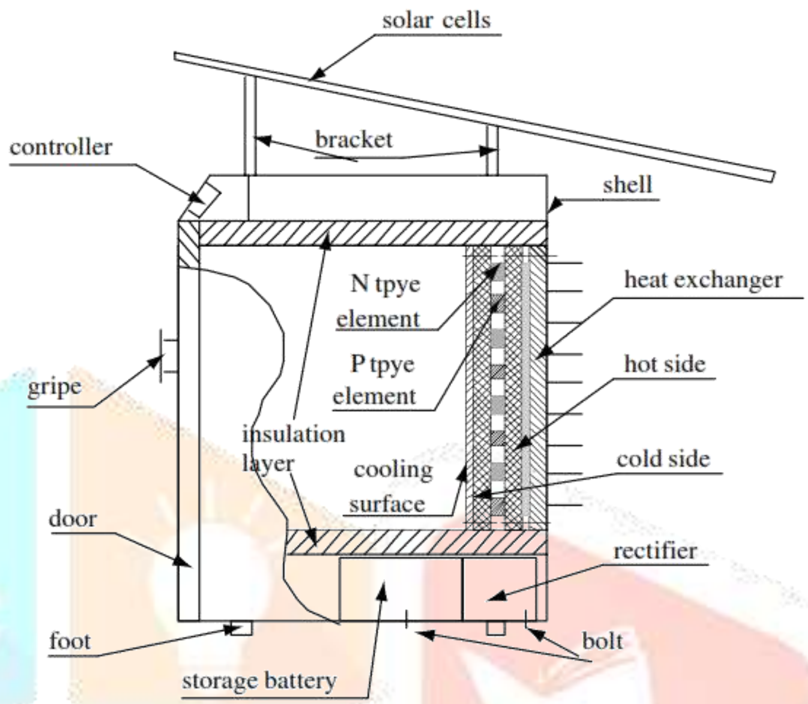

Fig.11:- Schematic of solar driven, thermoelectric refrigerator [33]

The specific input power of the thermoelectric cooling module is 45 W and specific voltage is 12 V. The lead acid storage battery has a capacity of 100 Ah, and can supply electric power for 24 h without sunshine. It is reported that the unit could maintain the refrigeration temperature at 5–10 ˚C, and has a COP of about 0.3; furthermore, the performance of the system is strongly dependent on intensity of solar radiation and temperature difference between hot and cold sides for the thermoelectric module.

Thermoelectric cooling products available for the food sector include compact refrigerators (15–70 l) for hotel rooms (mini bar), mobile homes, trucks, recreational vehicles and cars; wine coolers; portable picnic coolers; beverage can coolers and drinking water coolers.

Min et al. [34] tested and built prototype of domestic refrigerator of larger capacity (115 l to 250 l) achieving COP around 0.3-0.5 for a typical operating temperature of 5 ˚C with ambient temperature of 25 ˚C. A schematic diagram of proposed system is shown in Fig.12. It shows a cooling loop containing a liquid heat exchanger on the hot side of thermocouple and fin-type heat exchanger on the inside cabinet. It has been reported that the rate of heat dissipation from the Peltier module surface may be improved using an enclosed liquid circulating system.

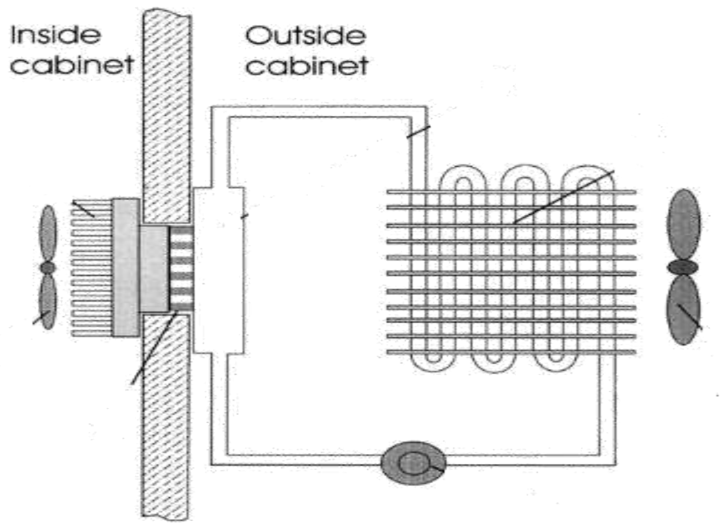

Fig.12:- Thermoelectric refrigerator with a closed loop heat exchanger [34]

The results show that an increase in its COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers.

Abdul-Wahab et al. [35] build a portable solar thermoelectric refrigerator for remote areas where electricity is not available all the time. 10 thermoelectric modules were used to obtain cooling in the refrigerator. The experimental setup is shown in the Fig.13.

The cold side of the thermoelectric module is utilized for refrigeration purposes; provide cooling to the refrigerator space. On the other hand, the heat from the hot side of the module is rejected to ambient surroundings by using heat sinks and fans. The designed solar thermoelectric refrigerator was experimentally tested for the cooling purpose. The results indicated that the temperature of the refrigeration was reduced from 27 ˚C to 5 ˚C in approximately 44 min. The co-efficient of performance of the refrigerator (COP) was calculated and found to be about 0.16.

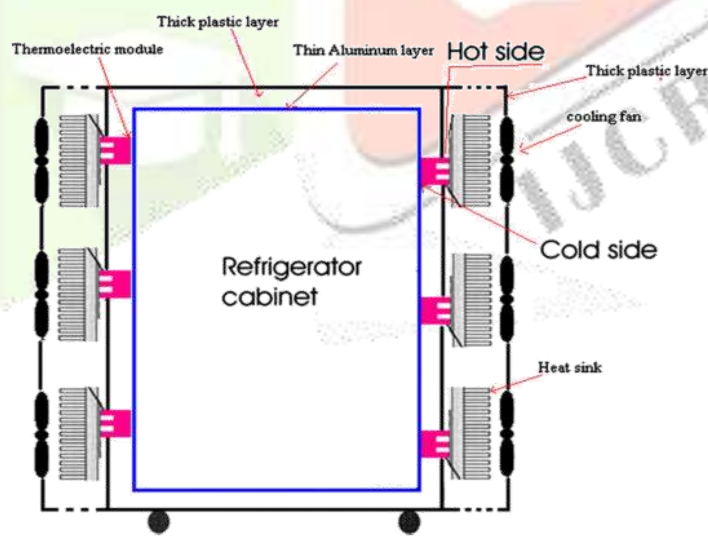

Fig.13:- Cross-section View of Refrigerator [35]

Palaniappana et al. [36] have explored the numerical examination of a thermoelectric refrigeration framework. The outcomes demonstrates that the COP for the Bi– Te framework was 13.4% higher contrasted with the Pb– Te under the same working conditions and the warmth consumed by the Bi– Te framework was 28.42% higher than that by the Pb– Te.

He et al. [37] did experimental investigation of thermoelectric refrigeration box used for medical service. 3 groups (total 17 conditions) of actual performance working conditions of the box have been studied. The paper provides an optimal working voltage range for the refrigeration and also a new refrigeration box model for medical use.

4 Summary:-

This paper reviews the development of thermoelectric cooling in the recent decade from aspects of advances in materials, the modeling approaches, and applications. Different thermoelectric modeling approaches have been summarized in this review. Different materials have been suggested to increase the efficiency of the system as well as to obtain better cooling (lower temperature).

Typical applications of thermoelectric cooling have been summarized in three categories, including refrigeration, electronic cooling, and cooling of buildings. However, thermoelectric cooling applications are not limited to these areas. More applications are there in areas like automobile and more are emerging with high quality thermoelectric materials being developed and thus the thermoelectric cooling devices are approaching higher performance efficiency.

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