International Journal of Advance Research in Science and Engineering
Vol. No.4, Issue 10, October 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

REVIEW ON PORTABLE SOLAR THERMOELECTRIC REFRIGERATOR CUM AIR COOLER

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ABSTRACT

This paper is a comprehensive review on existing technologies based on solar thermoelectric cooling applications. The primary objective of this portable solar thermoelectric refrigerator cum cooler is to provide a comparatively low cost alternative to existing cooling systems. Refrigerators in the confines of our homes are too traditional, besides a portable refrigerator with a cooler which runs on solar energy as an alternative is a better choice. As a developing civilization, we have been consuming large amounts of energy for our survival and the non-renewable sources of energy are depleting. This explains the focus of the research, ie. To harness renewable sources of energy, solar in this case; keeping in mind the world energy crisis. Solar energy is widely available as compared to other renewable energy sources. The system will utilize solar energy, where supply of conventional electricity is not dependable. Comparison has been made based of existing systems and feasibility. The system works on Peltier effect and Seebeck effect. Thermoelectric Modules are incorporated for space cooling application. The cold side of the thermoelectric modules is utilized for space cooling, and the heat generated in the thermoelectric modules is removed using heat sinks and an arrangement of fans. The coefficient of performance of the system is a criterion for evaluating the performance of the cooling system. An effort has been made to enhance the COP using a combination of solar cells and thermoelectric modules. The system is compact, which makes it portable and it can be customized and fabricated to meet different user's requirements. The problem with traditional refrigerators have been, high consumption of electricity, negative impacts on the environment, all these problems have been addressed by the thermoelectric cooler. It does not make use of refrigerants thus ensuring a green and eco- friendly technology for space cooling applications. The absence of Compressor leads to noiseless operation and lowered maintenance cost. It is an energy efficient initiative, consuming less power. For generations rural India does not have a dependable supply of electricity. Being highly reliable alternative it is intended for use in these places. Thus, making sure that *cooling and refrigeration facilities in portable form are made available to the masses in less privileged areas. Solar Thermoelectric Cooling is greener and cleaner.*

***Keywords:* COP of Thermoelectric Cooling, Refrigeration systems, Solar Thermoelectric Cooling, Thermoelectric Modules.**

I INTRODUCTION

Refrigeration can be defined as the process of extracting heat from a substance using a heat exchanger. Space cooling is the same phenomenon as refrigeration, though heat is extracted from a defined space, to ensure that the temperature in the space is maintained lower than the surroundings. Refrigeration has been required since early times. Food materials, start decomposing at higher temperatures. Preservation of food caused the commercial usage of a refrigerator. Refrigeration has been used commercially since 1900s. Traditional refrigeration and space cooling techniques have made use of the Refrigerator, Air Cooler or Air- Conditioner. The major components of a traditional refrigeration system are compressor, condenser, evaporator and throttle valve. Major drawback of these systems is that they consume large amount of electricity, are expensive and not feasible for use where electricity is not dependable. This has led to consideration of alternatives to space cooling and refrigeration. There is a huge market and demand for thermoelectric cooling, except for a few drawbacks which can be easily overcome with serious consideration. A thermoelectric module belongs to the family of semiconductors that acts as a heat pump. It works on Peltier effect to produce the required output. Peltier cooler performance is a function of atmospheric temperature, hot side of heat sink performance and cold side of heat sink performance, thermal load and electrical parameters of Peltier. This review also focuses on the use of solar energy to offer maximum usage of non-conventional energy sources to enable the use of greener technology. Thermoelectric cooling has not posed as very feasible system owing to high sensitivity to fluctuations in voltage and current. Fluctuations in case of Thermoelectric Modules make them function in reverse manner, causing flow of heat to the space meant for cooling. These drawbacks have been considered and a review of suggested methods that help to enhance performance of systems that employ thermoelectric cooling has been listed here. The concept of solar energy usage came to light after the growing energy crises in our planet. The need for sustainable fuels is higher than never before. Also cleaner and greener alternatives are encouraged to make up for the damage created by conventional fuels so far. The portability of this system helps in easy transportation. The use of solar energy as a source is a boon to a large number of people from economically backward sections. The COP and correct analysis of TEC application can be carried out using performance plots. It is important to note that thermoelectric cooler performance should depend upon atmospheric conditions.

1.1. Thermoelectric Cooling

Thermoelectric cooling employs Peltier effect to create a heat flux between two different kinds of metals. A Peltier cooler, after the consumption of electrical energy, transfers heat from one side of the device to the other, depending on the direction of the current. This is a relatively new approach of cooling designed to reduce the number of moving parts and to reduce the usage of refrigerants. It is a solid state heat pump that causes heating or cooling when electric current passes through two conductors. A voltage is applied at the free ends of two dissimilar metals, which causes temperature difference. With this temperature difference, the cooling due to Peltier will cause heat to move from one end to another. This is achieved through small p-n junction semiconductors called thermoelectric modules. The absence of refrigerants makes it a more eco-friendly cooling system. Thermoelectric Modules require heat sinks, fan, and cooling arrangement. The performance and efficiency of a thermoelectric cooling system is given by its COP. A typical circuit with thermoelectric module and the arrangement can be shown as follows:

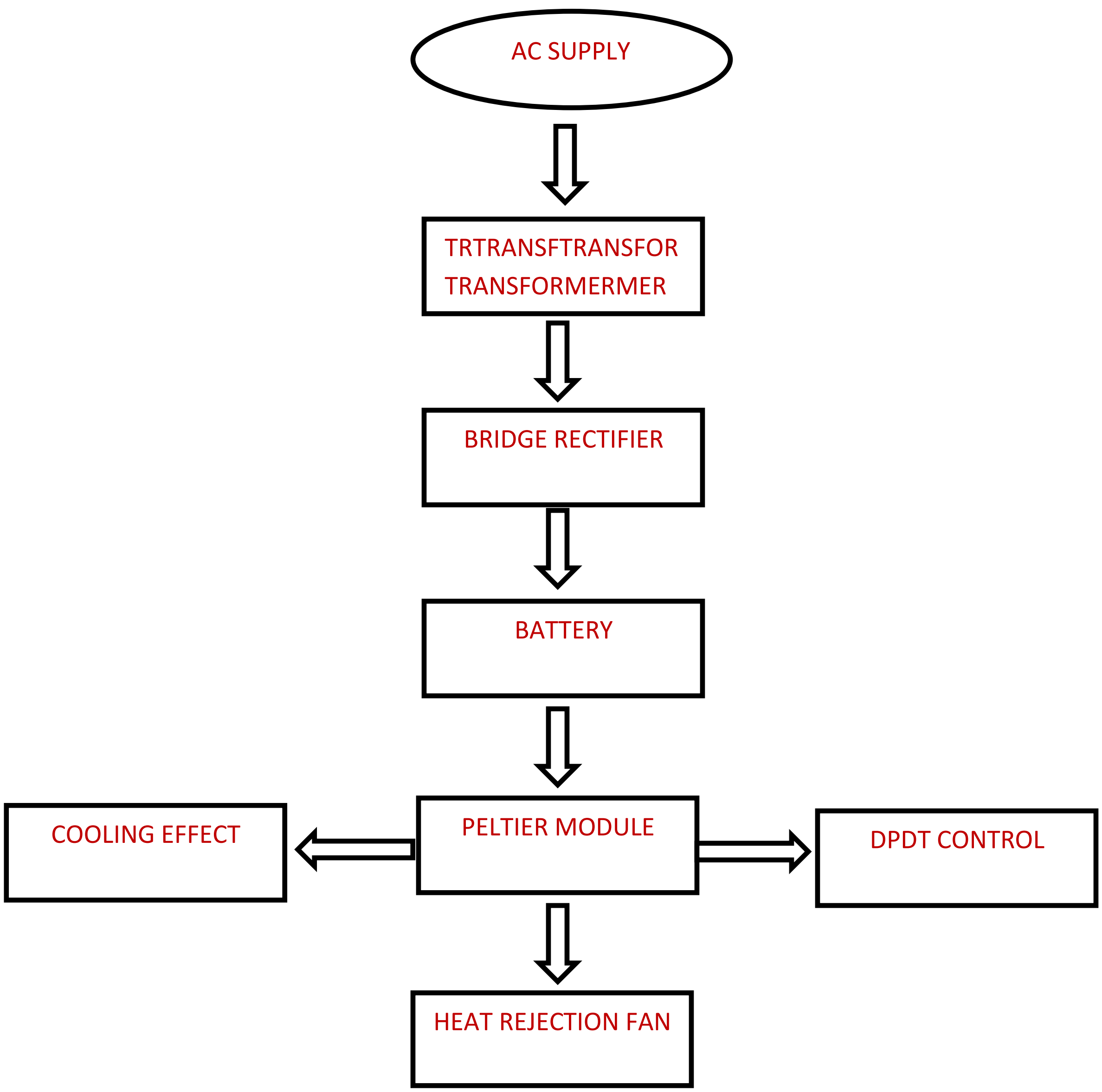

Fig 1: The arrangement of a thermoelectric cooling system

1.2. Coefficient of Performance(C.O.P)

COP can be define as, "the ratio of desire effect to work input". The more lucid definition can be given as "it is the ratio of cooling effect achieved to the electrical energy consumed".

$$C.O.P = \frac{W}{Q}$$

W= Work input.

Q= heat supplied/removed from the reservoir.

The C.O.P of TE module which is nothing but thermal efficiency must be considered for thermoelectric system.

The C.O.P is the ratio of thermal power O/P to electrical power I/P of TEC.

The calculation of C.O.P for a thermoelectric module can be done by taking the ratio of amount of heat absorbed at the cold side to the I/P power.

The conclusion that can be drawn is that the C.O.P of refrigerators ranges from 0.3 to 0.6, which is about the 1/6th value of traditional VCR refrigerators.

1.3 Thermoelectric Modules

A thermoelectric module is a TE device with intricate construction. Its construction can be shown by the following figure:

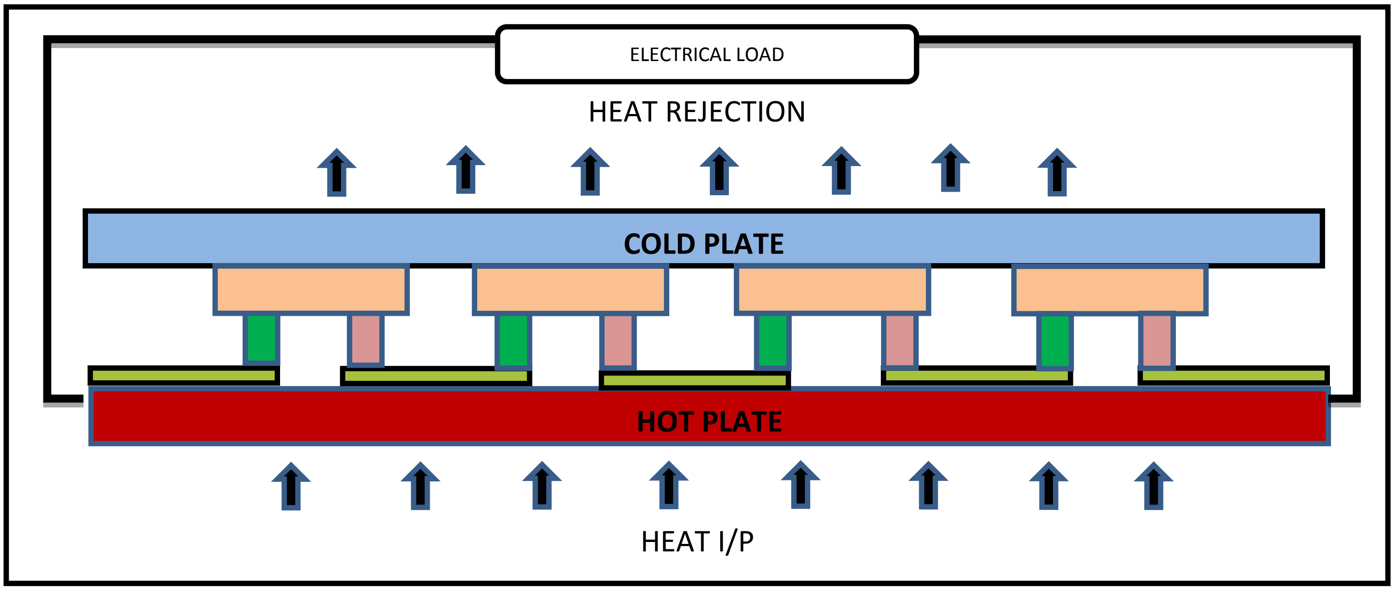

Fig 2: Construction of a TEC module

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A module is a p-n junction sandwiched between two conducting plates. There is a ceramic substrate which covers the layer; the p-n junctions are placed side by side as shown in the figure. The two sides are maintained at two different temperatures, the side which generates heat is the "hot side". The side which absorbs or extracts heat is the "cold side". The temperature difference needs to be maintained. It is necessary to ensure that heat from the hot side, be absorbed and dissipated in the surroundings effectively. This requires usage of heat sinks, fans or silica gel to be applied on the thermoelectric module. If heat is not dissipated effectively, the hot side will keep getting hotter, temperature will keep rising and by second law of thermodynamics it will flow to the side at lower temperature "cold side". Thus we maintain proper heat dissipation mechanism on the "hot side."

Thermoelectric Modules come with varying specifications. There is a specific set of rules for naming a Thermoelectric Module and they can be listed as follows:

A few specifications can be listed as shown in the table:

Table 1: STANDARD AVAILABLE TEC MODULES.[11]

Type Number	Couples	Imax (A)	Umax (V)	Qcmax ΔT =0 (W)	ΔTmax Qc=0 (℃)	Dimensions (mm)			(Ω)	(g)
				Th=27℃		L	W	H		
TEC1-07106T150		6		31.6	65	30	30	3.9	1.08	14
TEC1-07110T150		10		52.7	62	30	30	3.3	0.65	12
TEC1-07112T150		12		63.2	63	38	38	3.9	0.54	21
TEC1-07118T150		18		94.8	60	38	38	3.4	0.36	19
TEC1-07106T200		6		31.6	65	30	30	3.9	1.08	14
TEC1-07110T200	71	10	8.5	52.7	62	30	30	3.3	0.65	12
TEC1-07112T200		12		63.2	63	38	38	3.9	0.54	21
TEC1-07118T200		18		94.8	60	38	38	3.4	0.36	19
TEC1-07106T250		6		31.6	65	30	30	3.9	1.08	14
TEC1-07110T250		10		52.7	62	30	30	3.3	0.65	12
TEC1-07112T250		12		63.2	63	38	38	3.9	0.54	21
TEC1-07118T250		18		94.8	60	38	38	3.4	0.36	19
TEC1-12706T150		6		56.5	65	40	40	3.9	1.96	23
TEC1-12710T150		10		94.2	62	40	40	3.3	1.16	21
TEC1-12712T150		12		113	63	50	50	3.9	0.97	38
TEC1-12718T150		18		169.6	60	50	50	3.4	0.65	36
TEC1-12706T200	127	6	15.2	56.5	65	40	40	3.9	1.94	23
TEC1-12710T200		10		94.2	62	40	40	3.3	1.16	21
TEC1-12712T200		12		113	63	50	50	3.9	0.97	38
TEC1-12718T200		18		169.6	60	50	50	3.4	0.65	36
TEC1-12706T250		6		56.5	65	40	40	3.9	1.94	23

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ISSN 2319 - 8354

Selection of a Thermoelectric Module is based on the requirement of the system, its cooling capacity, temperature difference to be achieved, cooling duration, COP of the system and voltage supplied. Some of the parameters with which one can decide the type of module to be used are:

ΔT- Operating temperature difference.

Q- Operating cooling capacity.

I- Applied or available current.

U- Terminal voltage and dimensional restrictions and others.

An actual Thermoelectric Module can be shown as follows:

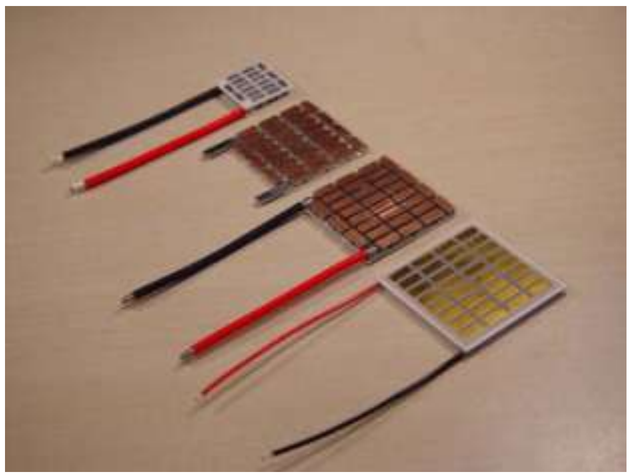

Fig 3: Actual TEC module

1.4 Types of Refrigeration Systems

Various refrigeration systems are being used commercially and for domestic use. They can be classified as shown in the figure below:

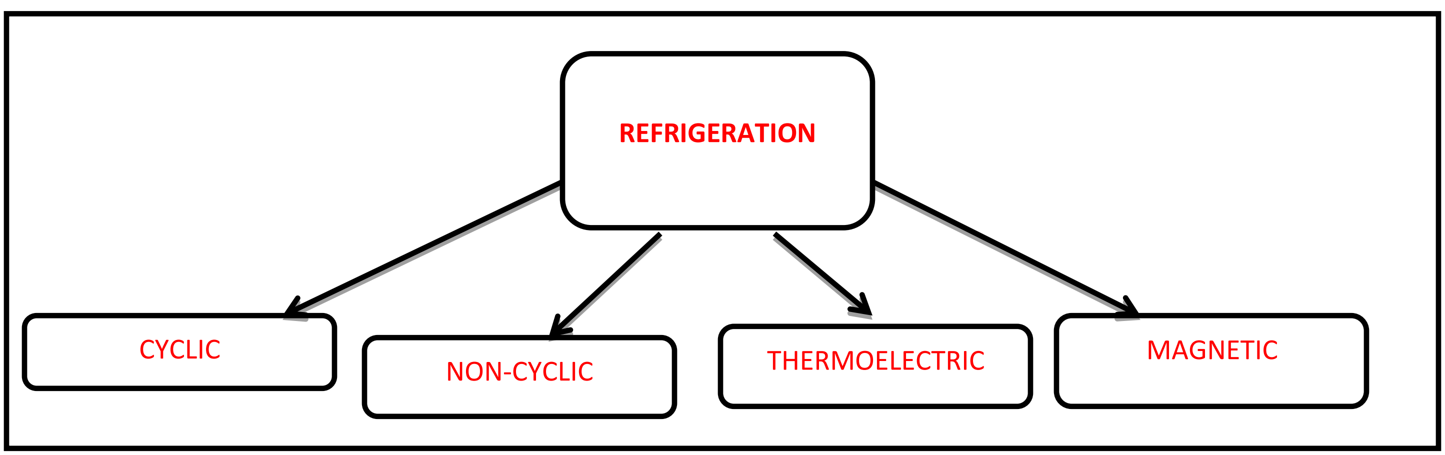

Fig 4: Classification of refrigeration systems.

1. Cyclic Refrigeration
2. Non-Cyclic Refrigeration
3. Magnetic Refrigeration
4. Thermoelectric Refrigeration

They can be explained as follows:

1.4.1 Cyclic Refrigeration: Another name for Cyclic Refrigeration is Reverse Carnot Cycle. Second Law of Thermodynamics states that heat flows from higher temperature to lower temperature. For reverse of this, work needs to be done. Thus in cyclic refrigeration heat is extracted from a system at lower temperature and it is rejected to the surroundings with higher temperature.

1.4.2 Non-Cyclic Refrigeration: Non-Cyclic Refrigeration does not require work to be done. Here we make use of a medium or agent like dry-ice for cooling the place. Such cooling application will be effective only in a small space, like a food storage unit, laboratory, small eateries and preservation units etc.

1.4.3 Magnetic Refrigeration: This works on the principle of Magneto Calorific Effect (MCE). When a substance is placed in a magnetic field, temperature increases and when it is removed from the field its temperature decreases. Entropy change leads to heat extraction and thus the cooling effect.

1.4.4 Thermoelectric Refrigeration: This works on the principle of Peltier effect. Peltier effect states when a constant current, steady voltage is applied at two ends of a thermoelectric module, as the current flows, a temperature difference is generated between the two sides. The side where heat is extracted becomes the cold side and the side where heat is generated is the hot side. Seebeck effect sees an application here. As per Seebeck an interesting phenomenon occurs when the polarity of current is reversed. The side which was generating heat now absorbs heat and the side that extracted heat, now generates it; as the polarity has been reversed, current flow is in direction opposite to previous scenario. This makes it much more feasible for space cooling as well as heating applications. This also counts as a drawback, making Thermoelectric Modules very sensitive.

II SOLAR THERMOELECTRIC COOLING

A combination of solar cells is used in the solar panel. In the Solar Thermoelectric cooler, solar cells are a dependable alternative. Constant voltage current is required for the thermoelectric modules, when source of electricity is not available or dependable; solar cells act as the source. They generate electric current that passes through the Thermoelectric Modules. Provisions can be made to store the electricity thus generated, for use at a later time. For instance, electricity generated can be stored in cells for use in the night time, when the sun is not overhead.

Following circuit shows how Solar cells can be connected to the Thermoelectric cooling module and the space defined.

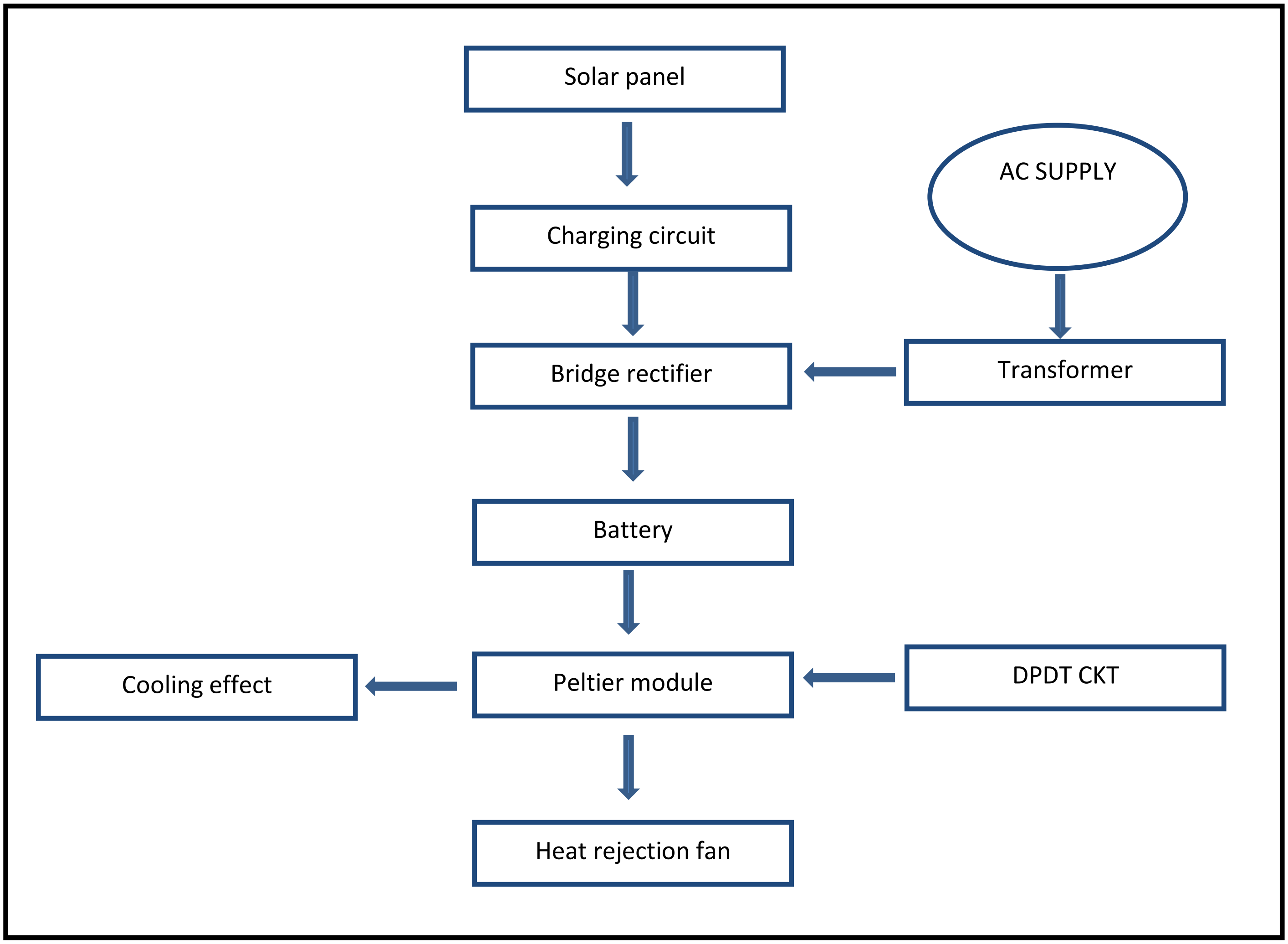

Fig 5: Schematic diagram of thermoelectric refrigeration (with solar panel)

2.1 Advantages of Solar Thermoelectric Cooling

There are many advantages of Solar Thermoelectric Cooling over the traditional cooling methods. Besides, various drawbacks of the conventional cooling systems have been overcome by this method. The following is a list of the advantages:

1. Thermoelectric Module require less electricity compared to any other cooling or refrigerating system.
2. Compressor has been eliminated from set-up that allows noiseless operation and lowered maintenance cost.
3. The system does not require a refrigerant for heat extraction from defined space, thus the cost of a refrigerant and its environmental impacts are kept at bay.
4. Solar power is an alternative where supply of electricity is not dependable.
5. Compact design has been preferred, thus making system portable.
6. Solar power can be stored and used at night or other situations where the sun is not overhead.

7. It is light in weight and has a simple circuitry.

2.2 Applications of Solar Thermoelectric Cooling

1. Solar Thermoelectric cooling finds application in many fields. A list would be the following:
2. Indoor space cooling, use for cooling substances in the refrigerator
3. Outdoor cooling, carrying the portable refrigerator along for food preservation, drinks preservation, medicines etc.
4. Cooling in cars
5. Cooling of electronic equipment
6. Cooling of an experimental set-up, in a laboratory
7. In rural India, in summers when there is no electricity, solar powered thermoelectric cooler comes as a relief
8. Can be carried along when travelling outdoors

III REVIEW

3.1 Tsung-Chieh Cheng et al [1]:- Studied the development of an energy-saving module, which is a combination of solar cells, thermoelectric coolers for green building applications. Entire focus was on waste heat regeneration unit which employed copper pipes carrying water. The water extracts the waste heat, thus utilizing it. Water gets heated for further use in a different application. Experiments were performed to ascertain the most economically viable and most efficient system considering parameters like flow rate of water and transient variation in temperatures of a Solar Cell. The experiment helps to ascertain the parameters for optimum operation.

3.1.1 Working and Experimental Set-up:

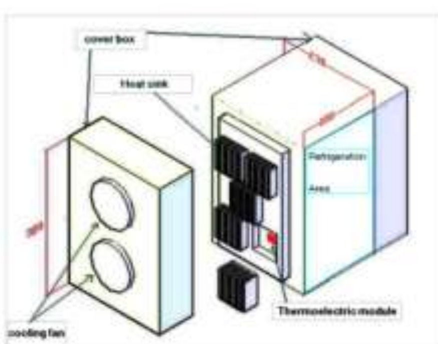

Fig 6: Experimental setup.

There were four major segments in the circuitry: the thermoelectric module, solar cells, waste heat regeneration unit and measurement unit.

3.1.2 Material Specification:

1. One piece of Silicon Crystal Wafer (0.4A-0.5A) with size120mmx120mm, mass 24g

2. Copper plate used in waste heat generation unit has hot and cold sides of the measurement 30mmx30mm

3. Heat regeneration channel made of copper has a c/s area of 5mmx5mm

4. Data logger used for measurement and recording of voltage and current in solar cell is Yokogawa MV100, sensitivity is 0.01mV and 0.01A in current

5. Model house measurements 30cmx12cmx10cm, walls are made of wood and floor is made of Bakelite plates

3.1.3 Uncertainty Analysis

Uncertainty is caused by many sources. Sources are basically divided into 4 categories: Environment-control uncertainty, Calibration Uncertainty, Measurement Uncertainty and Data Acquisition Uncertainty. Largest uncertainty is caused by flow rate of cooling water. Uncertainty percentage is calculated for all the involved parameters and data is extrapolated and tabulated in graphical format.

3.1.4. Experimental Results and Discussion

Temperature of solar cell is increased to 60.5^oC in 7.8 min. Temperature difference between hot and cold sides of the Thermoelectric Module is 10^oC. It has been observed after experimentation when cooling water is not passed is 44^oC and 34^oC respectively. Thus it can be concluded that without the waste heat regeneration unit the module will not be enough for cooling indoor space or replacing an air-conditioner. When heat transfer co-efficient on hot side is increased, thermoelectric coolers can reduce the temperature of thermoelectric coolers. When the flow rate of cooling water increases, the steady-state output power of solar cell.

3.2 Ashok Kumar Yadav et al [2]:- This research paper puts forward the idea of building an alternative option for AC, to provide the same space cooling effect. The paper presents a miniature prototype of a Thermoelectric Cooler that will replace the conventional air conditioner. It will consume less electricity compared to an AC and also reduce the pollution levels. Design and Fabrication has also been included in the paper. The working principle, i.e. Peltier effect is given in good detail along its working formulae, the parameters used are explained in a neat format. The consumption of electricity is given in this review which highlights the amount of energy usage.

3.2.1 Materials used and specifications:

1. Solar cell
2. Rectifier
3. Thermoelectric Module
4. Heat Sink
5. Cooling Fan
6. Battery

Block Diagram of the Thermoelectric Cooler:

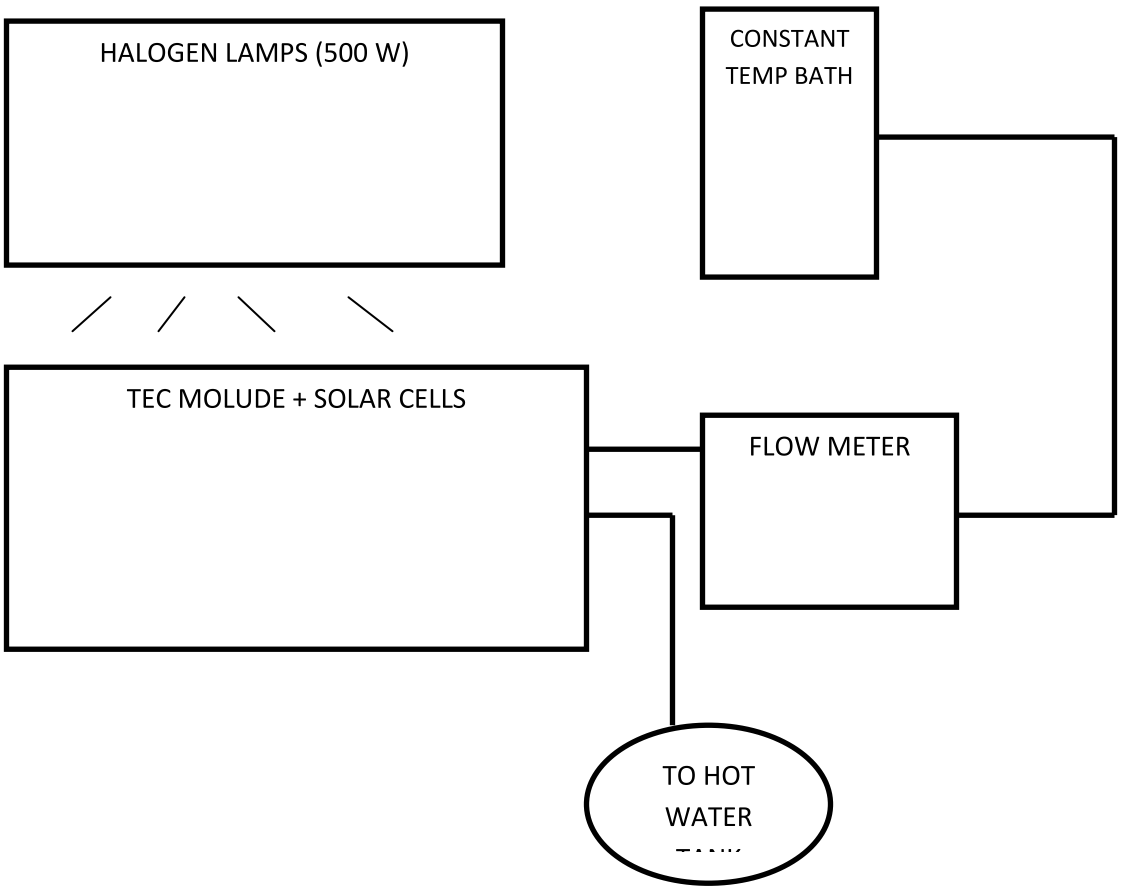

Fig 7: Block diagram of thermoelectric cooler

3.2.2 Results and Conclusion

Cooling effect is obtained without making use of a compressor. Heat from the hot side has to be rejected effectively for TE Module, for proper operation of the thermoelectric module. Cooling effect can be used to extract water from the air in dehumidifier. The experimental set-up can be used to cool 1'x1'x1' area by using 6"x6" solar plate. In spite of the higher initial cost, thermoelectric cooler proves to be more economical due to lower operating costs.

3.3 Ioan Sarbu et al [3]: The study gives a comprehensive review of solar photovoltaic and thermoelectric cooling. It implies hybrid cooling and alternative cooling systems. It uses ejector system representing thermo-mechanical cooling. The system has a higher source temperature than other systems and it also gives higher COP. The paper discusses various solar cooling methods in practice. It stresses the importance of the use of solar energy and its varied applications. The review highlights the concerns of growing population and decreasing energy resources and thus the need for sustainable and cleaner sources of energy. There's a comparison given between the different types of solar cooling systems at the end, which summarizes the review.

3.3.1 Working and Set-up: In the solar cooling system, thermal energy is converted to mechanical energy**.** Mechanical Energy is used to produce the refrigeration effect. The set-up makes use of a stand-alone photovoltaic system and arrangement for cooling water to come in and move out.

3.3.2 Results and Conclusion: Thermally activated cooling systems are being used globally and commercially for cooling purposes. They are free from pollution and rather than using CFCs (Chloro Fluoro Carbons) as refrigerants they use thermoelectric modules for cooling purposes. The biggest advantage is that solar cooling systems can function as a stand-alone. They can also be used in combination with conventional refrigeration and cooling systems.

3.4 Edson Nogueira et al [4]: This paper discusses the equations used to evaluate the performance of a system used for air-conditioning. It works on Peltier Effect. It discusses the important parameters for evaluation of performance of the cooling system, namely the rate at which heat is extracted from the defined space or substance, COP of the system, maximum temperature difference between the two sides of a thermoelectric module. The review talks about the advantages of thermoelectric cooling systems over traditional cooling systems in terms of the components used and working principle. It lays emphasis on the thermoelectric module and its applications in various fields of technology.

3.4.1 Conclusion: It has been concluded that the rate at which heat is extracted depends on electricity running through the circuit. COP can be increased by adjusting the voltage applied to the thermoelectric module. The point at which maximum heat transfer is obtained and the one at which maximum COP is attained may not the same, thus the approach is to look for the best operation point. It is also implied that once we know the temperature difference that can be obtained, and the inlet temperature, and specifications of the thermoelectric material, we can estimate the power to be provided.

3.5 Ali Elkamel et al [5]: Solar Thermoelectric refrigerator has a high initial cost. This paper focuses on making this available to the Bedouin people of Oman. In this remote village there is no supply of electricity. Thus a solar refrigerator provides an attractive and feasible alternative which can be used for preservation of food, medicines and other biological material. This cooling is achieved by means of Thermoelectric Module. The cold side of the module is then used for refrigeration and space cooling purposes. The heat that is rejected on the hot side is absorbed and dissipated by means of heat sinks, fans. The paper discusses an experimental set-up and the results obtained for the same. It stresses on the importance of usage of solar energy as a clean alternative to the present conventional energy sources. Also this review talks about the portability of the cooling system that can be achieved by minimizing the usage of moving parts and refrigerants.

3.5.1 Components used and Specification:

1. Thermoelectric Module with ceramic surface (2.5A, 3.8V)
2. Solar Cells manufactured by BP Solar with efficiency of 14%, size 12.5cmx12.5cm
3. Aluminum sheets for the sides of the cabin
4. Insulation by Plastic Plates
5. Heat sink with finned surface
6. Cooling fans

3.5.2 Design of the Thermoelectric Refrigerator:

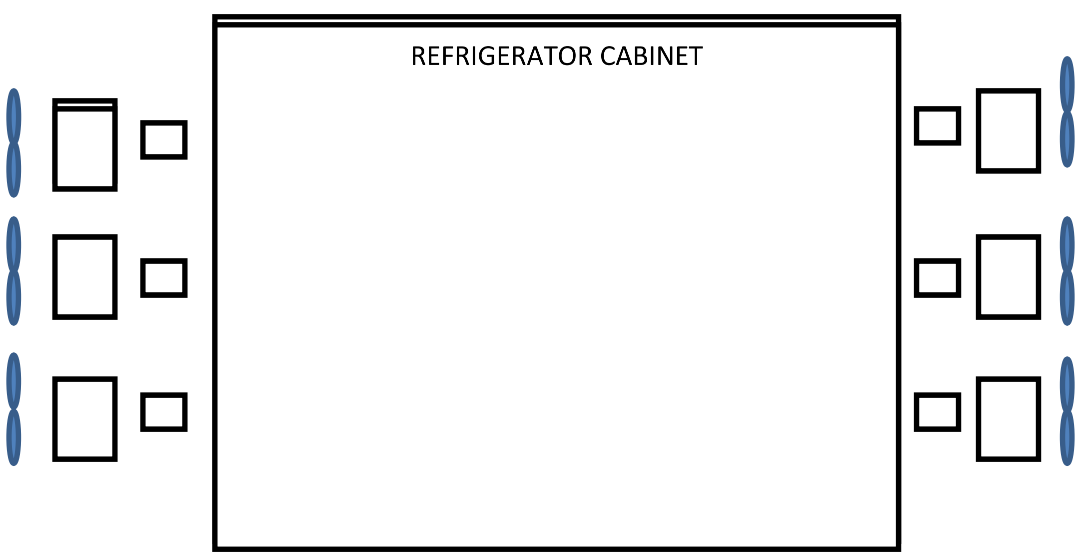

Fig 8: Design of thermoelectric refrigerator

3.5.3 Results: Temperature difference of up to 22°C was obtained over a time span of about 44 minutes. Temperature was reduced from 27°C to 5°C. COP of the system has been calculated as 0.16. Refrigerator was used to cool a closed can containing 0.5L of a liquid, and temperature reduced from 26°C to 4°C in about 50 minutes.

3.5.4 Conclusion: The set-up was tested and experiments performed to check the maximum temperature difference that can be obtained under different testing conditions. Maximum temperature difference of 22°C was obtained. Thermoelectric refrigerator needs further improvement before it becomes commercially available and cost efficient and the improvement can be made by increasing the COP by increasing Module Contact Resistance, increasing the heat dissipation from the hot side of the Module and covering more than usual area on the box used for refrigeration.

3.6 Sandip Kumar Singh et al [6]: This paper focuses on the performance results of a thermoelectric refrigerator after having tested it using Mat Lab, under varying operating conditions. The set-up consists of a Refrigerator with Thermoelectric modules attached to it. Space cooling efficiency has been tested with C.O.P as the criterion for the same. It talks of the importance of solar energy as a green fuel. The description of solar cells is given in appreciable detail and also the definitions of semiconductors are included which helps us to understand the usage of materials better. Details of conversion of solar energy into electrical energy are also included.

3.6.1 Results: Experimentation has revealed that a drop in temperature of about 12°C is achieved for 100 ml of water in first 30 minutes under optimized operating conditions.

3.6.2 Conclusion: There is better reliability, performance is enhanced and there is depreciation in the operating cost of the refrigerator by using the proposed system. It also highlights the fact that thermoelectric cooling has found real time applications in industries and domestically too. Thermoelectric solar devices have acted as generators of power and sensors for thermal energy. This makes it more or less a futuristic technology.

IV CONCLUSION

The paper covered almost all relevant aspects of a portable solar thermal refrigerator. The thermoelectric module which has been used covers a wide spectrum in the generation of power and space heating and cooling applications. The system has not been widely accepted for commercial use because of high initial cost, but as the study suggests by utilizing the waste heat and storing power from solar cells, the system becomes highly efficient compared to its traditional counterpart. After studying the prototypes and the experimental observation, it can be concluded solar thermoelectric cooling is a technology of the future. It is an environment friendly initiative, thus promoting greener technologies for the future. The idea appeals more as the vibration and noise of an air conditioner and refrigerator unit have been eliminated as the system works on completely different mechanics. This portable technology when marketed will definitely prove to be a boon to rural India.

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