Thermoelectric Refrigeration System Running On Solar Energy

[1]D.S.CHAVAN, [2]S.V.PAWAR, [3]M.S.DHAMAL, [4]S.K.KUTE, [5]PROF. P.B.BORADE, [6]PROF.G.S.DHUMAL

[1, 2,3,4,5,6] Department of Mechanical Engineering, JSPM's Rajarshi Shahu School of Engineering and Research, Narhe, Pune, India,411041

Abstract: **The global increasing demand for refrigeration in field of refrigeration, food preservation, storages, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 all over the world which it is contributing factor of global warming on climate change. With the increase awareness towards environmental degradation due to the production, use and disposal of Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in today's energy challenges. It does not require working fluids or any moving parts, which is friendly to the environment and it simply uses electrons rather than refrigerants as a heat carrier. Continuous efforts are given by researchers for development of thermo electric materials with increase figure of merit may provide a potential commercial use of thermoelectric refrigeration system.**

In this work it has been identified that there is enormous scope to develop TER system running on solar energy and its performance evaluation along with mathematical modeling. Mathematical results can be correlate by performing experimental test set up. Present paper especially focuses on evaluation of numbers of thermoelectric cooling module; heat sink fan assembly for each module which is used to increase heat dissipation rate and time required for attaining the cooling of heat sink fan assembly after a solar power is applied.

Keywords: **Thermoelectric refrigeration, thermoelectric micro cooler, solar energy and development**.

1. INTRODUCTION

With the increase awareness towards environmental degradation due to the production, use and disposal of Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in today's energy challenges. It does not require working fluids or any moving parts, which is friendly to the environment and it simply uses electrons rather than refrigerants as a heat carrier. Continuous efforts are given by researchers for development of thermo electric materials with increase figure of merit may provide a potential commercial use of thermoelectric refrigeration system.

2. THERMO ELECTRIC REFRIGERATOR CONCEPT

Thermoelectric refrigerator sometimes called a thermoelectric cooler module or Peltier cooler is a semi-conductor based electric component that functions as a small heat pump. However, the continued development of thermoelectric systems was slow owing to technical difficulties and the superior performance of vapor compression systems in terms of coefficient of performance (COP).

3. PRINCIPLE OF WORKING

Thermoelectric modules are solid-state heat pumps that operate on the Peltier effect (see definitions). A thermoelectric module consists of an array of p and n-type semiconductor elements that are heavily doped with electrical carriers. The elements are arranged into array that is electrically connected in series but thermally connected in parallel. This array is then affixed to two ceramic substrates, one on each side of the element. When a voltage is applied, there is a tendency for conduction electrons to complete the atomic bonds. When conduction electrons do this, they leave "holes" which essentially are atoms within the crystal lattice that now have local positive charges. Electrons are then continually dropping in and being bumped out of the holes and moving on to the next available hole [8]. In effect, it is the holes that are acting as the electrical carriers.

Now, electrons move much more easily in the copper conductors but not so easily in the semiconductors. When electrons leave the p-type and enter into the copper on the cold-side, holes are created in the p-type as the electrons jump out to a higher energy level to match the energy level of the electrons already moving in the copper. The extra energy to create these holes comes by absorbing heat. Meanwhile, the newly created holes travel downwards to the copper on the hot side. Electrons from the hot-side copper move into the p-type and drop into the holes, releasing the excess energy in the form of heat
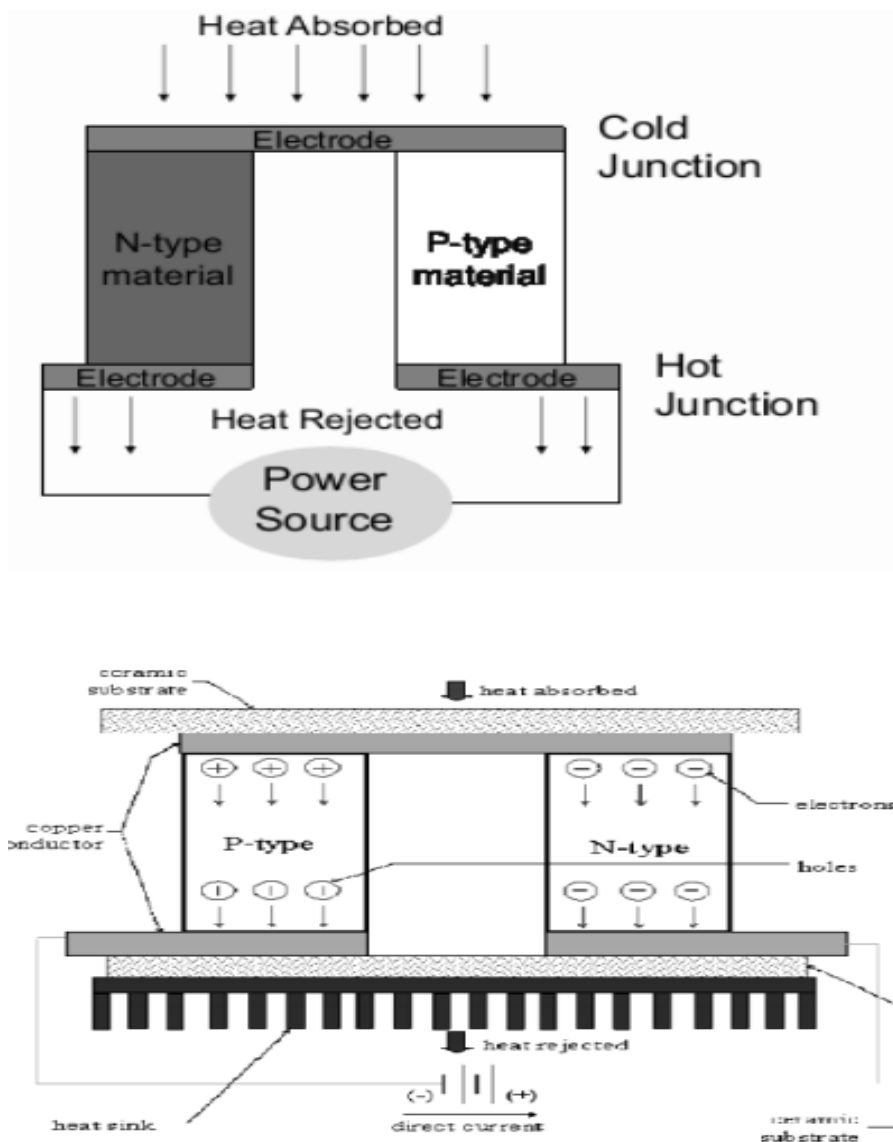

Fig. 1: simple Peltier heating/cooling design

The n-type semiconductor is doped with atoms that provide more electrons than necessary to complete the atomic bonds within the crystal lattice. When a voltage is applied, these extra electrons are easily moved into the conduction band. However, additional energy is required to get the n-type electrons to match the energy level of the incoming electrons from the cold-side copper. The extra energy comes by absorbing heat. Finally, when the electrons leave the hot-side of the n-type, they once again can move freely in the copper. They drop down to a lower energy level, and release heat in the process.
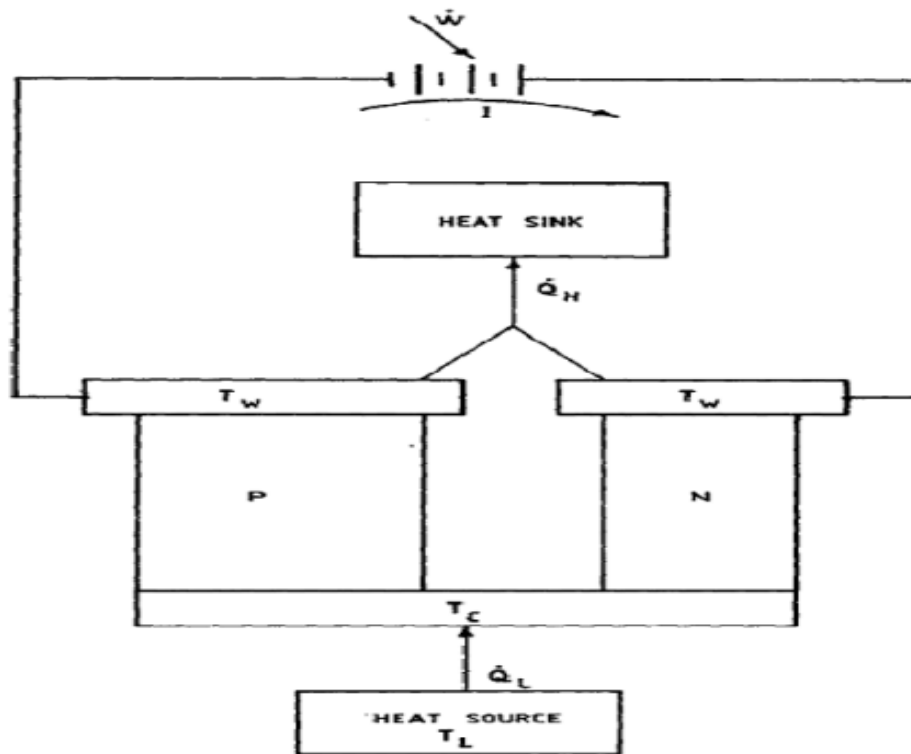

Fig. 2: A thermoelectric refrigerator

4. LITERATURE REVIEW

Solar refrigeration may be accomplished by using one of the following refrigeration systems: vapor compression, sorption or thermoelectric refrigeration systems. The first two systems need high and low pressure sides of a working fluid to complete the refrigeration cycle, and are somewhat difficult to be developed into a portable and light solar device used outside. The thermoelectric refrigeration system, which has the merits of being light, reliable, noiseless, rugged, and low cost in mass production, uses electrons rather than refrigerant as a heat carrier, and is feasible for outdoor purposes in cooperation with solar cells, in spite of the fact that its coefficient performance is not as high as for a vapor compression cycle [1]. In past years, much work has been reported on thermoelectric cooling [2–6]. The thermoelectric refrigeration system is having potential application of storage and transportation of life saving drugs and biological materials at remote areas of our country where grid power is unavailable. P.K. Bansal [7] has compared the performance of vapor compression, thermoelectric and absorption refrigerators. T. Hara [8] investigated a solar cell driven, thermoelectric cooling prototype headgear for outside personal cooling. V.C. Mei [9] studied a solar assisted automobile thermoelectric air-conditioner. Dai et al. [10] developed a thermoelectric refrigeration system powered by solar cells and carried out experimental investigation and analysis. Researchers developed a prototype which consists of a thermoelectric module, array of solar cell, controller, storage battery and rectifier. The studied refrigerator can maintain the temperature in refrigerated space at 5–10oC, and has a COP about 0.3 under given conditions. Wahab et al. [11] have designed and developed an affordable solar thermoelectric refrigerator for the desert people living in Oman where electricity is not available. In this study, they used 10 nos. of thermoelectric module in design of refrigerator. The experimental results indicated that the temperature of the refrigeration was reduced from 27oC to 5oC in approximately 44 min. The coefficient of performance of the refrigerator was calculated and found to be about 0.16. Abdullah et al. [12] have carried out an

experimental study on cooling performance of a developed hybrid Solar Thermoelectric- Adsorption cooling system. The developed system produced cooling via the Peltier effect during the day, by means of thermoelectric elements, and through adsorption (activated carbon-methanol) process at night. They evaluate the coefficient of performance by using derived equations, the average COP values of the hybrid cooling system were found about 0.152 for thermoelectric system and about 0.131 for adsorption. Thermoelectric cooling works on the principle of Peltier effect, when a direct current is passed between two electrically dissimilar materials heat is absorbed or liberated at the junction. The direction of the heat flow depends on the direction of applied electric current and the relative Seebeck coefficient of the two materials.

The thermoelectric refrigerator is a unique cooling device, in which the electron gas serves as the working fluid. In recent years, concerns of environmental pollution due to the use of CFCs in conventional domestic refrigerators have encouraged increasing activities in research and development of domestic refrigerators using Peltier modules. Moreover, recent progress in thermoelectric and related fields have led to significant reductions in fabrication costs of Peltier modules and heat exchangers together with moderate improvements in the module performance. It is now possible to develop an economically-viable thermoelectric refrigerator which has improved performances and the inherent advantages of environmentally-friendly silent operation, high reliability, and ability to operate in any orientation. Although the COP of a Peltier module is lower than that of conventional compressor unit, efforts have been made to develop thermoelectric domestic refrigerators to exploit the advantages associated with this solid-state energy-conversion technology (Min and Rowe, 2006).[13]

For utilizing solar energy efficiently and cost effectively, proper design of reliable solar devices and system have to be attempted to suit the radiation climate and socioeconomic conditions. From this perspective, sizing of PV system involves finding the cheapest combination of array size and storage capacity that will meet the anticipated load requirement with the minimum acceptable level of security. The information required is including the daily or hourly load requirement, peak current and voltage characteristics of the solar module, the number of autonomous days, the estimated percentage of energy losses in the battery and power conditioning equipment, and the estimated losses in the array due to module mismatch, cable, dust and shading (Bhuiyan and Asgar, 2003; Kaushika et al., 2005).[14-15] Francis et al.[16] evaluated the performance of thermoelectric refrigerator. The research focused on simulation of a thermoelectric refrigerator maintained at 4oC. The performance of the refrigerator was simulated using Matlab under varying operating conditions. The system consisted of the refrigeration chamber, thermoelectric modules, heat source and heat sink. Results show that the coefficient of performance (C.O.P) which is a criterion of performance of such device is a function of the temperature between the source and sink. For maximum efficiency the temperature difference is to be kept to the barest minimum.

Rawat et al.[17] presented the Design and developmental methodology of thermoelectric refrigeration in detail also the theoretical physical characteristics of thermoelectric cooling module used in his research work have been investigated. Authors have been designed and developed an experimental prototype of thermoelectric refrigeration system working on solar photo voltaic cells generated DC voltage. The developed experimental prototype having a refrigeration space of 1 liter capacity is refrigerated by using four numbers of Peltier module (Super cool : PE-063-10-13, Qmax=19W) and a heat sink fan assembly used (Model No: TDEX6015/TH/12/G, Rth=1.157 oC/W) to increase heat dissipation rate from hot side of Peltier module. The experimental result shows a temperature reduction of 11oC without any heat load and 9oC with 100 ml water kept inside refrigeration space in 30 minute with respect to 23oC ambient temperature. Also the COP of refrigeration cabinet has been calculated and it is 0.1.

5. NOMENCLATURE

A	Cross sectional area
COP	Coefficient of performance
ΔE	EMF output
I	Current
K	Thermal conductivity
L	Length
Le & Lph	Dimensionless Lorenz number
NS	Dimensionless entropy generation

Q	heating and cooling rate
q_h	Heat rejection
q_c	heat absorption
R	Electric Resistance
R_f	heat sink resistance factor
Sg	Entropy generation rate
T	Temperature
ΔT	Temperature Difference
TER	Thermoelectric refrigerator
TEC	TEC Thermoelectric cooler
U	Overall conductance
UA	cabinet thermal conductance
P	power consumption
Z	Figure of merit

Greek letters

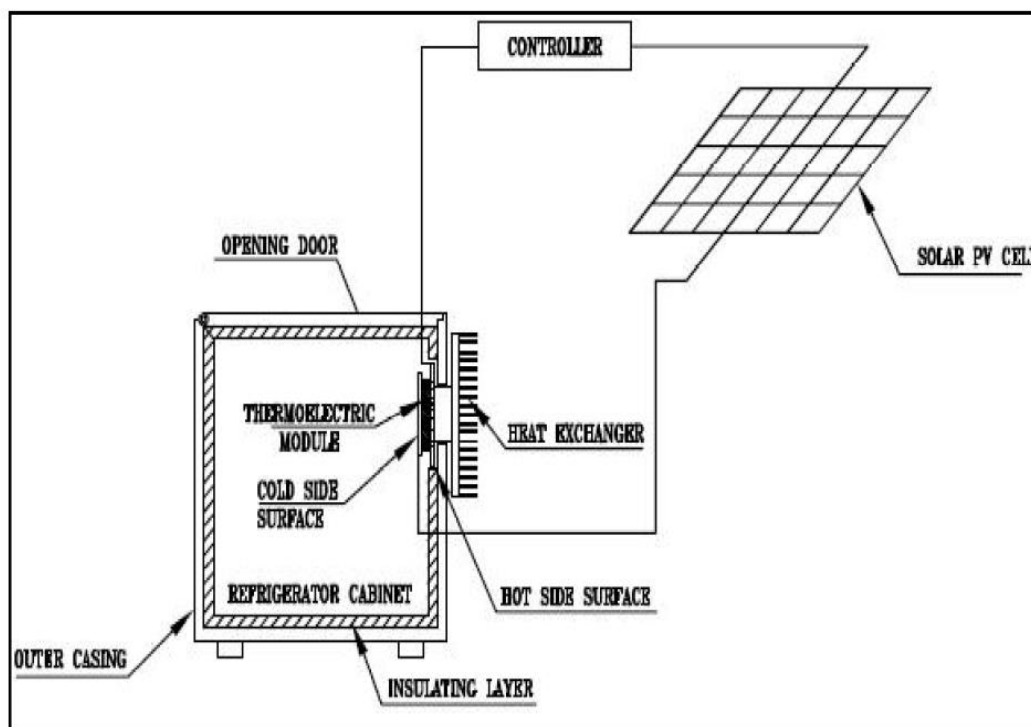|	
α	See beck coefficient
τ	Thomsion coefficient
ρ	Specific resistance
π_{ab}	Peltier coefficient
ε	ideal coefficient of performance
ε_{ii}	internally ideal coefficient of performance
ε_s	actual coefficient of performance
η_e	external thermodynamic efficiency
η_i	internal thermodynamic efficiency
η_s	Overall thermodynamic efficiency

6. EXPERIMENTAL SETUP

Fig 1:-Schematic diagram of a solar powered thermoelectric refrigeration system

The Experimental Investigation of Thermoelectric Refrigeration (TER) system running on solar energy based on the principles of a thermoelectric module (i.e. Peltier effect) to create a hot side and a cold side. Solar energy is applied to power input to the thermoelectric module. The cold side of the thermoelectric module is utilized for refrigeration purposes. On the other hand, the heat from the hot side of the module is rejected to ambient surroundings by using heat sinks and fans. Thermoelectric cooling systems are generally only around 5–15% as efficient compared to 40– 60% achieved by conventional compression cooling system. This is basically limited by thermoelectric material property (Figure of merit) and efficiency of heat exchange system. Continuous efforts are given by researchers for development of thermo electric materials with increase figure of merit may provide a potential commercial use of thermoelectric refrigeration system.

TER CABINE:

FIG: TER CABINE

Thermoelectric refrigeration system having a refrigeration space of 1 liter is cooling by numbers of thermoelectric cooling module and a heat sink fan assembly for each thermoelectric module which is used to increase heat dissipation rate, also time required attaining the cooling after a solar power is applied. Proposed prototype consists of a thermoelectric module, array of solar cell, controller, storage battery and heat sink fan. The proposed work for increase COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers. To improve the effectiveness of the Heat Exchanger, the surface area of the fins should increase also the increase the rate of convectional heat transfer and the higher the figure of merits of the thermoelectric module by using different technology.

7.   OBSERVATION AND REASULTS

In this section we are discusses the analysis of thermoelectric refrigerator by varying the various parameters such as current, Voltage and temperature difference their effect on COP.

Following table represent the varying given parameters

1.   varying in current with variation in the temperature:

Sr. no	Current (A)	$T_{Cold}°C$	$T_{Hot}°C$	Time (min)	$DTemp°C$
1	0	32.5	32.5	0	0
2	0.5	30.6	32.4	15	1.8
3	1	28	32.2	19	4.2
4	1.5	26.1	32.2	22	6.1
5	2	23.9	32.1	26	8.2
6	2.5	21.6	32	30	10.4
7	3	19	32	35	13
8	3.5	17.5	32	41	14.5
9	4	15.4	32	49	16.6
10	4.5	13.5	32	58	18.5

8. CALCULATIONS

System design on the basis of capacity:-

Design and develop an experimental thermoelectric refrigeration system with a refrigeration space of 1Liter capacity. Design of the system on the basis of following parameters

1. Given parameters:-

Sr.No	M	1 Lit.
1.	T_h	32°C
2.	T_c	10°C
3.	T_c	4180 j/kgk

Where,

m= Mass of water in kg

T_h=Hot side temperature in°C

T_c=Cold side temperature in°C

C_p=Specific heat of water in j/kgk

t= approximately time required for cooling=50 min,

2. Calculating parameter:-

$$Q_c = mCp \times (T_h - T_c)$$

$$= 1 \times 4180(31-10)$$

Q_c =91960 J

$$Q_c = \frac{Qc}{t}$$

$$Q_c = \frac{91960}{(50 \times 60)}$$

Q_c=30.65 watt

Where,

Qc=heat transfer for cooling

COP of the system-

The coefficient of performance (COP) of a thermoelectric module which is the thermal efficiency must be considered for a TE system. The selection of TEC will also be based on the OP factor.

COP is the ratio of the thermal output power and the electrical input power of the TEC. COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power,

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

Q_c = 30.65 watt,

W = I×V

= 9.8 × 3.5

= **34.3**

We are using two peltiermodule,

$= 34.3 \times 2$

W= 68.6 watt

$COP = \frac{30.65}{68.6}$

COP= 0.44

1. varying in current with variation in COP:

Sr. no	Current (A)	Voltage (V)	COP
1	0	12	0
2	0.5	12	0.418
3	1	12	0.487
4	1.5	12	0.472
5	2	12	0.476
6	2.5	12	0.489
7	3	12	0.503
8	3.5	12	0.481
9	4	12	0.481
10	4.5	12	0.477

From this analysis we are obtaining the following results.

1. The COP Increase with increasing the current upto certain value then it further decreases.

2. The COP Decreases with increase in input power.

3. The COP Decreases with Increase in the Temperature difference.

9.   CONCLUSION

The present study develops an optimization design method for thermoelectric refrigerator. The proposed simple model is used in the optimization of real thermoelectric refrigerator. The energy efficiency of thermoelectric refrigerators, based on currently available materials and technology, is still lower than its compressor counterparts. However, a market able thermoelectric refrigerator can be made with an acceptable COP. Improvement in the COP may be possible through improving module contact-resistances, thermal interfaces and heat exchangers. The device is applicable for cold storage of vaccine, foodstuffs and drink in remote areas, or outdoor applications where an electric power supply is absent.

REFERENCES

[1] Sofrata H. Heat rejection alternatives for thermoelectric refrigerators. Energy Conversion and Management 1996; 37(3):269–80.

[2] Min Gao, Rowe DM. Cooling performance of integrated thermoelectric microcooler. Solid-State Electronics 1999; 43:923–9.

[3] Khedari J, Maneewan S, Pratinthong N et al. Domestic hot water system combining solar and waste heat from thermoelectric air-conditioner. International Journal of Ambient Energy 2001; 22(1):19–28.

[4] Chen K, William SBB. An analysis of the heat transfer rate and efficiency of thermoelectric cooling systems. International Journal of Energy Research 1996; 20:399–417.

[5] Chen J, Andresen B. The maximum coefficient of performance of thermoelectric cooling systems. International Journal of Ambient Energy 1996; 17:22–8.

[6] Winder EJ, Ellis AB. Thermoelectric devices: solid-state refrigerators and electrical generators in the classroom. Journal of Chemical Education 1996; 73(10):940–6.

[7] Bansal PK, Martin A. Comparative study of vapor compression, thermoelectric and absorption refrigerators. International Journal of Energy Research 2000; 24:93–107.

[8] Hara T, Azum H. Cooling performance of solar cell driven, thermoelectric cooling prototype headgear. Applied Thermal Engineering 1998; 18:1159–69.

[9] Mei VC, Chen FC, Mathiprakasam B, Heenan P. Study of solar-assisted thermoelectric technology for automobile air conditioning. Journal of Solar Energy Engineering, Transactions of the ASME 1993; 115(4):200–5.

[10] Wang RZ, Dai YJ. Solar thermoelectric refrigerator, 2001, Patent, No. 01239142.5, China.

[11] Abdul-Wahab Sabah A., Elkamel A., Al-Damkhi Ali M., Al-Habsi Is'haq A., Al-Rubai'ey' Hilal S., Al-Battashi Abdulaziz K., Al-Tamimi Ali R., Al-Mamari Khamis H. & Chutani Muhammad U., Design and experimental investigation of portable solar thermoelectric refrigerator, Renewable Energy, 34(1), 2009, 30-34

[12] .Abdullah M. O., Ngui J. L., Hamid K. Abd., Leo S. L., & Tie S. H., Cooling Performance of a Combined Solar Thermoelectric-Adsorption Cooling System: An Experimental Study, Energy Fuels, 23, 2009, 5677-568

[13] Min, G., Rowe, D.M. (2006) Experimental evaluation of prototype thermoelectric domestic-refrigerator. Applied Energy. 83. 133-152.

[14] Bhuiyan, M.H.H., Asgar M.A. (2003). Sizing of a standalone photovoltaic power system at Dhaka. Renewable Energy. 28. 929-938.

[15] Kaushika, N.D., Gautam, N.K., Kaushik, K. (2005). Simulation model for sizing of stand-alone solar PV system with interconnected array. Solar Energy Material & Solar Cells. 85. 499-519.

[16] Onoroh Francis, Chukuneke Jeremiah Lekwuwa, Itoje Harrison John," Performance Evaluation of a Thermoelectric Refrigerator" International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 7, January 2013.

[17] Manoj Kumar Rawat, Prasanta Kumar Sen, Himadri Chattopadhyay, Subhasis Neogi, " Developmental and Experimental Study of Solar Powered Thermoelectric Refrigeration System", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 3, Issue 4, Jul-Aug 2013, pp.2543-2547.