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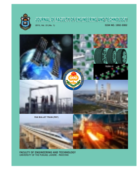

PERFORMANCE ANALYSIS OF A DIRECTLY COUPLED SOLAR POWERED THERMOELECTRIC REFRIGERATION SYSTEM

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Abstract

As the electricity crisis and prices are increasing day by day, it has established a thought provoking ideology to utilize solar energy for refrigeration processes and improving their performance in this regard. Photovoltaic Powered Thermoelectric Refrigerator is a special type of refrigerator which uses solar energy instead of conventional electrical energy and is based on the principles Peltier effect to create a cold side and a hot side. The cold side of the module is used for the cooling of refrigerator space while the heat from the hot side is rejected to ambient by using heat sinks and fans. The present work for the experimentation of Solar Thermoelectric Refrigeration unit was carried out at the Department of Mechanical Engineering, University of Engineering & Technology Lahore-Pakistan at KSK Campus. The results showed that at an ambient temperature below that of 25ºC, the unit could maintain the temperature in the refrigerator space at about 0ºC. The maximum COP recorded was about 0.65. It has been further analyzed that the temperature gradient of hot and cold sides of the thermoelectric module and solar irradiance greatly affects the system performance. An optimum value of solar insolation rate let the cooling production and COP to achieve maximum value. The refrigerator would be potential for cold storage in remote and outdoor conditions where electric power supply is absent. It has the advantages of being portable, small, reliable, lightweight, noiseless and low cost in mass production.

Keywords: Thermoelectric; Thermoelectric Cooler; Peltier Effect; Peltier Refrigerator; Portable Refrigeration System; Solar Refrigerator.

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1. Introduction

In the recent times, the increased worldwide demand of refrigeration directed to produce more and more electricity using conventional energy resources. The use of these conventional resources is the major factor for production of carbon dioxide and subsequently the global warming [1]. Conventional systems of refrigeration are energy intensive and the refrigerants are consisting of chlorofluorocarbons which are harmful for the environment by depleting ozone layer. To use solar energy for efficient refrigeration process in outdoor activities is a thought of one of the best practices to discourse this issue [2]. A distinct type of refrigeration system is a solar powered thermoelectric refrigerator which employs solar energy as a substitute of traditional electrical energy to supply power to a thermoelectric module which can be used for the cooling of portable refrigerator.

The objective of present study is to design and fabricate a portable thermoelectric refrigerator directly powered by solar energy for cold storage of vaccine and food items. The designed refrigerator is especially for the people living in remote and rural areas of the country like Pakistan, where the electric power supply is not rich enough. It is principally for those workforces working outside, for example, in road constructing, in mineral prospecting, and scenic spot outing. It is desired to preserve their food and their beverage chilled in sunny days. The purpose behind this design is also to facilitate the vaccination teams in order to keep the vaccine temperature below that of ambient, when these teams are working in remote parts of the country for vaccination of children. The performance investigation of the system under sunshine in the present climate of the country is the main heart of this experimental work.

Since the traditional domestic and commercial refrigerators consisting of the refrigerants having chlorofluorocarbons are contributing to environmental pollution to a greater extent. Current developments in the field of thermoelectric have significantly reduced the fabrication cost of thermoelectric modules and their cooling kits together with reasonable enhancements in their performance. Hence, the development of an economically feasible and environment friendly thermoelectric refrigerator is now possible with better performances, high reliability, and capability to function in any orientation [3].

The performance of solar thermoelectric refrigeration system is greatly dependent upon the system design, the heat loads, heat rejection methods and the solar system used to power the thermoelectric module. To make use of solar energy efficient and cost effective, appropriate design of solar system has to be attempted. This information includes the electrical load requirement, highest current and voltage of the solar panel etc. Thermoelectric refrigeration system, which has the advantages of being small, lightweight, reliable, noiseless, and low cost in mass production, utilizes electrons rather than any refrigerant as a heat carrier. It requires a little direct current to power the thermoelectric module and is viable to be used in collaboration with solar cells, in spite of the fact; its coefficient of performance is not as high as that of any other conventional refrigeration system.

2. Materials and Method

2.1 Specifications of the Photovoltaic Thermoelectric Refrigerator

The major components used in the photovoltaic powered thermoelectric refrigerator are; ABS plastic body, 158 luminium cold sheet, thermoelectric module, heat sink, photovoltaic cells, polyurethane insulation, and the cooling fan. ABS is used for refrigerator body due to its low thermal conductivity (0.20 W/m°C), acceptable working temperature range, good chemical resistance, reasonable cost, and easy availability in the market. It has a good resistance against intermediate temperatures, high impact strength and antistatic adjustment. It is considered as a rigid thermoplastic over its working temperature range -30 °C to +60 °C [14].

Insulation plays key role in an increase of energy efficiency and reduction of work input to the refrigerator by reducing its overall cooling load. Foamed polyurethane in form of thin layers is sandwiched between the plastic panels of ABS to make a protective layer to keep the refrigerator insides at low temperature. An insulation of thickness 50 mm was used in the refrigerator.

For uniform cooling effect inside the refrigerator cabinet, some metal sheets are used. The most important factor in the selection of a metal for heat transfer is its thermal conductivity. Aluminum has been used for the cold sheet of the refrigerator due to its acceptable thermal conductivity of 205 W/m°C, easy availability in the market, low cost, and good resistance to corrosion.

The specifications of the thermoelectric module, aluminum finned heat sink and heat sink fan used in this project are mentioned in Table 1, 2 and 3 respectively. Thermoelectric Module, Heat Sink and Fan are shown in Figure 1, 2, and 3 respectively.

Figure 1: TEC1-12705

Figure 2: Heat Sink

Figure 3: Heat Sink Fan

Table 1: Characteristic and Specifications of Thermoelectric Module

S/N	Specifications	Value
01	Model Number of Thermoelectric Cooler	TEC1-12705
02	Seebeck Coefficient of Thermoelectric Cooler (α)	0.04224 (V/ºC)
03	Electrical Resistance of Thermoelectric Cooler ®	2.90 (Ω)
04	Thermal Conductivity of Thermoelectric Cooler (κ_{t})	0.495 (W/m^{o}C)
05	Sealant used in Sealing of Thermoelectric Cooler	Epoxy
06	Maximum voltage of Thermoelectric Module	17.00 Volts
07	Maximum Current of Thermoelectric Module	5.80 Amperes

Table 2: Characteristics of Finned Aluminium Heat Sink

S/N	Specifications	Value
01	Width of Heat Sink Base	130 mm
02	Thickness of Heat Sink Base	5.0 mm
03	Heat Sink Fin length	160 mm
04	Heat Sink Fin Thickness	1.4 mm
05	Height Sink Fin Height	23 mm
06	Area of Heat Sink Base	20800 mm^2
07	Numbers of fins of Heat Sink	24
08	Thermal Resistance of Heat Sink	0.0152 ºC/W
09	Thermal Conductivity of Heat Sink	205.0 W/m°C
10	Total Surface Area of Heat Sink Fins	7584 mm^2

Table 3: Characteristics of Heat Sink Fan

S/N	Specifications	Value
01	Model Number of Fan:	D12SM-12C
02	Dimensions of Fan	120 x 120 x 20 mm
03	Fan Maximum Air Flow Rate	62.00 CFM
04	Maximum Noise Level	28.50 dbA
05	Maximum Fan Speed	1800 RPM ± 10% RPM
06	Rated Voltage of Fan	12 V DC Volts
07	Operation Voltage of Fan	6.50 ~ 13.80 DC Volts
08	Maximum Input current	0.30 Amps
09	Operation Temperature	-10.0°C to +65.0°C
10	Storage Temperature	-40.0°C to +70.0°C
11	Fan Air Velocity	3.61 m/s
12	Corners of Fan	Closed

2.2 Electric Power Input for Thermoelectric Refrigerator

In thermoelectric refrigerator the electric power is used to run its two major components. These are the thermoelectric module, and cooling fan. The maximum voltage and current consumption of both thermoelectric module and cooling fan are enlisted in Table 1 and 3 respectively. On the basis of these values, the maximum power consumption of components and the total power required by the whole system is shown in Table 4. A 20% factor of safety is added to overcome the power fluctuations due to variations in solar intensity. The total power consumption of the refrigeration system rounded up to 125 Watts. Hence a solar panel of 125 watts is selected for the designed thermoelectric refrigerator.

Table 4: Thermoelectric Refrigerator Electric Power Consumption

Maximum Power of Thermoelectric Module	17.00 × 5.80 = 98.60 Watts
Power consumed by Heat Sink fan	12 × 0.30 = 3.6 Watts
Total Power consumed by system	102.2 Watts
By adding 20% Factor of Safety	102.2 × 1.2 = 122.64 ≈125Watts

2.3 Specifications of Solar Panel

The characteristic of the solar panel (Fig. 4) used in the present research are shown in Table 5. The solar panel is portable and is capable to 161ulfil the electrical power requirements of the designed thermoelectric refrigerator. The refrigerator test unit (Figure 5 and 6) has the maximum cooling capacity of 63 Watts.

Table 5: Characteristics of Selected Photovoltaic Panel

Maximum Power of PV Panel, W	125.0 Watts
Maximum Voltage of PV Panel, V	18.40 Watts
Maximum Current of PV Panel, A	6.80 Amperes
Open Circuit Voltage of PV Panel, V	22.70 Volts
Short Circuit Current of PV Panel, A	7.20 Amperes

Figure 4: Solar panel

Figure 5: TER Front Side

Figure 6: TER Rare Side

2.4 Procedure

All the components i.e. solar panel and thermoelectric refrigerator test unit were connected with each other. Overall eight temperatures sensors were used to execute the temperature measurements. Three sensors were mounted at the inner wall of the refrigerator (Figure 6) to measure an average temperature of the refrigerator cabinet. One sensor was enclosed in a tube to make it water proof and that was used to measure the water temperature. A volume of 8 liter water was put inside the refrigerator and after that refrigerator door was closed. The door remained closed for the rest of the time during the experiments. The solar insolation rate was calculated with the help of radiometer. The refrigerator was directly connected to the photovoltaic panel and the variation in current, voltage, temperature was calculated for about 9 hours in a complete sunny day with help of voltmeter, ampere meter, and temperature sensors were measured.

2.4.1 Weather Data of Experimental Site

The weather data for the site, Mechanical Engineering Department, University of Engineering & Technology, Lahore (KSK Campus) was collected for whole year [13]. Altitude of Lahore is 215 m from see level and latitude and longitude angles are 31.54 ºN and 74.34 ºN respectively [16]. The Lahore weather conditions are hot and humid. The city experiences an extreme climate during the months of May, June and July, when the city observes summer season. The Weather of Lahore turns out to be extreme in the month of June, when the rise in temperature is exceeding 40.0°C. The temperature in Lahore ranges between 40.0°C to 46.0°C, during the summer months.

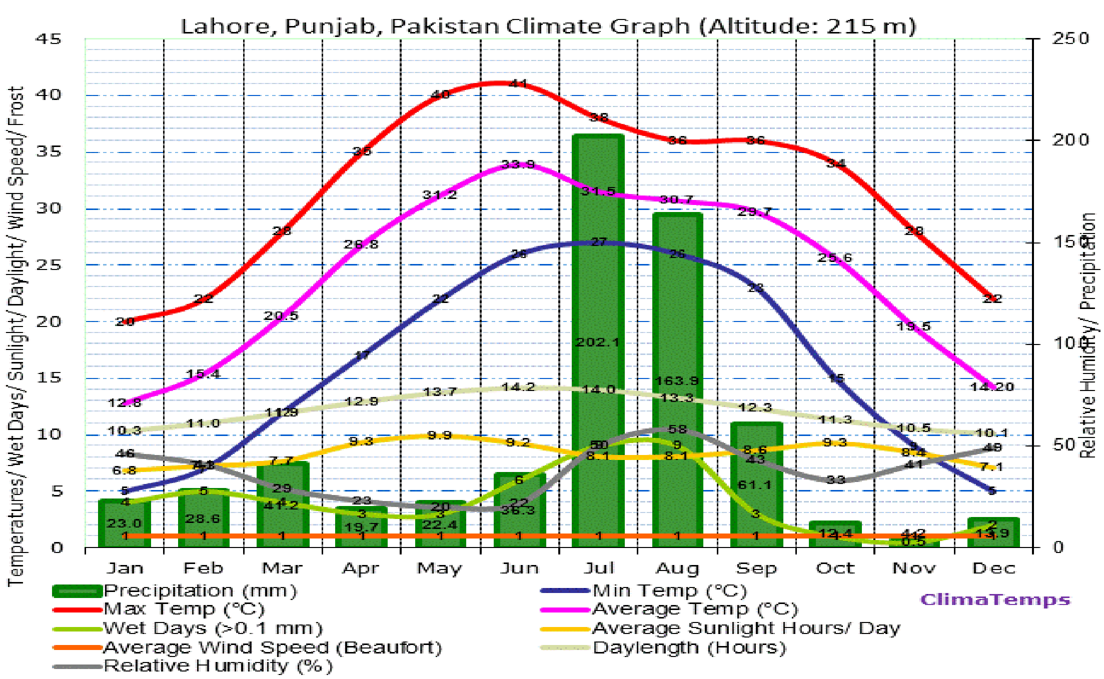

Figure 7: Lahore Punjab climate graph [13]

The typical weather temperature of Lahore falls below 5.0°C in the month of January. Lahore experiences winters during the months of December, January and February. The temperature during this season varies between 5.0°C to 8.0°C. The average maximum and minimum temperatures, and sun light hours of Lahore throughout the year are shown in Figure 7 [13].

Furthermore, Lahore experiences 52.4 mm of rainfall throughout the year. July is the wettest month of the city with an average precipitation of about 202 mm. November is the driest month of the year in Lahore. Average precipitation in the month of November is 4.20 mm. Lahore receives 10 hours of sunshine in the month of May.

2.4.2 Collection of Solar Insolation Rate

The solar insolation rate for the site has been calculated by using radiometer and variation in solar irradiance is plotted in Figure 8.

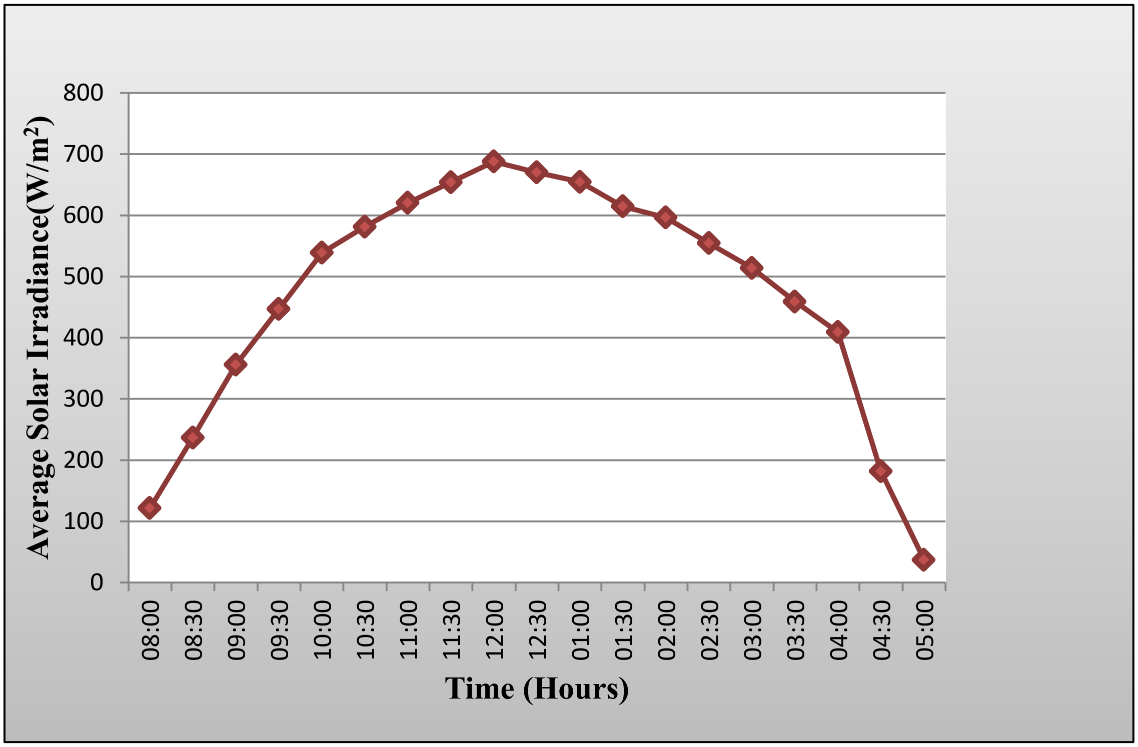

Figure 8: Solar insolation rate for a complete solar day of experimentation

Solar insolation rate is greatly dependent upon the intensity of solar radiations. It is clear from Figure 8 that the solar irradiance changes with time of the day. The solar insolation rate increases from early morning to its maximum value as 700 W/m^2 when sun is exactly at the middle of the sky, and then it again decreases until sunset. Solar insolation rate has its maximum value at 12:00 noon. Since early in the morning the intensity of solar radiations is less so the solar insolation rate is also less. At noon the sun is exactly at the middle of the sky and solar radiations have their peak value which result maximum solar insolation rate. The solar insolation rate is lowest in evening due to minimum solar intensity.

3. Results and Discussion

The experimental investigation of thermoelectric refrigerator was carried out for a complete solar day. Numbers of parameters were calculated after specific intervals. The thermoelectric refrigerator was without any cooling fan for the circulation of coldness inside the refrigerator cabinet. The relationship of temperature and time were measured for finding temperature increases rate, difference in temperature and calculation of coefficient of performance of thermoelectric refrigerator. The results showed that, the temperature inside the refrigerator was decreased with increasing time. The designed maximum power consumption of directly coupled photovoltaic powered thermoelectric refrigerator is 102.2 watts. Since the input power is dependent on solar insolation rate, hence in this case maximum input power is found as 96.3 watts as shown in Table 6. The difference in input power is due to variation in solar insolation rate. As the input power is dependent on input voltage and current and both of these parameters are dependent on solar insolation rate. With the increase in solar insolation rate current and voltage increases and hence the input power increases. Maximum solar insolation rate results in maximum voltage and current and hence maximum power.

3.1 Variation of Current and Voltage

The variation of voltage and current is shown in Figure 9 for stand-alone solar system for a time period of nine hours.

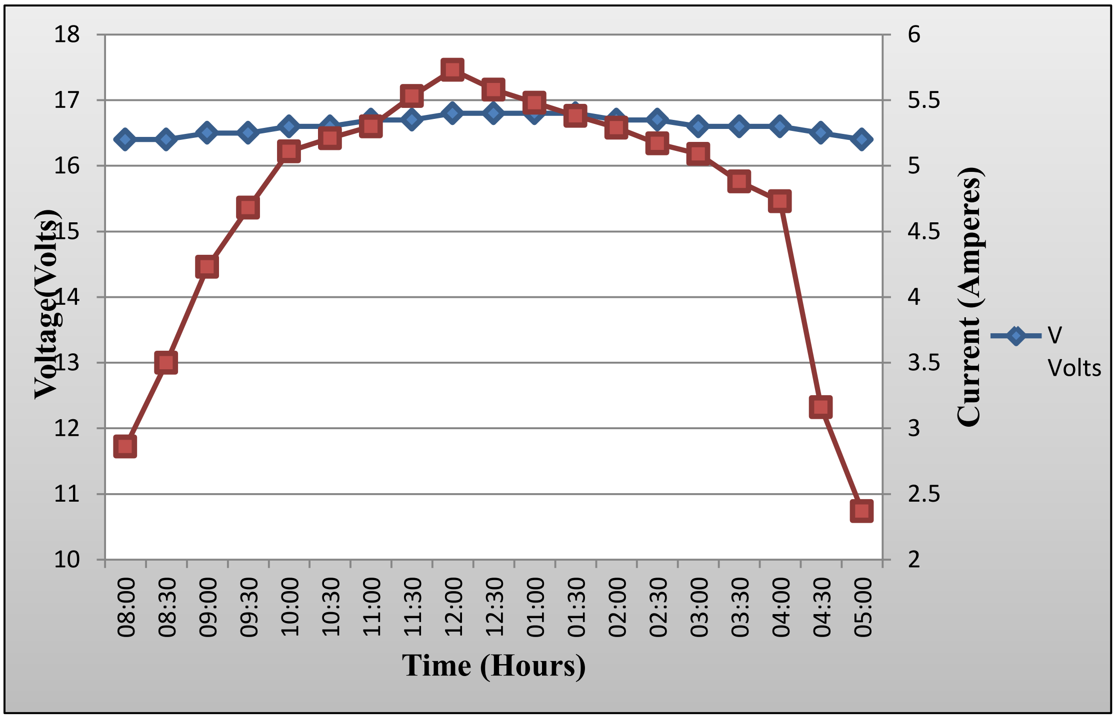

Figure 9: Variation of Current and Voltage with Time

It shows that in case of directly coupled solar thermoelectric refrigerator current and voltage varies with time because solar insolation rate varies with time and these values depend upon solar insolation rate. Figure 9 shows that the voltage and current of the system increases at 8:00 AM from 16.4V, 2.86A to 16.8V, 5.73A at 12 noon and then it decreases to 16.4V, 2.37A until 5:00 PM. These results actually depend upon the solar insolation rate which has a key role in the production of electricity. This is the reason due to which the output voltage and current of the solar system are maximum at 12:00 noon, since this time the solar intensity has its maximum value as shown in Figure 8.

3.2 Variation of Refrigerator Interior Cold Plate and Water Temperature

Figure 10 illustrates the variation of the inner wall (cold plate) temperatures of thermoelectric refrigerator cabinet. The average temperature of refrigerator walls and the temperature of water were used to find out the refrigeration effect of the thermoelectric refrigerator.

Figure 10 shows that temperatures T1, T2, T3 and Tw were continuously decreasing from their maximum values to minimum during operational hours. The heat is absorbed from water by cold plate and then from cold plate that heat is absorbed by thermoelectric module which is then rejected to atmosphere by heat sink. That is the reason due to which there is a continuous decrease in walls and water temperatures. The temperature of water decreased from an ambient temperature of 22ºC to 0 ºC in case of directly coupled photovoltaic system in its nine operating hours of the day.

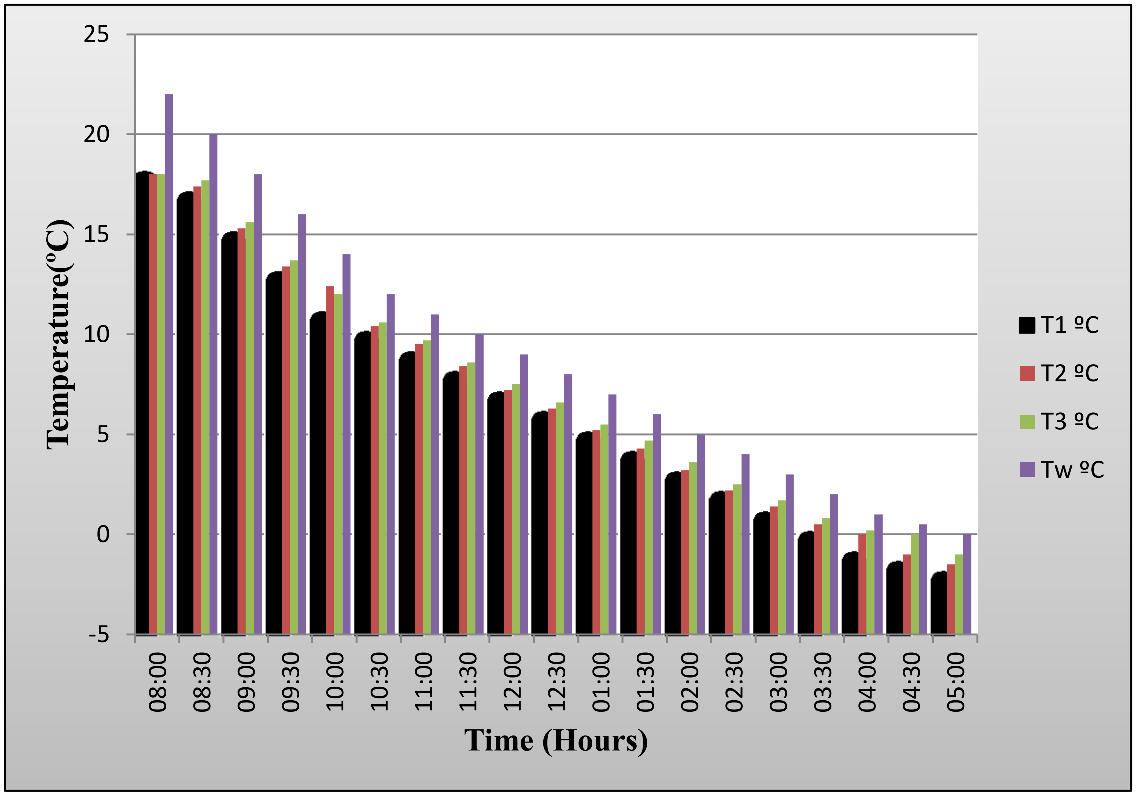

Figure 10: Variation of Refrigerator Interior Wall and Water Temperature with Time

It is observed from figure that the temperature distribution throughout the refrigerator wall is not even. T1 is closest to cold side of the module as shown in Figure 6 hence it has the minimum value while T3 is away from the cold plate hence it has a little higher value. This is because heat transfer is inversely proportional to the distance.

3.3 Variation of TEM, Heat Sink, and Ambient Temperature

The changes in temperatures of hot side and cold side of the thermoelectric module and the ambient temperatures are shown in Figure 11. It was observed that cold plate temperature T1 decreases to its minimum value of -2ºC. The hot side temperature varies with ambient temperature and every time it is approximately 10 ºC higher than that of ambient temperature. Figure 11 it is shows that the temperature of hot side and cold side of the TEM and surface temperature of the heat sink depend upon the ambient temperature. When ambient temperature varies with respect to time, these parameters also vary. This is due to the reason that the heat is rejected to atmosphere and with the change in atmospheric temperature the heat rejection rate varies which results in the change in temperatures.

A lower ambient temperature means very low temperature inside the refrigerator cabinet and hence a better refrigeration effect. This is also one of the drawbacks of thermoelectric refrigerator that in higher ambient temperature it results in poor refrigeration effect.

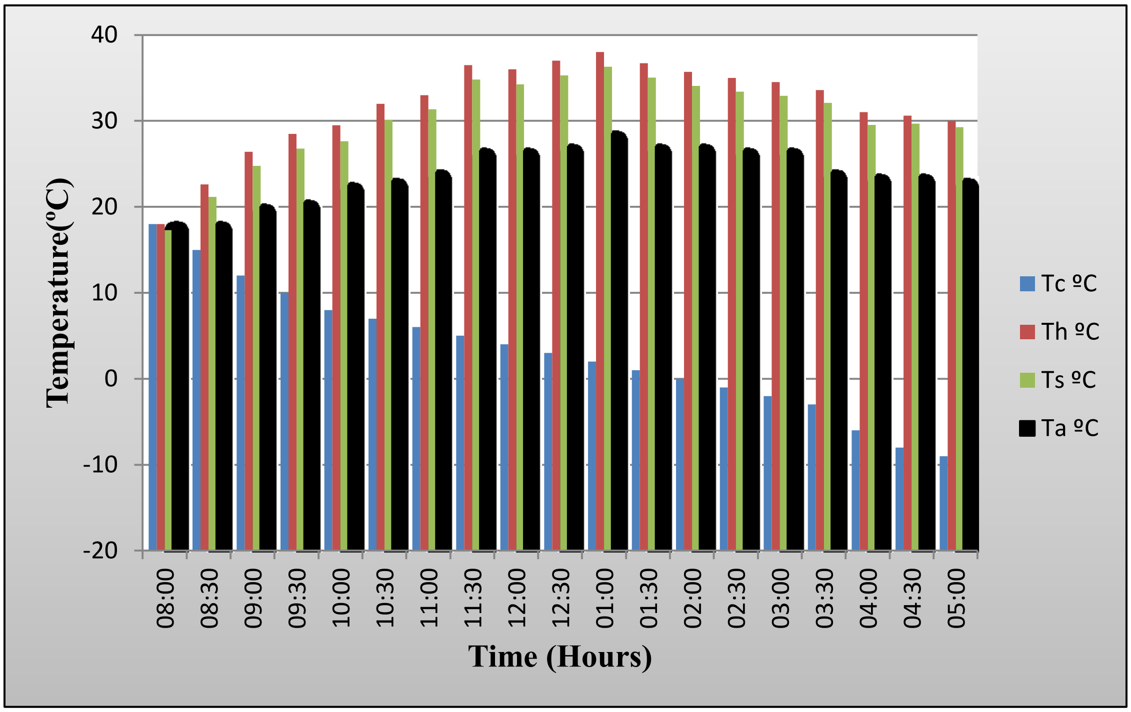

Figure 11: Variation of TEM, Heat Sink and Ambient Temperature with Time

3.4 Variation of Input Power, Cooling Rate, and Coefficient of Performance

Figure 12 shows the variation of input power, cooling rate, and COP of the system with respect to time. COP directly depends upon the input power of the system and cooling rate.

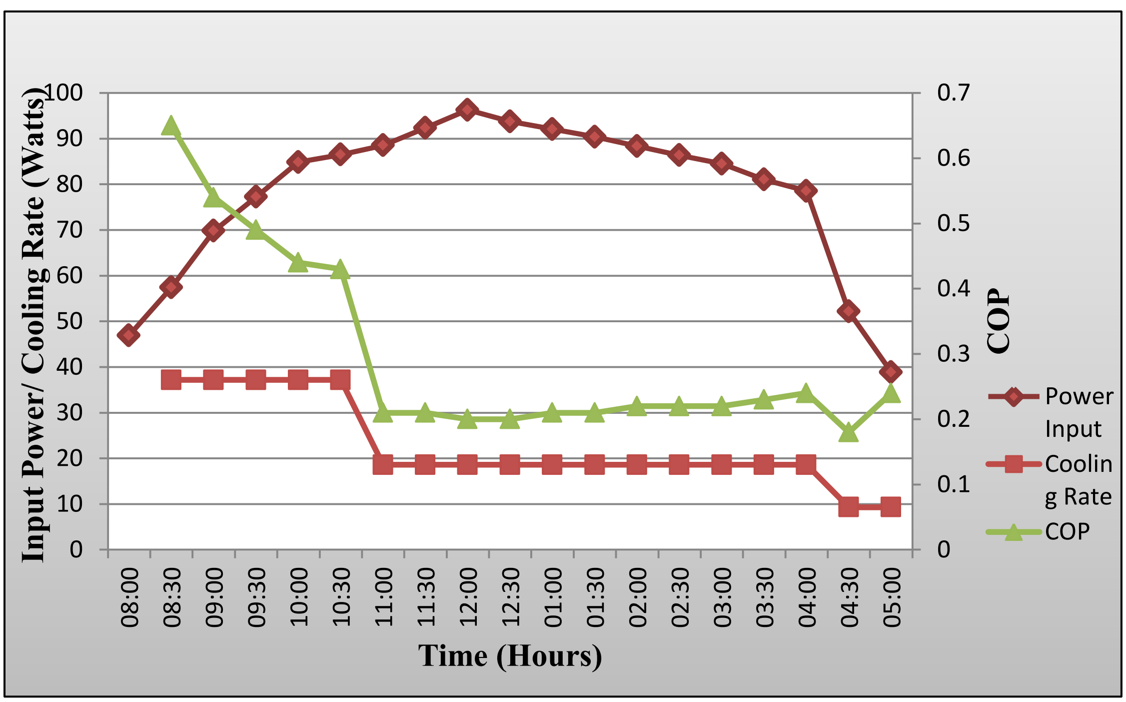

Figure 12: Variation of Cooling Rate, Input Power and COP of TER with Time

It can be seen that cooling rate is maximum at the start of operating hours, then it slightly decreases and remains constant for a long time interval and then finally it further decreases and then remained almost constant. The COP of the system varies with respect to change in cooling load and input power. For maximum cooling load and minimum input power the COP has its maximum value and vice versa. The maximum and minimum values of COP are 0.65 and 0.18 as shown in Figure 12.

It is clear that (Figure 12) in the morning the input power is low due to low solar insolation rate but due to high indoor and outdoor temperature gradient the heat transfer rate is maximum, which results in maximum cooling rate. Hence the COP of the system is maximum in the morning. The water temperature of 0ºC attained was due to very low ambient temperature since the efficiency of thermoelectric refrigerators greatly depends upon the ambient temperature.

Conclusions

In the present research experimental investigation of Solar Powered Thermoelectric Refrigerator is presented in this paper. It can be used domestically as well as in the absence conventional electrical resources. The following conclusions drawn from this work:

1. The performance of the system depends to a great extent on solar irradiance and the temperature gradient of the two sides of the thermoelectric module. The relation between the solar irradiance and electric current has the same trend.

2. The change in temperature of walls (cold plate) of refrigerator cabinet and water stored in refrigerator depends upon the heat absorbed by thermoelectric module.

3. The temperature of the hot side of the thermoelectric module greatly depends upon the ambient temperature, and it is approximately 10ºC higher than that of ambient temperature.

4. The cooling rate has its maximum value at the start of refrigeration process because of large temperature gradient between the temperature of stored product and temperature of refrigeration space.

   The cooling capacity of the system is greatly depends upon the ambient temperature. The maximum cooling capacity of the system is approximated to be 20-25ºC below that of the ambient temperature.

5. The COP of the system has its maximum value at start of refrigeration process due to larger cooling rate.

6. In spite of the fact thermoelectric refrigerators have low COP and high cost, but they are significantly desirable for developing countries to meet the need of daily life and little maintenance. Thermoelectric modules are environment friendly as no liquid refrigerant is present in the system.

7. The system is portable and is easy to carry while moving, especially during hiking, travelling etc. It is easy to use and is a best option for vaccination team to store vaccines at low temperatures during door to door visits.

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References

[1] Y.J. Dai, R.Z. Wang, L. Ni, Experimental investigation and analysis on a thermoelectric refrigerator driven by solar cells, Solar Energy Materials & Solar Cells 77 (2003) 377–391.

[2] Sabah A. Abdul-Wahab, Ali Elkamel, Ali M. Al-Damkhi, Ishaq A. Al-Habsi, Design and experimental investigation of portable solar thermoelectric refrigerator, Renewable Energy 34 (2009) 30–34.

[3] R. Saidur, H.H. Masjuki, M. Hasanuzzaman, T.M.I. Mahlia, C.Y. Tan, J.K. Ooi and P.H.Yoon, Performance Investigation of a Solar powered Thermoelectric Refrigerator, International Journal of Mechanical and Materials Engineering (IJMME), Vol. 3 (2008), No. 1, 7-16.

[4] Suwit Jugsujinda, Athorn Vora-ud, Tosawat Seetawan. Analyzing of Thermoelectric Refrigerator Performance, Procedia Engineering 8 (2011) 154–159.

[5] Manoj Kumar Rawat, Lal Gopal Das, Himadri Chattopadhyay, Subhasis Neogi, An Experimental investigation on Thermoelectric Refrigeration System: A Potential Green Refrigeration technology, Journal of Environmental Research and Development Vol. 6 No. 4, April-June 2012.

[6] Xi H, Luo L, Fraisse G. Development and applications of solar-based thermoelectric technologies.

Renewable and Sustainable Energy Reviews, Volume 11, Issue 5, June 2007, Pages 923–936

[7] T. Hara , H. Azuma, H. Shimizu, H. Obora, S. Sato, Cooling performance of solar cell driven, thermoelectric cooling prototype headgear, Applied Thermal Engineering 18 (1998) 1159-1169.

[8] Gao Min, D.M. Rowe, Experimental evaluation of prototype thermoelectric domestic-refrigerators, Applied Energy 83 (2006) 133–152.

[9] D. Astrain, J.G. Vian, M. Dominguez, Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation, Applied Thermal Engineering 23 (2003) 2183– 2200.

[10] H. Sofrata, Heat Rejection Alternatives for Thermoelectric Refrigerators, Energy Convers, Mgmt. Vol. 37, No. 3, pp. 269-280, 1996.

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

[12] P. K. Bansal, A. Martin, Comparative study of vapour compression, thermoelectric and absorption refrigerators, International Journal of Energy Research Volume 24, Issue 2, pages 93–107, February 2000.

[13] http://www.lahore.climatemps.com, Accessed 14/12/2012.

[14] http://www.gopolymers.com, Accessed 20/12/2012.

[15] www.tellurex.com, Accessed 30/12/2012.

[16] http://www.distancesfrom.com, Accessed 30/01/2013.