A Study on a Solar-Powered Refrigerator Based on Peltier Modules

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Abstract

The utilization of solar energy presents a broad spectrum of flexibility. This study conducted an experimental assessment of a solar-powered refrigerator that incorporated two Peltier modules for its cooling mechanism. The research was carried out in Dehradun's climatic conditions at Graphic Era Deemed University. The setup functioned on solar energy during daylight hours, while an auxiliary battery was utilized at night to sustain lower temperatures. After a duration of 22 minutes and 6 seconds, the temperature of the system was reduced from 30.9˚C to 16.9˚C, allowing the system to run for 3.18 hours with an 84W battery pack.

Keywords: Solar Energy, Solar Powered Refrigerator, Compressor less, Peltier Module, Thermoelectric Cooling.

1. Introduction

The generation of electricity serves as a primary driver of a nation's economic growth. Over recent decades, researchers have increasingly focused on renewable energy sources, shifting away from non-renewable options due to rising pollution levels, population growth, and the finite nature of non-renewable resources. In the late 18th century, electricity generation from non-renewable sources such as coal emerged, followed by a growing interest in alternatives like nuclear power. However, nuclear energy poses significant risks to surrounding communities due to its radioactive properties, as evidenced by the Chernobyl disaster in Kyiv, Ukraine. Currently, researchers are predominantly exploring solar energy systems, which offer numerous benefits, including being cost-free, environmentally friendly, and an inexhaustible energy source. Consequently, solar energy is now utilized across various applications, including heating and cooling through Flat Plate Collectors (FPC), electricity generation via Photovoltaic (PV) modules, solar distillation, and refrigeration, as illustrated in Fig. 1.

Numerous researchers have explored solar energy and the application of Peltier modules in refrigeration, as detailed in the literature review provided below.

Solar Powered Cooling and Heating:

Grignafinni et al. [5] conducted a case study examining solar-powered cooling systems for both modern and historic buildings. The study indicated that a total energy requirement of 465,450 kWh per year is necessary for cooling these structures. Adrian Kerr [6] undertook a theoretical analysis focused on the climatic conditions of Blenheim, New Zealand, proposing a cooling system with a capacity of 35 kW for the city, which would have a payback period of 15 to 20 years. Yasiri et al. [7] carried out a theoretical investigation recommending the use of evacuated tube collectors and parabolic solar collectors for cooling and air conditioning applications powered by solar energy in buildings. Adenane et al. [8] executed a numerical study to assess the impact of operating parameters such as temperature, condensation, and evaporation pressure on solar-powered refrigeration systems. The coefficient of performance (COP) was determined to be 0.346 for a combination of activated carbon and methanol, while a zeolite and water combination yielded a COP of 0.0972. Salilih et al. [9] conducted a simulation study exploring two scenarios: (1) variations in working saturation temperature and (2) a fixed working saturation temperature. In case 2, the performance metrics of refrigeration improve with increased solar intensity but decline in the evening. Conversely, in case 1, performance metrics such as cooling capacity and power consumption decrease, indicating that the system is more sensitive in case

1. Sarbu et al. [10] conducted a theoretical analysis and concluded that liquid desiccant systems and absorption cooling systems are preferable to solid desiccant systems and adsorption cooling systems due to their ease of handling, advocating for solar-based cooling systems as a final recommendation. Ullah et al. [11] carried out a theoretical study on various working pairs, examining minimum and maximum working temperatures, cooling capacity, and coefficient of performance (COP) for solar-powered cooling systems. Moria et al. [12] conducted an experimental investigation on a solar-based compressor-less refrigerator, utilizing a Peltier module for cooling. The cooling side of the module achieved a temperature of 10.6˚C, while the hot side reached 65˚C. Ramadan et al. [13] executed an experimental study on a solar-powered refrigeration system tailored to the climatic conditions of Egypt, with the COP of the system fluctuating between 0.47 and 0.52.

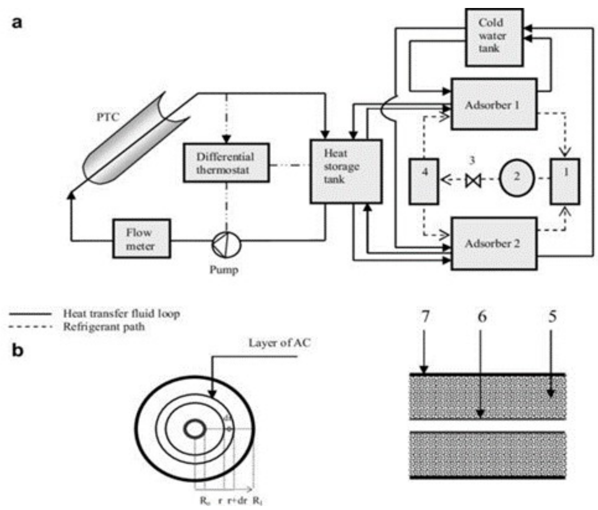

Fig.1 Block Diagram for Solar Powered Refrigeration Cycle 1. Condenser 2. Refrigerant Tank 3. Expansion valve 4. Evaporator 5. Adsorbent 6. Heat Exchanger 7. Insulation [4]

Solar Powered Cooling and Heating:

Grignafinni et al. [5] conducted a case study on solar-powered cooling systems for both modern and historic buildings, revealing that a total energy requirement of 465,450 kWh per year is necessary for cooling these structures. Adrian Kerr [6] undertook a theoretical analysis of the climatic conditions in Blenheim, New Zealand, proposing a 35 kW cooling system for the city with an estimated payback period of 15 to 20 years. Yasiri et al. [7] carried out a theoretical investigation, recommending the use of evacuated tube collectors and parabolic solar collectors for cooling and air conditioning applications powered by solar energy in buildings. Adenane et al. [8] executed a numerical study to assess the impact of operating parameters such as temperature, condensation, and evaporation pressure on solar-powered refrigeration, finding a coefficient of performance (COP) of 0.346 for a combination of activated carbon and methanol, while a COP of 0.0972 was observed for zeolite and water. Salilih et al. [9] conducted a simulation study examining two scenarios: (1) Variation in working saturation temperature and (2) Fixed working saturation temperature. In the second scenario, performance parameters of refrigeration improved with increased solar intensity but declined in the evening, whereas in the first scenario, performance metrics such as cooling capacity and power consumption decreased, indicating greater sensitivity in this case. Sarbu et al. [10] performed a theoretical analysis, asserting that liquid desiccant systems and absorption cooling systems are preferable to solid desiccant systems and adsorption cooling systems due to their ease of handling, ultimately advocating for the adoption of solar-based cooling systems as a concluding remark. Ullah et al. [11] conducted a theoretical analysis on various working pairs, as well as the minimum and maximum operating temperatures, cooling capacity, and coefficient of performance (COP) for solar-powered cooling systems. Moria et al. [12] carried out an experimental investigation on a solar-based, compressor-less refrigerator, utilizing a Peltier module for cooling. The cooling side of the module achieved a temperature of 10.6˚C, while the hot side reached 65˚C. Ramadan et al. [13] executed an experimental study on a solar-powered refrigeration system tailored to the climatic conditions of Egypt, with the COP of the system ranging from approximately 0.47 to

0.52.

Thermoelectric Cooling:

The Peltier effect was first discovered by the scientist J.C.A. Peltier in the mid-18th century. This phenomenon indicates that when an electric current flows through two different materials, thermal energy is absorbed at one junction while it is expelled at the other, resulting in cooling and heating on alternating sides of the materials. Figure 2(a) illustrates a systematic diagram of the Peltier effect. This effect is exemplified in the Peltier module depicted in Figure 2(b), which consists of N-type and P-type semiconductor materials.

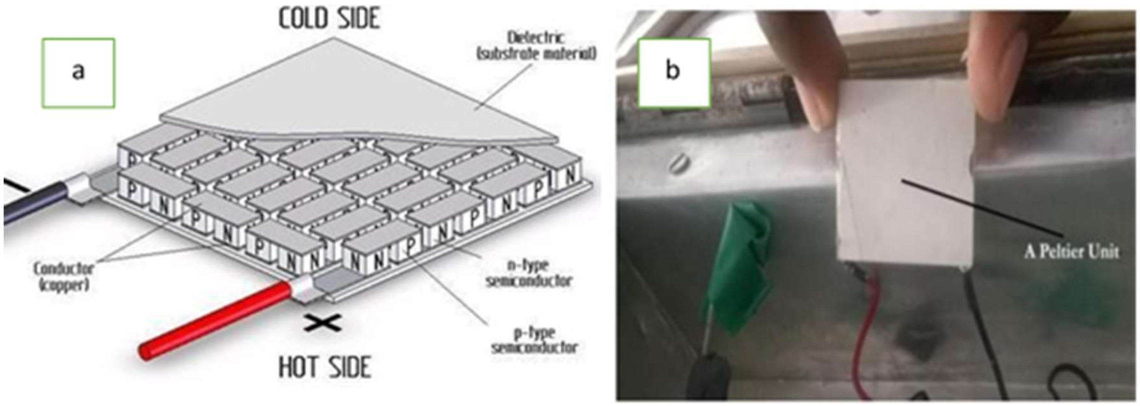

Fig.2 (a) Systematic Diagram of Peltier effect (b) Peltier Module (TIC 12073)

Sahu et al. [14] conducted an experimental study utilizing a Peltier module for cooling purposes. The coefficient of performance (COP) of the system was determined to be 0.458, with a temperature reduction of 12˚C observed in the Peltier module-based system. Anu Nair [15] undertook a theoretical analysis of Peltier module-based cooling, highlighting various advantages of the module as a cooling device. A review of the existing literature indicates that significant research has been conducted on solar-powered refrigeration systems; however, there remains a pressing need for further investigation in this area. The author noted that no experimental studies have been reported on a Peltier module-based, compressor-less mini solar-powered refrigerator. To address this gap, a simulation study has been performed.

Setup Specification:

The study utilized a Peltier unit TIC 12073 with a power rating of 20 watts. A heat sink measuring 7.5 cm x 8 cm x 4.5 cm was employed, accompanied by two cooling fans consuming 2.16 watts each on the hotter side to effectively dissipate heat. Insulation was achieved using Thermopolis and aluminum foil on the outer and inner sides of the refrigerator to reduce thermal losses to the environment. A 160W solar panel from Exide was implemented to power the refrigerator, supplemented by a 12V DC battery that serves as an additional cooling source and can be charged by the solar panel. Finally, a 6 Amp ON-OFF switch was installed to control the power supply from the solar panels to the refrigerator as needed. The outer and inner dimensions of the system are detailed in Table 1, while the circuit diagram of the refrigerator setup is illustrated in Fig. 3.

Table 1 Dimensions of the Refrigerator

Outer length (cm)	30
Outer Width (cm)	20
Outer Height (cm)	21
Inner length (cm)	25.5
Inner Width (cm)	15.5
Inner Height (cm)	8
Volume (L)	3.162

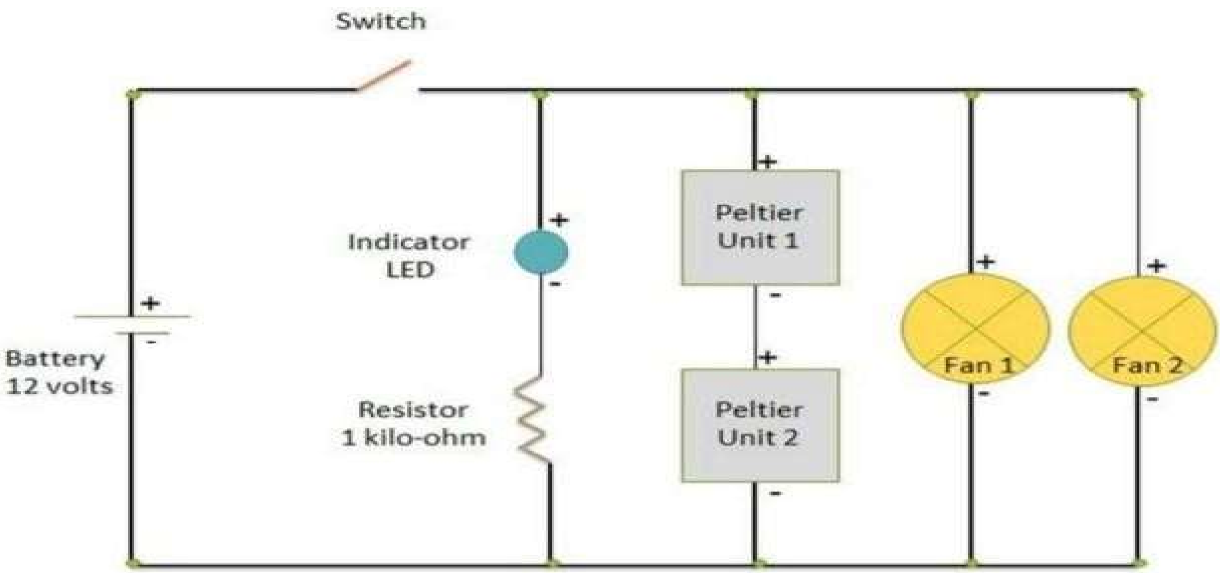

Fig.3 Circuit Diagram of the Experimental Study

Results and Discussions

Table 2 presents the comprehensive data collected from the experiment; the refrigerator's initial temperature was recorded at 30.9˚C, which decreased to 16.9˚C over a duration of 22 minutes and 6 seconds. Additionally, Fig. 4 illustrates the full temperature variation in relation to time.

Table 2 Data obtained from experiment

Reading	Sample	Starting Time	Duration	Max time	Max Temp	Average Temp	Min time	Min Temp	Result	End Time
1	30.9°C	26:02	00:12	26:02	30.9°C	30.5°C	26:14	29.7°C	Stable	26:15
2	29.6°C	26:15	00:07	26:15	29.6°C	28.9°C	26:21	28.4°C	Stable	26:22
3	28.3°C	26:22	00:08	26:22	28.3°C	27.8°C	26:30	27.2°C	Stable	26:31
4	27.1°C	26:31	00:18	26:32	27.1°C	26.5°C	26:44	26.1°C	Stable	26:49
5	26.0°C	26:49	04:39	29:23	26.6°C	26.1°C	31:28	25.0°C	Stable	31:29
6	24.9°C	31:29	00:08	31:29	24.9°C	24.4°C	31:37	24.0°C	Stable	31:38
7	23.9°C	31:38	00:17	31:38	23.9°C	23.5°C	31:54	23.0°C	Stable	31:55
8	22.9°C	31:55	00:45	31:55	22.9°C	22.4°C	32:37	22.0°C	Stable	32:41
9	21.9°C	32:41	01:02	32:43	22.1°C	21.7°C	33:42	21.0°C	Stable	33:43
10	20.9°C	33:43	00:17	33:43	20.9°C	20.4°C	33:59	20.0°C	Stable	34:01
11	19.9°C	33:01	00:28	34:01	19.9°C	19.4°C	34:25	19.0°C	Stable	34:29

12	18.9°C	33:29	01:29	34:34	19.0°C	18.3°C	35:36	17.9°C	Stable	35:58
13	17.8°C	35:58	03:30	39:27	18.8°C	17.6°C	38:42	17.2°C	Stable	39:29
14	17.4°C	39:29	00:06	39:35	19.8°C	19.3°C	39:29	18.9 °C	Stable	39:36
15	17.4°C	39.36	00:17	39:40	20.4°C	19.7°C	39:51	19.0 °C	Stable	39:53
16	17.3°C	39:53	00:44	39:53	18.9°C	18.5°C	40:35	18.0 °C	Stable	40:37
17	17.1°C	40:37	00:24	40:38	18.0°C	18.0°C	40:37	19.9 °C	Interval	41:02
18	17.0°C	41:02	03:48	42:35	18.1°C	17.5°C	44:33	17.0 °C	Stable	44:51
19	16.9°C	44:51	0.:17	48:05	17.5°C	16.9°C	46:34	16.6 °C	Stable	48:08
20	16.9°C	48:08	00:00						Stop	48:08

Calculations

1. Voltage supplied 12V DC
2. Voltage across Peltier module – 6V
3. Current drawn from battery – 2.2A
4. Power at one Peltier module = 6×2.2 = 13.2W
5. Power at Fridge with 2 Peltier module = 2×13.2= 26.4W/hr.
6. Capacity of battery 84W then operable time for Refrigerator = 84/26.4= 3.18hr.

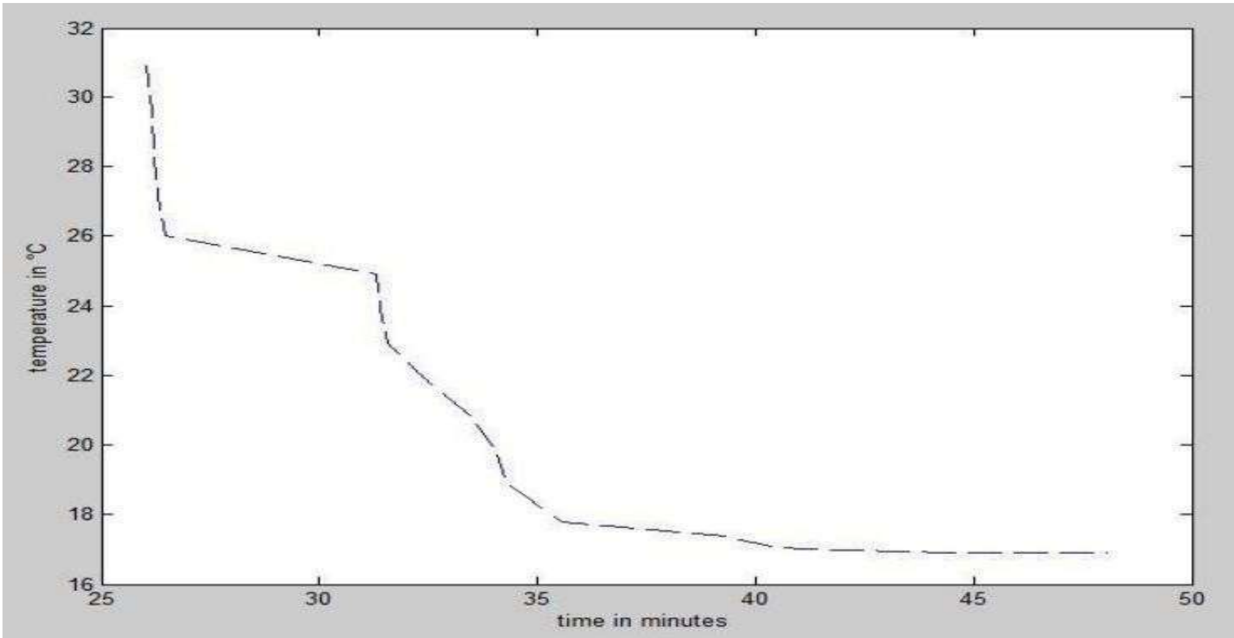

Fig.4 Variation in Temperature of Refrigerator w.r.t Time

Conclusions

Upon concluding the experimental study, several findings were established:

1. The Peltier module is applicable for refrigeration processes; however, further advancements are necessary for its use in larger refrigerators.

2. The refrigerator can function for a duration of 3.18 hours with two Peltier modules.

3. The operational time of the refrigerator can be extended by incorporating a larger battery into the system.

4. A temperature differential of 14˚C was recorded during an operational period of 22 minutes and 6 seconds.

5. The minimum temperature observed during the study was 16.9˚C.

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