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ARTICLE

# A REVIEW ON THE REFRIGERATION SYSTEM POWERED BY PHOTOVOLTAIC (PV) ENERGY

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## ABSTRACT

*Limited availability and pollution-prone tendency of traditional energy resources have encouraged the utilization of unconventional or renewable energy resources in daily use technology. The refrigeration process is an essential process which preserves the food, beverages, vaccines, lifesaving drugs and daily essentials for a longer duration of time. Irregular power supply and higher power cost significantly affect the efficiency of a refrigerator. The development of renewable energy powered refrigerators can be a reliable solution to this problem. This paper reviewed the development of solar powered refrigerators. Here, special attention has been paid on the performance and functioning of various configurations of photovoltaic energy powered refrigerators. In some refrigerators, solar energy (DC) obtained from PV panels was used directly by using DC motor, while in some cases it was transformed into an AC by using an inverter. In the maximum studies, it was found that a home refrigeration system irrespective of any configuration can be run successfully using solar energy. The factors like high installation cost, low conversion capability of PV modules, and poor energy accumulation and holding capacity of batteries played a major role in not being utilized this technology in everyday life. It is expected that the use of next generation miniaturized and efficient electronic components especially solar cells and batteries in the refrigeration system would bring a boom in this segment.*

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**KEY WORDS**
*Solar energy, Refrigeration, Photovoltaic effect, Pollution; Battery*

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## INTRODUCTION

Recently particular emphasis is being given on the production of renewable energy-driven appliances owing to increasing awareness and concerns about the environment. Among various renewable energy resources, solar energy is the most popular one and abundantly available on earth. There are considerable research initiatives worldwide, especially on the development of solar-powered equipment. A solar panel consists of silicon solar cells directly interact with sunshine and convert it into the electrical current as per photovoltaic (PV) effect. The ability to convert solar energy into usable electricity is usually presented as the efficiency of the solar panel. With continuous research efforts, the efficiency of a solar panel has been increased by almost 23%. Even today, the maximum efficiency of commercially available solar panels lies in between 15-18%. Over the last few decades, the problem of heat in many portions of the world is taking a perplexing form due to excessive global warming. This problem becomes even more distraught when energy production from conventional energy resources is low, and the power supply is irregular. Solar energy is capable of ceasing the electricity shortage problem if utilized on its maximum capacity. Considering this fact, extensive research is being conducted to increase the potential of solar panels across the globe. A considerable amount of energy is consumed in various types of refrigeration systems. Vehicles transporting milk products, fruits, vegetables, medicines, vaccines etc. are usually equipped with small cooling equipment. In addition to that, most of the luxury vehicles, caravans, boats, cars, etc. are also often equipped with small air conditioning units. For such applications, low capacity compressors are employed which operate on direct current (DC) and a small voltage (i.e. 12-24 V). Renewable energy systems, especially solar panels, also generate electrical energy in the form of DC voltage or current. For the storage of life-saving drugs, vaccines and food items, a solar-powered refrigeration system can be considered the most optimal. The photovoltaic (PV) refrigeration system has been in existence for quite some time, but its use is limited to some specific applications only. The main reason for this is that the cooling capacity of the PV-operated (DC) cooling system is less than that of the alternate current (AC) drove cooling system. Compared to AC powered compressors, DC powered compressors come in small sizes and are able to cool the small area only.

In this article, a comprehensive review of PV driven cooling systems and their development has been presented. The effectiveness of this system and the effect of various parameters on its performance have also been documented.

## PV POWERED COOLING SYSTEMS

A PV cooling system is made up of components like PV arrays, batteries, inventors, vapor compression refrigeration systems etc. This system can be classified into DC or AC cooling systems. A schematic diagram of a typical PV operated DC refrigeration system is shown in [Fig.1]. PV powered AC cooling system consists of an additional component named inverter to convert direct current to alternating current. In some PV powered refrigeration systems, additional energy generators in synchronization with the primary energy source are also employed to ensure uninterrupted power supply. De Blas et al. [1] designed a PV operated refrigeration system to preserve milk. On analyzing the performance of this system, they found that better performance of the system was mainly depended on the solar radiation level, motor speed and voltage required to run the motor. In this arrangement, two concentric vessels were used in which frozen

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water stored in the external container and milk in the inner container. Here, solar energy was collected in the form of latent heat of frozen water, and milk was kept at 4°C. The Coefficient of Performance (COP) of the system was enhanced when condenser and electric motors were kept outside the refrigeration chamber. In another study, De Blas et al. [2] evaluated the operation of the PV system powered DC motor required for refrigeration in various motor parameters. They prepared graphs to determine the optimum operating parameters to achieve the best electromechanical properties and extract maximum COP from the refrigeration system. Del Pero et al. [3] checked the feasibility of a PV powered refrigerator for food conservation in rural areas. In their energy model, they claimed that the electrical power obtained from the PV module was higher than the power required to operate the compressor. According to them, this model is very economical and can be easily manufactured using locally available low-cost materials. Del Pero et al. [4], in another study, tested a PV powered refrigerator kit in a climate condition of Cameroon village.

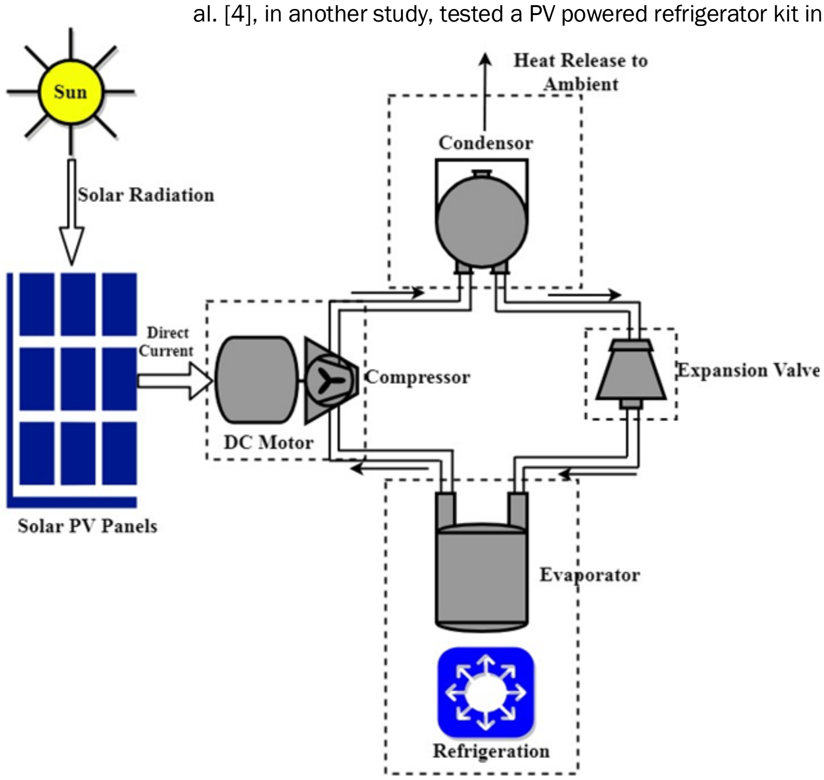


**Fig. 1:** Schematic diagram of solar PV refrigeration.

They found a 250 L refrigerator could be maintained at or below 10°C for approximately 48 h in a no-load condition. In a study conducted on a 66 W (PV powered) refrigeration system in Saudi Arabia, it was stated that solar energy is sufficient to run this system [5]. El-Tom et al. [6] studied the suitability of a PV solar refrigerator for preserving vaccines in Sudan. Power from the PV solar energy generator was provided to run the compressor (24 V DC motor) of the fridge. They noticed that the energy obtained from the solar generator was not enough to fully charge the battery so that it could operate the refrigerator overnight at full load. Gupta et al. [7] found that a refrigerator of 25 mm insulation thickness would run at optimal conditions when powered by a solar energy generator consists of 320W PV panel and 50 Ah battery capacity. However, 200W PV panel was sufficient if insulation thickness was 50 mm. Kattakayam and Srinivasan [8] found that the refrigerator operated by the PV energy source can work uninterrupted if it was backed up by gasoline/kerosene or diesel generator set and this is a suitable alternative for the storage of vaccines and life-saving drugs. In another experiment, Kattakayam and Srinivasan [9] drove a home fridge with non-sinusoidal AC input. This input was obtained from a PV-battery-inverter source. In this experiment, no degradation had been found in the thermal capacity of the fridge although they suggested that the vaccine should not be stored near the open end of the fridge door. Battery capacity plays an important role in the PV refrigeration system. To fetch maximum output from a battery, an appropriate system sizing is needed. Additionally, state-of-charge of a battery must occur in between 0.5-08 [10]. Modi et al. [11] redesigned a 165 litres domestic refrigerator to a PV powered refrigerator. After this modification, the COP of the system varied from morning to evening. The maximum COP, i.e. 2.102 was noticed at 7 am. The minimum requirements for this system to work properly was 140 W PV capacity and two 12 V/135 Ah battery bank. Nagaraju et al. [12] developed a PV-powered cold storage plant to store 10 tons of frozen fish at -15°C. This system worked at its full potential in one full year. Later on, performance degradation was noticed owing to deterioration in PV panels. Xi et al. [13] investigated the performance of a PV refrigerator of 24V. It was running steadily with a rate of 48.8% in no-load condition. In this operation, an average of 28.8W power was consumed. This system can be operated continuously for 25 days in sunny conditions, six days in cloudy state and five days in overcast or rainy condition. Rathore and Panwar [14] investigated the PV refrigeration system and obtained minimum -3.36°C temperature at no load condition

IIOAB JOURNAL
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and 2.34°C temperature at fully loaded conditions. In [Table 1], a compilation of different configurations of PV-driven refrigeration systems employed for various applications is provided.

**Table 1:** Various configurations of PV-driven refrigeration systems and respective parameters

| S. No. | Configurations | Parameters | DC or AC | Energy Storage | Applications | Ref. |
|---|---|---|---|---|---|---|
| 1. | PV+DC motor | PV Modules: 20 (120 Wp each) | DC motor: 650W/24V | Latent heat of frozen water | 150 L milk storage tank | [1] |
| 2. | PV+DC motor | PV module: 240 Wp Refrigerant: R134a | DC-powered compressor unit: 80 W | Latent heat of frozen water | 250 L Standalone DC solar refrigerator | [4] |
| 3. | PV+Battery+DC motor | PV module: 100 W Refrigerant: R134a DC power rating: 66W | Lead acid batteries: 12 V/50 Ah | Batteries charging | 80 L Domestic fridge | [5] |
| 4. | PV+Battery+DC motor | PV Modules: 6 (40 W each) Refrigerant: R12 | Batteries: 2 (12 V/105Ah each) DC motor compressor: 24 V | Batteries charging | 180 L Refrigerator | [6] |
| 5. | PV+Battery+DC motor | PV Modules: 2 (70 Wp each) Refrigerant: R134a | Battery: 2 (12V each) DC compressor: 66W | Batteries charging | 90 L Refrigerator | [13] |
| 6. | PV+Battery+DC motor | PV Modules: 134 (30 Wp each) Average efficiency per panel: 9% Refrigeration load: 21 kWh | Lead acid battery: 15 (6.3V/180Ah each) DC-powered compressor unit: 3 kW/90V | Batteries charging | Cold Chamber Volume: 21 $m^3$ | [12] |
| 7. | PV+Battery+Inverter | PV Modules (series parallel combination): 8 (35 Wp each) AC Refrigerator: 110W | Inverter: 1.5 kVA Lead acid battery: 2 (12V/135Ah each) | Batteries charging | 50 L Refrigerator | [7] |
| 8. | PV+Battery+Inverter | PV Modules (series parallel combination): 4 (35 Wp each) Refrigerant: R-134a AC Refrigerator: 110 W | Inverter-transformer system Lead acid battery: 2 (12V/135Ah each) | Batteries charging | 165 L Domestic Refrigerator | [11] |
| 9. | PV+Battery+Invertor+ generator set | PV Modules: 8 (35 Wp each) AC Refrigerator: 120-140 W | Invertor: 1.2 kVA Lead acid battery: 4 (6V/180Ah each) Back-up generator set: 1.0 kVA | Batteries charging | 165 L Domestic Refrigerator | [8] |

## MODELLING AND SIMULATION STUDIES ON PV REFRIGERATION SYSTEMS

Sukamongkol et al. [15] developed a simulation model to predict the performance of a PV system at specific loading conditions for a particular location. This system was validated by a similar experimental system. Results obtained from both the methods were almost in good agreement with each other. Cherif and Dhouib [16] had demonstrated the performance of PV refrigeration plant with latent storage through dynamic behavior and simulation responses. They found that PV systems showed good performance, reliability and autonomy if climate conditions were favourable. In these conditions, the system is almost invulnerable to situations like door-opening and load disturbances. However, the performance and efficiency of this system are relatively low with solar radiation disturbances. Del Pero et al. [4] proposed an energy model to analyze the energy performance of the PV powered refrigeration kit. Refrigerator temperature and water container temperature were accessed using the model. The model was validated by testing its results on a developed prototype, and it was noticed that the deviation was only 0.4°C from the predicted values.

## ECONOMICAL ASPECT OF PV REFRIGERATION SYSTEM

In a solar trailer, a roof-mounted PV array charges batteries and the battery power employed to run an electric fridge via inverters. For this type of application, a PV driven cooling system is a suitable alternative because its maintenance and operational cost are extremely low. A PV cooling system fitted aircraft catering uplift vehicle is also economical for a longer operational period than the conventional one. The same fact is also true for household milk delivery van. In the previously described applications, the use of a PV driven cooling system is not only cheap but also a long-lasting non-maintenance system [17]. El-Shaarawi et al. [5] found that a 66 W refrigerator powered by a PV mono-crystalline module with a 100 Ah battery bank is relatively costlier, and the payback period is around 25 years. Modi et al. [11] performed the economic feasibility of the redesigned refrigerator in the RETScreen simulations and found that the system is not economically viable without external aid. With the rise in refrigeration capacity and the increment in solar radiation, the specific price of refrigeration power decreases [18].

## PHOTOVOLTAIC/THERMAL (PVT) REFRIGERATION SYSTEMS

It is well known that PV cells convert solar radiation into electrical energy. However, the conversion efficiency of these PV cells is 10-20% only. Some complex multi-junction PV cells also have the conversion capacity of up to 39%, but still, this energy efficiency is not enough to run modern equipment. In addition, more than half of the solar radiation, stored with considerable effort is wasted in the form of heat. The efficiency of this system can be enhanced if, by any means, this waste heat is collected and utilized again. This idea can be embodied by placing a heat exchanger behind the PV cells. This system is known as photovoltaic/thermal (PV/T) collectors. The heat rejected by PV cells is used by the heat exchanger as input, resulted in minimum wastage of energy. Mittelman et al. [19] introduced a concentrating photovoltaic/thermal (CPVT) system to produce electrical as well as high-grade thermal energy simultaneously at high temperatures. The highest driving potential of the cooling machine was obtained at an operating temperature of 120°C. However, electricity production was lower. At 80°C, the electrical efficiency of CPVT was optimum. Xu et al. [20] proposed a new low CPVT system with constant volume refrigeration. The reported thermal and electrical efficiencies of the system were 39.4% and 14.1% respectively at a temperature of 40°C. Therefore the overall efficiency obtained from the experiment was 53.5%, which was lower than the simulated values (58.6%). The conversion efficiencies are considerable, and no external heating was needed for outlet flow. Renno [21] optimized the parameters of CPVT system to make it most conducive for the domestic application. They simulated the CPVT process using MATLAB and achieved the best possible parameters for extracting maximum output. To meet the energy demands of a home using CPVT process, two modules of 90 cells with 81 mm2 area and concentrating mirrors of high concentration factor is required. At 90°C fluid outlet temperature, the CPVT system can be employed with an absorption heat pump. Tiwari et al. [22] did numerical calculations of fully covered semitransparent photovoltaic thermal-compound parabolic concentrator (PVT-CPC) and photovoltaic thermal-flat plate collector (PVT-FPC) in MATLAB to check the feasibility of the systems for vapor absorption refrigeration system (VARS). They found that both the collectors are self-sustained for VARS.

## CONCLUSIONS

In this article, a detailed review of the development of solar-powered refrigeration system has been presented. Various approaches had been utilized to feed solar energy to the refrigeration system. In some cases, the PV current was supplied directly into the DC motor while in other cases the DC was converted to AC using an inverter, and after that, the compressor was operated using it. Alternative energy sources were also employed with PV energy in some studies to run the refrigeration system at its maximum efficiency. In many situations, it was affirmed that the energy obtained from the PV system is enough to run a household refrigerator. Nonetheless, the discrepancies of the solar-powered refrigeration system were also reported in some studies. The initial cost of establishing a PV powered refrigeration system was relatively high, which raises questions about its achievability. In the current scenario, the government aid or the availability of subsidized PV panels and other equipment can only provide this pollution-free technology to the public. Although this refrigeration technique has the potential, low conversion capacity of PV panels, rudimentary battery technology and the high cost of components are slowing down the progress of this green initiative. Upon the full development of this technique, not only domestic essentials and life-saving items can be preserved, but our environment will also be prevented from being polluted. The expansion of PV powered refrigeration technique is inherently dependent on the peculiar development of technologies such as PV panels and energy storage or holding devices. The development of high capacity portable energy storage devices and PV panels with more conversion efficiency can play an important role in popularizing this system.

### CONFLICT OF INTEREST

None

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### FINANCIAL DISCLOSURE

None

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IIOAB JOURNAL
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