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October 13, 2019

A review on modelling and performance evaluation of solar photovoltaic powered refrigeration system

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Abstract. In the present paper, an attempt has been made to review the performance of various solar powered refrigeration system. The refrigeration is closely related to the demand for cooling commodities. Solar refrigeration is the best alternatives to address this issue and it may be accomplished by using one of the refrigeration system like vapour compression system, thermo electric refrigeration. The simulation model of photovoltaic thermal hybrid system has been created by using TRANSYS and the performance of 1.44kW photovoltaic thermal hybrid system has been evaluated. The results of solar PV has been improved by using plane mirror which was inexpensive and cost effective. The average performance indicator of SPV powered refrigerator i.e. COP varies from 2.02 to 2.41 and maximum value obtained by using Nano refrigerant. Majority of the studies carried out on 40L to 50L direct cool refrigerator

I. INTRODUCTION

Photovoltaic thermal hybrid system has a device than can provide the electrical power and hot water at the same time. The simulation model of photovoltaic thermal hybrid system has been created using TRANSYS tool. The simulation model can provide the transient and In term evaluation to predict the system performance in different weather condition [1]. Solar energy is a clean, eco-friendly and profuse resource available everywhere on earth and almost all year. It has estimated that in just one hour, the solar energy solar energy finds its application in the diversified areas like solar refrigeration, solar pumping, solar water heater etc. These system are more popular because of they provides lot more benefits to the user in terms of cost, maintenance, portability, performance and usability [3]. The solar photovoltaic panels operated the refrigerators capable of cooling the vaccine for 24 hours a day. The SPV powered refrigerator under test was able to maintain the temperature as specified by the WHO for the vaccine preservation (2°C to 8°C) [4]. PV powered household refrigerator operated on PV power without any inverter. The highest COPR 0.670 is observed during the no storage condition and highest exergetic coefficient of performance is 0.068 at low load condition [5]. It is technically possible to operate both refrigerators VCRS and VARS as photovoltaic refrigerators. Under normal operating conditions both refrigerators working on photovoltaic power supply, behave similar to working on grid electricity. The VARS can be used for preserving the drugs and medicine in the remote areas where no more cooling is required only temperature is to be maintained and that too at much lower cost than the VCS [6]. The energy efficiency of a solar panel, the ratio of the power output to the energy originally delivered to the solar panel, conventionally it is used to measure solar PV efficiency. The average photovoltaic conversion efficiency and exergy efficiency found nearer to 8.5% and 11% respectively in both no load and full load condition for May month [7]. Energetic and exergetic techniques helps to evaluate the performance of the solar photovoltaic refrigerator with a view to get better information about useful work and lost work and design some alternate techniques in future to overcome on these losses. The installed system of solar photovoltaic refrigerator system is capable for cooling the vaccine for 7 hour in a day. The pull down test indicates that 375Wp photovoltaic capacity and 21Ah battery bank is the least possible configuration required for this converted system. The average COP during no load and full load tests were found high as 3.37 [9]. It can be seen from results of this study that the use of PV refrigerator system is suitable for applications in different sector field, required the low and medium cooling capacity. Such small-scale standalone system can suitably be used in many rural regions [11].

II. LITERATURE REVIEW

Chau-Yang Huang et.al [1] has made the study on photovoltaic thermal (PV/T) hybrid system with computer modelling and evaluated photovoltaic thermal hybrid system as per fig.1 has a device that can provide the electrical power and hot water at the same time. The simulation model of photovoltaic thermal hybrid system has been created using TRANSYS tool. The simulation model can provide the transient and long term evaluation to predict the system performance in different weather condition. The performance of 1.44 kW photovoltaic thermal hybrid system had been evaluated in differential location

in Taiwan. The results shown in Tainan in Taiwan was good place to install the PVT system better than another location in Taiwan. The simulation results shown the system electrical efficiency was 11.7-12.4% and thermal efficiency was 26.78~28.41% accordingly. They have derived results from simulation software as per fig.1 shown in below.

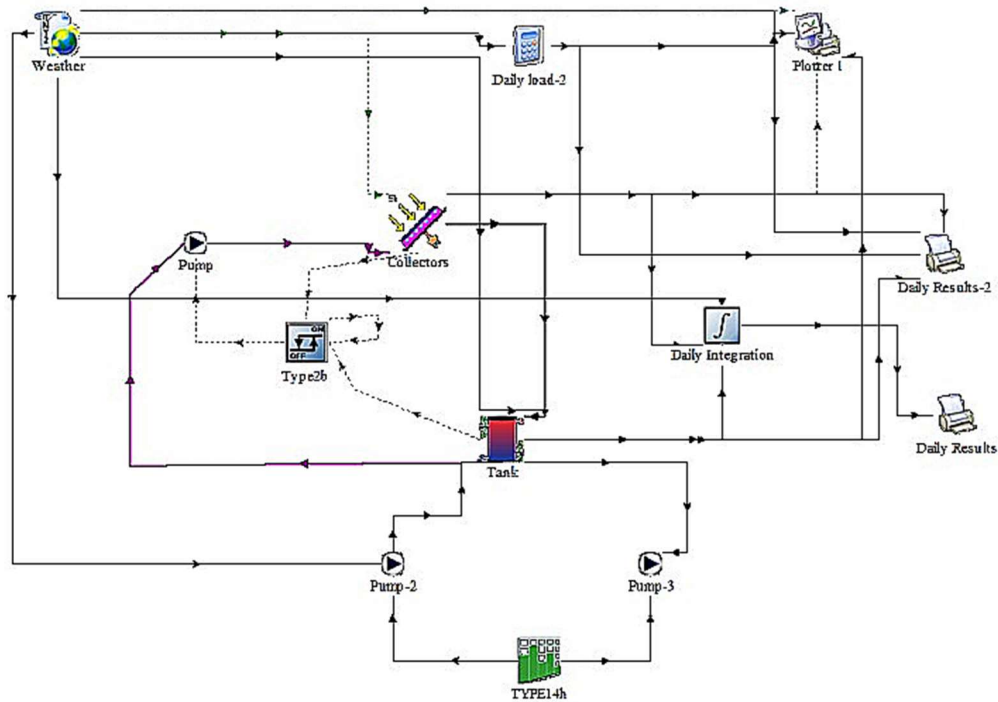


Figure. 1. Photovoltaic thermal hybrid system in TRANSYS [1].

Within TRANSYS tool, the photovoltaic hybrid system could model with transient and long-term period. The system has built with unglazed flat plate Photo voltaic thermal collector, storage tank, pump, temperature differential controller and local weather data as per table 1.

Component	Type	Comments
Controller	2	Temperature differential controller
PVT Collector	563	Unglazed tube sheet
Weather data	109	
Pump	3	
Tank	4	Storage tank

Table 1. List of TRANSYS types used in PV/T system

The PVT collector model in TRANSYS has the dual purpose of creating power from embedded PV module and providing heat to the fluid passing through the copper tube bonded to the metal sheet the heat recycle from PV module can cool the PV module allowing the high electrical power output and provide the hot water to apply in domestic heating, swimming pool and industrial preheating. The parameters of the hybrid PV/T system in TRANSYS has shown in Table 2. The system performance has been calculated with solar radiation (kWh/m^2) H, PV/T, electrical power (kWh) P and thermal capacity of water (kWh) Q at simulation period time.

Component	Description	Value
PV/T module	Module area	9.78m ²
	Thermal conductivities of the absorber	200W/m-°C
	Fluid specific heat	4.18 KJ Kg -°C
	PV efficiency at reference condition	14.74%
	PV cell reference radiation	1000W/m ²
	PV cell reference temperature	25°C
	Temperature coefficient of solar cell Efficiency	0.0042 °C
	Packing factor	1
Pump	Maximum flow rate	4 LPM
	Maximum Power	300W
Storage tank	Volume	500 l

Table 2. List of the experimental set up parts

Sanjaykumar A. Borikar et.al. [3] has made mathematical modelling for 40-liter prototype refrigerator for taking into consideration of following factors as per figure 2.

1. The natural convection heat transfer mode is considered.
2. The refrigerator cabinet has been divided into vertical horizontal surfaces.
3. Pressure variation in the direction perpendicular to the plate are neglected.
4. The viscous forces are assumed to be negligible.
5. The radiation heat transfer to the cabinet is neglected.

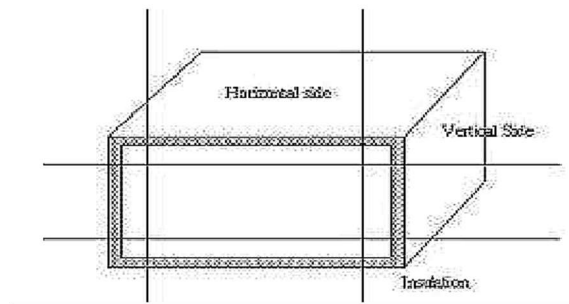


Figure 2 Refrigerator box

They have designed and developed prototype 40 liter solar refrigerator for monitoring its performance in Indian climate and evaluated economic feasibility and affordability in domestic, commercial and industrial applications. The test results obtained shows that the prototype set up confirms the cooling abilities and thus makes it suitable for refrigeration in domestic and commercial area.

The refrigerator was operated using an AC compressor and draws power from storage battery through inverter, which converts 12V DC in 260V AC supply by amplifying the voltage. The battery is connected to the photovoltaic panels. For testing, 48W panels are used with current rating of 1.9 to 2 amp-hr and voltage rating of 19 to 24V. With the economic analysis of solar refrigerator following tariff rates according to the consumer designated by MSEB were considered in May 2007 as per table 3.

Consumer	Demand		Tariff rates (Rs) per unit
	Units	Charge (Rs)	
Domestic	0-100	40 per month	1.90 + Fuel charges
	101-300	100 per month	3.40 + Fuel charges (0.40)
	301 above	100 per 10 KVA	4.50 + Fuel charges
Commercial	0-100	150 per month	2.90 + Fuel charges
	101-200	150 per month	3.79 + Fuel charges
	201 above	150 per KVA	4.90 + Fuel charges
Industrial	0-100	200 per KVA	0.70+ Fuel charges

Table 3. Tariff details with consumer category wise

It is found that the compressor requires 276VA continuously for performing its functions. In reality solar radiation is available typically 7 hours in a day.

Energy consumed by refrigerator = 1932 watts (1.932 units)

Energy consumed in an year = 708.180 units

Cost of electricity for refrigeration = units consumed*(tariff rates + fuel charge) + fixed demand charges.

Overall cost of electricity in domestic is Rs.3891.08 per year, Commercial is Rs.5836.63 per year and industrial rates is Rs.7223.44 per year accordingly.

Dhondge A.J et.al. [4], had an experiment on solar PV operated refrigerator for vaccine storage with different refrigerants, R134a and Nano refrigerant (R134a+Al₂O₃)

The performance of the system was evaluated for 24h of operation in controlled condition (at 25°C room temperature during January 2017) and in transient ambient condition during March 2017. A comparative study was carried out by using refrigerant R134a (tetrafluoroethene) and nano refrigerant (R-134a +0.5%Al₂O₃) and following variables are studied. The temperature of different points using temperature sensors connected to the data logger of the components of refrigerator like compressor inlet and outlet and cabinet temperature were taken during the test. The power to the refrigerator was supplied by the solar photovoltaic system (SPV) during day time (Sunshine) and battery backup was provided during off sunshine hours which was charged by SPV system during the sunshine hours.

SN	Tetrafluoroethane (R-134a)			Nano Refrigerant (R134a + 0.5% Al ₂ O ₃)		
	COP	Power consumption (kWh)	Cooling efficiency (%)	COP	Power consumption (kWh)	Cooling efficiency (%)
1	2.14	1.38	61.11	2.4	1.25	67.23

Table 4. Average performance parameters of SPV powered during no load test

From table 4 found that the COP, power consumption of compressor (kWh) and cooling efficiency of the SPV powered refrigerator was 2.14, 1.38 & 61.11 and 2.40, 1.25 & 67.23 using refrigerant R-134a and nano refrigerant (R-134a +0.5Al₂O₃) respectively. There was increase in all performance parameters found by using the nano refrigerant (R-134a +0.5Al₂O₃) with saving in the power.

Effect of three variables on COP of SPV powered refrigerator. Effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP in winter season.

SN	Temperature (°C)	COP			
		Type of Refrigerant			
		R1 - R-134a (Tetrafluroethane)		R2 - Nano refrigerant (R134a + 0.5% Al ₂ O ₃)	
		Load, Litre			
		L1 - Half Load	L2 - Full Load	L1 - Half Load	L2 - Full Load
1	T ₁ = 2	2.06	2.01	2.27	2.21
2	T ₂ = 5	2.18	2.13	2.39	2.33
3	T ₃ = 8	2.26	2.2	2.46	2.41
	F Test	Significant			
	SE (m) ±	0.003			
	CD at 5%	0.011			

Table 5. Combine effect of refrigerant, load and temperature in evaporation chamber on COP n winter season (Room temperature 25±2°C) Jan 2017

Table 5 revealed that the COP of SPV powered refrigerator was found to be 2.06 using refrigerant R-134a at half load condition and at temperature in evaporation chamber of 2°C. The COP was observed decreasing at full load condition to 2.01 and at this same situation the COP of refrigerator increases from 2.06 to 2.26 and 2.01 to 2.20 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load condition respectively. The similar effect of the COP of refrigerator was observed using nano refrigerant (R-134a +0.5%Al₂O₃) as it increases from 2.27 to 2.46 and 2.21 to 2.41 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load and full load condition respectively.

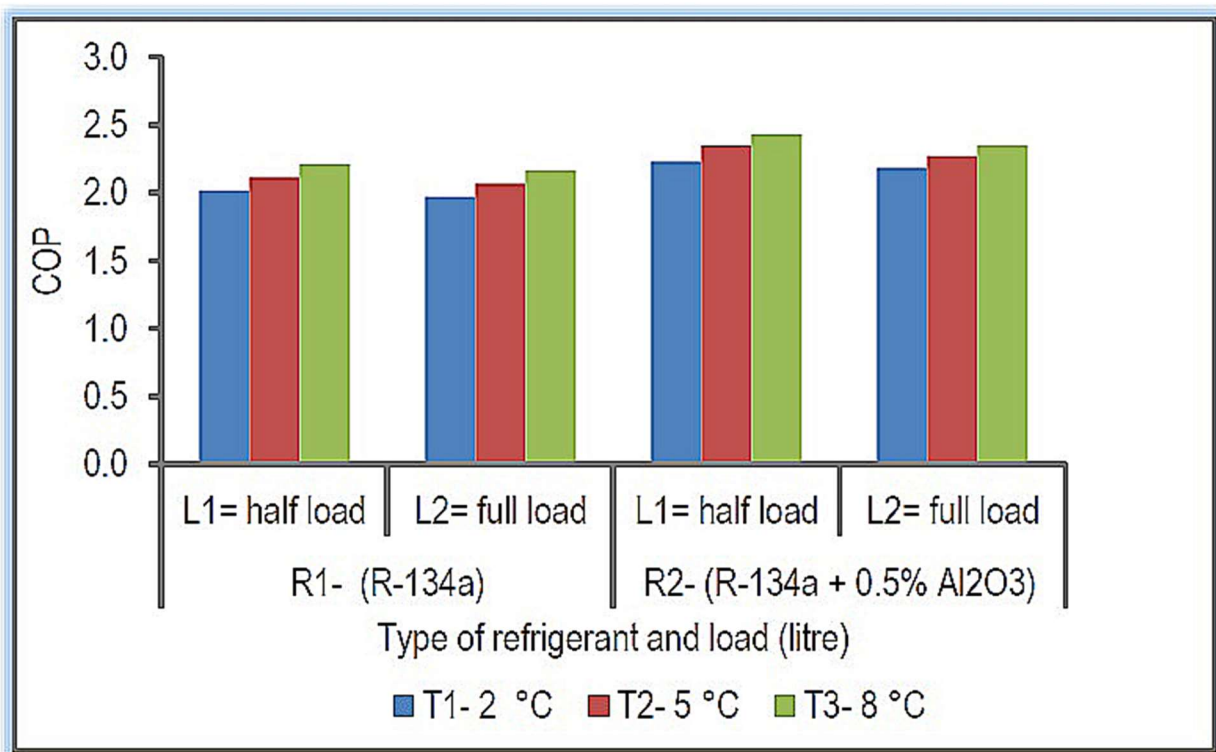


Table 6. Effect of refrigerant, load and temperature on COP of SPV powered refrigerator.

Table 6 shows that the COP also increases by using nano refrigerant (R-134a +0.5%Al₂O₃) in place of refrigerant R-134a from 2.06 to 2.27, 2.18 to 2.39, 2.26 to 2.46 and 2.01 to 2.21, 2.13 to 2.33, 2.20 to 2.41 at half load and full load condition during temperature in evaporation chamber of 2°C, 5°C and 8°C respectively.

The test carried out indicated that 900wp photovoltaic capacity and 150Ah battery bank is the least possible configuration required for this vapour compression refrigeration system. The average monthly efficiency of solar photovoltaic system varies from 14.4 to 16.3 percent for experimental duration it also supply the continuous power to the refrigerator 24 hours a day.

O. Ekren et.al [5], had conducted study to evaluate performance of PV powered refrigeration system of household refrigerator of 50 liter with DC powered hermetically sealed compressor. Its cooling capacity was 76W and the compressor of refrigerator consumes 50W in average. Several temperatures were recorded at several locations to calculate exergy analysis of the refrigerator. Also temperatures were recorded on aluminium surface of evaporator, center of inner volume of refrigerator, wall temperature of the refrigerator at outside, compressor surface temperature, PV surface temperature and environment temperature values were obtained experimentally. All temperatures are measured by insulated copper constantan (type T) thermocouples in association with 20 channel multiplexer and HP data logger.

A lead acid battery with the capacity of 80Ah was used during no sun period. It has capacity to run the refrigerator for 15 hours during night. The charge regulator maintains the power supply within the current and voltage range varied by the refrigerator and prevents overcharge of the battery. In this study 80Wp is used. As explained above, Fig. 3 shows the experimental setup.

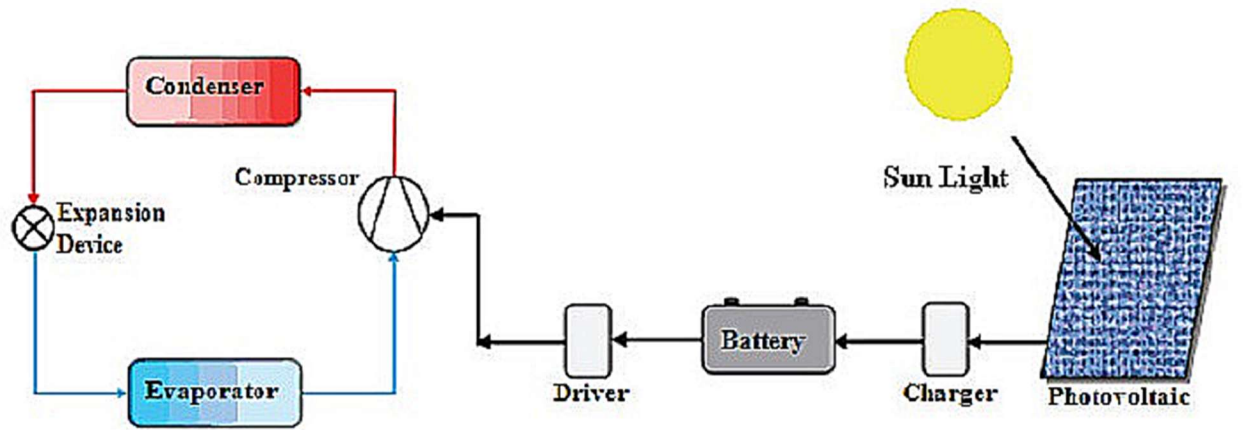


Figure 3. Experimental setup of PV powered Refrigerator

For the performance investigation, four cases are considered. The cases are determined with respect to different cooling loads including no storage (empty), low storage (10 cans), nominal storage (20 cans) and over load (30 cans) in the refrigerator. Cool down behavior has been obtained at 1°C temperature set value in the refrigerator. Compressor consumed 49.1 W, 49.51 W, 50.34 W and 52.46W in average for the no storage, low load, and nominal load and over load cases accordingly. It is observed that compressor consumes more energy than others during overloaded condition to reach set value even it seems lower. Solar radiation values on the 45° tilted surface for four experiments days in May 2009 are measured. Average energy efficiency values for PVs for the days 1, 2, 3, 4 are calculated to be 14.74%, 14.80%, 15.12% and 15.21% respectively. Average ambient and cell temperatures are measured as in Table 7.

Temperature (°C)	Day 1 No Storage	Day 2 Low Load	Day 3 Nominal Load	Day 4 Over Load
Ambient Temperature (°C)	26.9	29.19	31.05	30.34
Cell Temperature (°C)	56.89	61.61	61.89	63.64

Table 7. Average temperature and cell temperatures for the cases conducted on different days.

In this study, it is shown that a small household refrigerator with DC compressor can operate on PV powered system without any inverter. These decrease initial cost of the system since inverter is a big cost for the solar energy powered system. For performance investigation of the PV powered refrigerator with DC compressor exergy analysis carried out. According to energy analysis the highest COPR (0.670) was observed during the no storage condition. Also the compressor power consumption is low for that operation. However the highest exergetic coefficient of performance is 0.068 at low load condition.

Navneet Kumar Sharma et.al. [6], had studied on performance analysis of vapour compression and vapour absorption refrigeration units working on photovoltaic power supply with two different refrigerator units. They have conducted experiments on 50L single door appliances with solar PV panel and compared the results.

The test conditions were followed as explained below:-

1. The refrigerator and other equipment's are kept in a room.
2. The solar panel are kept on a roof of the room where there is no shade throughout the day at an angle of 30° to the horizontal facing south direction. The distance between panel and battery is minimized.
3. The thermostat position is set in such a way that when the temperature of the bottom cabinet goes down below 8°C the compressor is automatically off.
4. Without external load is kept inside the refrigerator during the experimentation. During the load condition only a water bottles was kept in the cabinet.
5. The door of the refrigerator is kept closed while tests are being performed.
6. No external heating system or cooling system was provided to the experimentation.
7. The panels are always kept dust free to take advantage of maximum possible solar insolation to generate electricity.

With this above experimental set up tests were carried out the concluded the results as

1. The temperature inside the cabinet were same irrespective of grid power supply or solar PV panel supply. In both the cases, compressor needed minimum 190V to start the compressor. In case of PV power, if battery is not charged then inverter does not allow to run the compressor.
2. Vapour compression refrigeration system required high current as up to 18A whereas vapour absorption refrigeration system required 4A.
3. VARS battery discharge rate is slower than comparison with VCRS system.
4. In VCs system, off cycles are more in comparison with absorption hence more times high value of current from battery is required consequently battery discharged quickly.
5. Keeping test condition same in both the cases, performance results shows that vapour compression refrigeration system has a very high cooling rate and more power consumption in comparison to vapour absorption system .

S. D. Deshmukh et.al. [7], had studied 25 liter refrigerator for performance evaluation of photovoltaic system designed for DC refrigerator. Considering the power requirement of its continuous operation, two 80W Solar photovoltaic panels were used to convert solar energy into electrical energy. The panel were arranged in parallel. The purpose of this arrangement was to have sufficient potential difference across 12V battery for properly charging of battery. The panel were kept on masonry structure at 35° tilt angle from horizontal facing towards south direction. A battery of 12V – 150Ah sealed lead batteries connected in parallel. Panel were connected to the battery through charge controller which has avoided the battery from complete discharge. Battery supplied DC current to refrigerator as it operates on DC current.

They conducted tests in March, April and May to evaluate solar radiation (W/m²), photovoltaic efficiency with respect to time and results were obtained as performance of photovoltaic system at no load and full load condition were carried out to assess the technical viability. This study indicated the necessity and usefulness of energetic and exergetic techniques to evaluate the performance of SPV refrigerator. The average photovoltaic conversion efficiency and exergy efficiency found nearer to 8.5% and 11% respectively in both no load and full load condition for May. This indicates that the full load condition does not affect the PV system. The photovoltaic and exergy efficiency was found less due to the module temperature hence exergy were destroyed highly in PV.

Raheem A.O [8], had studied on a comparative analysis of solar powered DC refrigerator and a conventional AC powered refrigerator to compare the current (A) and cooling effect of DC and AC refrigerator and also their reliability in terms of power supply. The comparison was done on designed 74W DC compressor powered refrigerator. A tertiary education trust fund (Tetfund) sponsored institute based research (Ibr) work 2016/2017 fund with a conventional 80W AC powered refrigerator with equal capacity and volume of items.

In this comparison the hourly current (I) of both units and the cooling effect were observed and measured using A multi meter and Lm35 was used to measure the temperature with liquid crystal display (LCD), 16x4 as a display. In experiment,

they have demonstrated the effectiveness and efficiency of using renewable energy from solar to power DC refrigerator over AC refrigerator especially in remote areas of developing countries. The DC refrigerator was running with voltage as low as 10.68V from the battery and continuously without interruption. Its temperature drop with time and corresponding current drop as low as 2.03A. Meanwhile the AC refrigerator was effective but not reliable as the voltage supply from the utility company is always low (120V and below) to power the unit the supply is epileptic. The results of this work indicates that appliances use in homes, place of works, hospital etc. can be powered directly using DC means with low power requirement. Therefore it is recommended that DC power refrigerator should be promoted in developing countries like Nigeria to improve in agro storage, SME business and clinical storage for sustainable development.

Kapil K Samar et.al. [9], had studied on thermodynamic and economic results of developed photovoltaic panels operated 20 liter refrigerator system.

They have designed solar power supply with solar PV panels of 125Wp with 3 numbers and 3 numbers of 12v DC battery with rating of 7 Ah and inverter of 1KVA with 36V input voltage. The installed system of solar photovoltaic refrigerator system is capable for cooling the vaccine for 7 hours in a day. The pull down tests indicates that 375Wp photovoltaic capacity and 21 Ah battery is least possible configuration required for this converted system. The average COP during no load and full load tests were found as 3.37. Second law efficiency of refrigerator remains close to 55% at no load, full load condition. The photovoltaic conversion efficiency and exergy efficiency found nearer to 10% and 8.5% respectively in both no load and full load condition. It shows that the product load condition does not affect the PV system. The reason for low overall efficiencies is due to both the energy conversion efficiency and exergy efficiency of the PV system is low so that it can be said that exergy are destroyed highly in PV. The payback period of proposed system was found 6 months. It is suggested that the design procedure may be improved by a variable speed compressor to cope with the variation of the refrigeration load due to different modes of operation.

Jitendra B. Satpute et.al. [10], has reviewed and understood various cooling techniques used to enhance cooling and electrical performance by using solar photovoltaic (PV) system. With the discovery of photovoltaic effect by French scientist Edmond Becquere in 1839, the first solar cell was designed by Charles Fritts with an efficiency of 1-2% in 1883. The solar module gives the best performance at specified operating conditions. As the surface temperature of PV module increases, semiconductor's properties tend to shift and thereby increasing the current and the trade off in a drop of voltage assimilating reduction in power output. Much excess temperature may damage PV module. The classification of solar energy collectors based on energy conversion as shown in below Fig 4.

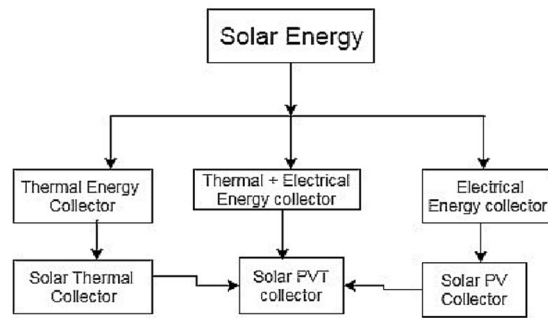


Figure 4. Classification of solar energy

During the review, T.T. Chow had performed a review on a recent advancement in PVT hybrid solar technology and conclude that the PVT has significant marketplace in coming years as per figure 5.

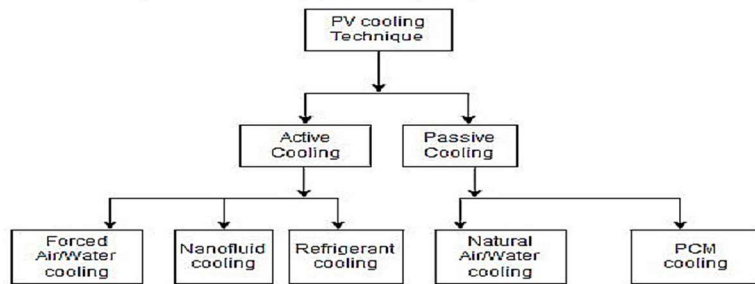


Figure 5. Experimental setup of PV powered Refrigerator Classification of PV cooling techniques

The present work describes technological advancement in cooling technologies as listed above with emphasis on design and operating parameters like different absorber configuration and flow pattern, flow rates, climatic conditions, radiation intensity, wind speed, thermal conductivity, glazing on the electrical and thermal performance of collector in the last decade.

In the conclusion it is seen that cooling of PV assists to reduce the surface temperature and results in improved electrical and thermal performance. Many comparative studies were performed and endorsed PV cooling for overall performance improvement per unit area. Performance of PVT mainly depends on the variables like incident solar radiation, wind speed, ambient temperature, and geometry of collector and heat transfer fluid. Each PV cooling technology has some merits and demerits hence it should be selected based upon climatic condition, cooling extent, budgetary constraints and end use of recovered thermal energy. Due to lower heat transfer characteristics of air and water and its effects on electrical performance; motivation has been shifted to phase change material (PCM), Nano fluid and refrigerant based cooling.

Mehmet Azmi Aktacir [11], had studied on a multipurpose PV refrigeration in this study system to investigate experimentally its daily and seasonal operating performance. Based on below schematic diagram, he has built standalone PV refrigeration system as per Fig.6

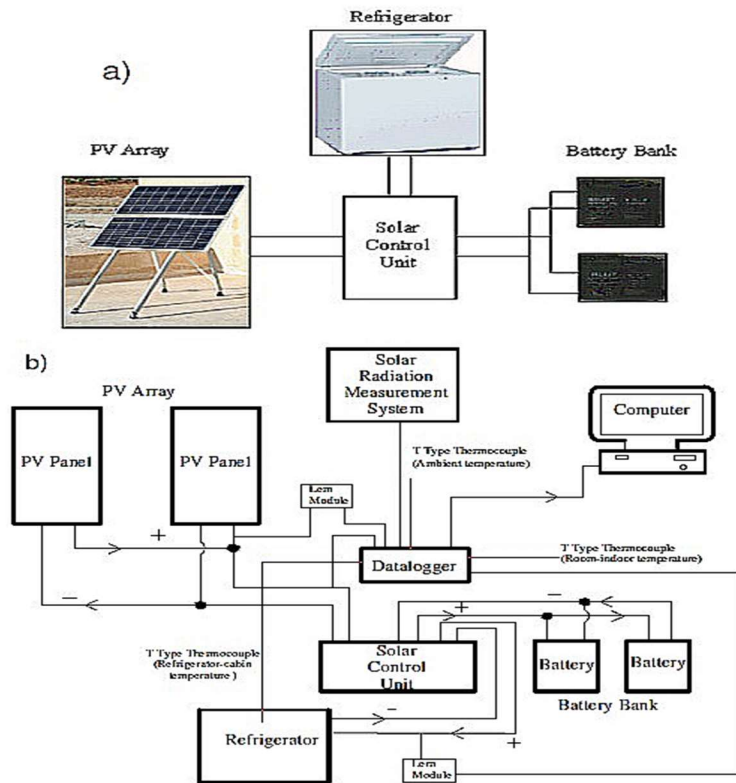


Figure 6. Schematic of the PV refrigeration system

In this study, a PV powered multipurpose refrigerator system has been established to investigate experimentally its daily and seasonal operating performance. The PV refrigerator system is independent of the local electricity available network area. Operation of this system under Sanliurfa climate conditions is continuously observed. During the daily operation of the refrigerator system, the parameters affecting the system capacity and performance were determined experimentally. The following findings were obtained from experimental study.

1. Low temperature of -10.6°C can be reached in the refrigerator while average indoor and outdoor temperature are 26.3 and 24.9°C respectively.
2. During the daily period the highest energy amount produced by PV panels is recorded between 11:00 and 14:00.
3. Under Sanliurfa local conditions for a typical hot day in May 2009, energy consumption amount of refrigerator was determined to be 347.7 Wh/day. The amount of energy stored in the battery bank is 78.2 Wh/day while the amount of electric energy produced by photovoltaic panel is 425.9 Wh/day.

- The energy required for refrigerator is provided by photovoltaic power, clean energy source. There is no negative impact of the electrical energy generated by PV panel on the environment.

It has been seen from this study that the use of PV refrigerator system is suitable for applications in different sector fields, required the low and medium cooling capacity. Such small scale standalone system can suitably be used in many rural regions where electricity is unreliable or non-existent but refrigeration is continuously critical.

Pradeep G. Bokde et.al. [12], had experimental study on design, construction and performance evaluation of solar operated dual purpose refrigerator using thermoelectric module. In this work, a portable thermoelectric refrigerator unit was fabricated and tested for cooling purpose. The refrigerator was designed based on the principle of a thermoelectric refrigeration module to create a hot side and cold side. The cold side of thermoelectric module was utilized for refrigeration purpose whereas the rejected heat from the hot side of the module was eliminated using heat sinks and fans is used for heating purpose. In order to utilize renewable energy, solar energy was integrated to power the thermoelectric refrigerator module in order to drive the refrigerator. Furthermore, solar thermoelectric refrigerator avoids any unnecessary electrical hazards and provide very environmentally friendly product. In this regard, the solar thermoelectric refrigerator does not produce chlorofluorocarbon (CFC), which is believed to cause depletion of the atmospheric ozone layer. In addition, there will not be any vibration or noise because of the difference in the mechanics of the system. In addition, the rejected heat from the solar thermoelectric refrigerator is negligible when compared to the rejected heat from the conventional refrigerator. Hence the solar thermoelectric refrigerator would be less harmful to the environmental impact. A 0.3L of water was used as refrigerated object in this tests. Experiment and analysis on the prototype was carried out mainly under sunny outdoor conditions. it was found that the system performance was strongly dependent on the intensity of the solar insulation and the temperature difference between hot and cold sides between the thermoelectric modules. The maximum temperature difference under outdoor conditions was found to be 18.23°C. The energy efficiency of the solar thermoelectric refrigerator based on the currently available material and technology, still lower than its compressor counterparts. Nevertheless, marketable solar thermoelectric refrigerator would be made with an acceptable performance through some improvements.

S.C. Kaushik [13], had studied with objective as theoretical and experimental investigation on solar photovoltaic driven thermoelectric cooler system for cold storage application. Small cold storage box of 3 liter capacity has been used for this investigation and evaluated its results in the composite climatic conditions in Delhi, India.

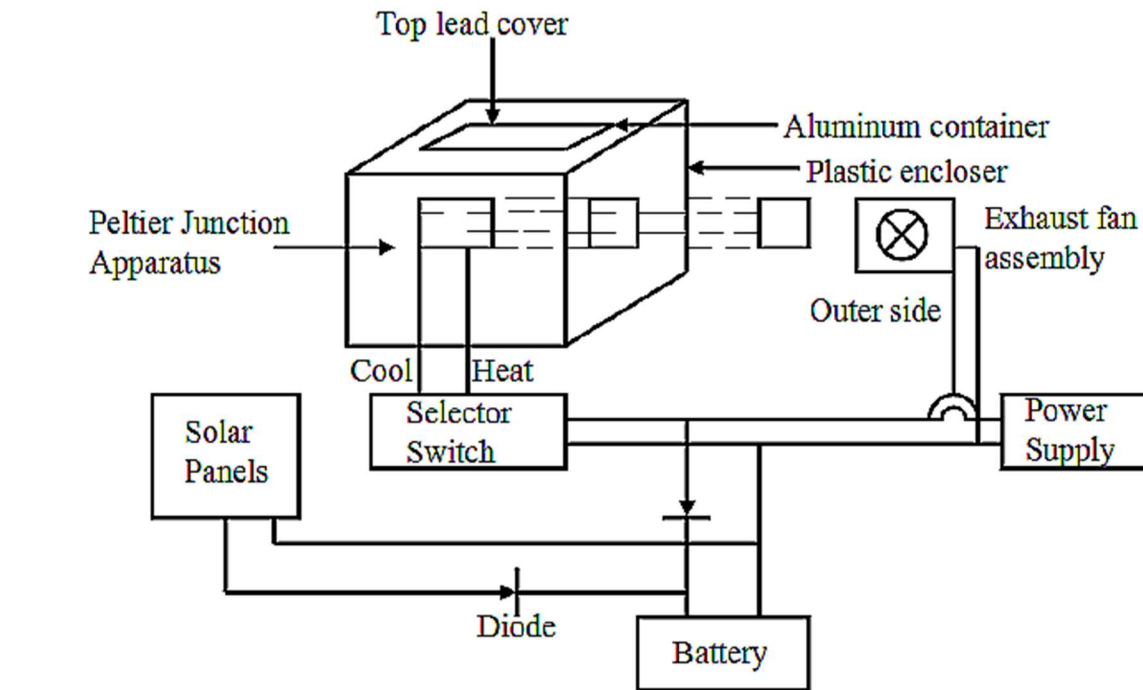


Figure 7. Schematic diagram of solar PV driven thermoelectric refrigerator system.

As per Figure 7, experimental set up made and carried out tests accordingly. Based on theoretical analysis and experimental investigations on solar thermoelectric cooler system, observations are captured as below.

1. The solar PV thermoelectric cooling system can maintain 13~16°C temperature with 500ml of water as cooling load.
2. This system can reach temperature of 15°C within 15 minutes.
3. The theoretical analysis shows that the cooling power increases with solar radiation and the energy efficiency decreases with solar radiation.
4. It is also clear that the cooling power is high during midday, when cooling power requirement is high.

This solar PV thermoelectric cooling system can be best suited for vaccine cooling, foods and milk products in remote rural areas.

It has been seen from the theoretical analysis and experimental results that the cooling power, energy efficiency and exergy efficiency are low for this system, but if the thermoelectric materials with high figure of merit is found, then these system will gain practical importance and it will become true in near future.

Sanket P. Chaudhari et.al. [14], has studied and experimented on performance analysis of solar thermoelectric refrigerator to evaluate performance analysis and change in performance when instead if single module two modules were used.

In this work, a portable solar thermoelectric refrigerator unit was fabricated and tested for the cooling purpose. The refrigerator was designed based on the principle of TEM (thermoelectric module) to create a hot and cold side. The cold side of the TEM was utilized for refrigeration purpose whereas the rejected heat from the hot side of the module was eliminated using fans and heat sink with continuous water supply to abstract the heat. Several tests were carried out by the system to determine the minimum temperature that a refrigerated object could be reached. A canned drink with 0.5 liter was used as a refrigerated object in this tests. Experiment and analysis on the system were conducted mainly under sunny outdoor conditions. It was found that the system performance was strongly dependent on the intensity of solar radiation and temperature difference of hot and cold sides between the thermoelectric modules to overcome that problem two batteries are used to store DC power so that solar radiation change could not affect the performance of the system. The maximum temperature difference under outdoor conditions was found to be 23.1°C. Experimental results of developed TER system show that the performance of the system differs when the supplied current is changed and also found that the desired temperature reaching time is reduced when more thermoelectric modules are combined. A 23.1°C temperature reduction at no load and 21.1°C at 0.5 liter water inside the refrigeration space with respect to 40°C ambient temperature in 50 minutes for 5 A current.

K. R. Ullah et.al [15], has reviewed on solar thermal refrigeration and cooling methods. In this study, they have reviewed different solar thermal refrigeration system with a specific focus on absorption refrigeration system within various working fluids. The different working pairs are illustrated by considering their coefficients of performance, specific cooling power, cooling capacity and minimum and maximum temperatures.

In summary, more countries were endeavoring to exploit renewable energy than ever before. Pollution, higher expenses and limited resources are the main obstacles to the widespread use of fossil fuels. Therefore, source of renewable energy, such as solar energy have been of considerable interest because of their promising advantages. Because of round the year availability of sunshine, solar energy can be easily captured all over the world. Though the solar photovoltaic system can provide electricity as well as refrigeration. Solar thermal refrigeration is much more efficient. Solar thermal cooling technologies are being used all over the world for industrial and home cooling purposes. These cooling systems are more applicable in remote areas or island where conventional cooling is difficult and solar energy is always available. These systems are also more suitable than conventional refrigeration system because pollution free working fluids are used as refrigerants.

This study also summarizes the different working fluids of solar absorption cooling systems and adsorption cooling system providing various results with their advantages and limitations. Though the coefficient of performance of absorption cooling system is better than that of adsorption systems, the higher temperature issues can be easily handled with solar adsorption system.

Dekui Yin et.al. [16], had reviewed of systems integrating solar PV phase change thermal storage and presented their work in Asia Pacific Solar Research Conference in 2015. They have reviewed basic solar system with PV configuration with PCM thermal storage with few research papers. Both AC and DC compressors can be utilized in solar PV refrigeration system. However AC compressor systems need a AC/DC inverter, which reduces the overall efficiency of the system. Previous research of solar PV refrigeration systems with or without battery has been reviewed. The solar PV refrigeration system with a battery can work continuously during non-sunny periods but increases the cost of the system. The PCM selected in most previous research for small refrigeration system is ice. Overall solar PV refrigeration system combined with phase change thermal storage is suitable in areas with high level of solar irradiance and it has been used in the pharmaceutical, medical and food industries.

Asmaa Ahmed M. El-Bahloul et.al. [17], had presented research paper in International conference on solar heating and cooling for building and industry on the topic of performance and sizing of solar driven dc motor vapor compression refrigerator with thermal storage in hot and remote areas. In this study, they have done an experimental investigation on performance of solar driven with direct current motor vapor compression refrigerator through indoor and outdoor tests with

and without thermal storage with and without loading is carried out in hot arid areas. The experimental setup main components are multi-crystalline Photovoltaic (PV) module, battery as a buffer for constant 12V DC and 50 liter portable refrigerator with and without PCM thermal storage. In addition, a theoretical model has established to evaluate the refrigerator performance when operated under different environmental conditions of the design point. The results show that this system can be used in remote hot arid areas for refrigeration of post-harvest crops transportation activities. It was found that single Philadelphia multi-crystalline PV panel used in this experiment fit the required cooling load needed by 50 liter DC refrigerator. For the operation of refrigerator with and without PCM, despite the higher COP in the without PCM condition, but it can be seen that when there is lack in solar energy, refrigerator begin to loss its thermal energy faster than when PCM is installed and nothing to compensate it until solar energy is available. for PCM full load condition, it could be seen that COP of refrigerator at indoor condition is higher than that of outdoor one. Also product stored in refrigerator reached required storage temperature first. This is due to the difference in surrounding ambient temperature.

S. R. Kalbande et.al. [18], had a case study on feasibility evaluation of solar refrigeration system. They have built experimental setup which consists of DC vapour compression refrigerator of 25 liter capacity. Considering the power requirement of its continuous operation two 80W SPV were used to convert solar energy into electrical energy. The panels were arranged in parallel. The purpose of this arrangement was to have sufficient potential difference across 12V battery for properly charging of battery. The above set up was able to maintain the temperature as specified by WHO for the vaccine preservation (2~8 °C). The average photovoltaic conversion efficiency and exergy efficiency of refrigerator found nearer to about 12.05% and 14.20% on full load condition in November 2015.

Abdul Hadi N. Khalifa et.al. [19], had experiment on thermal energy storage produced by solar energy for driving domestic freezer. A prototype of photovoltaic based domestic chest freezer was constructed, the prototypes incorporates Phase Change Material (PCM) as a thermal storage medium. Thereby the units can work without the aid of conventional batteries. A eutectic potassium chloride (KCl) Aqueous solution was prepared to serve as phase change material. The PCM was stored in an integrated tank inside the freezer box. Using PCM enables the freezer to preserve its cool storage at a temperature level below (-8°C) for a hold over period not less than 30 hours without the need of power supply. With the test results their conclusion and observations were as per below:-

1. Potassium chloride aqueous solution (concentration 19.5% KCl by weight) was used successfully as PCM for storage surplus current produced by PV panels in the thermal form in PCM instead of DC electricity of batteries.
2. For most experimental tests, freezer internal air temperature was kept below (-8°C) for more than (70%) of hold over periods without power supply.
3. For the 7mm and 18mm container thickness, test rig reached its steady state of storage condition in two and three days respectively, by powering the freezer on solar power for eight hours a day in summer season.

It is recommended that to replace high torque compressor that used in this work by a low starting torque compressor since PV array was unable to start compressor due to high torque of compressor the moment of starting.

Simson Pinto et.al. [20], studied on solar powered refrigeration system with cold bank. The energy requirement of the world is increasing daily and it has become difficult to meet the demand especially in the rural area where grid connectivity is unavailable. In this regard, a refrigerator was designed with sole purpose of running it with the solar power and cold bank is provided to give cooling load at night. From the testing, it has been seen that for the refrigerator of 150 liters capacity, six solar panels of 75W is sufficient to run on any ordinary sunny day. The COP of refrigerator was 1.4. It can share the load of the evaporator space and the cold thermal bank. The propylene glycol and distilled water solution in the volume ratio 20:80 can give the freezing temperature of -10°C. 10 liters of the solution can hold the cabin temperature below zero for almost 16 hours which meets our requirements. But as the load increased the time required to reach -100°C was also increased. The cooling effect of the thermal cabin can be enhanced by increasing the ratio of propylene glycol in the solution.

D. Revati et.al. [21] had experiment on enhancing the efficiency of solar cell by air cooling. The objective of this study was to investigate an effect of the temperature on the performance of the solar cell. In order to accomplish, solar panel has been tested under three different conditions such as solar panel without cooling, solar panel placed in the grass field and solar panel with air cooling. During testing, solar photovoltaic cell parameters such as open circuit voltage, short circuit current, surface temperature, panel temperature and ambient temperature have been observed. The results obtained clearly show that solar panel with air cooling has generated maximum open circuit voltage and short circuit current while comparing to others two test conditions. With intervals of 15 minutes, solar panel has been made to cool with air so as to decrease the temperature rise of the solar panel. Based on the results, it could be concluded that solar panel integrated with air cooling system is expected to achieve higher electrical efficiency owing to improved power generation.

A. Khelifa et.al. [22], had experiment on energetic study of hybrid solar PV/T collector. The hybrid solar thermal PV/T collector offer an attractive option because the absorbed solar radiation is converted into heat and electricity. The ongoing conflict is well known between temperature and photovoltaic systems by the increase in solar irradiance and thus the increase in ambient temperature, the cells becomes less efficient. For to stabilize operating temperatures the simple solution is to cool

the cell even though it requires refrigeration system power consumption, with which the overall performance is also low. A final aspect to be considered in favor of idea of combination of the collector is the reduction of initial production costs of products at the end of the installation, since many thermal elements are common in photovoltaic panels as (reinforcement, insulations, covers etc) is not required to reproduce. In addition to the photovoltaic part we get a better performance of the panel for which reasons its use does not change, with the removal of the evacuate thermal energy which is used in various other application exists such as water heating, drying, conditioning etc.

III. CONCLUSION

In this review paper, considering all previous studies and experiments, it can be concluded that solar PV panels are most useful for upcoming years due to no grid electricity availability in remote areas. At the beginning, high cost of PV panel set up but still it has potential to commercialize on mass level. Further studies can be done to improve solar PV panel overall effectiveness with lower cost.

ACKNOWLEDGMENTS

The author gratefully acknowledge the support provided by the guide and staff as well as colleagues.

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