Solar Refrigeration for Rural Household

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Abstract - Carbon-cutting and cost-saving technology has become the necessity of today's growing economies. Not only are the fossil fuels costly but these fuels also have caused enormous amount of pollution and many irreversible damages to the environment. The energy that has the highest demand is electricity. Electricity has transformed itself from being a privilege in olden days to a necessity in present day. There are many appliances that run-on electricity which have made our lives much easier. One of the most crucial out of them is the refrigerator. Its basic purpose is to preserve food by providing it a cooler temperature and an isolated atmosphere. Refrigerator runs on a refrigeration cycle mechanism and uses refrigerants as cooling agents. These refrigerants absorb the heat and give out cold. Also, the regular refrigerators are not very efficient as far as their working is considered. They consume an enormous amount of energy for their running. Hence, though refrigerators are a boon now, they could just as easily turn into a bane in the long run. But, there is a cheaper yet eco-friendly replacement for the present refrigerators i.e., the Solar Refrigerator. It is not only low in cost, but also very much efficient and eco-friendly in its nature. It is portable and can be used even in remote, rural areas where there is acute shortage of (or) no electricity at all. So, we have decided to take this up as our project in order to work on its design and make the people aware regarding its scope and benefits. In this way, we would be able solve out all the threats which our environment is currently facing.

Index Terms - Design, Solar, Refrigerator, Photovoltaic, Eco-friendly technology, Rural Areas

I. INTRODUCTION

Today, there is a need for refrigeration systems that are climate friendly, battery free and affordable. Over 2 billion people live in regions where there is inadequate electricity[1].Refrigeration of food and other perishable goods, such as vaccines and medicines, is a big challenge in off-grid areas of southern countries. Today, most off-grid refrigerators run on kerosene or diesel, causing GHG emissions and local air pollution. At the same time, solar radiation tends to be high in regions that have greater needs for cooling, thus, providing an ideal environment for solar powered cooling appliances. Solarrefrigeration technology is relatively simple. [2]The refrigerator is powered by two to three photovoltaic solar panels (total of 100-200W), which run a direct current (DC) compressor. The compressor runs the refrigerant cycle which produces an ice bank that maintains the required temperature in the cabinet. Instead of using a lead battery, which many photovoltaic refrigerators do, the Solar Refrigeration System uses thermal ice storage to cover fluctuation in sunshine and provide cold temperatures at nighttime. [3]Simply put, the lead battery is replaced by an ice battery. This avoids the use of relatively costly, intense maintenance and toxic lead batteries. A thermostat maintains the units at the required temperatures. [4]The required temperature range for vaccines is between 2°C and 8°C and has to be maintained all the time. The optimum temperature range for perishable food storage is around 3°C to 5°C; however, excursions are much less critical here. [5]In low-sun situations, the ice storage together with a reasonable insulation of the cabinet can maintain acceptable temperatures for up to 5 days.

1.2 Solar Energy:

Fig.1 shows the falling of solar radiations on the solar panel so as to accumulate charge

Solar energy is, simply, energy provided by the sun. This energy is in the form of solar radiation, which makes the production of solar electricity possible. Electricity can be produced directly from photovoltaic (PV) cells. (Photovoltaic literally means "light" and "electric") These cells are made from materials which exhibit the "photovoltaic effect" i.e. when sunshine hits the PV cell, the photons of light excite the electrons in the cell and cause them to flow, generating electricity. Solar energy produces electricity when it is in demand – during the day particularly hot days when air-conditioners drive up electricity demand. One megawatt hour of solar electricity offsets about 0.75 to 1 ton of CO_2.

1.3Solar Energy Harnessing Techniques:

- Photo voltaic system
- Concentrated solar energy system

- Solar water heating system
- Hybrid systems etc.

II. PRINCIPLE

2.1 Photovoltaic system:

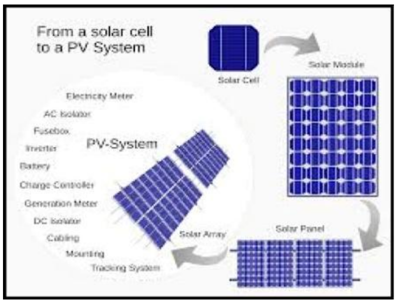

Fig.2 shows the formation of PV system by the individual solar cells

Photovoltaic (PV) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect. A typical photovoltaic system employs solar panels, each comprising a number of solar cells, which generate electrical power. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. Solar cells produce DC electricity from sunlight which can be used to power equipment or to recharge a battery. The first practical application of photovoltaics was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include Monocrystalline Silicon, Polycrystalline Silicon, Amorphous Silicon, and Copper Indium Gallium Selenide.

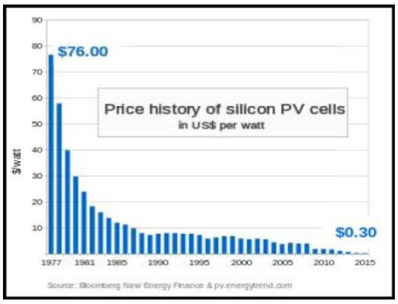

Fig.3 shows the price history of Silicon PV cells in USA per watt

Because of the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Solar cell efficiencies vary from 6% for Amorphous Silicon-based solar cells to 44.0% with multiple-junction concentrated photovoltaics. Solar cell energy conversion efficiencies for commercially available photovoltaics are around 14-22%.Crystalline silicon solar cell prices have fallen from $76.67/Watt in 1977 to an estimated $0.74/Watt in 2013. This is seen as evidence supporting Swanson's law, an observation similar to the famous Moore's Law that states that solar cell prices fall 20% for every doubling of industry capacity.

III. WORKING

3.1 Solar refrigeration:

Fig.4 shows a typical setup of a solar powered appliance

Refrigeration may be defined as lowering of temperature of an enclosed area by removing heat from that space and transferring it elsewhere. A device that performs this function by using solar energy as main source is called as a Solar Refrigerator.A Solar Refrigerator is a refrigerator which runs on energy directly provided by the sun, including photovoltaic system, for removing heat from an enclosed space for the purpose of lowering the temperature in controlled conditions. These solar refrigerators work on the principle ofVapor Compression cycle. In this, the compression energy is gained from the solar energy by using photovoltaic cells which then run a DC drive compressor.

3.2 Vapor compression cycle:

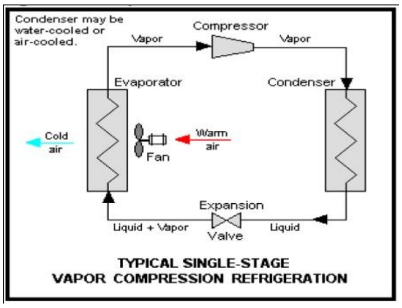

Fig.5 shows the graphical representation of a typical single stage vapor compression refrigeration

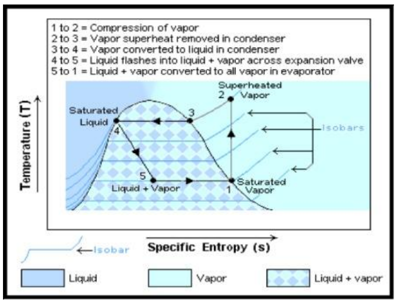

Fig.6 shows the T-S diagram for a simple vapor compression refrigerator

Vapor compression refrigeration system is process in which the refrigerant undergoes phase change, thereby providing cooling effect by absorbing heat at the evaporator and losing heat at condenser. This system has four components: a compressor, a condenser, a thermal expansion valve, and an evaporator and has interconnected discharge tubes. The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated. The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser. To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor.

IV. DESIGN ANALYSIS

4.1 Solar refrigerator design:

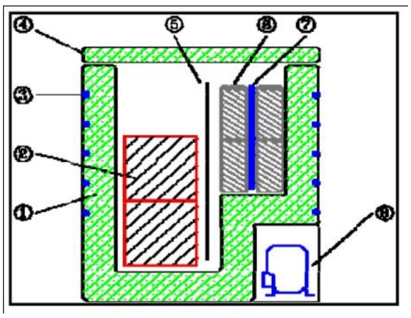

Fig.7 shows the outline of the proposed design

The design temperature interval is 0 ºC to + 8 ºC. The vaccine and food must be kept cool for four days without power, and this is the sizing criteria for the ice storage in the cooler. Those cabinets have 100 mm polyurethane insulation and are of the chest type.

1. Cabinet with 100 mm PU	5. Internal wall insulated
2. Vaccine compartment	6. Ice Storage
3. Skin Condenser	7. Evaporator, wire on tube
4. Lid	8. Compressor

The reason for choosing energy storage as ice was to avoid a lead battery for energy storage. Lead batteries tend to deteriorate, especially in hot climates, or they are misused for other purposes. This makes it necessary to install a new battery after a couple of years, and has in practice been an obstacle for the use of solar powered refrigerators. In addition to that some pollution of lead might be expected from the batteries. Instead kerosene or gas powered absorption refrigerated coolers are widely used in areas with poor or no grid electricity. Absorption coolers are used for both vaccine storage and for household applications and obviously needs regular supply of fuel. Furthermore, they are difficult to adjust, which does often result in destructive freezing of the medicine.

4.2 Compressor and control:

The prototypes were equipped with a standard direct current

Compressor and an external electronic control. A big electrical capacitor (60 mF) was used in order to overcome the start torque. Compressor is using R134a, which does not contribute to the greenhouse effect. This control has been developed to ensure that photovoltaic solar panels can be connected directly to the compressor without an external control and/or capacitor. The compressor is able to do a smooth start at low speed and is equipped with an Adaptive Energy Optimizer. By using this control, the compressor will slowly speed up from minimum to maximum speed (from 2000 to 3500 RPM). If the panels cannot give sufficient power, the compressor will stop and after a short while it will try to start again. If the start fails, the compressor will try to start again after another one minute. Once the power from the solar panels is sufficient, the compressor will start at low speed and slowly speed up again. The controller accepts a voltage between 10 and 45 Volts. The voltage from solar panels can vary, so this new feature is good for solar powered refrigerators and freezers. On a 12 V module, the compressor needs a current of about 4.5 A to start, and it can run continuously at 2 A.

Table 1: Solar refrigerator prototype specifications

Refrigerator size:	30 liters' size
Source of energy:	Sunlight i.e., solar panel of 100W*2 of photo voltaic type along with a solar charger.
Compressor used:	Reciprocating type compressor coupled with a dc motor to drive it along with a controller
Energy storage:	Energy is stored a form as ice in refrigerator to avoid the use of heavy and costly lead acid battery and avoid in pollution cause by battery and reducing hazards.
Insulation type:	Polyurethane type form along with polystyrene form to
Throttle valve used:	
Light used:	
Air circulation method:	

	prevent cooling effect. Capillary tube used of 0.6mm or 600 micro meter diameter is used of about a 2 meter length Led light used to reduce power consumption along with a battery A fan with a battery connected to maintain temp in refrigerator

Table 2: Advantages of Ice storage over Lead Battery storage

Lead battery defects	Ice storage (thermal storage)
1. Batteries are the inefficient form of storage devices.	1. Ice is simple to make.
2. They are venerable of theft.	2. It can be formed in the refrigerator itself.
3. They have less life span of about 500 cycles or 2 years.	3. It can provide cooling effect for up to 3 days in a refrigerator.
4. They are costly	4. It is cheap and can be replaced easily.
5. They are of chances of fire hazard.	

4.3 Specific energy of ice storage:

A simple calculation shows the interesting result, that the cooling capacity in the ice storage is at similar level as in a lead battery based on both volume and weight. One supplier of lead battery informs that a 50 Ah, 12 Volts battery has the weight of 13.6 kg. The dimensions are 0.24*0.175*0.175 meters. The energy content of 50 Ah can be calculated as a specific energy content of 0.159 MJ/kg or 294 MJ/m3. The cooling system will have a COP-value (coefficient of performance) of about 1.3. This will result in a specific cooling capacity of 0.206 MJ/kg or 382 MJ/m3. For the ice storage: the specific cooling capacity is identical to the melting heat of ice, which is 0.333 MJ/kg or 333 MJ/m3. The conclusion is, that the specific cooling capacity of ice is 62 % higher compared to lead battery on basis of weight and 13 % smaller compared with lead battery based on volume. In reality, the ice storage outperforms the lead-acid battery, because the allowed daily cycling is less than the nominal 50 Ah, which corresponds to 100% depth of discharge.

4.3.1 Refrigerant used:

1,1,1,2-tetrafluoroethane, R-134a, Forane 134a, Genetron 134a, Florasol 134a, Suva 134a or HFC-134a, also known as Norflurane (INN), is a Haloalkane refrigerant with thermodynamic properties similar to R-12 (dichlorodifluoromethane) but with insignificant ozone depletion potential and a somewhat lower global warming potential (1300, compared to R-12's GWP of 2400). It has the formula CH_2FCF_3 and a boiling point of −26.3 °C (−15.34 °F) at atmospheric pressure. R-134a cylinders are colored light blue. Attempts have been made at phasing out its use as a refrigerant with substances that have lower global warming potentials, such as HFO-1234yf are underway.

4.3.2 Properties:

Chemical formula:	CH_2FCF_3
Melting point:	−103.3°C (−153.9°F; 169.8 K)
Molar mass:	102.03 g/mole
Boiling point:	−26.3 °C (−15.3 °F; 246.8 K)
Appearance:	Colorless gas
Solubility in water:	0.15 wt%
Density:	0.00425 g/cm3, gas

4.4 Calculation for design of refrigerator:

$P_1 = 0.8$ bars (low pressure)

$P_2 = 7.2$ bars (high pressure)

Here values are

$h_1 = h_g = 380.45$

$S_1 = s_g = 1.7520$

Similarly, $s_1 = s_2$ as (isentropic)

$S_2' = 1.7155$

Then $C_p = 0.4059$ kJ/kg

$h_2 = h_2' + C_p*(t_2 - t_2')$

= 417 kJ/kg

Similarly, $h_3 = h_4$

$h_4 = 238.77$ kJ/kg

Let m =1

$Q_L = 380.45 - 238.77$

= 141.68 kW

Similarly

W = 37 kW

Then

Therefore, max cop is 3.8

So, cop of solar refrigerator is 2.5

By using 2.5 as cop we get W=60 kW

Therefore, the mass flow rate should be about 0.0013kg/sec

Thereby we get actual work as 80 J/sec or 0.08kJ/sec

So, we use a compressor of 100 Watts of efficiency of 0.8

So, the amount of solar panel needed is of 150 Watts

4.5 Cost estimation:

The cost of the prototype does not exceed 500 Dollars or say 30 thousand Indian Rupees

Solar panel with charger	:	10000
Compressor	:	6000
Refrigerator body	:	4000
Insulation	:	2000
Electrical connections	:	2000
Temperature measuring tools	:	2000
Miscellaneous	:	4000
Total	:	30000

V. APPLICATIONS

5.1 Practical application of solar refrigerator:

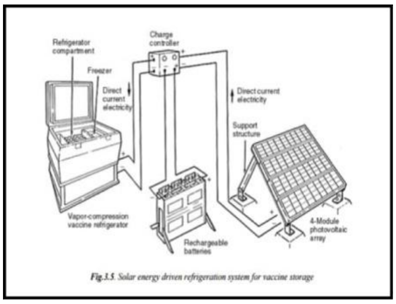

Fig.8

Fig. 9

Fig. 10

Fig. 8 Above is the prototype of a solar refrigerator along with all connections necessary to give an idea of its parts and working methods. Here a solar panel is connected through a solar charger with charged batteries while providing enough energy to compressor. To run this controller is to control the output of solar panels simple design of solar refrigerator using batteries.

Fig. 9 Use of solar refrigerator on ice vendor can be a very effective means of keeping cool all the ice-creams, they can avoid use of batteries and increase in their profit as its one-time investment.

Fig. 10 Use of solar refrigeration on military camps can be a great use as they are off grid and remote places where they need to keep their equipment's and vaccines at low temperature.

5.2 Prototype of Solar refrigerator:

Solar refrigerator prototypes have been successfully field tested over an 18-month period, in Senegal, Indonesia and Cuba. At anambient temperature of 32° Centigrade, the optimized prototypes maintained the required temperatures of 2° to 8° Centigrade under normal use, as well as a hold over temperature of 10° – 15° Centigrade for more than 3 days without any solar energy.

Getting a 50-liter-capacity fridge to a place where the road may not go is a problem no matter what refrigeration technology is used. Having to transport solar panels as well makes it no easier. However, solar panels are fairly robust, says Sanford A. Klein, a professor of engineering at the University of Wisconsin–Madison. "They are packaged in a metal framework that prevents them from being twisted or bent," he explains. "Many do have a glass surface which should be protected from sharp blows, but any reasonable type of packaging should allow them to travel."

Klein adds that solar panels should not require maintenance. "Some types slowly degrade so that their power output decreases with time, but this is not likely an issue, as this degradation is slow," he says. It may also be possible to reduce the size of the panels in the future. Klein explains, "There are high-efficiency solar cells that require less area to provide the same power, but they are considerably more expensive and likely not competitive since the size of the panel is not as important an issue as its cost."

However, other researchers are developing a light-capturing technology that could eventually provide an alternative to bulky solar panels. "Quantum dot" technology involves making a solution of particle-size semiconductors that capture light, including the infrared wavelengths currently unused by solar panels, to produce electricity. Since they can be painted onto any available surface, these solutions could turn rooftops into solar panels. "Researchers are working towards 'paint-on' solar cells that would allow efficient solar collection for a dramatically reduced cost," says Ted Sergeant, a professor of nanotechnology at the University of Toronto. "If we succeed in making solution-processed solar cells that are efficient and cheap, this could help the system vendors significantly reduce the cost of their offering."

Certainly, the solar fridge, with its projected $2,000 price tag, does not come cheap. However, explains Shendo, its zero maintenance and fuel costs should be balanced against the running costs and transport troubles of kerosene fridges. Further, the solar refrigerator is still less than half the price of solar-powered refrigerator of similar size now on the market, which cost up to $4,500, not including replacement batteries.

5.3 Scope:

1. It is assumed that solar panel prices are getting less every decade exponentially.

2. There is lot of research going on solar panels to increase efficiency.

3. Hazardous batteries are avoided.

4. It can be used in emergencies.

VI. CONCLUSION:

Solar powered refrigeration is a practical, cost efficient and simple solution to supply rural areas with necessary cooling power. It can support human health and contribute to food security by enabling users to store perishable goods in off-grid areas. However, there are further efforts needed to make solar powered refrigeration commercially available on a broader basis. There is a need for creating awareness among shareholders, political decision makers and end-users about the availability and the economic and environmental benefits of the technology.

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