PROJECT REPORT

Solar Refrigeration System, IIT Madras

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CONTENT

Problem Statement

Solar Energy can be used for refrigeration as well. IITM plans to use solar energy for refrigeration purposes, specifically for cooling portable water.

Amount of water needed to be cooled on a daily basis for drinking purposes?

- There are around 8000 students in the institute along with 1200 working staff
- Assuming each person consumes around 2.5L of drinking water a day. In which let us assume each person drinks 1L of cool water
- Then : Total total cool water consumed = 9200 persons * 1L = 9200L
- Therefore, the amount of water needed to be cooled on daily basis for drinking purposes = 9200L

The technology used for this application

1. Introduction

- As the sun is a source of abundant free energy, solar energy has vast prospects to be utilized in several areas to mitigate the energy demand of everyday life.
- Besides the conventional lighting purpose, solar energy can also be harnessed for refrigeration purposes.
- Solar refrigeration can be expected to be a new dimension in utilizing solar electricity use.
- Solar-powered refrigerators are typically used in off-the-grid locations where utility-provided AC power is not available.

2. Refrigeration working principle

- Refrigeration is a process in which work is done to move heat from one place to another, in this process heat is removed from a material or space so that its temperature is lower than that of its surroundings.
- Refrigeration involves removing heat from one region and depositing it in another. When you pass a low-temperature liquid, also called refrigerant close to objects that you want to cool, heat from those objects is transferred to the liquid, which evaporates and takes away the heat in the process.

3. Solar Refrigeration

- A solar-powered refrigerator is a refrigerator that runs on energy directly provided by the sun and may include *photovoltaic or solar thermal energy*.
- Solar-powered refrigeration system employs a PV panel, vapor compressor, thermal storage and reservoir, and electronic controls.
- The process that makes the refrigeration possible is the conversion of sunlight into DC electrical power, achieved by the PV panel.
- The DC electrical power drives the compressor to circulate refrigerant through a vapor compression refrigeration loop that extracts heat from an insulated enclosure.
- This enclosure includes the thermal reservoir and a phase change material. This material freezes as heat are extracted from the enclosure.
- This process effectively creates an "ice pack" enabling temperature maintenance inside the enclosure in the absence of sunlight.
- *Proper sizing* of the highly insulated cabinet, phase change thermal storage, variable speed compressor, and solar PV panel allow the refrigerator to stay cold all year long.

4. Photovoltaic Operated Refrigeration Cycle

- Photovoltaics (PV) involves the direct conversion of solar radiation to direct current electricity using semiconducting materials.
- In concept, the operation of a PV-powered solar refrigeration cycle is simple.
- Solar photovoltaic panels produce direct current electrical power that can be used to operate a DC motor, which is coupled to the compressor of a vapor compression refrigeration system.
- The major considerations in designing a PV-refrigeration cycle involve appropriately matching the electrical characteristics of the motor driving the compressor with the available current and voltage being produced by the PV array.
- The rate of electrical power capable of being generated by a PV system is typically provided by manufacturers of PV modules for standard rating conditions, i.e., incident solar radiation of 1,000 W/m2 (10800 W/AP) and a module temperature of 25°C (77°F).

5. Considerations made regarding the system

- The system must match the voltage imposed on the PV array to the motor characteristics and power requirements of the refrigeration cycle.
- For given operating conditions (solar radiation and module temperature), a single voltage provides maximum power output.
- Must find a compressor motor closely matched to the electric characteristics of the PV module.

Do a comparative analysis of conventional electric refrigerators & solar refrigerators. What is the better option economically? Give justification with Calculations.

- In the current situation, the energy demand is increasing with the increase in the population and improvement in the living standard. Rational use of energy brings both economic and environmental benefits, by reducing the consumption of fossil fuels, electricity, and pollutant emissions.
- The International Institute of Refrigeration in Paris has estimated that approximately 15 percent of all the electricity produced in the whole world is employed for refrigeration and air-conditioning processes. In a tropical country, like India, refrigeration is the most widely used and generally the most energy-consuming process.
- Out of the various renewable sources of energy, solar energy proves to be the best candidate for cooling because of the coincidence of the maximum cooling load with the period of greatest solar radiation input.
- Cooling from solar energy has great potential for lower running costs, greater reliability, and longer working life than other conventional cooling systems whereas it may also contribute to the reduction of global warming.
- Solar refrigerators operate continuously for years as proven by prototype units tested at various locations around the world.
- Solar refrigerators suit applications in a wide range of sizes, from portable 50-liter coolers to building-size air-cooling systems.
- Solar energy is a promising energy source that can be readily recovered and can be utilized for the purpose.
- The economic advantage of solar cooling systems results from much lower operating costs compared to conventional electric refrigerators which include the

costs of power and maintenance. Hence solar refrigerators are the better option economically.

- The standard use of AC electricity supplied by the electric utility to power a single-speed vapor compression cooling system in a moderately insulated cabinet ties refrigerators to an electric grid and limits where they can be used. This prohibits their use in off-grid applications and maintains dependence on fossil fuels for power. In contrast, the solar-powered refrigeration system developed at Johnson Space Center is environmentally friendly because it eliminates the need for an electric grid or batteries and provides enough reserve thermal storage for cooling in the absence of continual sunlight.
- Hence solar refrigerators are Environmentally friendly and harness the energy of the sun to reduce dependence on fossil fuels and eliminate the need for batteries that can be damaging to the Earth upon disposal.

1. Cost Analysis

- ### In single IITM Hostel: For Electric Water Cooler

Water Used Previously per hostel = 48 Cans
Water Can Capacity = 20-25 liters
Electric Device Used per hostel = 4 device / floor
Cost of one Electric device = Rs. 8000
Overall, the Cost of Devices in a single hostel is Rs. 1,28,000

Overall, Water used in a single hostel = 1200 liters
In general, 40 % of water needs to be cooled,
Total Cool Water in single hostel = 0.4 * 1200 liter = 480 liters
Total Hostels = 19
Overall, Total Cool Water = 9120 liters

Let, the cost of per unit electricity is 9 rupee
Power usage = 100 watts
Hours of Use per Day = 16 hours
Electricity bill per device per year = Rs. 5256
Overall, the Cost of electricity in a single hostel is Rs. 84,096

- ### In single IITM Hostel: For Solar Water Cooler

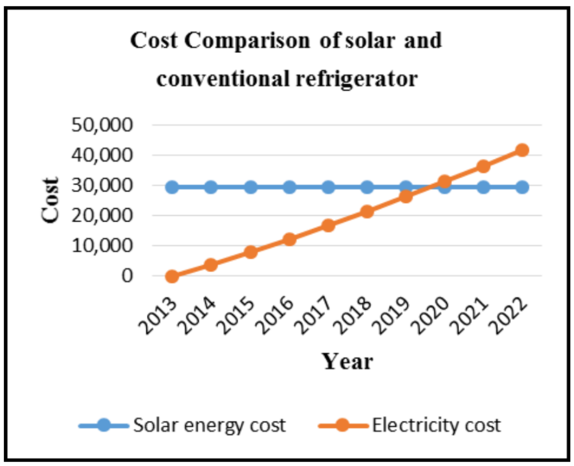
Water Used Previously per hostel = 48 Cans
Water Can Capacity = 20-25 liters

Solar Devices Used per hostel = 8
Cost of one solar device = Rs. 25000
Overall, the Cost of Devices in a single hostel = 1,25,000

Overall, Water used in a single hostel = 1200 liters
In general, 40 % of water needs to be cooled,
Total Cool Water in single hostel = 0.4 * 1200 liter = 480 liters
Total Hostels = 19 Overall, Total Cool Water = 9120 liters

Cost of installing PV Module Array for single hostel
Power Consumption per device - 100 W
Total Power Consumption - 800 W
Cost of PV Module Array/Watt - 40/watt
The total cost of installing a PV Module Array for a single hostel is Rs. 32,000

2. General Analysis



Energy and Electricity Consumption For 10 years					
Year	No. of years	Energy kWh/Year	Cumulative Energy (kWh)	Electricity Sales (Rs.)	Cumulative Electricity Sales (Rs.)
2013	Year 0	0			
2014	Year 1	700	700	3850	3850
2015	Year 2	700	1400	4200	8050
2016	Year 3	700	2100	4200	12250
2017	Year 4	700	2800	4550	16800
2018	Year 5	700	3500	4550	21350
2019	Year 6	700	4200	4900	26250
2020	Year 7	700	4900	4900	31150
2021	Year 8	700	5600	5250	36400
2022	Year 9	700	6300	5250	41650
2023	Year 10	700	7000	5600	47250

REVENUES AND EXPENSES								
	2013	2014	2015	2016	2017	2018	2019	2020
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Initial System Cost for Solar Refrigerator	29,300	Running Cost						
Running cost for Conventional Refrigerator (Rs.)		3,850	4,200	4,200	4,550	4,550	4,900	4,900
Cumulative Running Cost (Rs.)		3,850	8,050	12,250	16,800	21,350	26,250	31,150
Payback Cost (Rs.)		-25450	-21250	-17050	-12500	-7950	-3050	1850

Design a solution & give detailed steps for the implementation of the same

1. Components of the solar water cooler

The solar water cooler consists of a cooling storage water tank, a condensing wall, heat dissipation pipes, heat dissipation sheets, an upper cooling water tank, a temperature-insulating board, a lower chilled water tank, a reflux pump, an auxiliary refrigeration device, intra-connected pipes, water inlets, water outlets, and ports.

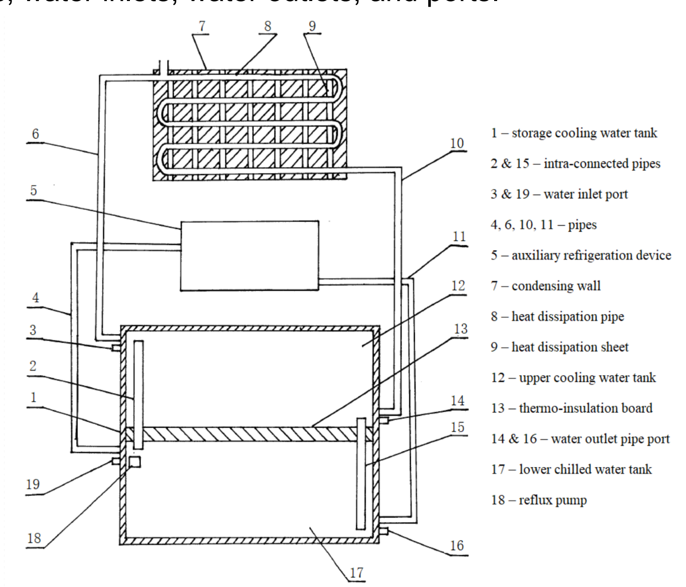


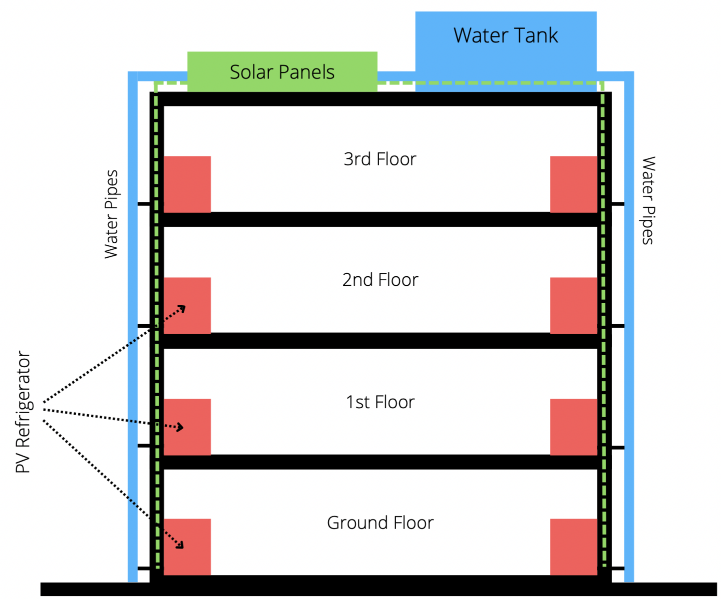
Figure 1. Components of the solar water cooler

2. Working Principle of the solar water cooler

- As shown in Figure 1, on the middle mid-section of the cooling storage water tank (1) is a temperature-insulating board (13) that divides the tank into an upper cooling water tank (12) and a lower water refrigeration tank (17); between these two tanks, there are connecting pipes (2 and 15) that connects these two tanks; inside the tank at the water inlet port of the chilled water tank, a reflux pump (18) is installed to recycle the chilled water; the condensing wall (7) is installed above the cooling storage water tank to dissipate heat, and at the water inlet of the heat dissipation pipe (8), there is an opening to the outside; between the condensing wall (7) and the chilled water tank (12), the pipe (6) connects the upper part with the upper part, and the pipe (10) connects the lower part with the lower part; above the chilled water tank (17) is installed the auxiliary refrigeration device (5) that consists of a thermopile cooling component and a temperature monitor.
- The pipes (4 and 11) connect the chilled water pipe of the auxiliary refrigeration device (5) and the chilled water tank (17).
- As the proportion of cool water is more significant than the chilled water, the water of higher temperature in the upper part of the cool water tank (12) should be pumped upwards to the condensing wall (7) for natural heat dissipation, and then flows back to the lower part of the chilled water tank. Through repeated circulation, the water temperature can be reduced to the minimum temperature of the day to obtain the chilled water that is then delivered to the refrigeration device via the water outlet (14) to chill the condenser in the refrigeration device to improve the refrigeration rate; the chilled water after being heated flows back to the upper part of the cool water tank (12) through the water inlet (3); as between the cool water tank (12) and the chilled water tank (17) are installed intra-connected pipes (2 and 15), the water temperature in the chilled water tank (15) also reduces to the minimum temperature of the day.
- If the water temperature in the chilled water tank does not meet the requirements, the temperature monitor in the auxiliary refrigeration device (5) starts the thermopile condensing component to further reduce the water temperature in the chilled water tank; in this way, the required chilled water is obtained, which absorbs heat and reduces the temperature in the pipes via the water outlet (16), and then flows automatically via the water inlet (19) or is driven by a reflux pump back to the upper part of the chilled water tank.
- Suppose the water temperature is higher than the chilled water. In that case, the chilled water flows upwards to the upper part of the chilled water tank via the pipe (2), and the chilled water in the lower part of the cool water tank flows back to the lower part of the chilled water tank via the intra-connected pipe. The storage cooling water tank consists of a liner made of stainless steel, a thermo-protective layer made of poly-foam, and a surface made of aluminum sheet.

3. Implementation of Solar water cooler in IIT Madras Hostel

- Firstly, To overcome the human labor effort to carry Water Cans to every floor which also consumes time, and Water Cans' unavailability at some locations. An overhead water tank is installed to provide a continuous water supply to the solar water cooler at each location.
- Secondly, due to a large number of people, two solar water coolers are installed on every floor.
- Line Diagram for a single hostel is shown below, similarly, the same setup can be installed at each required location.



Hostel Layout

- Line Diagram of IIT Madras Hostel where,
    - Red block → Solar Water Cooler
    - Blue block → Water Tank
    - Green block → Solar Panels
    - Green Line → connection electricity lines
    - Blue Lines → Water Pipes

How to Effectively Use the device?

- Performing condensing during the period of the minimum temperature of the day can save much electric power.
- Moreover, if the system uses electric power during the valley period, it can help achieve the goal of “balancing the peak and valley”. Using electric power during the valley period for cooling can reduce the household electricity bill by 2/3, which indicates a good social and economic efficiency