

Solar PV Refrigeration in Saharan Environment

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Abstract

The Adrar is the largest city in Algeria; predominantly an agricultural province with more than 70% of the population is living in rural areas living on agriculture. Some perishable vegetables like tomato account for about 25-30% losses, besides deterioration in quality. The climate of Adrar province, each year spreads over an important hot and dry period. Nevertheless, the storage of these products currently relies on refrigeration processes to vapor compression, a huge consumer of electrical energy. Considering that the demand for cooling increases with the intensity of solar radiation, this document presents the potential of the city of Adrar in southern Algeria to integrate the concept of sustainable development in the agricultural sector as the main alternative for transforming solar energy in cold. The case study of a storage capacity of around 3 tons of tomatoes gave an approach to calculating the GPV generator at around 27 kWh / day of electricity power. This technology considered as a promising concept for investment in the south of Algeria. This will ensure self-sustained, environment-friendly, economic development Saharan zone.

Keywords: Thermal load, Cold Room, Solar Photovoltaic; Electrical Power and Sahara Environment

1. Introduction

The use of cooling process exists in several areas among them we can find: the food industries, medicine, air conditioning, petrochemicals, etc. Cold generated on food storage is frequently achieved by applying a compression cycle of a refrigerant fluid; this methodology has provided until the present time a good price/efficiency ratio. In this cycle the refrigerant, usually a hydrocarbon compound is subject to a transformation of physical states, which leads it to transport heat from the evaporator (located in the chamber) to the condenser (located outside). It is commonly observed that refrigeration systems are responsible for a large amount of electric energy consumption in many industrial plants, which are mainly due to compressor operation. However, in the *Saharan Environment*, refrigeration for the preservation of food products, especially in summer, is often responsible for a sharp peak in electricity power consumption, which is around a third of total consumption. Considering that cooling demand increases with the intensity of solar radiation, solar cooling is considered as an alternative solution. Figure 1 summarized the different technologies that are available to deliver cooling from solar energy [1].

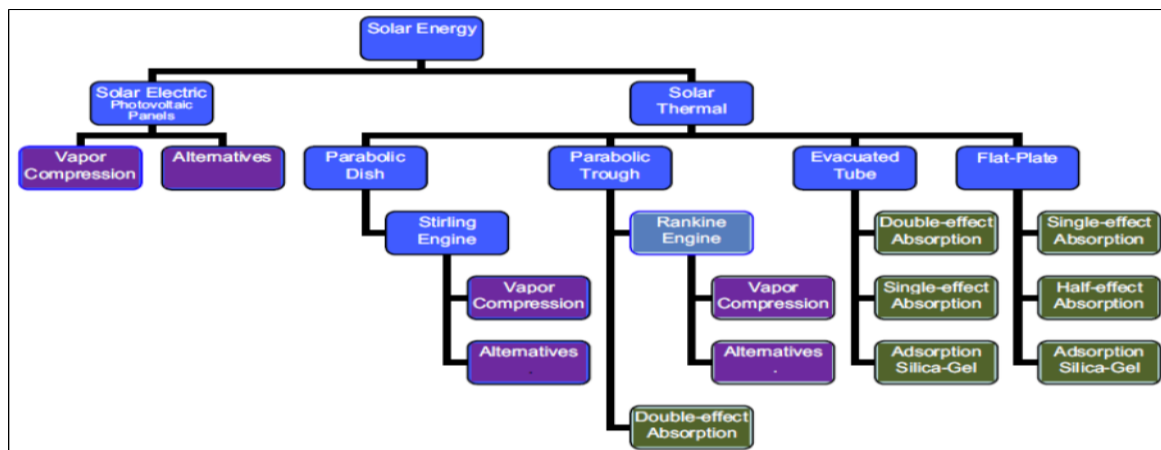


Fig.1. Alternative routes from solar energy into cooling effect using thermodynamic cycles [1].

Solar energy is therefore a very coherent energy source for covering cooling and air conditioning needs. Solar PV cooling technology is a process that produced an electric power by photovoltaic (PV) system. This energy driven to power a conventional vapor compression-refrigeration cycle. Solar PV cooling was limited by low PV efficiency and high initial investment and its application has been ignored until recent years [2-3]. Because of the sharp fall down of PV module price, the initial investment of PV air conditioner (PVAC) decreased as well, advantages of PVAC stand out among different kinds of solar cooling and more attention has been paid to PVAC. Some experimental results and practical data proved that PVAC has the merits of high performance, electricity saving, stable and reliable operation [4-

5]. A simplest way to utilize solar energy for cooling involves connecting a conventional vapor compression chiller to a PV power supply system. Individual solar cooling technologies are described below. A vapor compression chiller driven by direct current generated by PV modules is a relatively simple solution, but it requires using a battery. This limits the size and rating of such a system. As a result, this technology is used mainly in small-scale applications, often in portable devices used to store medicines or food. Figure 2 shows a schematic of a vapor compression chiller driven by electricity generated by PV modules [6].

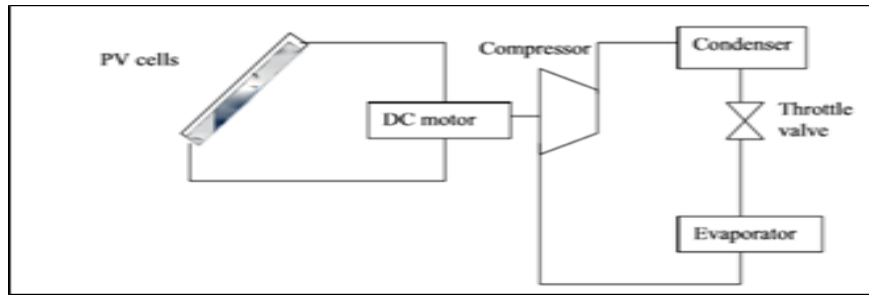


Fig. 2. Schematic of a PV-driven vapor Compression chiller [6].

This electricity is used to power a direct current motor that drives the chiller compressor. The cycle of the refrigerant is a typical cycle of a vapor compression chiller. The chiller shown in Fig.2 contains no battery. In fact, a battery with a solar charge controller may be placed between the PV modules and the motor. Such a solution enables charging the battery and consuming electricity by the compressor at the same time and enables operation of the compressor motor at steady power supply parameters. If a vapor compression chiller is an alternating current-driven design, then an inverter needs to be placed after the battery to convert direct current into alternating current. An alternating current chiller may also be powered directly from a power grid during periods when no solar radiation is available or when irradiance is too low to be effective. In this case, no battery is needed. The Adrar province is considered an advantage site over the world, which spreads each year on a large hot and dry period. This is often coincided on high solar radiation [7]. For this purpose, the case study focuses on integrating the concept of sustainable development by applying solar photovoltaic driven electricity for cooling warehouse storage located at the Saharan environment. This paper based on an analytical strategy that determines all energetic components. Moreover, an optimal sizing of GPV field driven electricity power requirements for the cooling unit preservation was conducted out.

2. Methodology

In this section, we propose an enhancement approach based on parametrical analysis to estimate energy requirements for the cold room storage, the following items are considered in the design steps of the cold storage:

- Calculate the size of the cooling system;
- Electrical energy required for the cooling system;
- Size of the solar PV field

2.1 Geographic location

In practice, Adrar town is located in the south western of the Algiers capital. This region of the Algerian desert is a part of the gigantic northern African Sahara and it characterized by a hot continental climate. This climate has only two seasons in the year: summer and winter. The winter season is short include only *December* until *March*. Nevertheless, the summer season is much too long and spread from *May* until *November*. The **July** considered as a critical month compared to others. The maximal temperature is very high and the measured ambient temperature exceeded more than 50°C .

Table 1. Data ener Mena high precision meteorological station in Adrar, Algeria [8].

Monthly average year (2014)			
Parameters	Maximum average of T_{amb} ($^{\circ}\text{C}$)	Maximum average of humidity RH (%)	Average of a global horizontal radiation GHI (kWh/m^2)
JAN	23	56	4.36
FEV	26	40	5.33
MAR	28	33	6.6
APR	34.4	22.9	7.53
May	39.8	18,6	7,91
Jun	42.5	18,5	8.09
Jul	47.9	13,0	7.48
Aug	45.9	21,6	6.96
Sept	44.0	23,1	6.13
Oct	36.5	26,6	3.99
Nov	27.5	53.3	4,2
Dec	20,7	62.7	4.26

Adrar is located in a region of very hot and dry climate at 28 ° north latitude, a longitude of -0.2 ° west and an altitude of 276m. The Adrar region has amongst the world's best production conditions for solar power: abundant sunshine, low humidity and precipitation, and plenty of unused flat land close to road networks and transmission grids. According to the data of the station [8], the maximum outside temperature of the ambient air taken for the optimization of the loads is of the order of 50°C (at the base of the hottest day of the year) and a humidity of 11% and an average daily radiation of 6.553(KWh /m² /day). For the calculation balance sheet, the July 28th, 2014 is selected as a hottest critical day.

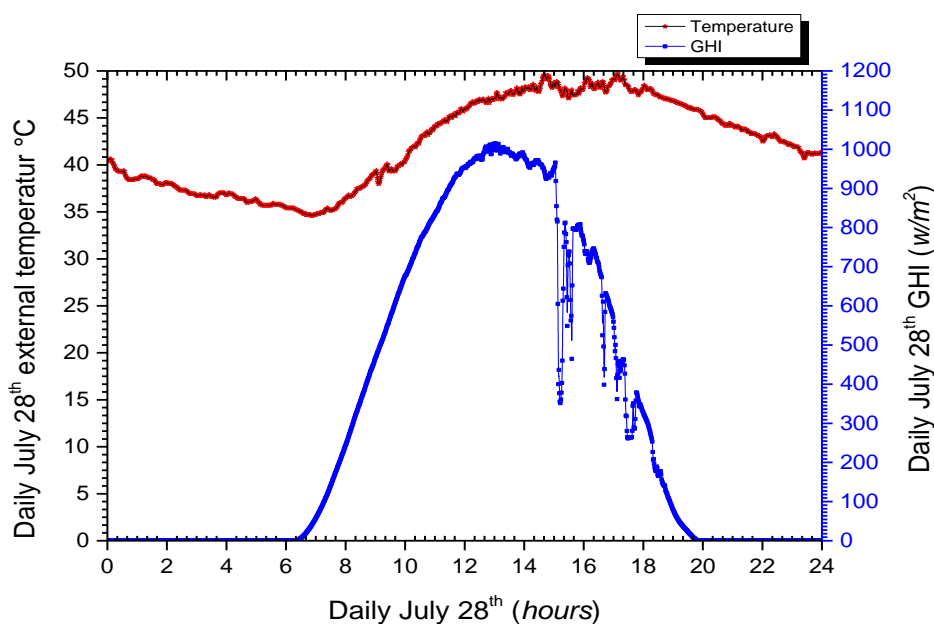


Fig.3. Summary GHI and External Temperature of Daily July^{28th} [8].

As shown in Figure. 3, the average external temperature is about 47°C and the global radiation can reach over 1013(w/m²) at 1:00. p.m. The beginning of electric power PV modules above 8:00.AM and finishing at 18: 00.PM, which mean 10 hours effective sun time.

2.1 Sizing the cooling unit system

The cold room to be tested is a modular manufacture with sandwich polyurethane panels. It is a single warehouse oriented North-South, East-West. Any refrigeration system is made up of a compressor, a condenser, an evaporator, thermostatic expansion valve, a network of pipes and finally control and regulation elements. The design unit feeding by about 3 tons tomato's product. The set temperature of preservation is about 12°C. We ended up with the sizing of the cold unit with the technical characteristics described in the table below:

Table 2: Technical sheet of the cold room

Design	Specification	
Mobile positive cold room	Inner dimension (m): L. l. H 2.00 1.5 X 2.50	Empty volume: 7.5 (m ³)
Materials Insulation	Polyurethane sandwich panels	Wall Thickness: 120 mm
Condensing group	AJ5515E compressor	Power consumption 2 CV = 1.30 KW
SECOOL evaporator	Evaporator with 02 Fans and Defrost Resistance	Cooling capacity = 3KW
Cold room accessory	Regulation kit Support frame Steel	External dimension Cold room
Voltage	Single phase	230 V- 50 Hz
Intensity	Current	7.1 A
Storage capacity	Fruits and vegetables	3 Tons
Storage temperature	tomatoes	12°C

3. Results and Discussion

3.1 Estimating Energy requirement

The sizing of the cold store allowed us to have the electrical power that the installation needs to function properly and optimally. This power is composed of: The power consumed by the fans of the evaporators, the defrosting resistance, the compressor, and by the lighting. These three electrical powers will not be consumed at the same time because the defrost resistors and the condensing unit never operate simultaneously. Thus, the maximum electrical power that the installation unit will have to absorb is of the order: $W_{(P_{installation})} = 1.7KW$

The energy absorbed by the refrigeration unit depends not only on the power required by the devices but also on the duration and frequency of use. It is expressed in watt-hours (Wh) for a given period (by day, month or year). Our food unit preservation will have to operate 16 hours per day. The daily energy absorbed expressed as based on ref [9] :

$$E_{absorbed} = W_{power;cooling\ unit} * t_{operating,max} \quad (01)$$

With the maximum time of compressor working: $t_{operating,max} = 16h$

The daily need in energy for the operation of the cold room, which is given by the formula (4). So, the maximum energy requirement estimation for our unit refrigeration is about: $E_{daily,absorbed} = 27\text{ kWh/day}$

3.2 Sizing the PV Energy Generator

Given that the maximum electrical power absorbed as well as the different voltages and intensities at the terminals of each component are obtained and also known the daily energy requirement for the operation of the cold room. We can start sizing the generating part of the photovoltaic field, it should be noted that for the sizing of solar panels, it is better to reason in energy and not in power. The table.5 summarize the photovoltaic generator driven electric energy that cold room storage needed in daily operation.

Table 3. The GPV parameters summary.

GPV Parameters description	Value
Power electric energy of the cooling unit $W_{power,absorbed}$	1.70 (kw)
Daily electrical energy requirement $E_{daily,requirement}$	27 (kWh)
Average global radiation energy of the GPV per 1meter surface consideration $H_{GPV,\beta=28^\circ}$	6.566 (kWh/m ² /day)
Nominal power at STC condition $P_{nom,mod}$	250 (wc)
Real power of the module $P_{real,mod}$	0.585(KWc/da)
Daily Produced Energy of a modules $E_{daily,mod}$	6.45 (KWc/day)
Number equivalent hours of sunshine (Duration Sunshine) N_{hours}	10 (h)
Total number of modules	8
Number of Modules in Series	8
Number of Branches in Parallel	1
Surface area of the GPV Field S_{GPV}	15 (m ²)

4. Conclusion

We are presenting the study on Solar PV based cold storage operating with a vapor compression-refrigeration cycle under hot summer conditions for the grid is unreachable or the access is expensive of Adrar province. The aimed object is to integrating this concept in cold storage under Saharan regions. The example of a study is the defy to keep tomato temperature at a set point of 12°C in July. Therefore, an optimal cold storage room design taking account of all parameters is required. The calculation methodology conducted analytically to present the energy requirement for cooling unit and the GPV field. The summarize result show for cooling capacity value of 3kw, the daily energy electric requirement about 27kwh obtained from a PV supply which estimated to connect 8 modules in series. In this, system we need inverter, charge-controller and batteries for off-grid situation. In the case of Saharan environment and for local investment development, vapor compression cycles driven by PV power solar energy appear to be the alternative solution in view with the electric consumption in hot season. The strategy on integrating GPV supply energy is less used regardless their required investments for specific applications in developing county like Algeria.

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