Conference Proceedings

EuroSun 2014
Aix-les-Bains (France), 16 - 19 Septembre 2014

Solar Refrigeration for Post-Harvest Crops Reservation: The State Of Art of the Systems

Asmaa Ahmed M. El-Bahloul[1], Ahmed Hamza H. Ali[1,2] and Shinichi Ookawara[3]

[1]Energy Resources Engineering Department, Egypt-Japan University of Science and Technology (E-JUST), P.O. Box 179, New Borg El-Arab City, Alexandria 21934, Egypt; asmaa.elbahloul@ejust.edu.eg

[2]Director; Center of Research Excellence for Energy Resources and Management, Egypt-Japan University of Science and Technology (E-JUST), P.O. Box 179, New Borg El-Arab City, Alexandria 21934, Egypt; ahmed.hamza@ejust.edu.eg

[3]Department of Chemical Engineering, Graduate School of Science & Engineering, Tokyo Institute of Technology, Tokyo 152-8552, Japan; sokawara@chemeng.titech.ac.jp

Abstract

Renewable Energy Resources is being used to provide an electrical power source through using appropriate technologies like Photovoltaic, Wind Turbine or Hybrid Technology associated with storage system to provide the needed power during the period when these renewable energy resources are not available. There are many agriculture crops that are being cultivated in Egypt reclaimed deserts areas. Therefore, to deliver such crops at high product quality, after harvest to the consumers, the transport storage environment need to be at appropriate temperature and humidity levels to maintain highest product quality to the end user. Solar energy is being utilized to be used for cooling and refrigeration. This paper presents the state of art of solar driven refrigeration systems that used for agriculture crops reservation. It concluded that solar driven vapor compression refrigeration system is the most appropriate system for this application. This due to it has higher COP than the solar thermal refrigeration systems. Moreover, its size (footprint) is smaller than other solar driven refrigeration systems as well as it could be easily transportable. The main hindrance of this its higher initial cost compared to other conventional driven refrigeration systems.

Key-words: Solar Refrigeration – Ejection – Absorption – Adsorption – Desiccant – Vapor Compression – Sterling Engine

1. Introduction

Global environmental concerns and the escalating demand for energy, coupled with steady progress in renewable energy technologies, are opening opportunities for utilization of renewable energy resources. Renewable Energy Resources is being used to provide electrical power sources through using appropriate technologies like Photovoltaic (PV), Wind Turbine or Hybrid Technology associated with storage system to provide the required power during the time when these renewable energy resources are not available. The fossil fuels are being drained, and in developing countries it represents one of heaviest load on the economic system of the countries. Unlike fossil fuel source, solar energy is considered to be the cleanest, inexhaustible and available energy among all renewable energy resources available till to date.

Egypt is located on the sun built and considered to be one of the world's richest countries with solar energy. The world's first solar thermal power plant was built in Maadi, Egypt (1912-1913) by the inventor Frank Shuman who was a pioneer in solar energy and this plant is shown in Fig. 1.a by (Phoebus, 1913). It worked successfully for almost a year, but this plant was shut down completely due to the onset of World War I and cheaper fuel prices (Kalogirou, 2009). There are many agriculture crops that are being cultivated at new reclaimed areas in Egypt deserts. In order to deliver such crops at high product quality, after harvest, to the consumers it's recommended that to control its storage and transportation environment at both appropriate temperature and humidity level to maintain highest product quality for longer time and control the development of insects and mould (Kitinoja and Kader, 2002). Moreover, in order to transport different crops in the same carriage, a transportable multi-store solar driven refrigeration system needed to be used.

doi:10.18086/eurosun.2014.07.08 Available at http://proceedings.ises.org

1. Solar Refrigeration

Solar refrigeration means when solar energy is used to produce refrigeration. It mainly consists of solar collector panel which is used to collect solar energy and refrigeration system which is used to produce refrigeration. Storage system could be added to store unrequited energy in it. Its type depends on solar refrigeration technology used. There are different technologies that are being used to obtain refrigeration from solar energy. However, the main two technologies are: (1) Solar thermal refrigeration, (2) Solar electrical refrigeration. The suitable working application for each solar refrigeration system depending on its working temperature is shown on Fig. 1.b from (Abdulateef et al., 2009).

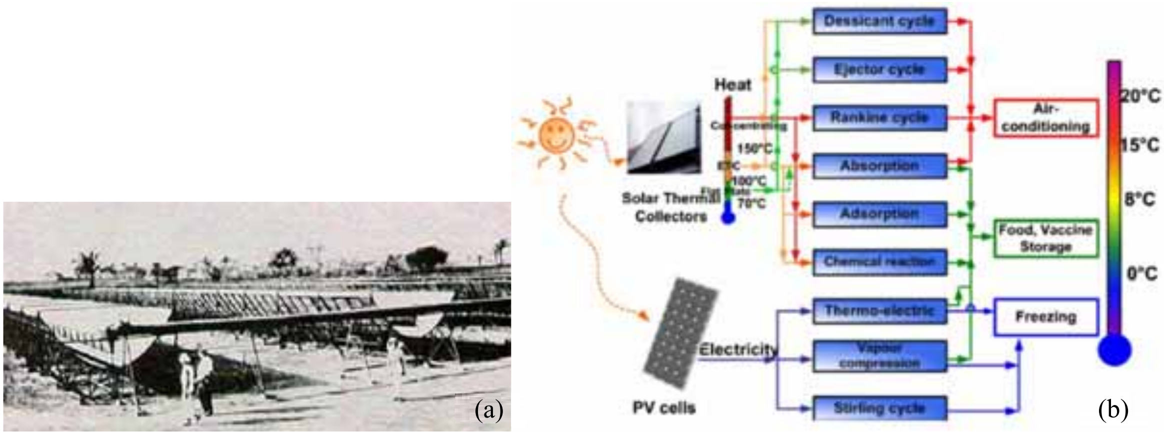

Fig. 1: (a) Frank Shuman's first solar thermal power plant in Maadi, Egypt (Phoebus, 1913), (b) Solar cooling paths (Abdulateef et al., 2009)

2.1. Solar Thermal Refrigeration Systems

Solar thermal refrigeration principle is to use solar energy in thermal form to drive a cooling machine. There are many machines utilize this principle such as Ejection chillers and Sorption chillers. The Sorption chillers are classified into Closed Sorption and Open Sorption chillers. Absorption system and Adsorption system are considered to be a closed sorption chiller. Desiccant wheels are considered to be an open sorption system (Ullah et al., 2013). In Ejection chillers, solar energy is collected by the solar collector then transfer to cooling system to generate the motive fluid for an Ejection refrigeration system. A schematic diagram of this system is shown in Fig. 2.a by (Chunnanond and Aphornratana, 2004). The ordinary refrigeration system consists of boiler and ejector which work as compressor to compress the refrigerant. Then refrigerant enter condenser to loss heat and then throttled by throttle valve then enter evaporator to cool cooling load. Solar system consisted of solar collector to collect heat and transfer it to circulated working fluid. This fluid then enter storage tank to be used when it's required. Then this fluid is circulated to boiler to heat refrigerant (Chunnanond and Aphornratana, 2004). Sorption refrigeration system uses physical or chemical attraction between pairs of substances to produce refrigeration effect (Kim and Ferreira, 2008). Absorption refers to a closed sorption system when a substance assimilates from one state into a different state. These two states create a strong attraction to make a strong solution or mixture (Ullah et al., 2013).

The schematic diagram of solar absorption system is shown in Fig. 2.b as presented by (Hassan and Mohamad, 2012). The refrigerant leaves evaporator to absorber to be absorbed and form a solution. Heat provided by solar collector is used at generator to separate the refrigerant from absorbent. This group (absorbent, pump and generator) is also used to compress the refrigerant vapor to the condenser which is used to condensate the refrigerant. The refrigerant is then expanded to the evaporator which is used to cool the load. Vapor refrigerant (heat) is then absorbed at the absorber and the cycle repeats. Solar cycle consist of solar collector to collect heat and thermal storage tank to store thermal energy to be used when solar energy is not available.

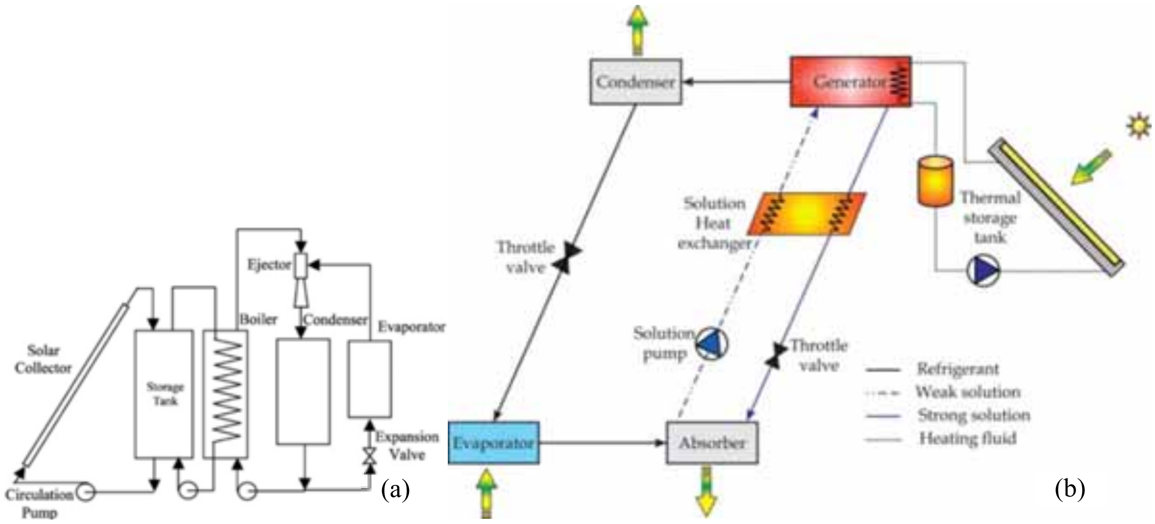

Fig. 2: (a) Solar Ejection refrigeration system (Chunnanond and Aphornratana, 2004), (b) Components of the solar absorption refrigeration system (Hassan and Mohamad, 2012)

Adsorption is considered to be a surface phenomenon as it doesn't depend on volumetric phenomenon like absorption. Adsorption involves a solid porous sorbent that attracts refrigerant molecules onto its surface and adsorbs them (Sarbu and Sebarchievici, 2013). Desiccation refers to a sorption process where a sorbent, i.e. a desiccant, absorbs moisture from humid air. This process is employed in open sorption cycles, which are classified into either liquid or solid desiccant cycles depending on the phase of the desiccant used. The schematic diagram of solar liquid desiccation system is shown in Fig. 3 as presented by (Kim and Ferreira, 2008). The liquid desiccant circulates between an absorber and a regenerator in the same way as in an absorption system. Main difference is that the equilibrium temperature of a liquid desiccant is determined not by the total pressure but by the partial pressure of water in the humid air to which the solution is exposed to. A concentrated solution is sprayed at point A over the cooling coil at point B while ambient or return air at point 1 is blown across the stream. The solution absorbs moisture from the air and it's simultaneously cooled down by the cooling coil. The results of this process are the cool dry air at point 2 and the diluted solution at point C (Kim and Ferreira, 2008).

For Ejection refrigeration systems, Guo and Shen (2009), investigated the performance of a solar-driven ejector refrigeration system using R134a as refrigerant. This system was applied to an office air conditioning in Shanghai, China on July with cooling capacity of 6kW. The operating conditions were: generator temperature of 85°C, evaporator temperature of 8°C and condenser temperature varying with ambient temperature. They concluded that their system could meet the cooling load of the office building. Its average COP from 9:00 to 17:00 was about 0.48 on a typical clear sky days. The average COP of the system at the remaining day time was between 0.43-0.53, except at 17:00, when it drops as low as 0.29. Also this system conserves more than 75% of electric energy when it is used to supply air conditioning during daytime for office buildings. COP is still considered to be too low.

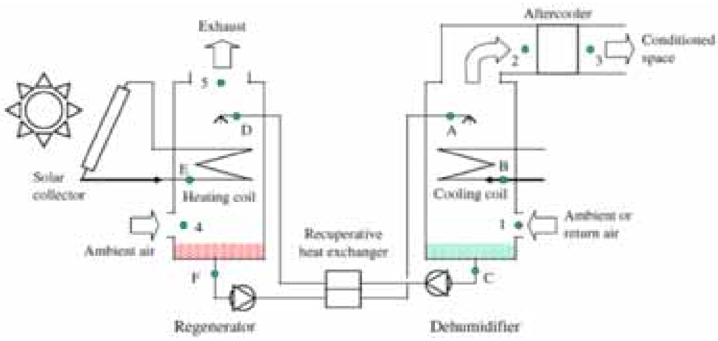

Fig. 3: A liquid desiccant cooling system with solar collector (Kim and Ferreira, 2008)

Yen et al. (2013), performed analytical study on variable throttle ejector at solar vapor ejector refrigeration system. They used commercial CFD package, FLUENT 6.3 to analyze the performance of the system. Cooling capacity of the system was 10.5kW with R245fa as refrigerant. Operating condition of the system was generation temperature between 90°C and 110°C, condenser temperature exceeded 35°C and evaporator temperature between 12°C and 20°C. They concluded that an ejector with a greater throat area and larger solar collector allows a wider operating range of generator temperatures, but may be overdesigned and expensive. But by decreasing the throat area the operating range of the generator temperature was limited, and the resulting system may be unable to use solar energy as a heat source. They also presented a regressive equation that relates the optimum throat area ratio to the operating conditions temperature ranges. Their system work properly when its operating condition was achieved.

For Sorption refrigeration systems, Afshar et al. (2012) reviewed application of solar refrigeration systems focusing on solar adsorption, solar desiccant cooling and solar absorption refrigeration systems. They also showed the thermodynamic analysis and COP calculating equations for each system. They didn't discuss the different types of solar desiccant cooling system. Also they should have carried out a modeling analysis as they showed a thermodynamic analysis. Sarbu and Sebarchievici (2013) reviewed different solar refrigeration and cooling technologies. They concluded that for open sorption system, liquid desiccant system had a higher COP than the solid desiccant system. For closed sorption system, adsorption cooling system has lower COP than absorption system but it need lower heat source temperatures than the absorption cooling. The ejector system has a higher thermal COP but it require a higher heat source temperature than other systems. They also were not concerned about PV solar cooling systems. Fadar et al. (2009), carried out a numerical study adsorption refrigeration system consisting of two adsorbent beds and powered by parabolic trough solar collector (PTC) on July at Tetouan, Morocco. Adsorbent was activated carbon and refrigerant was ammonia. They designed a FORTRAN program to simulate the behavior of the adsorption cooling system. Under the climatic conditions of daily solar radiation being about 14MJ per $0.8m^2$ ($17.5MJ/m^2$) and operating conditions of evaporating temperature was 0°C, condensing temperature of 30°C and heat source temperature of 100°C. The results indicate that the system could achieve a specific cooling power of the order of 104W/kg, a refrigeration cycle COP of 0.43, and it could produce a daily useful cooling of 2515kJ per $0.8m^2$ of collector area, while its gross solar COP could reach 0.18. They didn't give detailed specifications and capacities of each instrument used. Ozgoren et al. (2012), investigated the performance of a solar absorption refrigeration system with evacuated tube collector and ammonia-water solution at Adana province in Turkey on July 29. The system consisted of solar system consisted of evacuated tube collector which work at about 45°C and pump to circulate working fluid. Outlet temperature of ammonia from generator was assumed to be 110°C and evaporation temperature was taken as 10°C. The cooling capacity of the system was taken as 2.5, 3, 3.5 and 4kW to cover daily variation of heat gain with a corresponding condenser capacity of 3.02, 3.62, 4.23 and 4.83kW. They concluded that $COP_{cooling}$ varies in the range of 0.243 to 0.454 while that of the heating $COP_{heating}$ changes from 1.243 to 1.454 during the day. COP values depend on generator temperature as when it decreases COP decrease especially when it's lower than 1100°C. Evacuated tube collector area for cooling load capacity of 2.5, 3, 3.5 and 4kW was found to be 25.68, 30.82, 35.95 and $41.09m^2$ respectively. They determined both cooling load and heating load for the same day. They didn't mention when their system could work properly.

2.2. Solar Electrical Refrigeration Systems

Solar electrical refrigeration principle is to convert solar energy into electrical energy that is used to drive the refrigeration system. The refrigeration system could be vapor compression refrigeration system or sterling refrigeration system. Vapor compression refrigeration system is the widely used due to its higher COP. The schematic diagram of vapor compression refrigeration system is shown in Fig. 4.a as presented by (Kim and Ferreira, 2008). It consists of solar PV panel which convert solar energy into electrical energy (DC). This electrical energy is then used to drive DC compressor which compress the refrigerant to condenser. This condenser is used to cool the refrigerant. The refrigerant is then throttled through throttle valve into evaporator to cool the load. Then refrigerant is circulated back to compressor and cycle repeats.

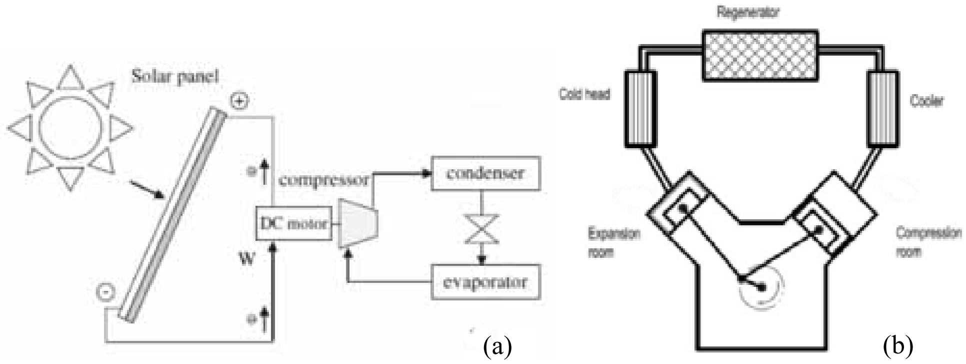

Fig. 4: (a) Schematic diagram of a solar electric compression air conditioner (Kim and Ferreira, 2008), (b) Schematics of the Sterling cycle refrigerator (Le'an et al., 2009)

Sterling refrigeration system basic principle is cyclic compression and expansion of air or other gas in a piston cylinder arrangement that is compressed in the colder portion of the cylinder and expanded in the hotter portion of the cylinder. The schematic diagram of Sterling refrigeration system is shown in Fig. 4.b as presented by (Le'an et al., 2009). System of pistons and displacers is used to move the working fluid between volume spaces with a regenerator used for thermal energy storage. The gas absorbs thermal energy from the environment during the isothermal expansion and releases heat to the environment during the isothermal compression process. Sterling cycle cooler designs are categorized as kinematic machines, where the piston and displacer are mechanically linked to the drive shaft, or free-piston machines, where the piston is coupled to the power supply by an AC linear motor and the displacer motion is driven by the gas pressure fluctuation in the system. The cooling capacity is determined by the piston amplitude, which is proportional to the voltage applied to the linear motor (Le'an et al., 2009; Hermes and Barbosa, 2012; Tassou et al., 2010). It has COP close to vapor compression systems, and performs better than vapor compression cycles if the temperature difference increases between sink and source. Moreover it can provide very low temperatures as 10K (Kalkan et al., 2012).

For solar driven vapor compression refrigeration systems, Axaopoulos and Theodoridis (2009), designed and experimentally tested a solar PV battery-less powered ice-maker prototype unit which could be used as a refrigerator on 2006 and 2007 at the Technological Educational Institute of Athens, Athens, Greece. They used a 4 DC variable speed compressor, 440W_p PV arrays, controller to connect between compressor and an ice storage tank to store energy in. They used ice storage tank to avoid the need for batteries which are responsible for a significant portion of the capital cost and much of the maintenance cost. Also storage tank had the advantage of being small as its size was smaller by about 14-21% compared to a chilled water store, and 40-48% compared to stores with eutectic salts. Its volume was about 175l and insulated with polystyrene. A PC-based automatic data acquisition unit was used to evaluate the performance of ice-making system. The system operated daily and the ice produced was weighed at the end of the day. They concluded that solar-to-compressor power efficiency was about 9.2% resulting from providing easy compressor startups, enabling operation at as low as 150W/m^2 of solar irradiance, accurate maximum power tracking and efficient power management. Also the system was capable of producing around 4.5 kg of ice at only 3kWh/m^2/ day and up to 17kg at about 7.3kWh/m^2/ day. They carry out their experimental study for only 2 days one at fall and other on spring. This system was not tested for heavy load on summer.

For compressor, Ekren et al. (2013), performed experimental analysis on a variable speed DC compressor used in a 79l refrigerator with refrigerant R134a. The speed of DC compressor was controlled by the cabinet temperature. Therefore they used a resistance circuit to change the speed of the DC compressor with minimum speed of 2000rpm and maximum speed of 3500rpm. They used Python software to construct the control algorithm for the system. They carried out the experimental analysis at four different constant speed operation modes and ON and ON/OFF operation modes. They concluded that variable speed operation of the DC compressor could be much more efficient than constant speed operation of the DC compressors, especially at higher speeds. According to the analysis, variable speed operation of the DC compressor provided higher COP (0.380) and exergy efficiency (7.4%) than the constant speed operation at 2500, 3000 and 3500rpm but at 2000rpm it had higher COP and exergy efficiency than variable speed condition but required temperature was reached faster at variable speed condition. This was related to lower power consumption at the same cooling capacity. He should have used a much accurate system rather than resistance circuit as it can break down due to rapid change in load also it might not handle the load.

Relative humidity (RH) has a big effect on the crop; as each crop has its own RH storage condition. Sobrinho and Tuna (2013), performed an experimental analysis to evaluate the influence of air RH on the COP of a small air conditioning system using refrigerant R-22. They used laboratory (LAMOTRIZ) test bench at Sao Paulo, Brazil to perform their experiment. It consisted of scroll compressor with capacity of 7700W, condensing unit with capacity of 7034.4W, evaporator unit with capacity of 7034.4W and expansion valve. They used InduSoft software to control the supervisory system of the test bench and CATT3 (Computer Aided Thermodynamic) software to obtain the values of specific enthalpy and specific volume of measured data. They concluded that the cooling capacity depended mainly on the dry bulb temperature of ambient air and the air flow through the condenser, as cooling capacity decreased with the increase of the evaporation temperature and the condensing temperature increased with the increasing of the ambient temperature. Also RH had influence on the heat transfer coefficient responsible for the performance of the system and the amount of heat removed from the airflow passing through the evaporator and when RH was in range between 40-65% it did not have large variations in on COP. Therefore when RH was much higher from these values, COP had to be modified.

Speaking of PV panel systems, Parida et al. (2011) and Tiwari et al. (2011), reviewed and discussed different PV technologies including PV power generation, Hybrid PV generation, various light absorbing materials, environmental aspects, storage systems, performance and reliability of PV system, sizing, distribution, control and applications. For thin film technology Amorphous silicon, it had cell efficiencies ranged of 5-7% and for double- and triple-junction designs, efficiency was about 8-10% and commercially available multi-crystalline silicon solar cells had an efficiency around 14-19% and widely used storing electricity is electrochemical battery storage. But Tiwari et al. (2011) were also concerned about PV thermal (PVT) technology which was adding a conventional solar thermal system to PV module. Therefore PV module was used to generate electricity and solar thermal system was used to produce thermal energy. They carried out numerical model analysis and qualitative evaluation of thermal and electrical output in terms of an overall thermal energy and exergy. From the energy payback time and energy production factor point of view, the Copper-Indium-Gallium-Diselenide solar cells in the building integrated PV thermal (BIPVT) system was the most suitable while from the life cycle conversion efficiency point of view the use of mono-crystalline solar cells in the BIPVT system was the most suitable.

For Sterling refrigeration systems, Hermes and Barbos (2012), compared and tested the thermodynamic performance of four small-capacity portable coolers in Brazil. They employ sterling and vapor compression technologies. Tests were carried out at two different ambient temperatures 21 and 32°C using a climatized chamber. They concluded that for the same input conditions that sterling system cooling capacity was 18.1W at 21°C and 23W at 32°C and power consumption was 18.3W at 21°C and 30.5W at 32°C. For vapor compression system, cooling capacity was 20.4W at 21°C and 24.3W at 32°C and power consumption was 25.7W at 21°C and 32.9W at 32°C. For overall thermodynamic efficiencies, the sterling and the reciprocating vapor compression refrigeration systems presented similar efficiencies about 14%. They didn't give the capacities of each component of each system.

2.3. Solar Thermal vs. Solar Electrical Refrigeration Systems

There were a lot of researchers who were concerned about performance of solar thermal vs. solar electrical refrigeration systems. Thermal systems represent smaller ozone depletion potential and smaller contribution to greenhouse effects than electrically operated refrigeration plants which uses synthetic refrigerants.

Kim and Ferreira (2008), illustrate different solar thermal and electrical cooling systems available from the energy efficiency and economic feasibility point of view. For solar electrical cooling systems, their main system was vapor compression refrigeration system. They cited that its COP ranged from 1.1 to 3.3 at evaporator temperatures between -5 and 15°C and condenser temperatures between 45 and 61°C. When Monocrystalline PV modules with 10% efficiency and variable-speed compressors were used with batteries, the overall efficiency was about 30% when COP was 3. Also they illustrated Sterling refrigerator and concluded that its COP was lower than that of vapor compression refrigerator for the same input. For solar thermal cooling systems, they performed a comparison between thermo-mechanical, absorption, adsorption and desiccant solutions systems by assuming constant solar energy input. They summarized their work in Fig. 5 by assuming constant input of 1000W for all solar refrigeration systems. The three last columns indicated the specific cost of PV solar panels, thermal solar collectors plus engine and the specific chiller cost. They concluded that Solar thermal with single-effect absorption system had highest performance and lowest required investments per $kW_{cooling}$ followed by the solar thermal with single-effect adsorption system and by the solar thermal with double-effect absorption system, also they compared absorption and adsorption in terms of performance they concluded that adsorption chillers were more expensive and bulkier than absorption chillers and the total cost of a single-effect LiBr-water absorption system was the lowest.

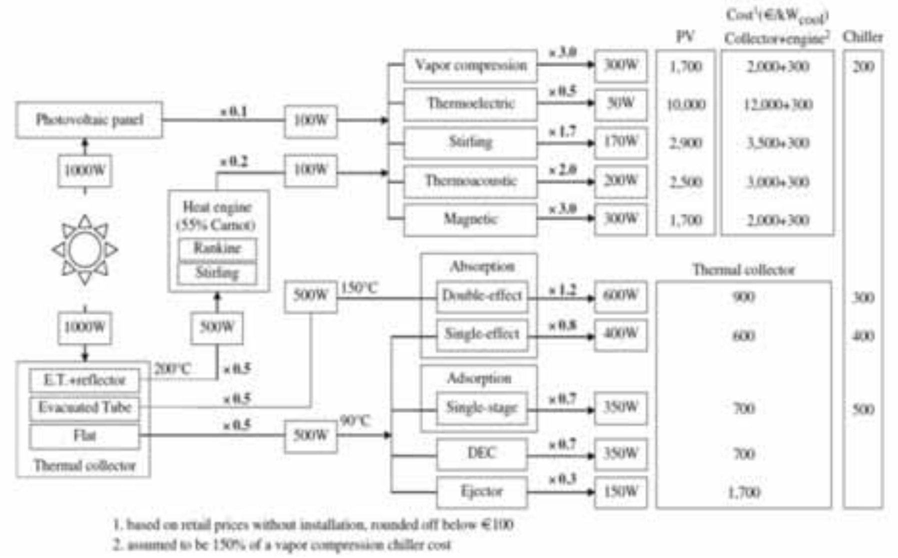

Fig. 5: Performance and cost of various solar refrigeration systems (Kim and Ferreira, 2008)

Also they concluded that solar electric and thermo-mechanical systems were more expensive than thermal sorption systems. The resulted cost shown in Fig. 5 would have been changed by now due to improvement in these technologies. Mekhilef et al. (2013), illustrated new and feasible technologies of solar energy applications in the agricultural sectors. They discussed the important of lowering storing temperatures of grain to prevent invasion of insect and growing mold. Also it had a great effect on the time of storage. They compared different technologies in the solar cooling systems; they concluded that desiccant dehumidification was more efficient in controlling its humidity than the other technologies and solar desiccant dehumidification system could be a suitable alternative when a large ventilation or dehumidification was required. For PV refrigeration system they cited that to made the system functional for some application, the problem of varying of the rate of producing electricity with time can be solved by adding devices such as electric battery, mixed use of solar-grid-electricity or a compressor with variable-capacity. Also the price of a solar PV panel was consider high when compared to other solar cooling systems but they informed that PV systems and/or solar thermal system would be the suitable option for remote areas. They just gave a brief description for each system they discussed.

Hartmann et al. (2011), presented an analytically comparison between solar thermal and solar electric cooling and heating for small office building exposed to two different European climates (Freiburg and Madrid) with a floor area of $309.9m^2$. They carried out the analytical study by using a compression chiller as a reference system which is assumed to cover the load, solar electric cooling system on a PV-driven compression chiller and a solar thermal system on an absorption chiller. The total cooling demand was 10818kWh/a in Freiburg and 16478kWh/a in Madrid and total heat demand was 19337kWh/a in Freiburg and 7288kWh/a in Madrid. The simulation resulted that PV module area was smaller five times the scale of the thermal collector area. They concluded that for large collector areas, up to 40% (Freiburg) and 60% (Madrid) of primary energy could be saved with the solar thermal system as well as with the solar electrical system. The collector area of the solar thermal system had to be more than six times larger than the corresponding solar electrical collector to achieve the same amount of saved primary energy. For their study, solar electric system was found to be the applicable solution as the solar thermal system had larger planning and system cost and cost of the adsorption chiller was higher. Their study was done on only small office building. They didn't mention if this system could be applicable for larger scale building.

Also Otanica et al. (2012), performed an analytical study on both solar electrical cooling system and solar thermal cooling system of 17.58kW cooling focusing on economic and environmental comparison between solar-thermal-driven and solar-PV-driven air conditioning technology. They concluded that for solar electrical driven cooling system, it had much higher COP and a lower PV footprint that ranged between 24 to 48m^2 but it had highest cost depending on required COP impact. For vapor compression refrigeration system with a COP of 3 its cost was considered to be about $3501 and for a COP of 6 cost would be three times. For solar thermal driven cooling system, they cited that its PV area footprint ranged between 78 and 106m^2 in 2010 and they assumed that cost was constant over the time for different thermal unit used in the analysis, but cost of solar collection was much lower as a percentage of overall cost. Also they discussed the environmental impact of using refrigerant R-22 as its global warming potential (GWP) was about 18g CO_2/kW h of cooling and Refrigerant like R-410A had lower ozone impact but similar GWP and would not have a drastic result on the projected equivalent carbon dioxide release over the life of the system. They were only concerned about cost and area footprint. In another words they didn't show how to improve these systems.

Lazzarin (2014), performed an analytical study between PV driven compression chiller and solar thermal driven sorption chiller with respect to overall system efficiency and its investment cost. He concluded that to produce 1kWh cooling, PV driven compression chiller efficiency was about 12% but its COP was much higher (4 for the water cooled and 3 for the air cooled chillers) and the specific required area was about 0.27 and 0.36 m^2/kWh.day respectively for water and air cooled. For the same 1kWh cooling as product, the specific required area for ETC (Evacuated Tube Collectors) driven double effect chillers was about 0.24 m^2/kWh, ETC single effect was about 0.29m^2/kWh and PTC double effect was about 0.33m^2/kWh. Also he showed an evaluation for investment cost for a daily production of 10kWh$_{cooling}$ for the PV and solar thermal system and found that it was between 1900 and 2200 € per 10kWh$_{cooling}$ /day with the cost of PV systems just in the middle of the thermal technologies. He cited that PV driven system was considered too expensive with respect to the solar thermal in the past, now it is quite comparable if the system was air cooled. These numbers are considered to be changed when these systems applied experimentally.

2. Storage Systems

The storage systems are being used to store solar energy to be used when there is a lack of it. It has the advantage of minimizing the high cost of solar refrigeration system by doing load management. Toledo et al. (2010), reviewed different energy storage system and their redistribution for PV system. They cited that sodium-sulfur batteries were one of the best options for PV system. Its energy density was about three to five times that of lead-acid battery. Also it had long useful life, high efficiency in relation to other batteries and it require minimal space for installation but one of its biggest problems was its cost. They only discussed batteries as energy storage system; they didn't give any other option that could be used. Li et al. (2012), illustrated different cold storage systems used for air conditioning application. They are classified according to the type of storage media and the way it's used like water storage, ice storage, phase change material (PCM) storage and sorption storage systems. They concluded that for water storage and static ice storage systems, they still need further study cause of efficiency and reliability of a water or aqueous solution converting to ice crystals or ice slurry. For PCM storage, salt hydrates had serious issues of phase separation, super cooling, and corrosion. Paraffin waxes and fatty acids were mostly chemically inert, stable and recyclable, exhibit little or no super cooling and they show no phase separation or non-corrosive behavior but they had the shortcomings of low thermal conductivity and high flammability. For sorption storage system, they concluded that the suitable and efficient working pair was water and solid/gas reaction used as the refrigerant and sorbent. They didn't mention the suitable cooling system that each cold storage system could be applicable.

Kaldellis et al. (2009), illustrated analytically different types of energy storage systems like Pumped hydro storage (PHS), Compressed air energy storage (CAES), Flywheels energy storage (FES), Battery energy storage (BES), Flow batteries (FB), Fuel cells (FC). They carried out electricity generation cost analysis applied to four Aegean Archipelago Islands. They concluded that sodium-sulfur batteries might be thought as suitable for very small island cases with a peak load demand up to 600kW. For small (peak load demand up to 5MW) and medium (peak load demand up to 35MW) sized islands PHS was found to be slightly better than sodium-sulfur batteries for a given autonomy period of 12h, while they present a clear advantage in the case of 24h. they were only concerned about producing electricity to be used at homes.

3. Conclusion

This study presented the state of art of solar driven refrigeration systems that is used for agriculture crops reservation. Throughout the open literature discussed above, it's found that Solar PV driven vapor compression refrigeration system has advantages of: suitable for remote areas, have a relativity higher COP, lower PV area footprint, can work for temperatures lower than 0°C, solar energy can be stored batteries in form of electrical energy to be used when there is a lack of solar energy, and lower CO_2 emission. However, there are some considerations that had to be taken in count when considering using such system as: reduction of performance at higher temperatures. The necessary total PV panel area of the system should be determined to cover daily power consumption of the compressor. DC compressors should be used as it requires low voltage and direct current supply such as 12-24 V which make it suitable for green energy technologies. Such system has relativity high initial cost and suitability for small capacity application

While, for solar thermal driven refrigeration system, it has advantages of: relativity lower cost, suitable for remote area, Suitable for large cooling capacity applications, doesn't have problems of the GWP and ODP of many refrigerants used in vapor-compression systems and requires minimal mechanical power. While, the system disadvantages are: lower COP, higher collector area foot print, need a large space to store solar energy (cold storage) and much more complicated in design. However, it concluded that solar driven vapor compression refrigeration system is the most appropriate system for agriculture crops reservation. This due to it has higher COP than the solar thermal refrigeration systems. Moreover, its size (footprint) is smaller than other solar driven refrigeration systems as well as it could be easily transportable. The main hindrance of this its higher initial cost compared to other conventional driven refrigeration systems.

4. Acknowledgement

The first author would like to acknowledge Mitsubishi Corporation for its financial support to study for a M.Sc. Degree as well as the Egypt–Japan University of Science and Technology, E-JUST for offering the facility and tools needed to conduct this work.

5. References

Abdulateef, J.M., Sopian, K., Alghoul, M.A., Sulaiman, M.Y., 2009. Review on solar-driven ejector refrigeration technologies. Renew. Sustain. Energy Rev. 13, 1338–1349.

Afshar, O., Saidur, R., Hasanuzzaman, M., Jameel, M., 2012. A review of thermodynamics and heat transfer in solar refrigeration system. Renew. Sustain. Energy Rev. 16, 5639–5648.

Axaopoulos, P.J., Theodoridis, M.P., 2009. Design and experimental performance of a PV Ice-maker without battery. Sol. Energy 83, 1360–1369.

Chunnanond, K., Aphornratana, S., 2004. Ejectors: Applications in Refrigeration Technology. Renew. Sustain. Energy Rev. 8, 129–155.

Ekren, O., Celik, S., Noble, B., Krauss, R., 2013. Performance evaluation of a variable speed DC compressor. Int. J. Refrig. 36, 745–757.

Fadar, A. El, Mimet, A., Pérez-García, M., 2009. Modelling and performance study of a continuous adsorption refrigeration system driven by parabolic trough solar collector. Sol. Energy 83, 850–861.

Guo, J., Shen, H.G., 2009. Modeling solar-driven ejector refrigeration system offering air conditioning for office buildings. Energy Build. 41, 175–181.

Hartmann, N., Glueck, C., Schmidt, F.P., 2011. Solar cooling for small office buildings: Comparison of solar thermal and photovoltaic options for two different European climates. Renew. Energy 36, 1329–1338.

Hassan, H.Z., Mohamad, A.A., 2012. A review on solar cold production through absorption technology. Renew. Sustain. Energy Rev. 16, 5331–5348.

Hermes, C.J.L., Barbosa, J.R., 2012. Thermodynamic comparison of Peltier, Stirling, and vapor compression portable coolers. Appl. Energy 91, 51–58.

Kaldellis, J.K., Zafirakis, D., Kavadias, K., 2009. Techno-economic comparison of energy storage systems for island autonomous electrical networks. Renew. Sustain. Energy Rev. 13, 378–392.

Kalkan, N., Young, E.A., Celiktas, A., 2012. Solar thermal air conditioning technology reducing the footprint of solar thermal air conditioning. Renew. Sustain. Energy Rev. 16, 6352–6383.

Kalogirou, S.A., 2009. Solar Energy Engineering: Processes and Systems. USA: Elsevier Inc.

Kim, D.S., Ferreira, C.A.I., 2008. Solar refrigeration options – a state-of-the-art review. Int. J. Refrig. 31, 3–15.

Kitinoja, L., Kader, A.A., 2002. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops.

Lazzarin, R.M., 2014. Solar cooling: PV or thermal? A thermodynamic and economical analysis. Int. J. Refrig. 39, 38–47.

Le'an, S., Yuanyang, Z., Liansheng, L., Pengcheng, S., 2009. Performance of a prototype Stirling domestic refrigerator. Appl. Therm. Eng. 29, 210–215.

Li, G., Hwang, Y., Radermacher, R., 2012. Review of cold storage materials for air conditioning application. Int. J. Refrig. 35, 2053–2077.

Otanicar, T., Taylor, R.A., Phelan, P.E., 2012. Prospects for solar cooling – An economic and environmental assessment. Sol. Energy 86, 1287–1299.

Ozgoren, M., Bilgili, M., Babayigit, O., 2012. Hourly performance prediction of ammonia–water solar absorption refrigeration. Appl. Therm. Eng. 40, 80–90.

Parida, B., Iniyan, S., Goic, R., 2011. A review of solar photovoltaic technologies. Renew. Sustain. Energy Rev. 15, 1625–1636.

Phoebus, H., 1913. Sun Works Machinery. Egypt. Gaz. Newsp.

Sarbu, I., Sebarchievici, C., 2013. Review of solar refrigeration and cooling systems. Energy Build. 67, 286–297.

Sobrinho, P.M., Tuna, C.E., 2013. Experimental research on the influence of the air humidity conditions in an air conditioning system. Exp. Therm. Fluid Sci. 49, 152–159.

Tassou, S.A., Lewis, J.S., Ge, Y.T., Hadawey, A., Chaer, I., 2010. A review of emerging technologies for food refrigeration applications. Appl. Therm. Eng. 30, 263–276.

Tiwari, G.N., Mishra, R.K., Solanki, S.C., 2011. Photovoltaic modules and their applications: A review on thermal modelling. Appl. Energy 88, 2287–2304.

Toledo, O.M., Oliveira Filho, D., Diniz, A.S.A.C., 2010. Distributed photovoltaic generation and energy storage systems: A review. Renew. Sustain. Energy Rev. 14, 506–511.

Ullah, K.R., Saidur, R., Ping, H.W., Akikur, R.K., Shuvo, N.H., 2013. A review of solar thermal refrigeration and cooling methods. Renew. Sustain. Energy Rev. 24, 499–513.

Yen, R.H., Huang, B.J., Chen, C.Y., Shiu, T.Y., Cheng, C.W., Chen, S.S., Shestopalov, K., 2013. Performance optimization for a variable throat ejector in a solar refrigeration system. Int. J. Refrig. 36, 1512–1520.