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Solar Air Conditioning and Refrigeration with Absorption Chillers Technology in Australia – An Overview on Researches and Applications

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Abstract

The air conditioning sector demand for energy has increased incessantly in Australia in the past few years due to global warming and the increase of life standards. This added more loads on the electricity demand and a significant increase in peak demand due to the use of conventional air conditioning systems, in addition to the environmental impact of energy producing from fossil fuels. Nevertheless, to minimise the environmental impact associated with air conditioning/ refrigeration system operation it is logical to evaluate the alternative options for energy sources and/or refrigerant systems. The solar assisted air conditioning /refrigeration system is presented as an attractive substance utilise the free, clean and sustainable solar energy. In this study, an overview of the different solar assisted air conditioning technologies available and their applications with a brief literature of the current related research and study in Australia, the review cover the solar thermal assisted cooling system (Absorption, Adsorption, Ejector systems, Desiccant cooling, thermo-mechanical) and the Solar electric cooling technology. From the study, the Solar cooling system applied Absorption chillers present as the most promising technology available.

Keywords: **Solar energy, air conditioning, refrigeration.**

1. Introduction

As a consequence of various effects and phenomena, the world is looking forward to effective, cheaper and environmental clean power sources, Most of Australia's greenhouse gas emissions come from the burning of fossil fuels for energy (e.g. for electricity and transport). When oil, gas or coal burns, carbon contained within it combines with oxygen in the air to create carbon dioxide. If we know that 50% of Australia's greenhouse gas emissions are from stationary energy, primarily electricity generation (WWF-Australia), we should seriously look for alternative power sources rather than the fossil fuels.

Other factors such as the global economy crises and political crises are affecting the prices of fossil fuel which already in its way to exhaust its resources and with the huge increasing demand from a country like China, and may reach unaffordable prices soon (IEA).

The sun is a generous star that supplies earth with a huge, long and endless energy since millions years and obviously will last for very long time hereafter. Each second the sun exposure up to 173,000 TW of energy to our planet, equivalent to millions tons of fossil energy, although the solar radiation energy to the Earth's atmosphere is only the total radiation energy of 2.2 billion to one, but its more than enough to run the life cycle on earth.

Australia has a very sunny climate, with high demand for air conditioning. Air conditioning's impacts upon the electricity network and the environment threaten to affect our quality of life. On hot summer's days, the electricity grid increasingly faces the danger of overloading due to air conditioner use, which would cause essential service disruption and severe economic impact. Associated with the air conditioning's high use of energy is significant environmental pollution, namely in the form of greenhouse gas emissions with the resultant climate change impacting not only upon our environment, but also our health and productivity. Fig.1 shows where solar energy has the maximum effect.

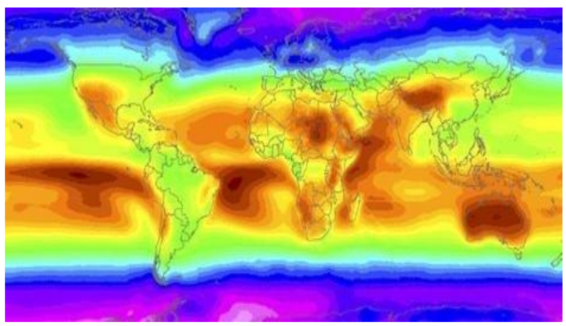

Fig.1. Hot spot: the colour-coded world map, with, produced by NASA to show where solar energy has the maximum effect. Photo: Reuters

Many individually ways are addressing the air conditioning's impact upon the grid and environment, solar air conditioning (or solar cooling) is one of the few solutions that provides cooling and addresses peak loading, and does so with reduced environmental impact.

Australia is one of the tops ranked countries in active solar estimated annual yields for glazed flat plate collectors 700 kWhth per m², while its 400 kWhth per m² in Germany (Philibert, 2005). But the Technology of using the solar thermal assisted air-conditioning system in not in focus in Australia as it is in Germany and other European countries as well as Asia and USA. The new developments as well as the climate changes, energy prices and other impacts urge us to call for further studies to investigate the feasibility of the solar thermal air-conditioning system in Australia.

The solar air conditioning is highly attractive as more cooling is needed when the solar intensity is strong and higher ambient temperatures are present. There is a notion that the present cost of these equipments is still prohibitive, not only for the price of the solar cooling equipments and solar collectors themselves, but also for the cost of required backup systems. In fact, even though they cannot compete with conventional technologies. It is often forgotten the indirect benefits in terms of image and marketing this technology can bring. The concept itself is highly marketable to generate cooling with the Sun.

2. State Of The Art Solar Cooling Systems for Buildings Air Conditioning.

2.1 Solar Driven Sorption Cooling Systems

In Solar thermal driven air conditioning systems, the heat generated by the solar is used to power the cooling process. The Solar thermal air conditioning systems generally classified into two types:

Closed systems: refrigeration equipment powered by thermal carriers (hot water or steam) directly producing chilled water, which can be used in the air conditioning systems air handling unit (cooling, dehumidification) or distributed through a network of pipes decentralized terminal conditioning in several rooms to be conditioned (e.g., fan coil). These systems are already available in the markets long time ago, mostly not solar driven except few hundred units around the world (mainly in Europe) with growing interest for solar powered application. The most common ones are the absorption and adsorption chillers.

Open systems: The most common systems based on the principle of desiccant cooling and using rotary dryers with solid sorbents, these systems allow a full treatment of the air that is cooled and dehumidified to ensure the needs of comfort. The refrigerant is water, in direct contact with the ambient air.

2.1.1. Absorption Refrigeration Equipment

The thermal powered absorption refrigerating machines the most common worldwide. By combining a liquid solution refrigerant absorbent and a heat source can replace electromechanical compressor. For typical air conditioning applications (chilled water temperature above 5 ºC) an H2O/ LiBr liquid solution is usually used, for refrigeration application (chilled water temperature below 5 ºC) an NH3/H2O mixture is applied.

Absorption chiller electricity consumption is limited to an internal pump, which consumes a small amount of electricity, besides new machines made by YAZAKI use bubble pumps replacing the electric pump. The crystallization of lithium bromide solution during operation of a machine with H2O/ LiBr absorption cycle was the main disadvantage of these units, but it’s simply avoided with controlling the inlet hot water temperature by valves.

Fig.2 shows the main components of an absorption refrigeration machine compared to the conventional machine.

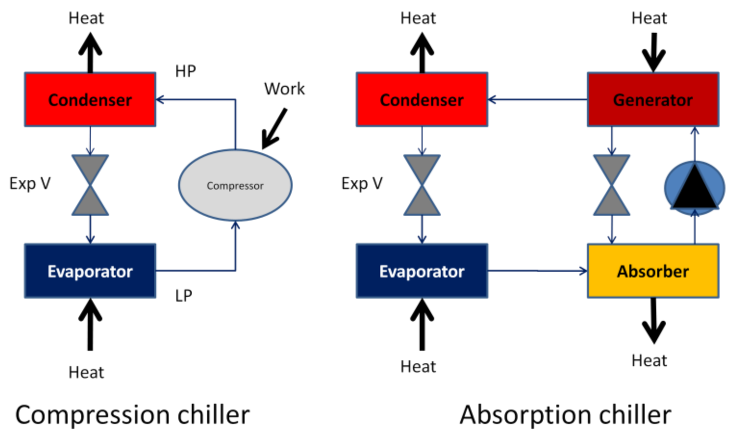

Fig.2. Main components of the absorption chillers compared to compression chillers.

The refrigerating effect is based on the evaporation of refrigerant (water) inside the evaporator at a very low pressure. The evaporated refrigerant is absorbed in the absorber, diluting the solution H2O/ LiBr. In order to optimize the absorption process, the diluted solution must be cooled. The solution is continuously pumped into the generator, within which is regenerated by supplying heat (e.g. hot water). The refrigerant leaving the generator is condensed in the condenser cooling water through and from there back to the evaporator via an expansion valve.

The cooling capacity of typical absorption machines is the order of several hundred kW. The range varied from 7.5 kW- 1500 kW for the single effect machine as shown in Fig.3.

Fig.3. Single – effect absorption chillers (M/s Broad)

These machines are powered by heat from a district heating, heat recovery or cogeneration heat. Units required in solar thermal driven air conditioning system applications are frequently small sizes. The temperature required for operating the absorption chillers is normally higher than 70 ºC for a single effect machine with a COP maintained in a range between 0.6 and 0.8. Double-effect machines with two stages of generation require operating temperatures above 120 C, the COP, in these cases, can reach values close to 1.2. Triple effect absorption chillers still under development.

One type of machine recently developed to meet the small capacity is capable of operating at partial load with cooling load with a temperature of 65 ° C and with an estimated COP of around 0.7, compromise ideal for solar applications. This shows that there is still potential for improving the performance of absorption machines.

The CSIRO system was installed a year earlier (CSIRO). the main application is to provide cooling to the CSIRO office building in Newcastle, a single stage Chillii WFC18 (YAZAKI) chiller from Solar Next with cooling capacity 17.5 kW connected to 50 m² solar array of parabolic trough collector Type PolyTrough 1200 supplied and installed by Nepsolar, 2010 and wet cooling tower of 43 kW capacity.

Ipswich hospital, Ipswich, QLD, installed a solar air conditioning system complemented with a cooling capacity of 300 kW double effect absorption chillers, the hot water provided by a solar filed consists of 43 solar collectors (parabolic trough collector) installed on the top of the multistory car park, a 6000 Liter thermal tank is applied, the solar thermal cycle has two loops, oil and water with heat exchanger to transfer the heat between the loops.

The hot water supplied to the chillers within the necessary temperature required to produce chilled water, the chilled water distributed through the hospital main chilled water circuit. The system is a positive participation in the efforts of reducing the green houses' gases ,The total cooling load of the Hospital is 4.5 MW (Burger and Newman, 2009).

GPT Group, The developer of Charlestown Square in Newcastle, NSW, contracted with two Australian companies, NEP Solar and Solem consulting to design a solar assist air conditioning system for a shopping centre. According to the available data, double-effect absorption chillers with cooling capacity of 230 kW connected to a solar thermal loop of 354 m² PolyTrough 1200 solar collectors installed by NEP solar. The project expected to start operate in 2011 as the first shopping centre in Australia cooled with solar energy. The project is fully funded Under the NSW government Renewable Energy Development Program (NSW Environment, Climate change and water (NEPSOLAR, 2010).

Insufficient data about the demonstration solar cooling project installed in Padstow, NSW, applying double effect absorption chillers with cooling capacity 175 kW (Broad), linked to a parabolic trough collector field, the information listed on NEPSOLAR web page indicate that this project was funded under SERDF (New South Wales Government’s Sustainable Energy Research Development Fund) in 2008.

Kohlenbach and Ziegler, 2008b; Kohlenbach and Ziegler, 2008a studied the performance of transient absorption chillers, the study described the model of the absorption chillers’ in details, including the basic and dynamic modeling, the thermal energy balance and the mass balance methods fully explained, a comparison between simulation and experimental data took a place in the first part of the study and further detailed in second part of the study which also included the model performance analysis, sensitivity analysis of heat exchangers beside the experimental verification. The study results make it a good reference for a researcher after the design of absorption chillers

In 2009, Sustainability Victoria commissioned Solem Consulting to undertake a study investigates the opportunity of solar cooling technology in dairy farms and cold stores. 4 different sites where subjected to study, 2 dairy farms and 2 cold stores, all within Victoria state. After simulation it was concluded that the solar cooling system may furnish up to 80% of the cooling load and about 60% of the heating load and reduced the greenhouse gas emission by 23% in the dairy farms (air conditioning), but the cold store case was not promising with the same level, as the cold stores demanding 24 hours daily operation , accordingly the solar cooling saved up to 4% of the total energy consumption in 20 years comparing to 21% average in dairy farms air condition cases (Kohlenbach, 2009).

One of the major challenges in any cooling system (compression type or thermal driven) is the heat rejection process (via the cooling tower), the system coefficient of performance (COP) is proportional to the amount of heat rejected. The technology of the cooling tower is mature, but the cooling water in wet type cooling tower may be consists a problem in some dry rural areas. Bandopadhayay et al., 2007 studied the absorption solar assisted air condition system in high ambient location in Abu Dhabi (UAE), one of the simulation result show the possibility of use the dry type cooling tower with hot water driven ammonia/water absorption chillers in case of lack of fresh water.

2.1.2. Adsorption Refrigeration Chiller

In adsorption chillers case, an alternative to liquid solutions, solid absorbent materials are used: those available on the market use water as refrigerant and silica gel as absorbent. These machines consist of two absorption compartments (1 and 2 in Fig.4), an evaporator and a condenser.

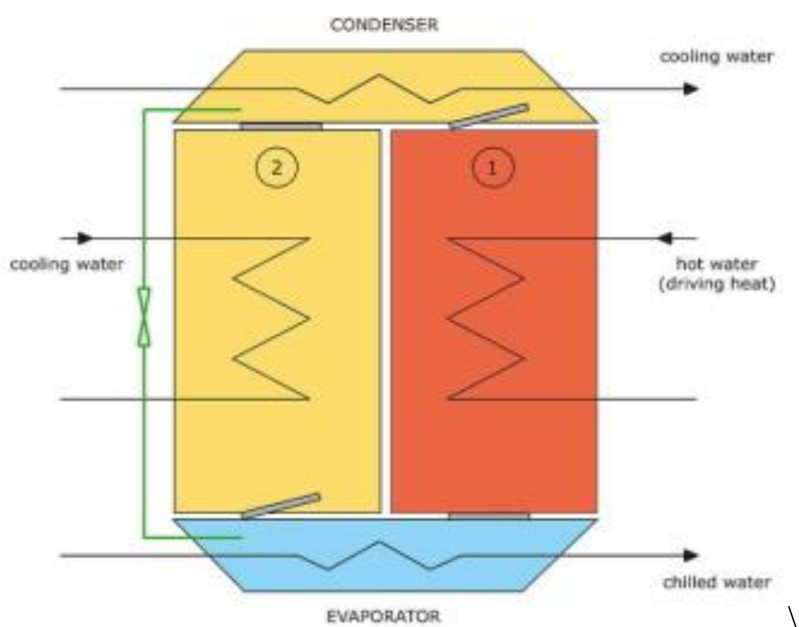

Fig.4. Schematic drawing of an adsorption chiller (SOLAIR)

When the absorbent in the first compartment is regenerated using hot water from an external heat source such as solar collectors, the absorbent in the compartment 2 (adsorber) adsorbs the water vapor coming from the evaporator (this compartment must be cooled to to ensure a continuous adsorption). The water in the evaporator is transformed into the gaseous phase having been heated by an external water circuit, in this part of the product machine is cold. If the cooling capacity is reduced beyond a certain limit due to saturation of the absorbent, operation of the two chambers is reversed. Currently only a few companies are able to produce adsorption refrigeration equipment.

Typical operating conditions with a temperature of hot water of about 80 ° C can achieve a COP of about 0.6, although the machine operation is guaranteed even at temperatures of 60 ° C. The range of cooling capacities of these machines is between 50 and 500 kW.

Saha et al. (2001) examined a double-staged four-bed cycle machine operated with a 55 °C hot water to produce 3.2 kW with a COP of 0.36. The simple design of adsorption refrigeration equipment and their robustness are unquestionable advantages.

There is no danger to crystallization and, consequently, there is no limit to the cooling water temperature. Inside the machine is expected to pump the solution and the power consumption is limited. The disadvantages consist of size, far from negligible, and weight.

Furthermore, because of the limited number of producers, the price of adsorption refrigeration equipment is relatively high. For future generations of these machines is desirable to improve the performance of heat exchangers inside the two compartments and a consequent reduction of weight and volume. Saman et al., 2004; Núñez et al., 2007 listed the available commercially adsorption chillers, all system are using the Silica gel – water bases, But other pairs are also available for adsorption chillers, e.g., water/ zeloite, ammonia / activated carbon, etc. Fig.5 shows the adsorption chiller manufactured by Weatherite Manufacturing in UK.

Fig.5. Adsorption chiller (Weatherite Manufacturing, UK)

In Australia, there is one known installed systems using the technology of solar assisted driven adsorption chillers, the system is at Wyong- Milk factory coffee shop air conditioning system, Wyong, NSW.

The Wyong system utilize a evacuated tube collector with total area of 34.8 m² as a solar thermal heat source to operate an absorption chiller (Type Chillii®ISC10 (water/ zeolith)) with cooling capacity of 10 kW, the chilled water distributed by fan coils units, the system include hot water storage of 1500 Litres capacity and chilled water storage of 500 Litres. This system installed in 2009, no published data found concerning the system performances (SOLARNEXT).

2.2. Desiccant Cooling Systems

Traditionally, the dehumidification is carried out by cooling the air below the dew point (i.e. the temperature below which condensation begins when the air requires an isobaric cooling) generally require a subsequent reheating to restore the operating temperature and humidity conditions.

Through this process condensate can be extremely disadvantages, such as in a forced air cooling, it would be enough to cool the air at 18-20 ° C range, but when it comes down to values lower than ten degrees, it will requiring the need of air post heating process, which would decrease COP (Coefficient of performance). Desiccant cooling systems dehumidify the air without requiring a phase of reheating, resulting in an appreciable energy advantage.

DEC systems (Desiccant and Evaporative Cooling), consists of the combination of drying process by absorption of water vapour in the air and evaporative cooling of water in the air to be treated. The drying is done on the surface of an adsorbent material such as Silica gel, activated Alumina, Zeolite, Lithium Chloride and Lithium Bromide.

The dehumidification system most widely used in air handling units of desiccant cooling systems is the dehumidifying wheel or a rotating device consists of concentric structures supporting substances dehumidifying. The air can pass through corrugated sheets arranged concentrically; a sector of the cylinder is affected by the air to be dehumidified an, the reminder by air regeneration, a fixed partition separating the two sectors as in heat recovery application.

The slow rotation of the cylinder around its axis (0.5-6 revolutions per hour) shall contact surfaces after adsorption with the air by dehumidifying and air regeneration. The dehumidification by adsorption exploits the physical process whereby molecules of a gas (refrigerant) are deposited on the inner surface of a material with high porosity that is in liquid or solid, typically silica gel or chloride lithium. This process is reversible, ie the refrigerant can be removed again by a process of regeneration of the adsorbent material. To this end, request heat temperature of the order of 45-95 °C which is supplied from a solar collector.

The performance improvement is the greater the stronger is the change in specific humidity between input and output. The best performance you have to lower air inlet temperatures. (Kim and Ferreira, 2008, Saman et al., 2004).

Evaporative cooling is achieved by spraying water instead of air under conditions that produce vaporation, in this way a part of sensible heat is transformed into latent heat, the air temperature drops, but there is a consequent increase in moisture absolute and relative. The efficiency of evaporative cooling is measured by comparing the lower temperature cooling the lower temperature actually obtained, with the maximum theoretically achievable gap, i.e. the difference between dry bulb temperature of treated (i.e. the temperature is measured with a standard thermometer) and the wet bulb temperature (i.e. the temperature measured with a thermometer whose bulb is covered with a cotton gauze soaked in water over which sends a current of air) the outside air, size of water-related content air.

The cooling process is achieved through adiabatic humidifiers or washers. The desiccant cooling (cooling with desiccant) is a system that is based on an open cycle, using water as refrigerant which exchanges directly with air. The term "open" indicates that the refrigerant, transferred to the environment immediately after the cooling treatment is supplemented by another refrigerant in a continuous cycle. For this reason, the only method of cooling can be used is water, since the refrigerant comes into direct contact with atmospheric air (Ashare, 2004).

2.2.1. Solid Desiccant Cooling

Fig.6. describe the solid desiccant cooling system with solar collector (Kim and Ferreira, 2008). The system includes two revolving wheels (i.e. Dehumidification wheel and the Heat exchange wheel) with the other components within an air handling unit (AHU).

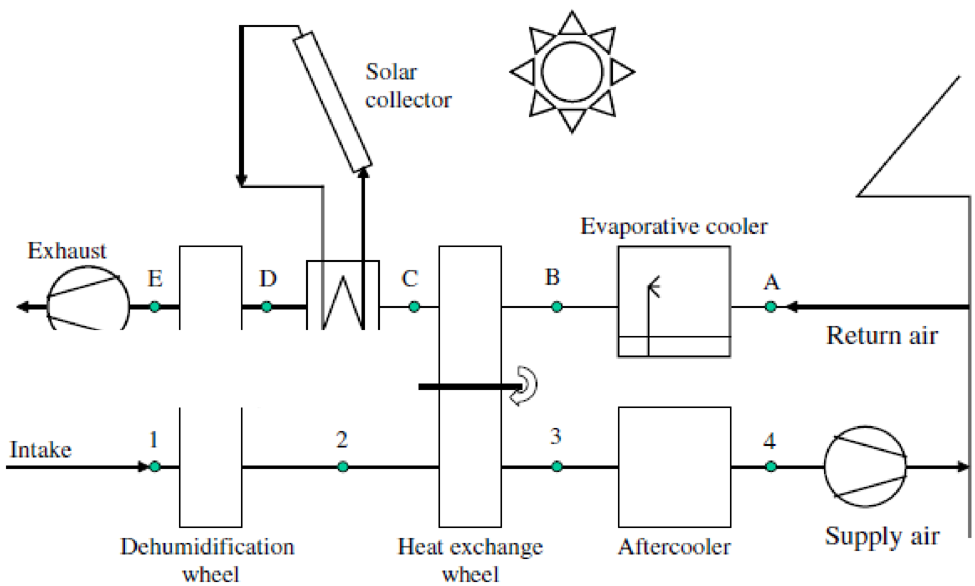

Fig.6. A solid desiccant cooling system with solar collector (Kim and Ferreira, 2008)

The warm moist air from the environment conditions pass through the dehumidification desiccant wheel that turns slowly, part of the water contained in air is absorbed, so dehumidifying the air (wheel absorption).

The air heated by the absorption process, through a rotary heat exchanger, transfers its heat (recovery wheel) and is then pre-cooled. Then depending on temperature and humidity requirements the air is humidified and cooled by a humidification system (humidifier). The return air from the cooling space is humidified (humidifier, i.e. direct evaporative cooler) to reach the saturation point, in order to recover the maximum potential cooling and thus ensure efficient operation of the heat exchanger, by passing through the heat exchange wheel the warm and humid air stream resulted is heated by means of heating coil supplied by solar heated fluid (Water or air).

The wheel absorbent must be regenerated using heat at relatively low temperature (50-75 °C) to ensure continuity in the dehumidification process, the hot stream from the heating coil is applied for this purpose. The COP of a solid desiccant cooling system may reach the value of 0.7 under normal conditions (Henning, 2004). The thermodynamic process is similar to this of the closed sorption process (Kim and Ferreira, 2008).

Saman et al. 2004 described another solar solid desiccant cooling approach uses solid desiccant in a fixed bed process, where the sorbent is coated the surface of a plate heat exchanger, the heat exchanger is operated with fresh air in one side and the treated return air (humidified) on the other side, this treated return air will provide the cooling for the absorption process in air-conditioning phase, while the fresh air heated by the solar energy handle the regeneration process in this system. This system known as (ECOS), evaporative cooled sportive heat exchanger.

Ward et al., 2005; Kohlenbach et al., 2007 illustrate the only known installed desiccant evaporative air conditioning system in the public library of Hornsby, Sydney, NSW. This system installed and operates since April 2004. Non-solar thermal backup applied, instead a 60 kWel micro-turbine supply the required regeneration heat. Ward et.al.2004, listed the advantages of the system further to the system efficiency, energy saving and CO2 emissions. Kohlinbach et.al. Simulated the system in different climates zones within Australia, presented the simulation results and compared it to reference conventional air conditioning systems.

White et al. (2009) modeled and simulated a solar desiccant cooling system without auxiliary backup heat source or mechanical cooling backup, in this model the supply air to the cooling space been cooled down after the heat exchange wheel by using two-stage evaporative cooling process (indirect/direct). The outside air was used for the recovery of the heat exchange wheel instead of the return air. The system simulated with TRNSYS software and subjected to different climates conditions within Australia (i.e. Sydney, Melbourne and Darwin), the outcomes show that the performance of the desiccant cooling cycle is proportional with the indirect evaporative cooler effectiveness which is in turn increase as the humidity ratio decrease. The use of low temperature for the generation of desiccant wheel process resulted a higher energy efficiency thus encouraging the use of low temperature solar thermal collectors (reduce the system cost). The high ventilation rates also resulted maintains of a comfort indoor conditions (Temperature and humidity) within the acceptable levels.

2.2.2. Liquid Desiccant Cooling

Recent development is close to commercialization, the desiccant cooling systems using a solution as absorbent liquid lithium chloride. These systems offer several advantages, such as, for example, a higher level of dehumidification at the same temperature of the carrier thermal power, compared to systems using solid materials and the ability to store many energy storage systems through the concentrated solution. This technology is an attractive option in the near future in the field of air conditioning solar energy.

Similar to the absorption system, the desiccant solution is circulate between the absorber and a regenerator, as shown in the Fig.7, the strong solution is sprayed over the cooling coil in opposite direction to the ambient or return air stream, desiccant spray absorbs the moisture from the air, leave it dry and cooler after passing the cooling coil, the cooling requirements decided a further cooling via the after cooler device.

The watery solution is pumped and sprayed over a heating coil against an ambient air stream to reject the water and reconcentrate the desiccant solution. The heat required fir this process can be supplied from a solar collectors array.

Saman carried an early works in the field of the solar desiccant cooling systems (Saman, 1993). Saman and Alizadah, publications 2000-2005 enriched the knowledge in this technology in Australia (Alizadeh and Saman, 2002b; Alizadeh and Saman, 2002a; Saman and Alizadeh, 2001b; Saman and Alizadeh, 2001a; Saman and Alizadeh, 2002).

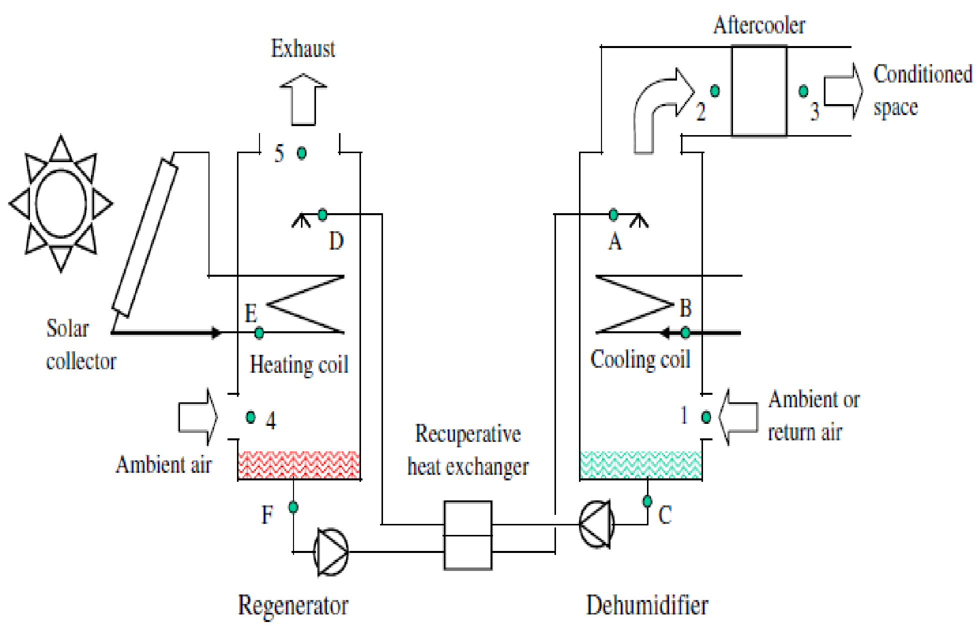

Fig.7. Liquid desiccant cooling system with solar collector (Kim & Ferreira, 2008)

The University of South Australia in partnership with the University of Kassel in Germany work on the developing of a solar assisted evaporative cooler applying the liquid desiccant cooling approach assisted by solar heat source for regeneration process (Krause et al., 2006;

Krause et al., 2005a; Krause et al., 2005b) in addition to the SA university continues research in the Solid desiccant cooing field. Alizadeh (2008) analyzed the performance of a solar liquid desiccant air conditioner in the tropical climate of Queensland, it was found that the solar liquid desiccant system is effective in for dehumidification and cooling in hot and humid climates , the solar liquid desiccant cooling prototype was sufficiently controlled the air conditioning for a 120 m^2 commercial site in Brisbane.

2.3. Ejector Refrigeration Systems

The Ejector refrigeration is a thermally driven technology that has been in used for cooling applications for many years. Although the COP of these systems is very low comparing to vapour compression systems or other solar cooling systems, nevertheless it does offer many advantages of simplicity, no moving parts and the ability to produce refrigeration buy utilizing the waste heat or solar thermal energy as a heat source at temperatures above 80 ºC.

As shown in Fig.8, the system contains two loops, the power loop and the refrigeration loop. In the power loop, during process 1-2 (Generator) the high pressure vapour is generated (Primary fluid) the liquid refrigerant is evaporate by the low grade heat, Qb.

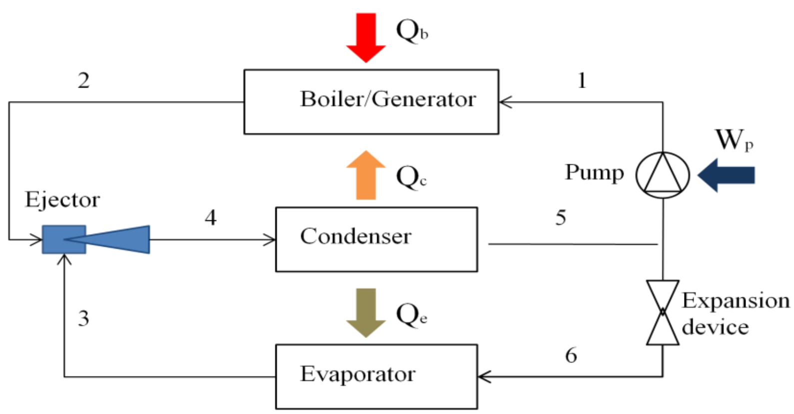

Fig.8. Schematic diagram of Ejector refrigeration system

The primary fluid (high temperature and pressure) accelerate as flows through the ejector nozzle. The reduction in the pressure that take place induces vapour from the evaporator (The Secondary fluid) at point 3, the primary and the secondary fluids mix in the mixing chamber and entering the diffuser section where the flow is deceleration and a pressure recovery take a place. The mixed fluid rejecting heat (Qc) and condensed as passing through the condenser unit, the power cycle is completed as a part of the liquid in the condenser is pumped to the generator at point 5, the reminder of the fluid is expanded through the expansion device and enter the evaporator at point 6 as a mixture of liquid and vapour.

The refrigerant mixture is evaporate in the evaporator producing the cooling effect, Qe, the resulting vapour is drained into the ejector at point 3 as the secondary fluid which mixed with the primary fluid in ejector unit and repeat the cooling loop (Chunnanond and Aphornratana, 2004).

COPs values between 0.2 -.33 recorded for a ejector refrigeration units with generator temperature between 85 – 95 ºC and condenser temperature between 28-32 ºC (Alexis and Karayiannis, 2005; Nguyen et al., 2001). While Balaras et al. (Balaras et al., 2007a) with a pilot steam ejector plant supplied with 200 ºC heat source , recorded a high performance with a COP value of 0.85.

There are various designs of solar driven ejector refrigeration systems. Abdulateef et al., (2009) reviewed the different ejector refrigeration systems driven with solar thermal energy including single stage, multi-stage ejector system, Ejector refrigeration system with booster or compressor, solar driven combined ejector and absorption refrigeration system and solar driven combined ejector and adsorption refrigeration system. in addition to a review to the used working fluids.

The Solar Thermal Group in Australian National University (ANU) developing a hybrid thermal air conditioning system for the residential use adopting the ejector refrigeration principle mentioned earlier, the university researches covering the Hybrid designs, systems integration, advanced analytical control system, cool storage , advanced high performance ejectors and CFD analysis of ejectors, the low temperature sub- group leaders, Keith Garzoli and Mike Dennis published many articles describe the research development in the field of solar ejector refrigeration systems (Dennis, 2009; Dennis and Garzoli, 2009a; Dennis and Garzoli, 2009b; Garzoli and Dennis., 2009).

2.4. Thermo-Mechanical Solar Cooling

The thermo-mechanical solar cooling based on the theory of Rankin cycle adopted in power plant, the water is heated to high temperature to produce pressurized steam, the steam pass through a turbine to produce work as shown in Fig.9. This work is utilized to operate a compressor in the refrigeration cycle, a Stirling engines also used for the same purposes as shown in Fig.10. The available technology of the solar thermal collectors make this process possible, the Parabolic trough collectors can provide water with a temperature of up to (400 °C) by the concentrated sun’s rays on the thermal fluid inside the tube, other collectors such as Parabolic dish can heat up the water to higher temperature with higher cost and the Linear Fresnel collectors on opposite provide lower temperature with less cost.

The complexity of the system and the high installation and maintenance cost were limitations on take this application out of the research field, and the utilization of the Rankin cycle applications in solar thermal field restricted to mass power generation. The power can be used to operate a refrigeration cycle and the solar cooling system complete by another way.

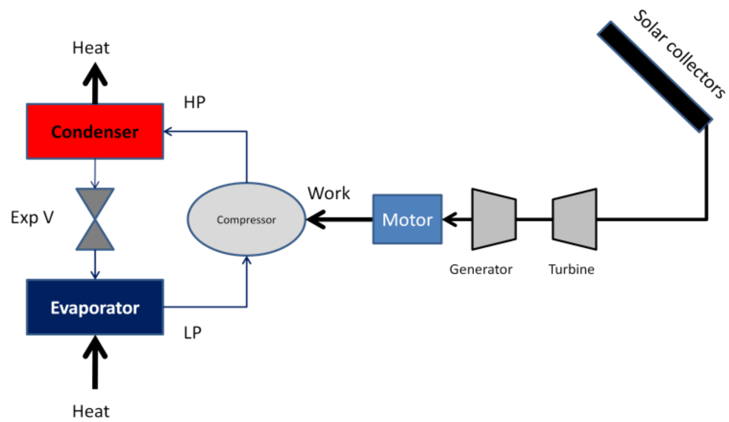

Fig.9. Schematic drawing of the solar thermal cooling system with turbine and generator.

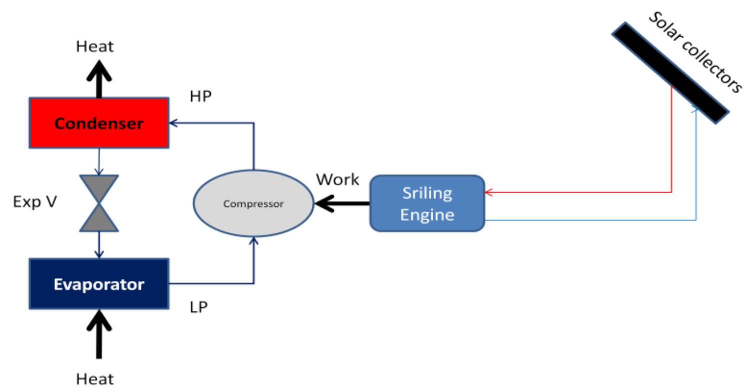

Fig.10. Schematic drawing of the solar thermal cooling system with Stirling engine.

The application of similar system in small units is far from reality, due to high cost, complication and sophisticated maintenance operation. The comparison between the solar electrical refrigeration system and the thermo mechanical refrigeration systems on the bases of cost and efficiency is usually trend towards the solar electric system of higher efficiency and lower cost (Henning, 2004; Kim and Ferreira, 2008; Harper, 2009). Thermo mechanical solar plant are an alternative when part of the electricity produced is running an air conditioning units, some solar thermal driven power stations are in their experimental working and many in designing stage in Australia (Mei et al., 1991).

3. Discussion

The solar refrigeration technologies discussed in previous sections describe the mature system in the solar technology, other technologies still in Laboratory stage or as a registered patent. Each different technology has its own advantages and disadvantages, a full study, careful design and economic evaluation should be considered before adopt the solar air conditioning system in practical.

Many studies have been done since the earlier days of absorption chillers when Mouchot produced Ice cubes utilizing the solar thermal energy in 1878 ,Trombe and Fox (Alizadeh and Khouzam, 2005) reported a successful test for a lab experimental to operate an absorption chillers with solar thermal powered, followed by many researchers, e.g. Nakahara (Alizadeh and Saman, 2002b), now days many researches cover the different aspects of the different solar refrigeration technologies, these studies can be significant in decision making in the first stage of Solar cooling system choosing process.

The comparing between different technologies should be base on the terms of performance and cost, the performance evaluation of solar cooling technology is based on the efficiency of the solar collectors, the coefficient of performance for the cooling technology (e.g., absorption chillers, evaporative cooler with desiccant wheel, conventional Vapour compression, etc.), also the efficiencies of other system components like the energy storage systems (thermal tank, batteries, etc.) and engine (e.g. Thermoelectric, Stirling and Thermoacoustic) according to the solar cooling technology used.

All these factors decided the technology efficiency, Kim and Ferreira (Kim and Ferreira, 2008), explained a comparison method can be imperative for future work, a flow chart based method fed with information regarding the commercially adopted solar technology with estimated and/or assumed components efficiencies and costs, simply change the efficiency value with accurate one and the cost with updated value, the flow chart could estimate the overall system efficiency and initial cost in the primary stage of solar cooling technology selection.

From Kim and Ferreira method in comparison between the different solar electrical driven system equipped by an assumed 10% efficiency solar Photovoltaic panels and €5/w cost, only the solar electrical driven conventional vapour compression system and the solar electrical driven magnetic chillers are competitive among the solar electrical refrigeration technologies. More over the solar electric system is less cost than the solar thermo-mechanical systems commercially available in both initial cost and running cost terms. The solar thermal driven system, i.e. the absorption (single and double effect), adsorption and ejector chillers are strong challenger to the solar electric air-conditioning system, the total costs of these systems are lower compared to these for solar electrical and thermo-mechanical units, on the other hand the desiccant cooling units are more expensive.

The disadvantages of the solar thermal cooling systems are mainly with their low Coefficient of performance values (0.2-0.33 for ejector refrigeration, 0.6 for Adsorption chillers, 0.86 for single stage absorption chillers and 1.2 for double-stages absorption chillers), also the high cost of desiccant cooling and the adsorption chillers are a limitation for these technologies, yet, this technology is able to result a good indoor air quality and ventilation effectiveness. Though the solar cooling system has the advantage of energy saving and green house gases production cuts, nevertheless, the technology evaluation in the past decade take in consideration the high annual cost of solar system comparing to conventional systems (Alizadeh and Saman, 2002a; Balaras et al., 2007b; Henning, 2007) due to the cost of solar collectors and the low COP values. Desideri et al., 2009 studied the economic feasibility of a Thermo-Solar Trigeneration system, where the solar thermal system backed up with a boiler burning a natural gas, to run the absorption chillers at cooling season, as well as supply hot water for heating season, the study show an optimistic result could overcome the disadvantages of the solar cooling system with absorption chillers.

Fong et al., 2010 supports Kim study, in a comparison between five different technologies, i.e., Solar electric compression refrigeration, Solar absorption, Solar adsorption, Solar solid desiccant cooling and Solar thermo-mechanical compression refrigeration. For a subtropical climate of Hong Kong, the solar absorption air conditioning system with evacuated tube or flat plat collector recorded an energy saving rates of 15.6 % and 48.3% respectively when compared to the conventional electrical air conditioning system.

4. Conclusion

The Different Solar cooling technologies discussed in this article has a potential significantly ability to reduce the electricity consumption in Australia, the authors attempts to survey the art of state of the technology in Australia. Obviously in a continent with a generous solar energy effect, rising power Tariff, tendency to reduce green house gases rates and growing demand for air conditioning, we find a little concerning in adoption of Solar air conditioning applications. More researches and development activities are required, continues updating and assessment of the technologies and equipments is essential.

Among the solar refrigeration technologies, the Solar thermal with single-effect absorption system with the mature technology come into view to be the best option, the single-effect adsorption system, double-effect absorption system to follow, Desiccant system will be perfect in climates with moderate weather and high relative humidity, the ejector technology high cost and low COP need more time to be evaluate.

Solar electric driven refrigeration system is good option, but the high cost and low efficiency of photovoltaic panels retreat the option beyond the solar thermal systems, the complexity of solar thermo-mechanical system and its high cost make it unfavoured selection.

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