



## USE OF RENEWABLE SOLAR ENERGY IN DESICCANT ASSISTED COOLING TECHNIQUES

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### ABSTRACT

The main aim of the present article is to provide fundamental understandings of the need of renewable solar energy in cooling systems and to give useful guidelines regarding different operational parameters of various cooling techniques and the applicability of solar cooling in both in air-conditioning and refrigeration with the improvement of the coefficient of performance. Solar based refrigeration devices are of significance to meet the needs for cooling requirements such as air-conditioning and ice-making and medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. For these reasons the research activities in this sector are still increasing to solve the crucial points that make these systems not yet ready to compete with the well-known conventionally used vapor compression system. There is an increasing interest in the development and use of solar based cooling technologies due to their various economic and impressive environmental benefits, enabling solar energy or waste heat to be used for applications such as district networks and cogeneration plants. Compared to traditional systems this creates new possibilities for utilizing low temperature based naturally available free energy.

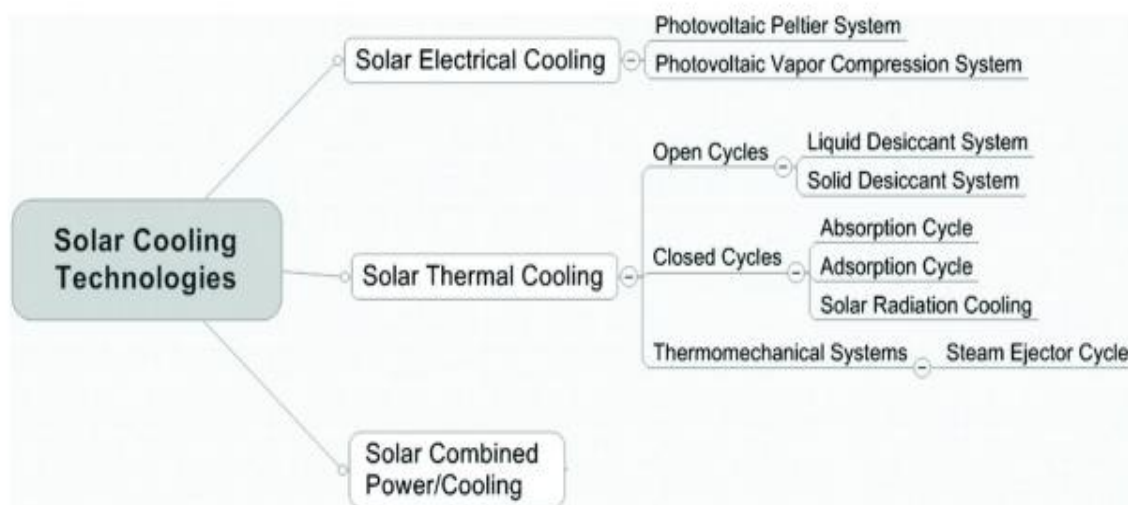
**Keywords:** Solar adsorption; Air-conditioning; Adsorption chillers; Refrigeration; Desiccant cooling

### INTRODUCTION

Encouraged by the successful worldwide combined critical effort and strict environmental policies to protect the ozone layer, researchers and investigators were committed to minimize and reverse the harming environmental effects of global warming. Global warming occurs when carbon dioxide and other green house gases, released mostly from the burning of fossil fuels (oil, natural gas, and coal) and other gases, such as methane, nitrous oxide, ozone, CFCs, HCFCs and water vapor, accumulate in the lower atmosphere surrounding earth. As results of the faster growth in world population and the economy worldwide—especially in developing countries—total world energy consumption has increased and is projected to increase by 71% from 2003 to 2030 [1]. Fossil fuels continue to supply much of the electrical energy used worldwide, and oil remains the primary energy source. Therefore, fossil fuels are the major contributor to global warming. The awareness of global warming was intensified in recent times and has reinvigorated the search for energy sources that are independent of fossil fuels and lead less to global warming. Among the major energy sources alternative to fossil fuels, renewable energy sources such as solar and wind garner the public's attention, as they are available and have fewer adverse effects on the environment than do fossil fuels. Four energy sources represent renewable energy: hydro-

energy, geothermal energy, solar energy, and wind energy. The main source of renewable energy is freely available solar energy [2].

Air-conditioning systems are the dominating in electrical energy consumers in buildings in several countries, and their operation causes high electricity peak loads during the summer. The solar cooling technology as shown in Figure 1 can lower the environmental impact and the energy consumption issues raised by conventional air-conditioning systems. Therefore, the purpose of the review is to provide an overview of the cooling technologies that utilize freely available solar thermal energy and introduce their prospects as alternative cooling technologies as compared to conventional ones.



**Figure- 1. Types of solar cooling technologies [3].**

### SOLAR THERMAL COOLING

Thermal energy produced from the radiations available from solar energy can be transformed to useful cooling and heating through the thermo chemical or thermo physical processes by using thermally activated energy conversion systems. Thermally activated energy conversion systems are further classified into three categories: open sorption cycles, closed sorption cycles, and thermo-mechanical systems.

The solid or liquid desiccant systems that are used for either dehumidification or humidification. Mainly, desiccant systems transfer moisture from one airstream to another by using two processes. In the first process, called the sorption process, the desiccant system transfers moisture from the air into a desiccant material by using the difference in the water vapor pressure of the humid air and the desiccant. If the desiccant material is dry and cold, then its surface vapor pressure is lower than that of the moist air, and moisture in the air is attracted and absorbed to the desiccant material. During the sorption process, the latent heat of the water vapor is released so the temperature increases. After the desiccant material becomes wet, the second process starts. In the second process, called the desorption process or regeneration process, the captured moisture is released to the airstream by increasing the temperature of the desiccant. After regeneration, the desiccant material is cooled down by the cold airstream. Then it is ready to absorb the moisture again. When these processes are cycled, the desiccant system can transfer the moisture continuously by changing the desiccant surface vapor pressures, as illustrated in Figure 2. To

drive this cycle, thermal energy is needed during the desorption process. The desiccant has to be heated to release the moisture from point 2 to point 3 in Figure 2, and then cooled to start the process again. This is an opportunity to use the waste heat instead of an electrical-driven refrigeration cycle to transfer the moisture. Although desiccants can either be solid or liquid, both behave in the same principle so that their water vapor pressure is a function of temperature and moisture content. The difference between solid and liquid desiccants is their reaction to moisture. Solid desiccants, such as silica gel, mostly adsorb the moisture, which means there is no chemical reaction. However, liquid desiccant materials usually absorb the moisture by undergoing a chemical or physical change.

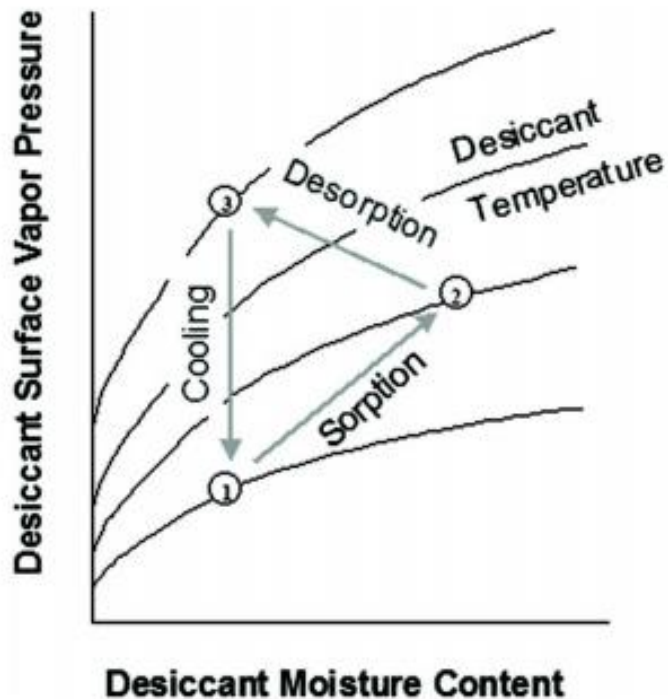
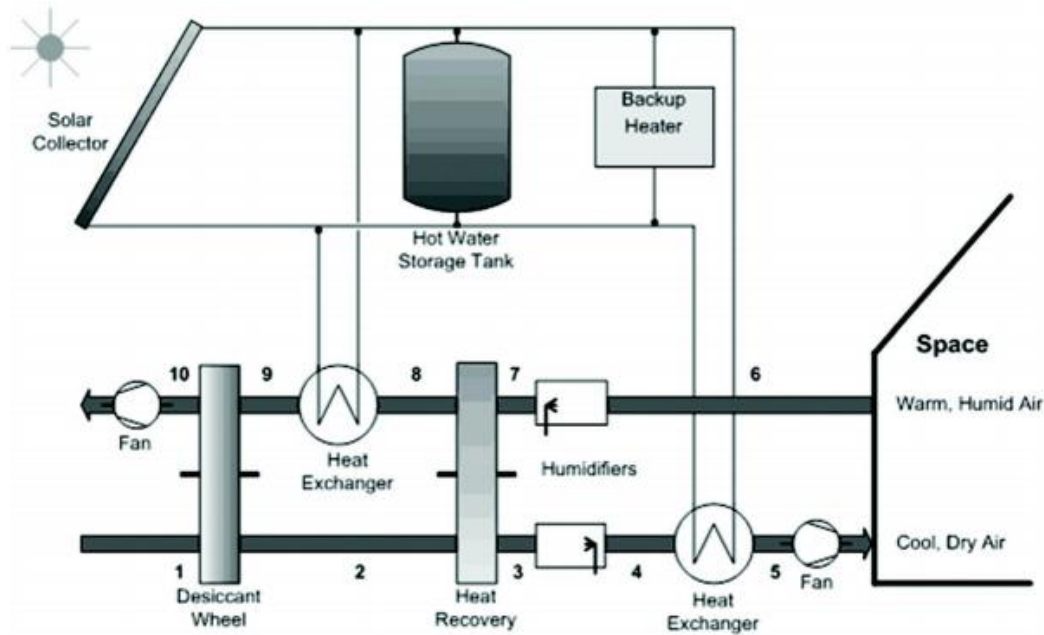


Figure- 2. Working of desiccant cooling systems [4].

Desiccant solar systems lower the moisture of the ambient air by utilizing thermal energy from the solar collector to regenerate desiccants. Then the dry air is cooled through indirect and/or direct evaporative stages, as illustrated in Figure 3. It is found that a solar fraction of the cooling between the solar heat and auxiliary heat provided was 76%, with an overall collector efficiency of 54% and a cooling COP of 0.6 during typical summer conditions. In addition, they proposed a combination of a solar-assisted solid desiccant cooling system with a conventional vapour compression chiller for warm and humid climates, and claimed up to 50% of primary energy savings [5].



**Figure- 3. Working of solar powered desiccant cooling systems.**

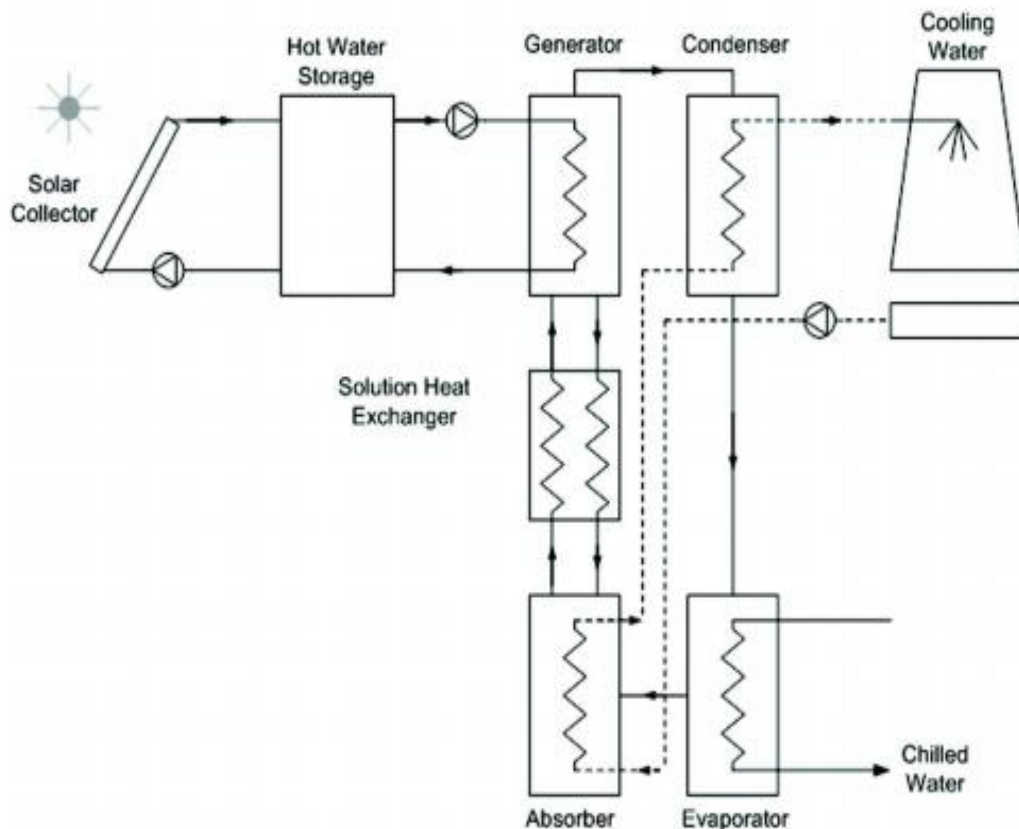
The absorption cycle (Figure 4) is one of the oldest refrigeration technologies. The refrigerant side of the absorption cycle essentially works under the same principle as the vapor-compression cycle. However, the mechanical compressor used in the vapor-compression cycle is replaced by the thermal compressor in the absorption cycle. The thermal compressor consists of the absorber, the desorber, and the solution pump. In the absorber, the absorbent-rich solution is diluted with the refrigerant. During this process, the absorber pressure is kept in low level by releasing the absorption heat to the ambient. Then the solution pump increases the pressure of the absorbent/refrigerant mixture to the high level. The power consumption of the solution pump is relatively small compared to that consumed by the mechanical compressor. In the desorber, the refrigerant is separated from the solution through the desorption process by adding heat. The attractive feature of the absorption cycle is that any types of heat source, including solar heat and waste heat, can be utilized in the desorber. The refrigerant separated in the desorber is then condensed in the condenser, expanded through the expansion device, and evaporated in the evaporator. Then the refrigerant vapor is again absorbed in the absorbent-rich solution. Typical refrigerant/absorbent pairs used in the absorption cycle are water/lithium bromide ( $\text{H}_2\text{O}/\text{LiBr}$ ) and ammonia/water ( $\text{NH}_3/\text{H}_2\text{O}$ )

The operation of the  $\text{H}_2\text{O}/\text{LiBr}$ -based absorption cycle is limited in the evaporating temperature and the absorber temperature, due to the freezing of the water and the solidification of the  $\text{LiBr}$ -rich solution, respectively. The operation of the  $\text{NH}_3/\text{H}_2\text{O}$ -based absorption cycle is not limited in either the evaporating temperature or the absorption temperature. However, ammonia is toxic and its usage is limited to the large capacity system, which requires mandatory supervision. The solar technologies considered relevant are:

- flat plate collectors;
- evacuated tubes;
- stationary
- non-imaging concentrating collectors such as CPC;
- dish type concentrating collectors;

- linear focusing concentrators;
- solar ponds;
- photovoltaic systems; and
- thermoelectric systems.

The solar powered solid adsorption refrigeration system is the most promising technology because it is environmentally friendly with low cost, high efficiency, simple manufacture and low maintenance requirements.



**Figure- 4. Layout of absorption solar cooling cycle [6].**

The steam ejector cycle represents the thermo-mechanical cooling system. Figure 5 illustrates the steam ejector cycle integrated with a parabolic solar collector. The steam produced by the solar collector is passing through the steam ejector. During this process, the evaporator pressure is reduced, and water is vaporized in the evaporator by absorbing the heat from the cold water. When cooling is not needed, the steam turbines can be used to produce electricity. Most of the steam ejector cycle requires steam at pressures in the range of 0.1–1 MPa, and temperatures in the range of 120°C–180° proposed and demonstrated that the steam ejector cycle could be operated using low-temperature solar heat by reducing the operating pressure under atmospheric pressure.

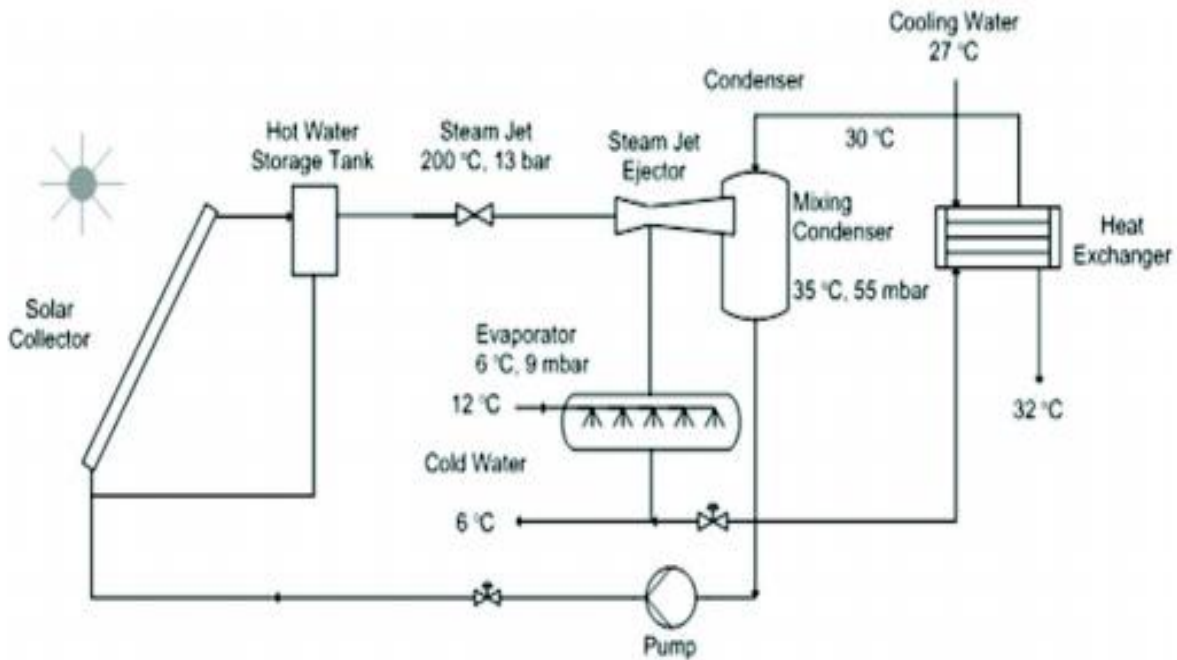


Figure- 5. Layout of steam jet solar cooling system [7].

#### COMPARISON AMONG DIFFERENT SOLAR COOLING TECHNIQUES

They reported the thermal COP ( $COP_{\text{thermal}}$ ) of various solar cooling technologies, as shown in Table 1. They reported that the single-effect absorption systems had a  $COP_{\text{thermal}}$  in the range of 0.50–0.73, adsorption systems had a lower average  $COP_{\text{thermal}}$  of 0.59, a liquid desiccant system had a  $COP_{\text{thermal}}$  of 0.74, solid desiccant systems had a  $COP_{\text{thermal}}$  of 0.51, and a steam jet system had a relatively high  $COP_{\text{thermal}}$  of 0.85. Regarding the driving temperature of the systems, absorption systems operated at 60°C–165°C, adsorption systems operated at 53°C–82°C, a liquid desiccant system operated at 67°C, and a steam jet system operated at 118°C. For most of these systems operated below 100°C, the flat-plate solar collectors could be used, while concentrating solar collectors had to be used for driving temperatures higher than 100°C. They also compared the annual thermal COP, which is defined as the ratio of the annual cold production and the annual heat input, both expressed in kW-hour. According to the available data on actual performance, the average annual thermal COP was 0.58 for all systems investigated. The H<sub>2</sub>O/LiBr absorption systems had the best annual performance, while the adsorption systems had low annual performance. This result reflects the fact that 70% of the systems employed an absorption cycle, and 75% of the solar-assisted absorption systems used H<sub>2</sub>O/LiBr as their working fluid.

**Table 1. Comparison of various solar cooling techniques [8].**

Process Type	Closed		Open		Thermo-mechanical
Cycle	Adsorption cycle	Absorption cycle	Solid desiccant	Liquid desiccant	Ejector cycle
Sorbent type	Solid	Liquid	Solid	Liquid	—
Working fluids (refrigerant/sorbent)	H <sub>2</sub> O/silica gel	H <sub>2</sub> O/LiBr; NH <sub>3</sub> /H <sub>2</sub> O	H <sub>2</sub> O/silica gel; water/LiCl/cellulose	Water/CaCl <sub>2</sub> ; Water/LiCl	Steam, FC
Thermal COP	Average 0.59	0.50–0.73 (single stage) <1.3 (two stage)	0.51	0.74	0.85
Typical operating temperature	53°C–82°C	<97°C (most) 60°C–110°C (single stage) 130°C–165°C (two stage)	45°C–95°C	67°C	118°C

Desiccant technology has become a valuable tool in the industry's arsenal of space-conditioning options. In certain cooling applications, desiccant cooling units provide advantages over the more common vapour compression and absorption units. For example, desiccant units do not require ozone-depleting refrigerants, and they can use natural gas, solar thermal energy, or waste heat, thus lowering peak electric demand. The use of air-conditioning and refrigeration is increasing day by day for providing thermal comfort in industrial and residential areas. This technology requires energy consumption and responsible for the emission of CO<sub>2</sub> and other greenhouse gases such as CFCs, HCFCs, which are considered to be major ozone-depleting gases [9-12].

Recent research in the development of a solar desiccant cooling system has focused on the development of advanced desiccant materials that give improved sorption capacity, favourable equilibrium isotherms, and better moisture and heat rates. Improved performance of these systems will lower their initial costs and make these systems a more attractive alternative to existing vapor compression systems. In air-conditioning in order to improve the indoor air quality, solar solid desiccants and liquid desiccants are still used because they are also environmentally friendly. This concept, called a desiccant enhanced nocturnal radiation (DESRAD), utilizes a desiccant bed integrated in the roof along with a conventional vapor compression system to achieve both latent and sensible cooling in hot and humid climates [13-15]. In this system, sensible cooling is provided during the night and the desiccant is regenerated during the day by solar heat. The system operates in two modes: adsorption mode; and daytime desorption mode. During the night, air is circulated to the desiccant bed on the roof where the moisture is removed. The heat of sorption is transferred to the atmosphere. After the air passes through the desiccant bed, it goes through an evaporative cooler to increase the humidity level and to further cool the air. This air is then passed into the conditioned zone where it absorbs both the heat and moisture from the space. The process of attracting and holding moisture is described as either adsorption or absorption, depending on whether the desiccant undergoes a chemical

change as it takes on moisture. Adsorption does not change the desiccant except by the addition of the weight of water vapor, similar in some ways to a sponge soaking up water. Desiccants are subset of sorbents—they have a particular affinity for water. With respect to the use of solar energy the regeneration step is especially important: the regeneration, of course, can be performed directly by solar energy. Current interest, however, concentrates more and more on using the waste heat chillers for that purpose. The following parameters may be used as a basis for designing the such system: ambient conditions; inside (room) conditions; regeneration air temperature before the dehumidifier; supply and return airflow rates; and design sensible and latent cooling loads. Combinations of sorptive dehumidification with a conventional, electrically driven backup system allow for primary energy savings to 50% at low increased overall costs. This track seems to be worthwhile for future research and demonstration projects.

## **CONCLUSIONS**

As the world population is projected to increase and the supply of the fossil fuel is projected to decrease, the increased supply of the renewable energy for the post-fossil fuel period is inevitable. Since the cooling demand has been increased associated with the recent climate change and is projected to increase with the projected future climate condition, cooling technologies based on solar energy are promising technologies for the future. Through the review of the avail-able cooling technologies assisted by solar energy, their performance potential and their advancement have been investigated. Although the vacuum tube collectors have higher solar collector efficiency, most of the research has been conducted to lower the heat source temperature requirements so that a cheaper flat-plate collector can be utilized. Thermally powered cooling technologies were classified into three categories: closed cycle, open cycle, and thermo-mechanical cycle. Adsorption and absorption cycles represent the closed cycle. The adsorption cycle needs a lower heat source temperature than the absorption cycle. Solid and liquid desiccant cycles represent the open cycle. The liquid desiccant cycle has a higher thermal COP than the solid desiccant cycle. The ejector cycle represents the thermo-mechanical cycle and has a higher COP, but needs a higher heat source temperature than other cycles. Based on the thermal COP of each cycle, the absorption cycle is preferred to the adsorption cycle, and the liquid desiccant system is preferred to the solid desiccant system. Although these cycles have similar thermal COP values, advanced solar collector technologies, such as the mini-dish, open up new opportunities of achieving higher overall system efficiencies with these thermally powered cooling technologies, and enables the solar thermal system to out-perform the solar electric one. Therefore, research on the advanced solar collector to achieve higher solar collecting efficiency and temperature is the most important research topic in addition to developing more efficient and more compact thermally activated cooling systems.

## **NOMENCLATURES**

COP coefficient of performance  
VCR vapour compression refrigeration  
PV photovoltaic  
DC desiccant cooling  
CPC concentrating plate collectors

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