Chapter 3

Solar Cooling Technologies

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Additional information is available at the end of the chapter

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Abstract

This chapter describes different available technologies to provide the cooling effect by utilizing solar energy for both thermal and photovoltaic ways. Moreover, this chapter highlights the following points: (i) the main attributes for different solar cooling technologies to recognize the main advantages, challenges, disadvantages, and feasibility analysis; (ii) the need for further research to reduce solar cooling chiller manufacture costs and improve its performance; (iii) it provides useful information for decision-makers to select the proper solar cooling technology for specific application. Furthermore, some references, which include investigation results, will be included. A conclusion about the main gained investigation results will summarize the investigation results and the perspectives of such technologies.

Keywords: cooling, air conditioning system, solar cooling, performance, absorption machines, adsorption machines

1. Introduction

Today, the increase of requirements for indoor cooling demands improves thermal human comfort inside residential buildings, reduces the divergence between the energy supply and energy demand by the use of low-grade heat sources such as solar energy and industrial waste heat, lowers the CO_2 emissions in the building sector due to the use of air condition systems, and finally reduces the peak of energy consumption of air conditioning processes generated by the use of conventional vapor compression system especially during summer period for the buildings and spaces that have high latent loads. All above reasons make the solar cooling that has been received much more attention as innovative, promising, efficient, and environmentally friendly air conditioning systems as alternative options for conventional air conditioning systems [1, 2]. The building sector is considered as a major contributor to energy consumption in the world. Numerically, 41.1% of the total energy in the United States in 2011 was consumed in the building sector, and this state is expected to increase to 42.1% in 2035 [3]. In Europe, buildings consumed for 39% of total energy consumption, which 26% is for residential buildings and 13% for commercial architectures [4]. In China, 25–30% of the total energy is consumed by civil and industrial buildings [5]. A same scenario in Australia which the building industry consumes 40% of the total energy produced [6]. According to the report issued by EU strategy on heating and cooling 2016, the energy consumption for cooling and heating in buildings demonstrated about 80%. Although less than 20% is presently exploited for cooling purposes, the domestic cooling building still has a high potential for growth. Moreover, the use of the innovative low-energy cooling technologies for heating and cooling will bring fuel savings of 5 Mtoe per year in 2030, corresponding to 9 million ton of CO_2 [7]. Therefore, the annual energy for air-conditioning purposes for a room was increased considerably, which was 1.7 GWh in 1990 and it reached 44 GWh in 2010 [8]. The Mediterranean countries have saved 40–50% of their energy consumed for refrigeration and air-conditioning by using solar-driven air-conditioning system techniques [9, 10]. It is stated that the solar system was able to contribute up to 70% of total energy consumption for heating and air-conditioning for domestic buildings. Many solar cooling technologies such as solar absorption, solar adsorption, desiccant, and ejector systems have been studied by researchers. Among these technologies, solar absorption is the most widely used technology with 59% of the installed systems in Europe against 11% for solar adsorption and 23% for desiccant cooling [11]. Many investigations have been done on solar thermal-driven absorption refrigeration machines in the small range of refrigeration capacity (5–30 kW). Some of the investigation results have been published in [12–14]. A design guide for solar cooling systems is presented in [15].

2. Classification of solar cooling technologies

Solar cooling systems can be classified into two main categories according to the energy used to drive them: solar thermal cooling systems and solar electric cooling systems. In solar thermal cooling systems, the cooling process is driven by solar collectors collecting solar energy and converting it into thermal energy, and uses this energy to drive thermal cooling systems such as absorption, adsorption, and desiccant cycles; whereas in solar electric cooling systems, electrical energy that is provided by solar photovoltaic (PV) panels is used to drive a conventional electric vapor compressor air-conditioning system. Both types of solar cooling can be used in industrial and domestic refrigeration and air-conditioning processes, with up to 95% saving in electricity [16].

2.1. Electricity-driven solar refrigeration systems

In general, the solar electrical cooling system consists of two parts: photovoltaic panel and electrical refrigeration device. Photovoltaic cells transform light into electricity through photoelectric effect. The power generated by solar photovoltaic panel is supplied either to the vapor compression systems, thermoelectrical system, or Stirling cycle.

2.1.1. Solar-powered vapor compression systems

Photovoltaic powered refrigerators are an alternative option to produce cooling in remote areas of developing countries. Photovoltaic cell converts the incident solar radiation to DC power which can drive the compressor of vapor compression system. This system as depicted in **Figure 1** consists of a DC compression refrigerator connected to controller, a battery to supply and store energy, and a photovoltaic (PV) generator which supplies the refrigerator and charges the battery with excess energy. The main advantage of this system compared to the other air-conditioning systems is that it does not require an outside fuel supply. In order to run the system at highest efficiency, the voltage should be close to the voltage produced at the maximum possible power.

2.1.2. Thermoelectric cooling systems (the Peltier cooling system)

Thermoelectric device utilizes the Peltier effect to make a temperature gradient by creating heat flux between two different types of semiconductors materials. Riffat and Qiu [17] defined the Peltier effect as presence of cooling or heating effect at junction of two different conductors due to electricity flow. The main principle of working thermoelectric cooling systems is shown in **Figure 2** and follows these steps: an electric current flows across the joint of n- and p-type semiconductor materials by applying a voltage. When the current passes through the junctions of the

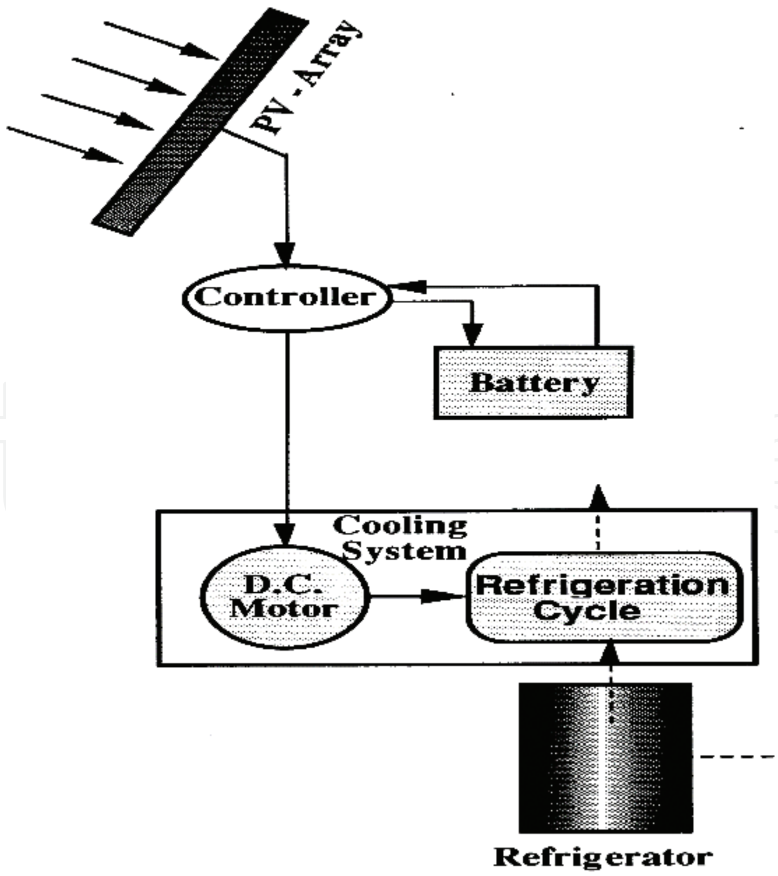

Figure 1. A configuration of a PV solar-powered vapor compression systems.

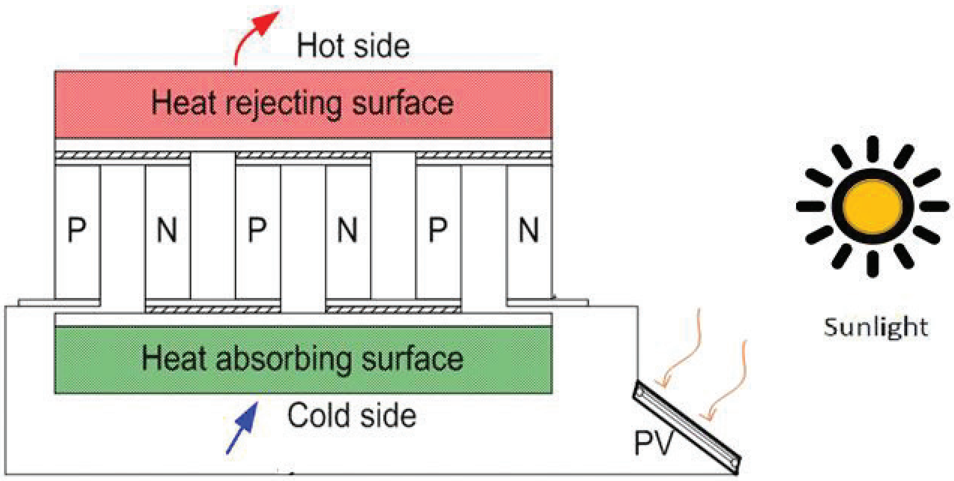

Figure 2. Thermoelectric cooling configuration.

two conductors, heat is removed at one junction and absorbs the heat from its surrounding space to create a cooling effect. Heat is deposited at the other junction. When a direction of the current is reversed, the air-conditioning system operates in the heating manner due to reverse of the heat flow direction. The main advantages of using thermoelectric cooling compared to vapor compression cycle are as follows: (a) compact and lightweight due to no bulky compressor units needed; (b) no moving parts; (c) environment friendly due to no hazardous gases; (d) silent operation; (e) high reliability in which a mean time between failures (MTBF) is more than 100,000 h; (f) precise temperature stability in which a tolerance of better than +/−0.1°C; and (g) finally cooling/heating mode option, which is fully reversible with switch in polarity and supports rapid temperature cycling. But on the other side, high cost and low efficiency are the main disadvantages.

2.1.3. Stirling systems

The cooling cycle is split into four steps as depicted in **Figure 3**. The cycle starts when the two pistons are in their most left positions:

- Process (a→b): Isothermal compression process and heat rejection to the surrounding. Initially, the left warm piston moves to the right while the cold piston is fixed. The isothermal compression process was occurred and the pressure rises, so the heat transfer Q_a is taken to the surroundings at ambient temperature T_a.
- Process (b→c): Constant volume. The two pistons move to the right at the same rate to keep the volume constant, so the volume between the two pistons is kept constant. The hot gas enters the regenerator with temperature T_a and leaves it with temperature T_L. The heat is transferred to the regenerator material.
- Process (c→d): Isothermal expansion process and heat addition from the external source. The cold piston moves to the right while the warm piston is fixed. The isothermal expansion was occurred and the pressure decreases, so the heat transfer Q_L is taken up. This is the useful cooling power.

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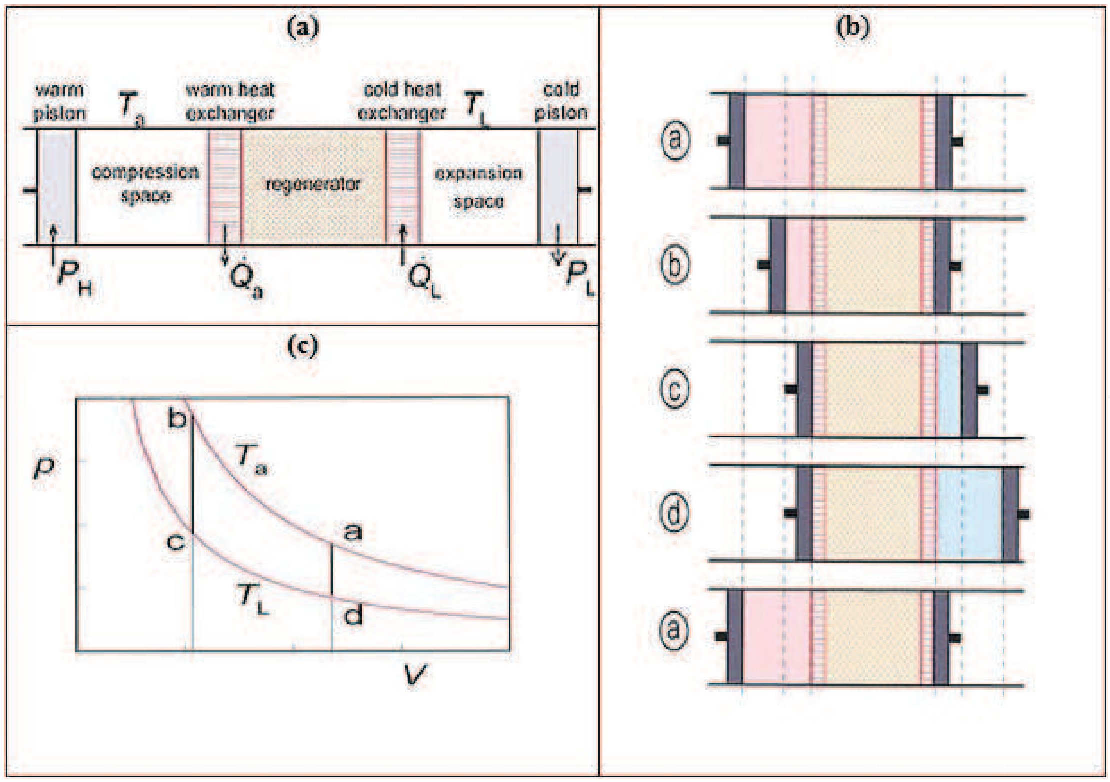

Figure 3. (a) Schematic diagram of a Stirling cooler; (b) four states in the Stirling cycle; and (c) PV-diagram of the ideal Stirling cycle.

- Process (d→a): Constant volume. The two pistons move to the left to keep the total volume constant.
- The gas temperature rises from *TL* to *Ta* so heat is taken up from the regenerator material. This completes the cycle.

2.2. Solar thermal cooling systems

2.2.1. Absorption systems

The absorption refrigeration cycle is one of the oldest refrigeration technologies. Absorption refrigeration cycle operates under the same principle as the conventional vapor compression refrigeration cycle in the refrigerant side. The mechanical compressor in the conventional vapor compression refrigeration cycle is replaced by the thermal compressor in the absorption refrigeration cycle. The thermal compressor consists of absorber and generator. **Figure 4** shows the general schematic of a single effect absorption cycle [18]. The absorption chiller cycle consists of the following steps:

1. The rich solution (rich on coolant) will be pumped from the absorber to the generator passing the solution heat exchanger (economizer).

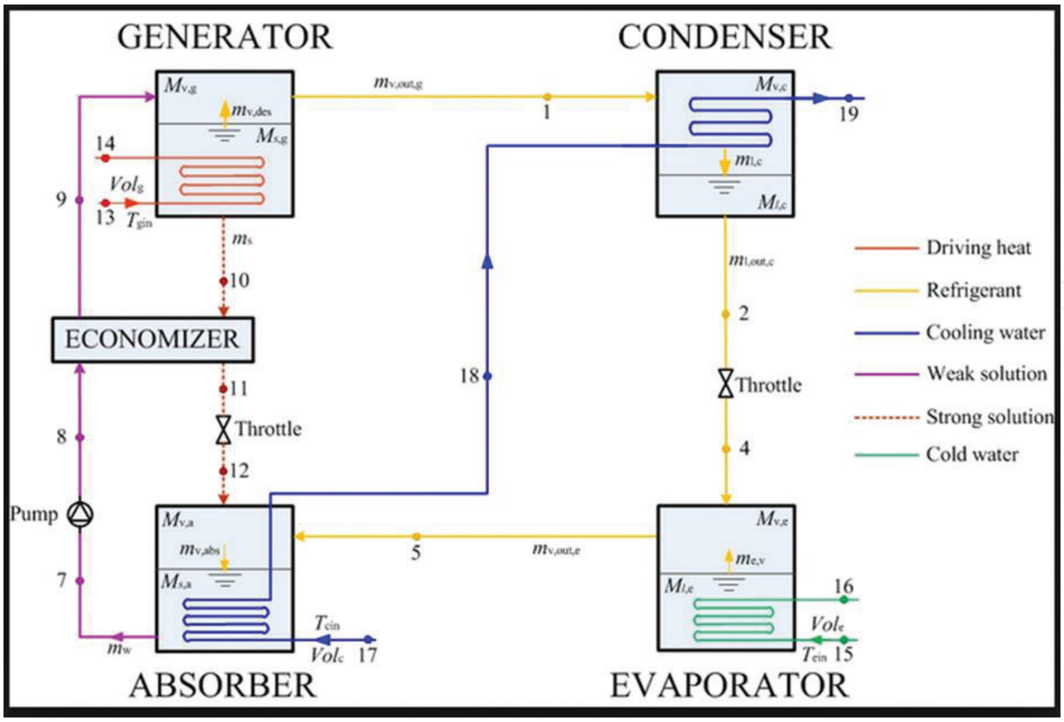

Figure 4. Schematic of the absorption chilling cycle [18].

2. Through the heat supply in the generator from a driving heat source (solar collectors), a part of the coolant will be driven out from the rich solution and flows to the condenser. After that, the remaining poor solution (poor on coolant) flows back to the absorber.

3. In the condenser, the refrigerant vapor from the generator condenses in the condenser. The heat of condensation must be rejected at an intermediate temperature level by the use of the cooling water supplied from a cooling tower.

4. The refrigerant condensate flows back to the evaporator at low pressure through an expansion device. The cycle of the coolant then repeats.

5. In the evaporator, the refrigerant is vaporized at very low pressure to produce the cooling power by extracting heat from the low-temperature medium. The coolant vapor flows to the absorber.

6. In the absorber, refrigerant vapor is absorbed by the poor solution, which flows back from the generator passing the economizer and the throttle. Then, the heat of absorption and mixing is rejected by the cooling water stream supplied from a cooling tower. After that, the cycle of the solution will repeat again.

The two main pairs of refrigerant/absorbent that are widely used are water/lithium bromide (H_2O/LiBr) and ammonia/water pair (NH_3/H_2O), where water is the refrigerant (coolant) and LiBr is the absorbent; while for the second pair, ammonia and water are the refrigerant and absorbent, respectively.

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List of advantages of using water/LiBr pair, which is the most common for solar air-conditioning application, is as follows:

- uses nontoxic substances;
- low working pressures; and
- nonvolatile absorbent, i.e., there is no need of rectification of the refrigerant.

However, there are disadvantages associated with the water/LiBr pair and are as follows:

- Water cooling is required, which is commonly accomplished by a cooling tower. Cooling towers have the risk of legionella;
- Systems have bigger sizes which are due to the large volume of the water vapor;
- Risk of corrosion of the components; and
- Risk of the crystallization of the solution at very low cooling temperatures.

2.2.2. Adsorption systems

Adsorption refrigeration cycle is similar to absorption refrigeration cycle. The main difference in the former is that the refrigerant is adsorbed on the internal surface of highly porous solid material instead of the refrigerant being absorbed by a liquid solution. In the adsorption refrigeration cycle, the solid sorbent and the refrigerant form the adsorption pairs such as activated carbon-ammonia, activated carbon-methanol, activated carbon-ethanol, silica gel-water, and zeolite-water.

Adsorption is a physical or chemical process that is different from absorption, which is a chemical process. Just as there is an attraction between a liquid and a solid at a surface, there is also an attraction between a gas and a solid at a surface. Adsorption is a surface phenomenon which can be divided into physical adsorption (physisorption) and chemical adsorption (chemisorption). Physical adsorption generally resulted by the Van der Waals forces through physical process, and chemical adsorption usually achieved by valency forces through chemical process. The heat of adsorption is usually large in chemical adsorption and small in physical adsorption. Adsorbent substances can be retained to original properties by a desorption process under the application of heat.

The adsorption refrigeration cycle consists of two sorption chambers, a condenser, and an evaporator, as illustrated in **Figure 5**. The adsorption cycle achieves a COP of 0.3–0.7, depending upon the driving heat temperature of 55–90°C.

The working cycle of 5–7 min consists of the following four steps [19]:

1. In the first step, the adsorbed water is desorbed after the application of thermal energy (as example from solar energy). The collector becomes the generator (1).

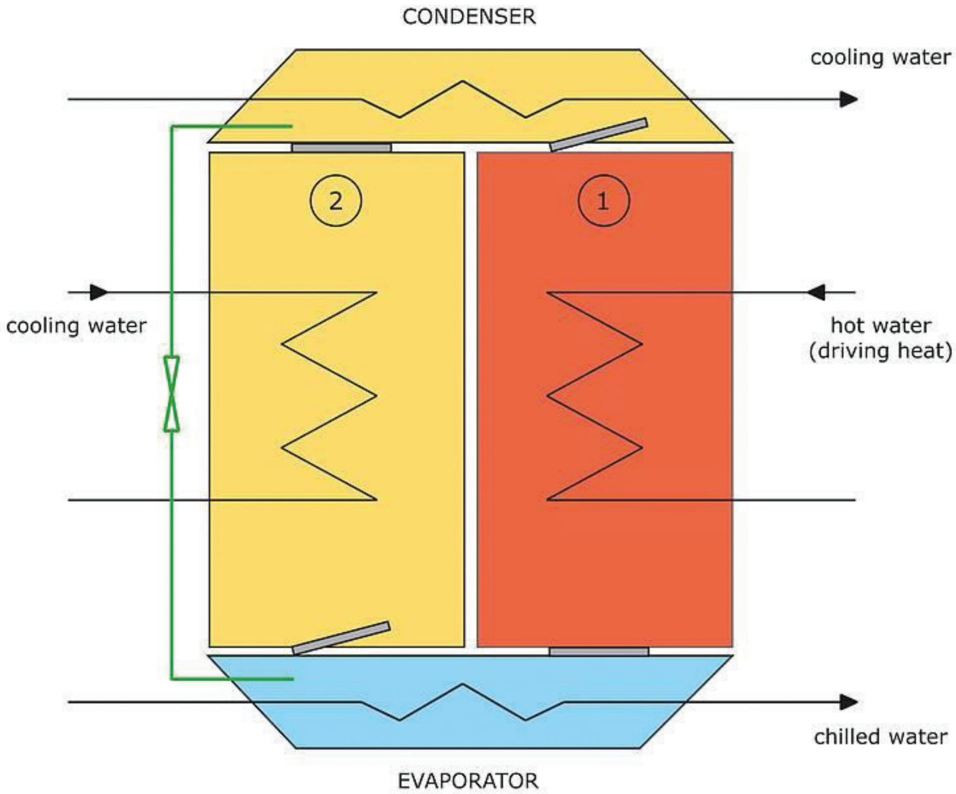

Figure 5. Schematic of adsorption cycle solar cooling system.

2. In the second step, the desorbed refrigerant (water) is cooled and condensed to liquid in the condenser by rejecting the heat through the cooling water supplied from a cooling tower.

3. In the third step, the condensed water flows through the expansion valve to the evaporator, where it vaporizes under low partial pressure and low temperature in the evaporator while the useful cooling is produced, then heat is taken away from the chilled water.

4. In the fourth and final step, the vaporized water is adsorbed in the collector (2) until the silica gel is saturated, then it is switched to the second adsorber chamber.

5. The circuit is completed as the condensed water is fed back into the evaporator through a valve.

6. The functions of two sorption chambers are reversed by alternating the opening of the butterfly valves and the direction of the heating and cooling refrigerants. In this way, the chilling refrigerant is obtained continuously. The cycle then repeats.

Advantages of adsorption chiller systems compared to absorption chiller systems [20, 21] are as follows:

1. The operating temperatures can be lower, e.g., 55–90°C as compared to 70–120°C for absorption chillers.

2. There is no low limit to the temperature reservoir.
3. There is no limitation for the low cooling water temperature, because there is no risk of crystallization problem as in the case of absorption chillers.
4. No risk of corrosion problem as in the case of absorption chillers, because there are heat sources with temperature close to 500°C that can be used directly.
5. The adsorption systems have flexibility in regeneration temperature and do not require frequent replacement of adsorbent.
6. The adsorption systems do not need a rectifier for the refrigerant or solution pump in comparison with absorption systems.

The disadvantages of adsorption chiller systems include [22]:

1. Adsorption technology is more expensive than absorption technology.
2. The average COP of adsorption chillers is lower than the absorption chillers.
3. The adsorption chillers are both heavy weight and larger than the absorption chillers.
4. Heat recovery is very complex, because the adsorption system is intermittent system.

Advantages of absorption and adsorption chiller systems compared to vapor compression systems:

1. Absorption and adsorption systems are environmentally friendly. The equipment uses completely harmless working fluids.
2. The maximum cooling load can be achieved with the maximum available solar radiation and hence potential of the refrigeration system.
3. Maintenance costs are lower due to fewer moving parts like solenoid valves and vacuum pumps. It is almost noiseless system, where there are not many moving parts, other than the solution pump in the absorption refrigeration systems.
4. Taking advantage of solar thermal plants in the sorption refrigeration technology even when there is no heat demand.
5. Operation costs are lower due to low electricity consumption in comparison with vapor compression systems.

2.2.3. Desiccant systems

The desiccant air-conditioning system utilizes the capability of desiccant materials in removing the air moisture content by sorption process. All materials that attract moisture at different capacities are called desiccant [4]. The desiccant cooling system can be a suitable selection for thermal comfort especially in climates with high humidity. Moreover, this technique allows us to utilize renewable energy or low-temperature gains from solar energy, waste heat, and cogeneration to drive the cooling cycle. The comparison between desiccant system and conventional systems is listed in **Table 1**. There are many required properties for any desiccant materials selected in open-cycle cooling based on [23]: (i) mechanical and chemical stability; (ii) large moisture capacity per unit weight; (iii) low heat of adsorption/absorption to regenerate; (iv) sorption rate; (v) large adsorption/absorption capacity at low water vapor pressures; (vi) cheap cost; (vii) sorption at low relative humidity; and (viii) finally ideal isotherm shape.

Two configurations were described in detail below: ventilation and recirculation modes. The schematic of the ventilation mode representation is demonstrated in **Figure 6a**. On the conditioning side of the system (air processing side), warm and humid air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1–2). Since the air is heated up by the adsorption heat, a heat recovery wheel is passed (2–3), resulting in a significant precooling of the supply air stream. Subsequently, the air is humidified and thus further cooled by a controlled humidifier (3–4) according to the set-values of supply air temperature and humidity. In order to control the sensible heat factor, the remix air is introduced by the mix evaporatively cooled room air with the cooled and dried room make-up air (5–6). On the regeneration side of the system, the exhaust air stream of the rooms is humidified (6–7) close to the saturation point to exploit the full cooling potential in order to allow an effective heat recovery (7–8). After that, the sorption wheel has to be regenerated (8–9) by applying heat in a comparatively low temperature range from 50 to 75°C and to allow a continuous operation of the dehumidification process. Finally, the cold and humid air is exhausted to the atmosphere (9–10) and the cooling cycle is completed.

Parameter	Conventional system	Desiccant system
Operation cost	High	Low
Performance	High	Low
Energy source	Mainly electricity	Low-grade energy
Environmental safety	Less	High
System care	Less	High
Control over humidity	Average	Accurate
Indoor air quality	Less	More
System installation	Simple	More complicate
Energy storage capacity	Mainly not applicable	Applicable
Installation cost	High	Low
System control	Average	Complicate

Table 1. The comparison between desiccant system and conventional systems.

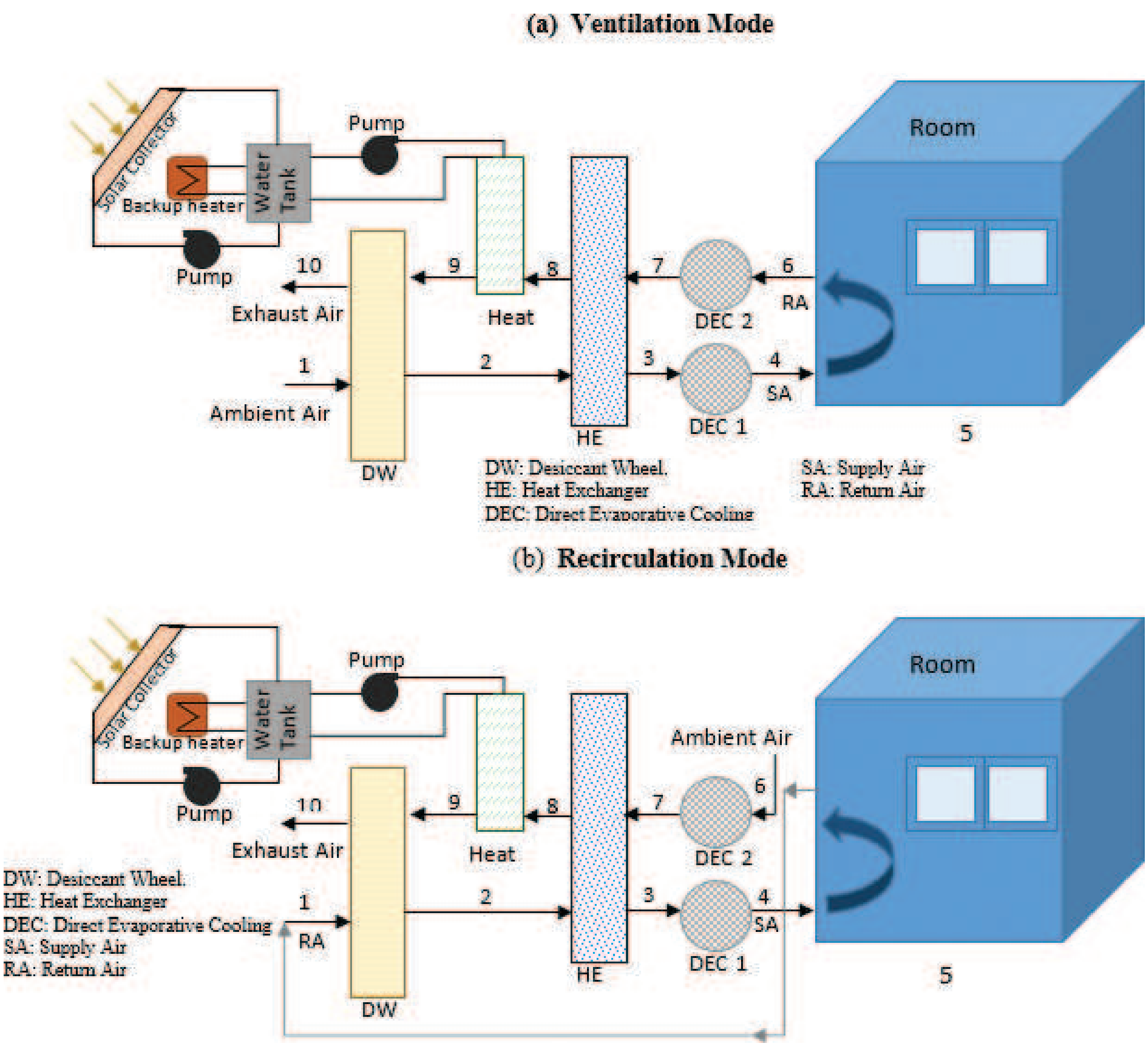

Figure 6. Schematic of desiccant cooling system in (a) ventilation mode and (b) recirculation mode.

The recirculation mode representation is depicted in **Figure 6b**. It uses the same components as the ventilation mode except the process air side in the recirculation mode is a closed loop, whereas the regeneration air side is an open cycle where the outdoor air is used for regeneration.

2.2.4. Ejector systems

A solar-driven ejector cooling system consists of an ejector cooling cycle and a collector circuit. The main components of the system are collector array, generator, ejector, condenser, expansion valve, evaporator, and cycle pump. A schematic diagram of the solar ejector cooling system and its component is presented in **Figure 7**. The working principle of the ejector systems follows the below states [24, 25]:

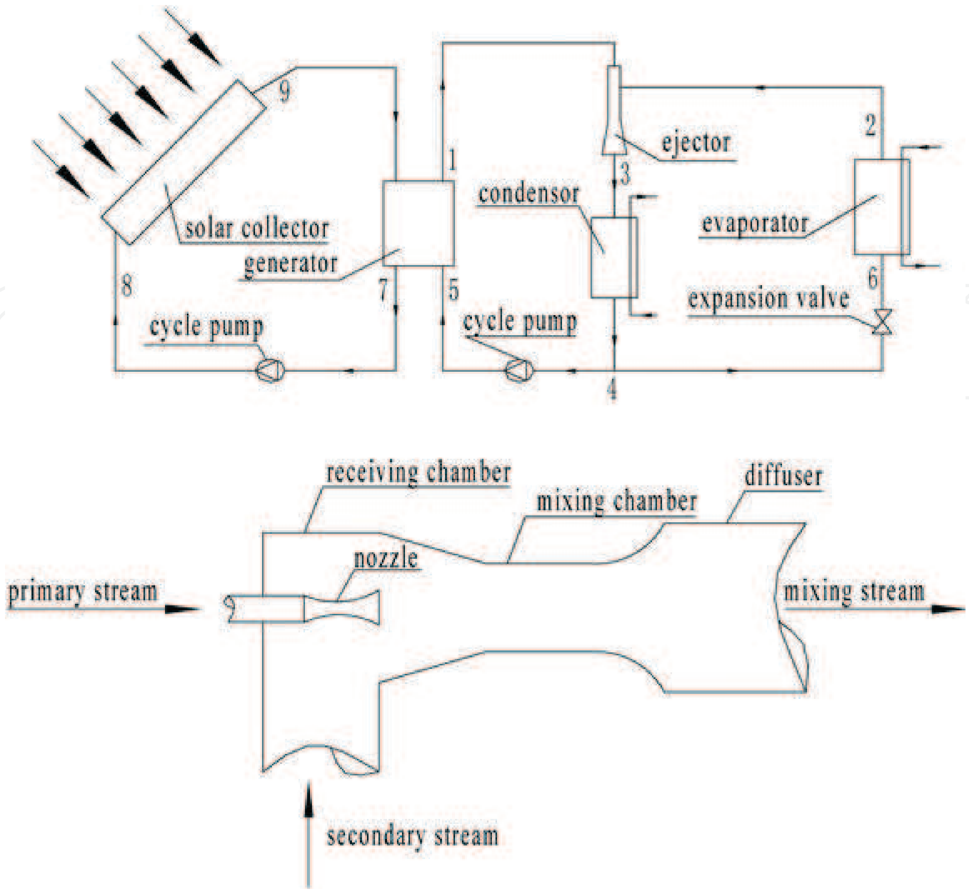

Figure 7. Schematic presentation of the solar ejector cooling configuration.

In the generator, the refrigerant is vaporized as a primary steam by utilizing the solar energy coming from the solar collector. This primary steam leaves the generator at a relatively high pressure and enters the supersonic nozzle of the ejector to accelerate it at supersonic velocity and creating low pressure at the nozzle exit section. This low pressure draws the secondary flow coming from the evaporator into the chamber. The primary and secondary streams are mixed in the mixing chamber. These mixing steams enter into diffuses where increases its pressure to the condensing pressure. The mixing stream discharges from the ejector to the condenser, where the stream is converted into liquid refrigerant by rejection heat to the surrounding. Some part of the liquid refrigerant pumps to the generator and the remaining liquid part leaves the condenser and enters the evaporator through expansion value.

In expansion value, the refrigerant pressure is dropped and this refrigerant enters the evaporator to absorb heat from space that required to cool and the refrigerant is converted into vapor and enters to the ejector.

2.2.5. Rankine systems

One of the promising methods that utilize solar heat to produce mechanical work and then use it to drive a conventional vapor compression cycle is solar Rankine cooling systems. Two different configurations of solar Rankine cooling systems were suggested by different scholars [26]. One

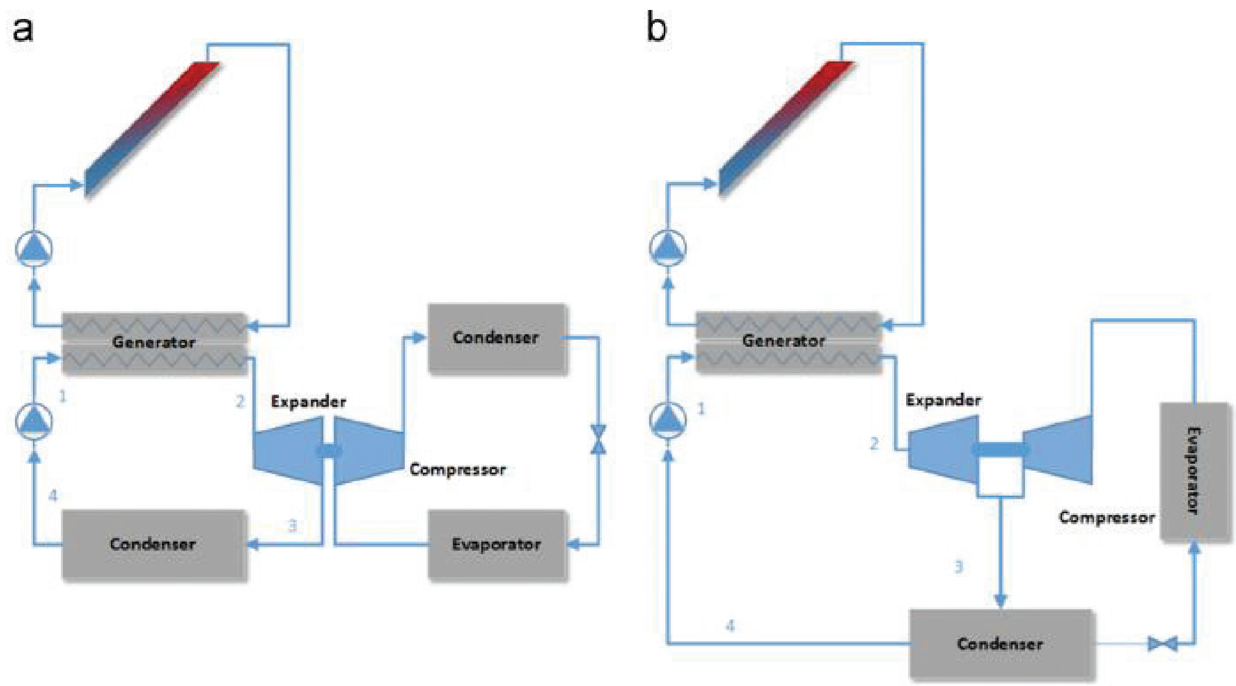

Figure 8. Representation of a Rankine solar cooling system as (a) separate configuration for power and refrigeration cycles and (b) integrated configuration for power and refrigeration cycle.

arrangement is using separate power and cooling system where the compressor of the vapor compression cycle is mechanically coupled with the expander of organic Rankine cycle. Another arrangement is an integrated system by the use of one joint condenser for both cycle coupled with the expander-compressor.

The main advantages of a second configuration are the use of a same working fluid in both loops to remove a leakage and mixing problems. Moreover, the integrated design is simpler but on the other side reduces the system flexibility.

Figure 8 depicts a schematic for two widely solar Rankine cooling system arrangements. In the first loop of organic Rankine cycle, high-pressure liquid coming from the pump is vaporized inside the boiler (state 1) that absorbs the heat from solar collector. The vapor (state 2) enters the expander and produces a useful work which is used to drive a compressor of a conventional refrigeration cycle. The working fluid pressure from the expander outlet is same to the condenser pressure (state 3). After that, a rejection heat to the surrounding inside the condenser converts the working fluid to saturated fluid. Subsequently, a pressure of the working fluid is increased by using pump to enter a boiler as subcooled liquid (state 1).

3. Conclusion

The executed investigations on the field of solar thermal-driven cooling systems and the gained results can be concluded as follows:

- The investigations on solar thermal-driven systems show that solar thermal refrigeration systems are promised technologies, especially in the small and middle cooling capacity ranges.
- The work temperatures have a big impact on the refrigeration capacity of the chiller.
- The higher is the required chilled water temperature, the higher are the refrigeration capacity and the coefficient of performance (COP) of the absorption refrigeration machine.
- The lower is the cooling water temperature; the higher are the refrigeration capacity and the COP of the absorption refrigeration machine.
- There are a big potential for further research at this field to optimize the system operation and to reduce the specific costs (€/kW cooling capacity).

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References

[1] Alahmer A, Wang X, Al-Rbaihat R, Alam KA, Saha BB. Performance evaluation of a solar adsorption chiller under different climatic conditions. Applied Energy. 2016;**175**:293-304

[2] Ajib S. An overview on solar thermal energy for cooling and air conditioning. Annals of Arid Zone. 2010;**49**(3 & 4):275-284

[3] Henning HM. Solar assisted air conditioning of buildings—An overview. Applied Thermal Engineering. 2007;**27**(10):1734-1749

[4] El-Samadony Y, Hamed AM, Kabeel AE. Dynamic performance evaluation of single bed desiccant dehumidification system. International Journal of Renewable and Sustainable Energy. 2013;**2**(1):18-25

[5] U.S. Department of Energy. 2011 Buildings Energy Data Book, Table 1.1.3. D & R International Ltd; 2012. Available: https://ieer.org/wp/wp-content/uploads/2012/03/DOE-2011-Buildings-Energy-DataBook-BEDB.pdf [Retrieved 18th August, 2018]

[6] Boyano A, Hernandez P, Wolf O. Energy demands and potential savings in European office buildings; case studies based on energy plus simulations. Energy and Buildings. 2013;**65**:19-28

[7] Zhu S, Chen J. A simulation study for a low carbon consumption HVAC project using energy plus. International Journal of Low Carbon Technologies. 2012;**7**(3):248-254

[8] Baniyounes AM, Ghadi YY, Rasul MG, Khan MM. An overview of solar assisted air conditioning in Queensland's subtropical regions, Australia. Renewable and Sustainable Energy Reviews. 2013;**26**:781-804

[9] EU Commission. Communication from the Commission to the European Parliament: The Council, the European Economic and Social Committee and the Committee of the Regions—An EU Strategy on Heating and Cooling. Brussels; 2016;**2**:2016. Available: https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-51-EN-F1-1.PDF [Retrieved 18th August, 2018]

[10] Clausse M, Alam KC, Meunier F. Residential air conditioning and heating by means of enhanced solar collectors coupled to an adsorption system. Solar Energy. 2008;**82**(10):885-892

[11] Balaras CA, Grossman G, Henning HM, Ferreira CA, Podesser E, Wang L, Wiemken E. Solar air conditioning in Europe—An overview. Renewable and Sustainable Energy Reviews. 2007;**11**(2):299-314

[12] Hamdeh NH, Mu'Taz A. Optimization of solar adsorption refrigeration system using experimental and statistical techniques. Energy Conversion and Management. 2010;**51**(8):1610

[13] Ajib S, Günther W. Solar thermally driven cooling systems; some investigation results and perspectives. Energy Conversion and Management. 2013;**65**:663-669

[14] Kohlenbach P, Jakob U. Solar Cooling: The Earthscan Expert Guide to Solar Cooling Systems. 1st ed. Routledge; 12 August 2014

[15] Daniel Mugnier D, Neyer D, White S. The Solar Cooling Design Guide—Case Studies of Successful Solar Air Conditioning Design. Wilhelm Ernst & Sohn, Verlag für Architektur und Technische Wissenschaften GmbH & Co. KG; 2017. DOI: 10.1002/9783433606841

[16] Desideri U, Proietti S, Sdringola P. Solar-powered cooling systems; technical and economic analysis on industrial refrigeration and air-conditioning applications. Applied Energy. 2009;**86**(9):1376-1386

[17] Riffat SB, Qiu G. Comparative investigation of thermoelectric air-conditioners versus vapour compression and absorption air-conditioners. Applied Thermal Engineering. 2004;**24**(14-15):1979-1993

[18] Wang J, Shang S, Li X, Wang B, Wu W, Shi W. Dynamic performance analysis for an absorption chiller under different working conditions. Applied Sciences. 2017;**7**(8):797. DOI: 10.3390/app7080797

[19] Al-Rbaihat R, Sakhrieh A, Al-Asfar J, Alahmer A, Ayadi O, Al-Salaymeh A, Al_hamamre Z, Al-bawwab A, Hamdan M. Performance assessment and theoretical simulation of adsorption refrigeration system driven by flat plate solar collector. Jordan Journal of Mechanical and Industrial Engineering. 2017;**11**(1):1-11

[20] Behbahani-nia A, Sayfikar M. Study of the performance of a solar adsorption cooling system. Energy Equipment and Systems. 2013;**1**(1):75-90

[21] Alsaqoor S, Alahmer A, Chorowski M, Pyrka P, Rogala Z. Performance evaluation for a low temperature heat powered for 3-beds with dual evaporators silica gel water adsorption chillers. In: 2017 8th International Renewable Energy Congress (IREC); IEEE; 2017. pp. 1-6

[22] Fasfous A, Asfar J, Al-Salaymeh A, Sakhrieh A, Al_hamamre Z, Al-Bawwab A, Hamdan M. Potential of utilizing solar cooling in the University of Jordan. Energy Conversion and Management. 2013;**65**:729-735

[23] Alahmer A. Thermal analysis of a direct evaporative cooling system enhancement with desiccant dehumidification for vehicular air conditioning. Applied Thermal Engineering. 2016;**98**:1273-1285

[24] Varga S, Oliveira AC, Diaconu B. Analysis of a solar-assisted ejector cooling system for air conditioning. International Journal of Low Carbon Technologies. 2009;**4**(1):2-8

[25] Zhang B, Lv JS, Zuo JX. Theoretical and experimental study on solar ejector cooling system using R236fa. International Journal of Low Carbon Technologies. 2013;**9**(4):245-249

[26] Zeyghami M, Goswami DY, Stefanakos E. A review of solar thermo-mechanical refrigeration and cooling methods. Renewable and Sustainable Energy Reviews. 2015;**51**:1428-1445

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