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Review Article

Solar Assisted Sustainable Built Environment: A Review

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Abstract

The present review summarized the application of renewable solar energy in various cooling techniques to produce thermal comfort of the built environment. Solar assisted cooling is the newer sustainable cooling technology which can be used to develop thermally stable built environment within residential and commercial buildings. Furthermore, the same is environment friendly and energy efficient. It is stronger tool to fight the devil of global warming. It may also be used for air conditioning in medical emergency in remote areas where the electricity supply is not available. There is an ameliorated interest in the progressive development and elaborated use of solar assisted cooling technologies due to their various economic and impressive environmental benefits, enabling freely available renewable solar energy to be used for applications such as district cooling system networks. Compared to traditional systems this creates new possibilities for utilizing low temperature based naturally available free energy.

Keywords: Desiccant cooling; Green energy; Renewable solar heat; Sustainable cooling energy

Abbreviations: CFC: Chloro Fluro Carbon; CPC: Concentrating Plate Solar Collectors; COP: Coefficient of Performance; DCS: Desiccant Cooling System; DESRAD: Desiccant Enhanced Nocturnal Radiation; VCS: Vapour Compression System; PVC: Photovoltaic Solar Collectors; TE: Thermo-electric systems

Introduction

Sincere efforts are required in the energy production sector to save the planate earth against global warming phenomenon by rapid growth of renewable solar energy. Global warming mainly responsible for the release of CO_2 from fossil fuel based thermal power plant. Worldwide strict environmental policy should be implemented to minimize the use of CFC based air conditioning system to protect the ozone layer. Day by day world overall energy consumption have been increased exponentially. So, it is high time to minimize the production of greenhouse gases for energy sector by use of sustainable solar energy. Maintaining thermally comfort environment in building indoor space is responsible for around 56% of overall building energy consumption. This figure may increase in hot and humid environment. Moreover, the life of fossil fuels is limited to regular supply across the world as oil remains the primary energy source. So, it is high time to reconsider the renewable energy sources as regular energy supply sources to dampen the global temperature rise due to global warming. Public awareness should be increased to develop more and more application of this solar energy sources like as solar roof top energy supply system and renewable solar based sustainable cooling technologies. This energy supply is independent of the petroleum-based fossil energy sources to provide major part of primary energy supply for various building heating and cooling applications to make sustainable built environment. Solar energy resources are mainly available at cheaper rate due to its free availability during most of the sunny days round the year in most part of the world.

The solar cooling availability is in-line with the peak demand of cooling at the time of hot summer when the intensity of solar radiations is also found very high. Various types of solar cooling technology in the different applications as shown in Figure 1 can substantially dampen the environmental impact and the energy consumption issues demanded mostly by conventional vapor compression based traditional air-conditioning systems. Therefore, the purpose of the review is to provide an overview of the renewable solar energy based comfort cooling technologies that utilize freely available solar radiations to supply the primary energy and introduce their prospects as environmentally sustainable solar powered cooling technologies as compared to traditional cooling [1-3].

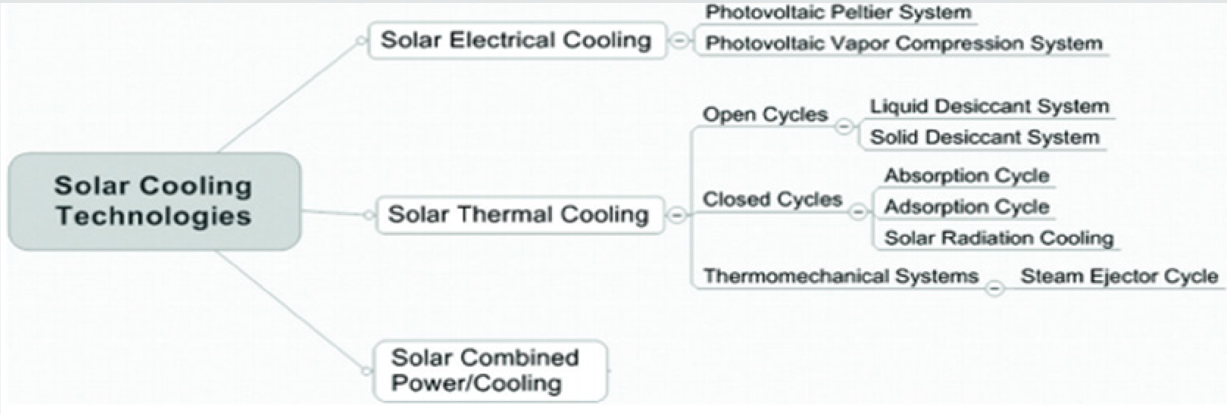

Figure 1: Classification of various solar cooling systems.

Solar Thermal Cooling

In solar powered cooling thermal energy produced by solar heat receiving by use of different solar collectors is utilized for cooling the indoor building space. Solar radiations received from sun are converted into electricity by chemical process occurs in various PV modules. This solar-thermal energy conversion process can be categorized into open sorption cycles, closed sorption cycles, and thermo-mechanical systems [4].

The solid or liquid desiccant assisted sorption cooling systems that are used for either dehumidification or humidification by use of moisture control and cooling the humid air especially in hot and humid climate. Mainly, desiccant systems dehumidify the moist air by travel from one airstream to another by using two fundamental sorption principles. The former convey moisture from process to regeneration air stream due to the deviation in vapor pressure among the two. i.e. moisture laden humid air and dry desiccant matrix of the rotary dehumidifier. Moisture from humid air transfers to the surface of desiccant material by the process of adsorption between two air streams. The exited dry and heated air is further processed to the cooling in heat exchanger. The rotary dehumidifier needs periodically reactivating the same by passing the hot air in regeneration section of the same to make the dehumidifier working for the next cycle as shown in Figure 2. To provide the heat for the regeneration of the dehumidifier can be utilized by use of renewable solar energy. This can be explained in detail in the Figure 3. The silica gel is commonly used solid desiccant while the $CaCl_2$ is commonly used liquid desiccant material in the cycle [5].

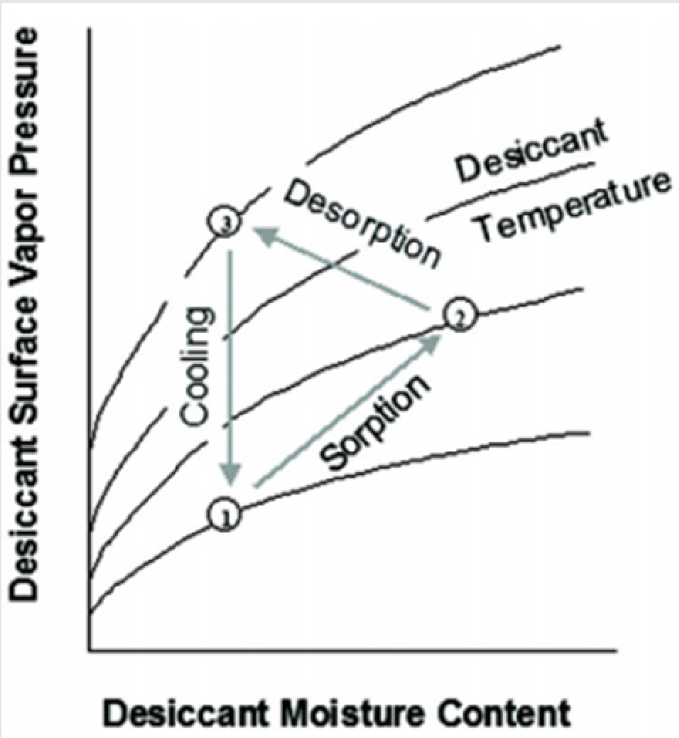

Figure 2: Operating principle of desorption cooling systems.

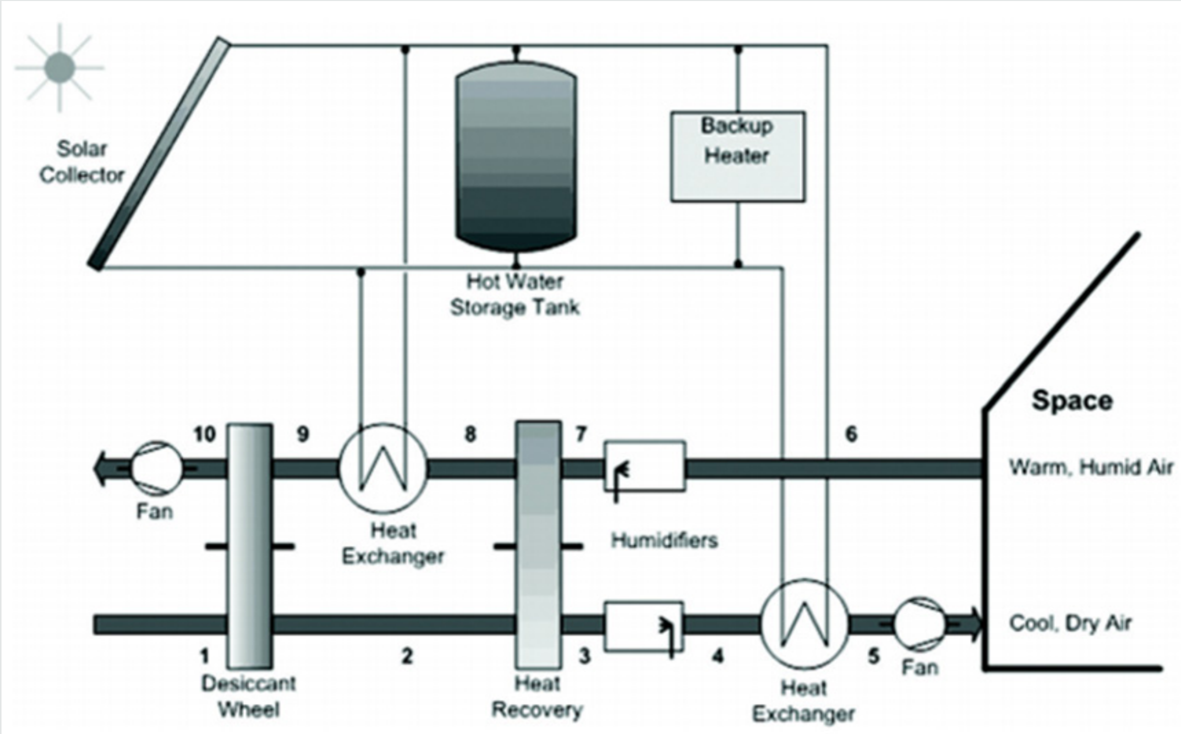

Figure 3: Schematic layout of solar powered desiccant cooling.

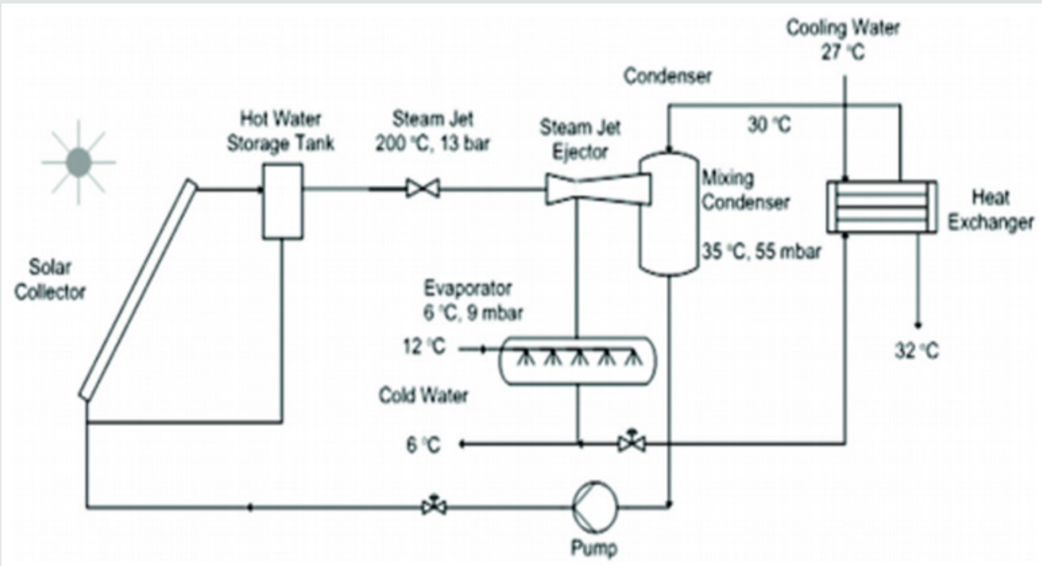

Figure 4: Working principle of solar powered absorption cooling system.

The solid desiccants adsorb the moisture at its surface without any further chemical reaction. However, liquid desiccant materials remove water vapor form the moist air by undergoing a chemical or physical change during absorption of the same [6]. There are different ways to provide regeneration energy for the desiccant reactivation. Solar thermal energy can save the high-grade electricity for reactivating the desiccant materials having temperature in the range 50-70 °C. Different types of solar collectors available in the market having their efficiency between 30-65%. The coefficient of performance (COP) obtained by this solar powered desiccant cooling cycle is in the range 05-1.8 based on primary energy supply. The performance of the solar powered hybrid cooling system can be ameliorated further if the humidity is increased further in the tropical climate [7]. The absorption cycle explained by the schematic layout in Figure 4 shows to be used as the absorption refrigeration cycle. In which compressor used in the conventional vapor compression (VC) cycle can be replaced with the absorber-regenerator assembly in the cycle. In the absorber, the absorbent-rich solution is mixed with the refrigerant in some fixed proportion according to cooling requirement. During this process, the absorber pressure gets reduced by removing the absorption heat to the outdoor environment. Then the solution pump adjusts the high-pressure requirement according to mixture strength. The heat necessary for the regenerating the solution can be provided from solar thermal energy. The rest of function of condenser is same as the conventional cooler. Some commonly used absorber and refrigerant pair are as water and lithium bromide as well as ammonia and water. This absorption system can be generally suited to large capacity for cooling and refrigeration requirement [8].

The working of water and lithium bromide can be limited by the early freezing point temperature of water. This can be extended further by use of ammonia and water absorption system by using water as absorber and ammonia as refrigerant used in the system. The toxic nature of ammonia needs special precautions against leakage in the system [9-11]. The solar collectors mainly used in solar powered cooling technologies can be categorized as following:

- flat plate solar thermal collectors;
- evacuated tubes air and water thermal collectors;
- stationary solar thermal collectors;
- non-imaging concentrating collectors such as CPC;
- dish type concentrating solar thermal collectors;
- linear focusing type solar thermal concentrators;
- solar ponds;
- photovoltaic (PV) systems; and
- thermoelectric (TE) systems.

The solar assisted adsorption refrigeration system is the most promising alternative cooling technology because it is eco-friendly with cheaper in first cost, ameliorated efficiency, easy to manufacture and minimum maintenance requirements [12-16].

The steam ejector cooling cycle depicted in Figure 5 is type of the thermo-mechanical cooling system. It shows that the steam ejector cycle coupled to parabolic type solar thermal collector. The steam generated by high temperature developed by the solar collector is first passing through the steam ejector. During this process, the evaporator pressure is lowered due to pressure difference, and water is evaporated in the evaporator by absorbing the heat from the cold water. When cooling is not required, the auxiliary connected steam turbines with the cooler can be used to produce electricity. Most of the steam ejector cycle requires steam at pressures in the range of 0.11-1.2 MPa, and temperatures in the range of 122 °C-185 °C. The rest of the whole cycle is working at normal atmospheric pressure [17-20].

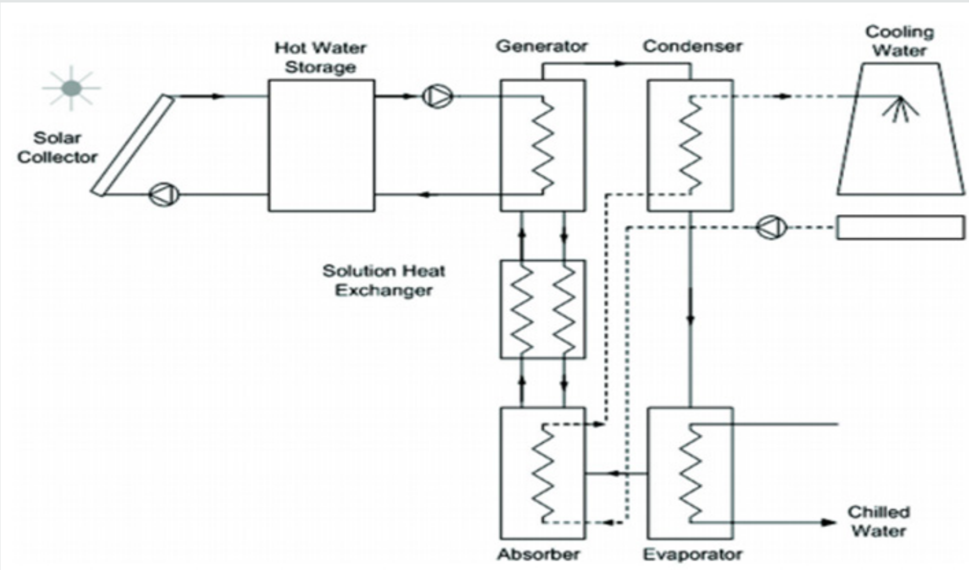

Figure 5: Working of steam jet assisted solar cooling cycle [7].

Comparison between different solar cooling cycles

The coefficient of performance based on the primary energy (thermal) supply can be compared for the different types of solar thermal cooling techniques has been tabulated in Table 1. It is seen that the single-effect absorption systems had a thermal coefficient of performance obtained between range of value 0.502-0.731, while in the case of the adsorption systems, thermal coefficient of performance obtained is comparatively lower around 0.591, similarly, in case of liquid desiccant based thermal cooling system having thermal coefficient of performance slightly higher for solar heat supply as 0.742, while in case of the solid desiccant assisted cooling thermal coefficient of performance based on solar heat for the regeneration of desiccant is obtained around 0.512, and a steam jet thermal cooling the value of thermal coefficient of performance has obtained maximum among the all above discussed cased is 0.85. The range of operating temperature in solar thermal cooling is different for different configurations as absorption systems working in the range of 62 °C-164 °C, while adsorption systems working at comparatively lower temperature range of 54 °C-85 °C, similarly, a liquid desiccant based solar thermal cooling temperature obtained as 68 °C, and a steam jet system working at temperature comparatively higher as 118 °C. For most of these systems operated below 105 °C, the flat-plate solar thermal collectors can obtain this limit temperature, similarly in case of the concentrating type solar thermal collectors obtained comparatively temperature higher than 105 °C. The annual thermal coefficient, can be given as ratio between the annual cooling capacity and the annual solar thermal energy input, can be given by kW-hour. It is found that the lithium bromide water absorption cooling is having highest annual performance, while the adsorption thermal cooling found poor annual performance. Based on above result is seen that the 72% of the all cooling systems employed an absorption cycle due to its better performance [21-22].

Table 1: A brief review about various solar assisted cooling systems.

Process type	Closed		Open		Thermomechanical
cycles	Absorption cycle	Absorption cycle	Solid desiccant	Liquid desiccant	Ejector cycle
Sorbent type	Solid	Liquid	Solid	Liquid	_
Working fluids (Refrigerent/sorbent)	H_2O/silica gel	H_2O/LiBr	H_2O/silica gel	Water/$CaCl_2$	Steam, FC
		NH_3/ H_2O	Water/LiCI/cellulose	Water/LiCl	
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° (most) (single stage) 60 °C - 110°C 130°C-165°C (two stage)	45°C – 9s5°C	67°C	118°C

Desiccant assisted cooling and air conditioning system is the future technology for the large cooling requirement by the industries to condition large area because of applicability of renewable solar energy for regeneration heat supply for its economy operation. So that is environmentally viable and eliminate the use of CFCs based refrigerants which are responsible for ozone layer depletion. Moreover, it may possible to make use of industrial waste heat of process and power plant industries. Thus, it lowers peak electricity demand. Also, this innovative cooling technology can make use of the renewable solar thermal heat energy for its working and minimize the use of high-grade electricity. This will minimize the emission of CO_2 in environment by the thermal power plant which is mainly responsible for the global warming [23].

Current investigations on advances in solar powered desiccant cooling systems aims to research on hybrid desiccant materials that are regenerate at nearly ambient temperature conditions so that the use of solar heat or industrial waste heat can be effectively used. Due to its eco-friendly and greater operational economy desiccant cooling can be emerged as potential alternatives to the vapor compression based traditional air conditioners in the coming days. Moreover, the use of the desiccant cooling can ameliorate the indoor air quality, solar solid desiccants and liquid desiccants are still under research as to find out most efficient and effective way of their regeneration heat supply. The recent concept of hybrid cooling in which a desiccant bed integrated in the roof along with a traditional vapor compression-based cooling system to achieve both latent and sensible cooling in hot and humid climates in the tropical regions called a desiccant enhanced nocturnal radiation (DESRAD). By use of this innovative cooling concept, the sensible cooling is obtained during the night and the desiccant is reactivated effectively during daytime by application of freely available renewable solar energy.

The operation of this hybrid cooling can be carried out in two operating modes: adsorption mode during nighttime; while the other is daytime desorption mode. During the cooled nighttime, comparatively cooled air is circulated by passing through desiccant material laden bed provided on the roof where the water vapor from humid air eliminated to make it dry. The heat of sorption is transferred to the outside colder ambient during nighttime. After the dry and comparatively warm dehumidified air coming out of the desiccant material laden large bed area, it passes over an evaporative cooler post cooling of desorbed air before supply to the conditioned indoor space. While circulating through room, it absorbs both the heat and moisture from the space while maintaining the indoor conditioning of room. The process of attracting and holding evaporate room depending on proportion of water vapor as per latent heat load of the room or humidity level. For the regeneration of desiccant bed use of solar energy is the prominent option. Thus, integration of desiccant cooling with the traditional vapor compression-based cooling results into hybrid system which saves more than 46% of cooling power and substantially lowers its operating cost. Thus, solar powered thermal cooling is the key to ameliorate the cost energy savings in cooling the building. This way of sustainable cooling is the new way for future research and demonstration projects in field of built environment [24-25].

Conclusion

Energy dependency of indoor thermally cooling system can be reduced to the great extent by use of renewable solar energy in various cooling and air-conditioning applications in residential and industrial sector. Exponential rise in building cooling demand is associated mainly with the recent climate change and is projected to increase further in the coming future due to globally changing environmental condition; the cooling technologies based on solar energy are promising alternatives for the future cooling and air-conditioning applications. Through this review of the available solar powered renewable space cooling systems, their performance potential and their advancement have been reviewed in detail. Moreover, the further research and investigations on the use of advanced solar collectors to achieve still better solar collecting efficiency and generation temperature can be seen as the most important topic in additional investigations in near future in the field of renewable solar cooling technologies in maintaining sustainable built environment.

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