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A REVIEW ON SOLAR COOLING TECHNOLOGIES

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ABSTRACT

Solar energy is a renewable and efficacious source of energy which is most fundamentally used in recent and evolving technologies. Solar Cooling is one such technology which uses the energy produced from the solar photo-voltaic cell to generate cooling which further can be utilized for refrigeration and air conditioning applications. Developments in the field of solar-powered cooling systems have increased the scope of future research and global usage. This paper provides a review and analysis of different solar cooling technologies that can be implemented to generate a cooling effect in various applications. In this paper, Solar Thermal and Electrical technologies are discussed with different attributes which can be utilised for comparison, reflecting the advantages and correct usage for each technology.

Keywords: Cooling technologies, photovoltaic cell, solar cooling, solar electrical cooling, solar thermal cooling.

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1. INTRODUCTION

As the growth rate of industrialization is increasing exponentially, energy consumption is also increasing rapidly. These energy requirements must be assisted well with renewable resources, as the dependency on fossil fuels will soon exhaust them fully. Studies show that the reserve for oil and natural gas will last up to 50 years [1]. Solar energy is the most fundamental and powerful source of renewable energy. It is easy to collect, available in abundance and environment-friendly. The potential estimates of Solar energy in India are about 68% [2]. Solar photovoltaic cells can efficiently generate energy from solar radiation. The photo-voltaic cells are semiconductor devices which transform solar energy into the electrical energy by the photoelectric effect. Use of several techniques in the scope of photo-voltaic grids can generate maximum energy [3]. Experiments show that the efficiency of a photo-voltaic panel increases with a decrease in its temperature [4]. For every 274.15K rise in temperature, the efficiency of the panel decreases by 0.4-0.65% [5]. The Research concluded that water cooling can enhance the efficiency of the panel by 14% [6]. Solar Cooling is a technique which takes energy from solar radiation and uses its energy to decrease the temperature and produces cooling. Solar Cooling technologies that are majorly used are Solar Thermal and Solar Electrical Cooling technology. In solar thermal cooling systems, the thermal energy generated from solar radiations is used to drive thermal cooling systems such as desiccant, absorption and adsorption cycles and in solar electrical cooling systems, electrical energy is used for conventional vapour compression cycles.

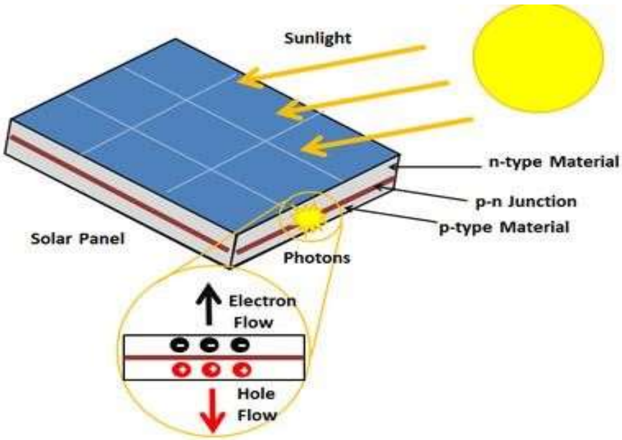

Figure 1 Diagram of a solar panel *[20]*

Thermoelectric technology based on Peltier effect can also be effectively used in solar cooling. Among other solar cooling technologies, absorption cooling has the highest COP of approximately 0.8 [7]. Further, these technologies are compared based on various attributes such as COP, cost, applications, size, etc.

Solar Cooling has great potential in future involvements in innovation and researches. It can fulfil the huge cooling demands with effective pollution control.

2. LITERATURE REVIEW

Yunho Hwang et al. [8] reviewed the solar-assisted cooling technologies based on their COP and efficiency. Further, the implementation of collector technology coupled with the technologies is discussed that will enhance the overall system efficiency. The performance of the solar technologies is evaluated and results are generated. They investigated, that the Adsorption cycle is more efficient because it required less heat source temperature. Also, vacuum tube collectors have higher solar collector efficiency. Future researches can help to achieve cheaper versions of flat plate collector with greater efficiency.

Albers et al. [9] reviewed developments on sorption cooling systems. Sorption process Solar Assisted Cooling can be achieved by either using closed-cycle to generate cold water and further using it fan coil units or ceilings and the heat is rejected by using a heat rejection coil, or by using an open cycle. Both technologies are further used with chillers. Optimum technology combination of system and collector can be founded by considering the cooling magnitude. Future innovations are for sure required to achieve an efficient chiller with optimized cost.

Abdul Ghafoor et al. [10] analysed different installed solar thermal cooling technologies based on several aspects such as COP, area of the collector (Ac), per unit chiller capacity and volume of the storage tank (V) per unit area of the collector. Further, the experimental data has been simulated. The simulated COP of a combination of solar thermal collectors and sorption chillers are greater than the experimental data. Also, the COP increases by increasing the hot water inlet temperature of the chiller.

Abo Elmaaref et al. [11] investigated that the coefficient of thermo-electric performances can be enhanced by optimum design considerations and configuration. Use of better semiconductor metal can improve the efficiency of the system. Future development can improve thermoelectric based cooling technologies which can help in preventing O-zone depletion and will be a clean form of technology.

Ayman Jamal Alazazmeh et al. [12] reviewed and compared different solar cooling technologies i.e. solar electrical refrigeration system, thermo-mechanical combined power cooling systems and advanced triple effect refrigeration cycles based on different attributes. Then further, advantages and disadvantages can be made considering different attributes of comparison. Processes based on absorption cycles are implemented and used in the recent market by several different companies.

M. Usman [13] calculated the overall performance of the cooling technologies based on COP, capital cost, environmental Impact, operating temperature and technology maturity. Considering the advantages in each area, the best technology can be selected by blending the advantages of all. Also, Adsorption cooling is recommended for future improvement in this field.

Swapnil Ghatol et al. [14] discussed the use of the two-wheel desiccant system using solar heat for desiccant regeneration. A heat exchanger wheel is purposely matched with the desiccant wheel due to which, the heat exchanger recycles the heat for regeneration improving the efficiency. Research indicated that the Hybrid Desiccant/Vapour Compression Air-conditioning can be a better option due to its 30 to 80% increase in energy saving. Simulations can be considered for energy saving when operating under variable load conditions. Systems like Dehumidifier with vapour compression system in series and indirect evaporative cooler can be considered for future research.

Salman Ajib et al. [15] analysed different available Solar Cooling Technologies based on different attributes to recognise their advantages and disadvantages. Technical input parameters considered are performance, humidity control, indoor air quality, energy storage capacity, installation and costs involved. Research indicated that the capacity of chiller is greatly affected by variations in the temperature range. Also, the temperature of the cold water depends on the magnitude of COP and refrigeration capacity.

Rishi et al. [16] analysed various factors that can be used in choosing the right solar cooling technology for suitable implementation. Factors considered are an effect of temperature on efficiency, solar radiation and operating conditions. Solar cooling techniques are also suggested such as active cooling, passive cooling, heat pipe cooling, nano-fluids and thermoelectric cooling. The study indicates that the efficiency of Passive cooling is generally low due to natural ventilation. Active cooling has higher efficiency so they can be implemented where large cooling is required. On the other hand, Active cooling is costly due to heavy maintenance in comparison to Passive cooling.

3. CLASSIFICATION OF SOLAR COOLING TECHNOLOGIES

Solar thermal cooling technology can be broadly classified into open and closed cycle technology. The comparison of open-cycle cooling technology includes solid and liquid desiccant systems. On the other hand, closed-cycle cooling technology includes the comparison of absorption and adsorption cooling technologies. Solar electrical cooling technologies can be categorised into thermo-electrical (Peltier) and vapour compression cycle technology. These are further compared based on key attributes. In Solar thermal cooling technologies, thermal energy generated from solar radiations is transformed to cooling through different chemical and physical processes. Open sorption cycle represents Desiccant systems that can be utilised for humidification and de-humidification in air-conditioning applications.

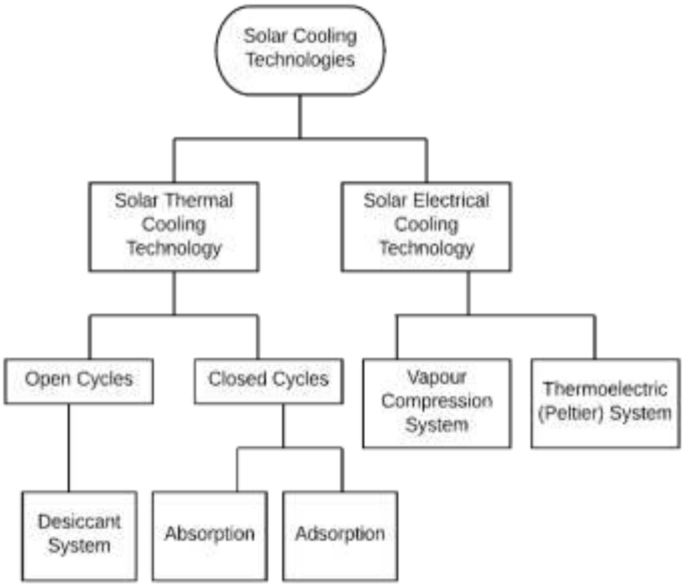

Figure 2 Classification of solar cooling technologies

These systems transfer moisture from one air stream to another. The liquid desiccant system uses a conditioner and a regenerator for generating the cooling. Dehumidification and regeneration are important processes for a liquid desiccant system. In solid desiccant systems, the air is passed through a solid desiccant such as silica gel for dehumidification and further to decrease its temperature by evaporative cooling. Closed sorption system represents absorption and adsorption cooling systems. Absorption cooling systems use a thermal compressor in its refrigeration cycle. The thermal compressor consists of an absorber and a generator. The basic absorption cycle can be depicted in fig. 3.

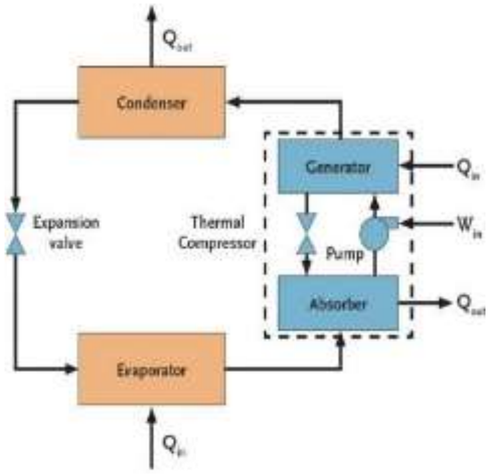

Figure 3 Schematic of absorption cycle [21]

In Adsorption cooling system, the refrigerant is absorbed on the surface of the solid sorbent material. The refrigerant thus forms a pair with the solid sorbent. Some commonly used pairs are water-silica gel and water zeolite.

Solar electrical cooling systems use electricity obtained from photovoltaic panels for vapour compression systems and thermoelectric systems. Vapour compression systems use electricity generated by photovoltaic panel to drive mechanical compressors. These systems have a higher COP in comparison to other systems. The solar vapour compression cycle is represented in fig. 4.

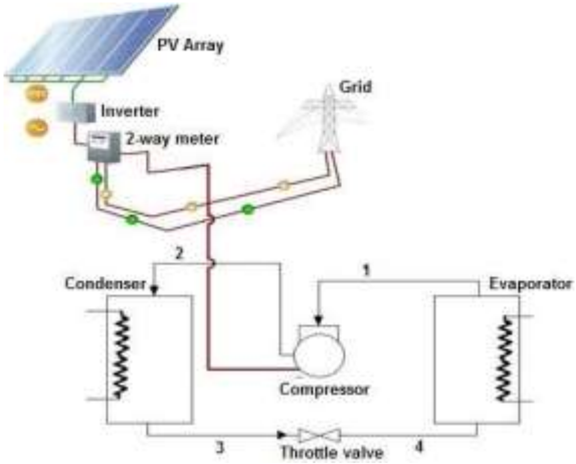

Figure 4 Solar vapour compression cycle [22]

Thermoelectric cooling technology uses the Peltier effect to generate cooling. A temperature difference is created when dissimilar electrodes connected with a semiconductor are given voltage. One side of the plate produces cooling and the other side produces heating. Thermoelectric cooling is less efficient than the compressor-based cooling systems.

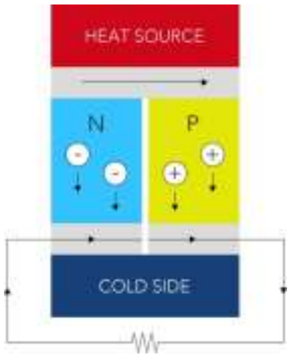

Figure 5 Thermoelectric cooling [23]

Fig. 5 represents thermoelectric effect. The efficiency of the whole module and system can be enhanced by using multi-stages [17].

4. METHODOLOGY

In this paper, a review of present solar cooling technologies is presented. The first step followed towards generating this review, is to create a database and further a literature review based on the rectified database. The literature review is an outline of different contributions by various authors on the relevant context. The next step towards the development of this review was to select the key attributes that will be used in the comparative study of the technologies. Further, the technologies are evaluated based on key attributes that are considered for analysing their potential. The key attributes considered in this review are Performance (COP), applications, cost, size (dimensions) and advantages & disadvantages.

Figure 6 Methodology

5. SELECTION OF KEY ATTRIBUTES

The solar cooling technologies are compared based on some key attributes that can reflect their potential and ability to perform for a specific application as per the requirement. These attributes represent their performance parameters in terms of COP, their operating parameters and their advantages and disadvantages. Further, this comparison can help analyse and select the correct type of technology that can be implemented for a specific application. The key attributes that are considered for this review are shown in the table below-

Table 1 Key Attributes Considered for the Review

Key Attribute	Criteria for Analysis
COP	Performance criteria
Size, Solar Collectors	Design parameters
Cost, operating range, working fluid	Operational criteria
Applications	Scope of implementation
Advantages, Disadvantages	Pros & Cons

6. COMPARISON OF DIFFERENT SOLAR COOLING TECHNOLOGIES

Different solar cooling technologies are implemented for different applications according to their potential and requirement. For selecting the technology to be implemented for a specific type of application, the technologies are compared by the help of the considered key attributes of the review. The analysis of this comparison can be utilised to select proper technology considering its performance, advantages & disadvantages and operational cost.

1. In table 2, a comparison between Solar thermal closed-cycle technologies is made.

Table 2 Comparison between Solar Absorption and Adsorption Cooling Technology

Key Attribute	Absorption Cooling	Adsorption Cooling
COP	0.7-1.2	0.6-0.8
Size	Small	Large
Cost	Low	High
Operating range	15 KW- 5 MW	50- 430 KW
Working fluid	Ammonia/ Water or LiBr/Water	Refrigerant- Water Adsorbent- Silica Gel
Solar Collectors	Vacuum tube, concentrated	Flat plate, vacuum Tube, concentrated
Applications	Space cooling, chilled ceilings, refrigeration, hospitals	Underfloor cooling, fan coils, refrigeration, laboratories

Advantages	Higher COP higher reliability. Smaller weight enhances the efficiency of the cycle.	Can be operated with a single flat collector, lower operational temperature range, simple design in comparison to absorption system, no risks of corrosion.
Disadvantages	Higher maintenance issues, corrosion risks, higher maintenance costs, only efficient and suitable for larger buildings.	Large sizes in comparison to the absorption systems, longer run cycle, lower COP.

Alazazmeh et al. [12] compare absorption and adsorption cooling technologies and the COP range can be referred from it. Prieto et al. [18] discuss the advantages and disadvantages of these technologies. Consideration of advantages can reflect the potential of the technology in fulfilling the required demand. Absorption cooling technology has higher maintenance issues due to more moving parts, and higher chances of corrosion.

2. In table 3, a comparison between Liquid and Solid Desiccant cooling system is made.

Table 3 Comparison between Solar Liquid and Solid Desiccant Cooling Technology

Key Attribute	Solid Desiccant cooling	Liquid Desiccant cooling
COP	0.5- 0.6	0.6- 0.8
Size	Large	Small
Cost	Low	High
Driving temperature	45- 95° C	45- 70° C
Working fluid	Water, silica gel	LiCl, LiBr, CaCl
Solar Collectors	FPC/Solar air collectors	FPC/Solar air collectors
Applications	Production of conditioned air.	Used in existing fan coils, cold storage
Advantages	Non-corrosive technology, low maintenance costs, temperature control, humidity flexibility.	Higher dehumidification, scope of high energy storage, higher COP, continual passage of fresh air, compact sized units.
Disadvantages	Larger in size, complicated system.	Corrosion risks, health hazards due to supplied air streams, crystallisation of salts, higher maintenance costs.

Salman Ajib et al. [15] discusses the pros and cons of using liquid and solid desiccant systems. The Solid desiccant system is a non-corrosive technology with low maintenance. Considering performance parameter, liquid desiccant technology dominates over solid desiccant technology in terms of COP.

Gagliano et al. [19] investigate that the desiccant technology is about 40% more energy saver and it saves about 150% energy than the conventional vapour compression system.

3. In table 4, a comparison between Solar Thermo-electric (Peltier) cooling system and Solar Vapour compression cooling system is made.

Table 4 Comparison Between Solar Thermo-Electric (Peltier) Cooling System and Solar Vapour Compression Cooling System

Key Attribute	Thermoelectric (Peltier) cooling	Vapour compression cooling
COP	~ 0.5	1.5-4
Size	Small	Large
Cost	High	Low
Working fluid	-	R134a, R407c, R410a
Applications	Solar refrigerators, automotive cooling, semiconductor and processor cooling	Commercial and industrial refrigerators, air-conditioning
Advantages	Small size. No moving parts. Does not produce sound. Lightweight. Absence of working fluid eliminates the risk of leakage.	Higher COP. Easily available. Quicker action.
Disadvantage	Lower COP. High Cost. Lower reliability.	Requires more space. Higher installation cost. Complex design in comparison to Peltier cooling.

Jatin Patel et al. [17] found that the COP of thermoelectric cooling can be increased by multistage TE module. Research indicates that the COP can be increased to 1.2151 by using a 3 stage TE module. Also, thermoelectric cooling does not contribute to the depletion of the O-zone layer due to absence of refrigerants. TE cooling can be a great scope of further research to enhance its COP up to the level of the conventional vapour compression system. Also, cost optimisation can be effective for further implementations.

4. A graphical comparison of the reviewed solar cooling technologies can also be made based on the performance criteria i.e. COP. Fig. 7 represents the graphical comparison between solar cooling technologies.

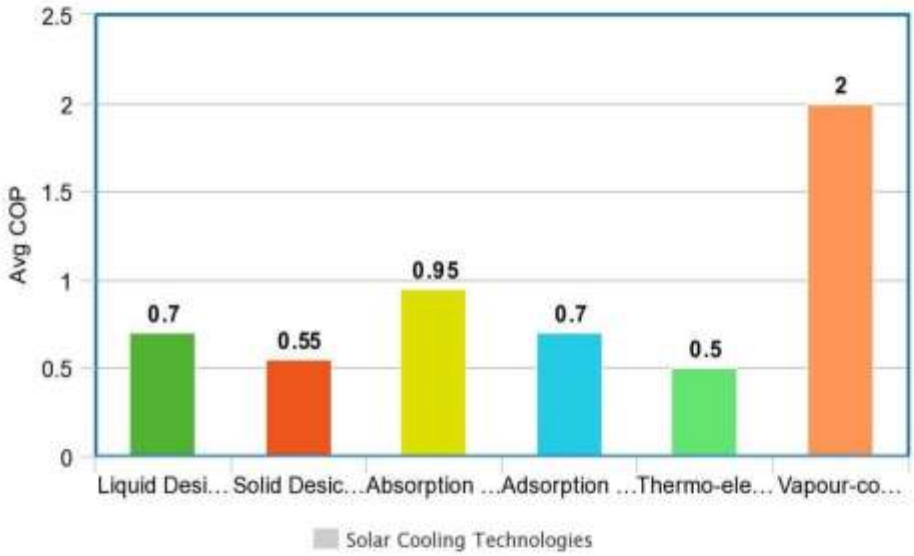

Figure 7 Graphical comparison based on average COP.

7. CONCLUSION

Solar cooling has a great potential for research and development in future. The cooling demands are increasing due to environmental aspects and need for generation of artificially cooled surroundings for human comfort are also increasing. Several key aspects which are considered in the review can help in better understanding the potential and correct selection of technology for key implementation for specific applications. COP of adsorption and absorption cooling systems can be further enhanced by using optimum solar collectors and innovation in flat plate collector technology can enhance the overall efficiency of closed systems. Implementation of hybrid systems in case of open-cycle systems can be effective in improving the COP and ability to deal with variations in the operating temperature range. Also, the need to decrease energy consumption in vapour compression systems can be a great area of research. Future researches are to be made in the region of semiconductor components so that the thermoelectric technology can be enhanced further. Future works and researches can help improve and optimize technologies and make processes cost-effective.

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