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Review

An overview on use of renewable solar energy in desiccant based thermal cooling systems

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ABSTRACT

The use of thermal energy produced by renewable solar heat is an interesting option for desiccant regeneration in comfort space cooling system. Various options available for collecting the solar radiations to provide reactivation heat for desiccant regeneration in desiccant assisted dehumidification and cooling system. This means of thermal cooling is economically viable as well as environment friendly. The integration of different solar collectors with the desiccant cooling cycle is resulted to the green cooling as it eliminates the use of CFC based ozone depleting refrigerants and CO_2 as green house gases which is responsible for global warming. An overview is presented to introduce different configurations of the combined system and performance evaluation of the same under different climatic situations.

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1. Introduction

In the present era, exponential rise in energy requirement with its associated cost and relevant environmental pollution problems are causing accentuation in exploring most efficient ways to provide the air-conditioning in enclosed space without degrading the climate. In moist climate, major part of conventional produced electrical energy is consumed by air conditioning for both residential and industrial applications at rapid growth. It set dilemma as green house effect and ozone depletion by use of CFC based refrigerant in conventional vapor compression based traditional cooling system. Use of solid desiccant based cooling system neglects the requirement of low temperature for dehumidification of moist air and post-reheating in overcooling the supply room air. For regenerating the dehumidifier used in desiccant cooling, use of renewable solar energy is a good source. It also reduces use of green house gases. Hence, the use of freely available solar energy for desiccant regeneration is the great option for the commercial air conditioners. The need of high cooling in the summer season also coupling availability of intensive solar radiation during the same summer period. Thus, use of solar energy in regenerating the desiccant is attracting much attention due to lower energy consumption and less environmental pollution. During the last decades desiccant cooling received increased attention, since it works without CFC based traditional refrigerants. Moreover, it allows the use of renewable solar energy as low temperature heat to drive the cooling cycle by the desiccant regeneration. So, the desiccant air conditioning can be suggested as alternatives to the vapor compression based traditional air conditioning systems. These systems reduce the peak electric demand and electrical power consumption. Use of freely available solar heat collected by solar collector array will further reduce the cost of cooling. Solar powered desiccant cooling can provide air conditioning in building to meet indoor air quality (IAQ) standards at reduced energy demand at the same time ameliorates the economics of solar-desiccant combined cooling.

Thus, the vapor compression based traditional building cooling technology using CFC refrigerants and having high electrical power consumption has a severe environmental

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impact results into global warming. Desiccant cooling with rotating dehumidifier coupled to the sensible cooler and powered by renewable solar energy represents an alternative cooling technique for vapor compressing systems (Jurinak et al. [1]). During the last decades this hybrid thermal cooling technique was subject of an increasing interest due to its green cooling technology. Some researches focus on the modeling process of the desiccant wheel (Jurinak [2]) and (Stabat [3]), many others were also working on the optimization of the desiccant cooling cycle by introducing new configurations and components (Kang and Maclainecross [4]). Studies were achieved by evaluating the system performance which was compared to the reversal coefficient of performance (Lavan et al. [5]) and (Pons and Kodama [6]). Other works were dedicated to the control of the system and its different operating mode like as ventilation and recirculation according to the climatic requirement of the cooling and geographical locations on the different parts on the earth (Maalouf et al. [7]), in fact desiccant cooling can operates under different mode depending on outside climatic conditions and the availability of the solar energy during the part of the year. (Maalouf [8]) studied the potential of desiccant cooling and the limitations of this hybrid thermal cooling technique due to outside temperature and outdoor humidity. All of the cited studies assumed that solar energy is available when needed considering that the regeneration temperature demanded by the desiccant type is low and can be provided by the renewable solar energy. Or it is true that solar energy can provide the regeneration energy but it is very important to evaluate the global efficiency of the solar installation. (Henning et al. [9]) studied the potential of flat plate collectors in autonomous operation as well as the solar fraction for solar assisted desiccant cooling system for providing thermal comfort in building air conditioning. Few studies were also dedicated to the global efficiency for solar desiccant cooling using direct flow vacuum type solar collectors [10-13]. This paper compares the efficiency of such installations and the effect of solar radiations on the performance of the system.

2. Construction and working of solar assisted desiccant cooling system

Fig. 1 illustrates the schematic layout of solar assisted solid desiccant based thermal cooling system. The system consists of rotary dehumidifier in tandem with the air-to-air heat recovery wheel with direct contact evaporative coolers. Flat plate solar collector provides thermal energy necessary for the desiccant regeneration. This integrated system allows both dehumidification as well as cooling of room process air without using the CFC based traditional refrigerants. Depending upon the outside ambient conditions and on the available building cooling loads, the air installation can be any of the four following configurations for its operating mode [14-15].

(i) Ventilation type in which only supply fan is working (state 4-5).
(ii) Direct humidification type in which the supply air to the conditioned room is directly humidified (state 3-4).
(iii) Indirect dehumidification type in which supply air to the conditioned room is sensibly cooled through the rotating air-to-air heat exchanger (state 2-3). On the opposite side of the same return room air is cooled by humidification (state 6-7).
(iv) Desiccant dehumidification mode in which ambient air is dehumidified by the rotary dehumidifier (state 1-2). During the adsorption of moist air water vapor separates out due to vapor pressure difference between hot desiccant matrix and the process air. The regeneration heat necessary for the desiccant desorption (state 9-10) is provided by the flat plate solar collector via thermal heater (state 8-9).

The important states of process and regeneration air are depicted on the psychrometric chart in Fig. 2.

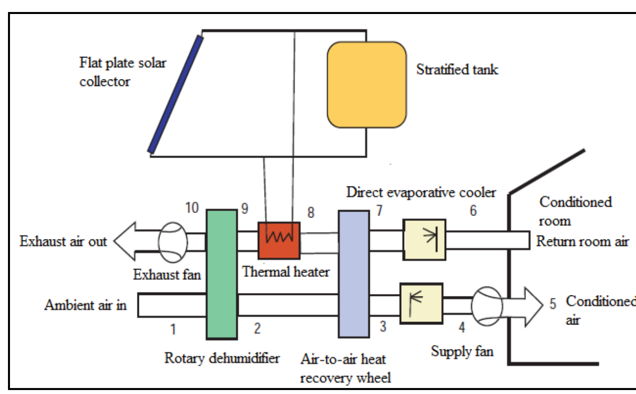

Fig 1. Working of solar assisted solid desiccant thermal cooling system.

The adsorption as well as desorption processes are adiabatic in nature but the wave propagation effect during the reactivation process of rotary dehumidifier would make slight deviation from the theoretical process. Solar collector is the first choice for desiccant regeneration heat supply. Since it can be directly coupled to the desiccant dehumidification and cooling system without the need of thermal storage [16-18]. Furthermore, solar air collectors are mostly efficient as the cooling load profile is in-line with the existence of the intensive solar radiations during the same time. The air-to-air heat recovery unit is used to conserve the sensible heat and pre-cool the ambient air. Two evaporative coolers of direct contact types are provide in both the process air side as well as the regeneration air side each to control the supply humidity [19]. The direct evaporative cooler provided in supply air line to cool down the supply air up to the humidity level capable of tackling the space latent load [21-25]. Another direct contact type evaporative cooler is installed to cool down the return room air, for furnishing better sensible heat extraction at the air-to-air heat recovery wheel [26-28].

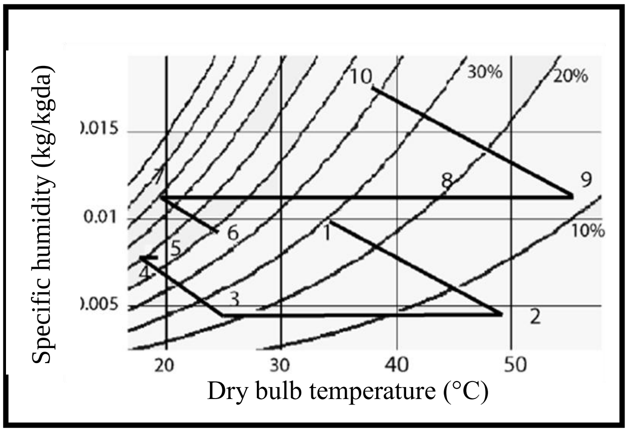

Fig 2. Psychrometric chart representation of solar assisted solid desiccant thermal cooling system.

3. Performance study of solar assisted solid desiccant integrated cooling system

The design and installation of solar assisted desiccant cooling system mainly incorporates the two sub-systems namely solar energy system which is made up of solar collectors and water to air heater system along with hot water storage system. While the second subsystem consists of a desiccant wheel integrated conventional cooling system [29-30]. The performance desiccant assisted cooling system can be evaluated by calculating the overall coefficient of performance of the system. It is found by taking the ratio among cooling capacity and regeneration heat supply [31-34]. The COP of the system can be defined by

$$COP = Q_c/Q_R \quad (1)$$

The need of solar power for reactivation [35] the desiccant materials can be given by

$$\eta_{solar} = \eta_o - C_1 \times \frac{t_m - t_a}{G} - C_2 \times \frac{(t_m - t_a)^2}{G} \quad (2)$$

Where η is the collector efficiency, is the η_o optical efficiency C_1 and C_2 are the collector heat loss coefficient. The global solar radiations received during a year can be given in the following graph (Fig. 3).

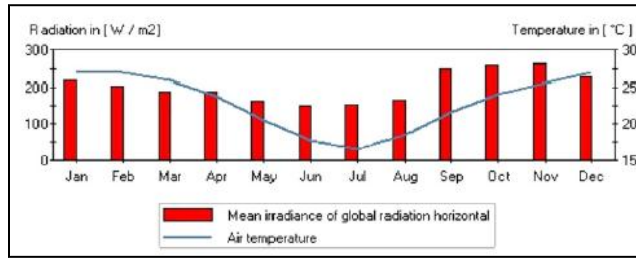

Fig 3. Yearly global solar radiations received by the earth.

The effect of solar collector area on performance of the system during the year has been depicted in Fig. 4. The results show that the similarity exists between performance curve of the collector area selected for 5 m^2 and 10 m^2 during a year.

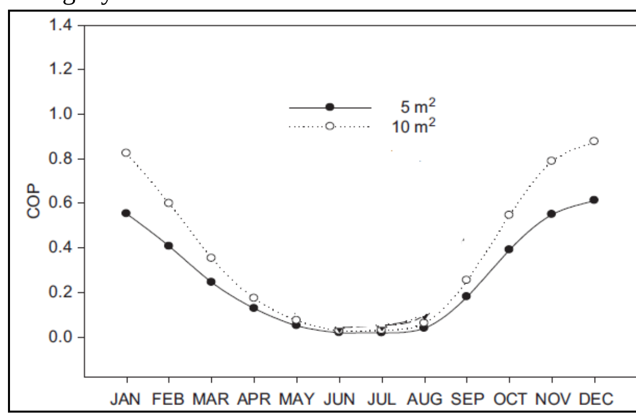

Fig 4. Effect of variations in solar collector area over system performance during the year.

Maximum coefficient of performance is achieved during initial phase of the year as well as at the end of the year. This is because the system received almost 70% solar radiations during the cooling seasons [36]. It is also seen that the received solar fraction is almost proportional to the area of solar collector. As the area increases, solar fraction received by the collectors increases which resulted to the higher system performance as shown in Fig.5.

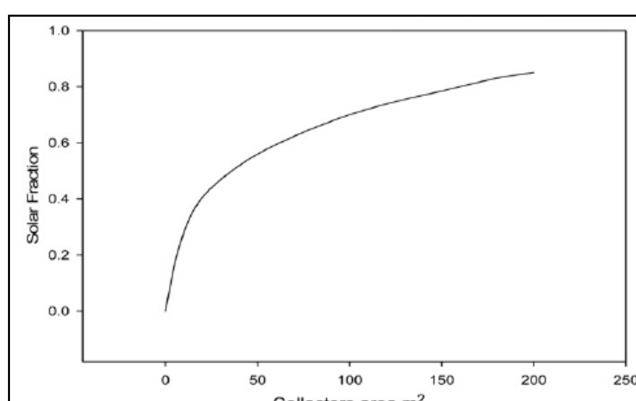

Fig 5. Effect of variations in annual solar fraction with the change in the total collector area.

Fig. 6 illustrates the electric energy consumption when solar assisted desiccant cooling as compared with the conventional vapor compression air-conditioning system. The peak consumption is found during the month August due to excess cooling demand during that period. Moreover, the capability of desiccant cooling to control the humidity is better as compared to the vapor compression based conventional cooling [37].

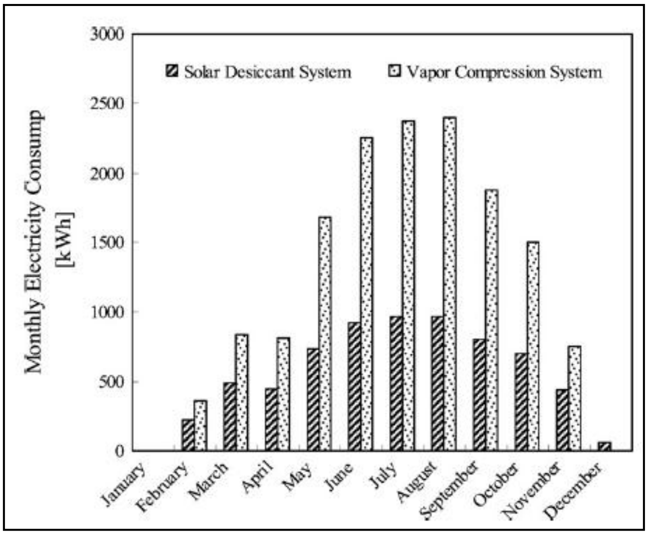

Fig 6. Comparison between VCR based conventional cooling and solar desiccant cooling system on basis of electricity consumption.

4. Conclusions

Residential and industrial buildings require different types of functional spaces which demand specific cooling and dehumidification rates by use of heating, ventilation and air conditioning (HVAC) systems to maintain necessary indoor thermal comfort. Moreover, the buildings should be designed to maintain optimal indoor comfort condition within minimal energy consumption and minimal negative environmental impact. Recently, there has been significant interest in implementing solar powered desiccant assisted thermal cooling systems within the both residential and commercial buildings for efficient cooling and air conditioning. Solar assisted desiccant based hybrid thermal cooling systems are most reliable in performance, environmentally friendly and capable of improving indoor air quality at a lower cost. The solar powered desiccant based thermal cooling can thus significantly contribute in energy saving and environmental protection.

Nomenclature

CFC	chlorofluorocarbon
DBT	dry bulb temperature (°C)
DC	desiccant assisted cooling
EC	evaporative cooling
HVAC	heating, ventilation and air conditioning
IAQ	indoor air quality
IHX	interchange heat exchanger
SHR	sensible heat ratio
VCR	vapor compression refrigeration
WBT	wet bulb temperature (°C)
DW	desiccant wheel
RH	relative humidity (%)
t_m	collector temperature (°C)
t_a	ambient temperature (°C)

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