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Feasability of Solar Desiccant Evaporative Cooling: A Review

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Abstract— **-** This term paper presents a review based study of the solar desiccant evaporative cooling technology, which was undertaken from a selection of aspects including background, history, current status, concept, types, system configuration, operational mode, research and industrialization, as well as the future focuses on R&D and commercialization. This review work indicated that the DEC technology has prospective to be an alternative to conventional mechanical vapor compression refrigeration systems to take up the air conditioning duty for buildings and transportation also. Owing to the continuous progress in technology innovation, particularly the heat and mass transfer and material optimization, the DEC systems have obtained significantly enhanced cooling performance over those the decade ago and now a days it is using with Solar apparatus also.

Index Terms— *Solar Energy, Desiccant Cooling , Evaporative cooling , wet bulb temperature ,dry bulb temperature ,vapor compression system ,vapor sorption system,dessicant material.*

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1 Introduction

1.1 Solar Energy and Cooling

The largest powerful source of energy on earth is the Sun .It supplies light and heat .which is essential for enables existence on earth. In addition to that, the sun is the most environmentally friendly and continuous source of energy. Available solar energy is 1.5×10^{18} kWh per year; It will accomplish all our energy requirement 10000 times of world. The maximum intensity of solar irradiation on the surface of earth can be over 1000 W/m^2 but it is very difficult to make the most of for our purposes.
"With in 6 hours deserts receive more energy from the sun than humankind consumes within a year" [1].

In the year 2013 over 70 % of our energy was produced by burning fossil fuels in India. By burning fossil fuels, greenhouse gases such as methane and carbon dioxide are released to the environment. These greenhouse gases are raising the natural greenhouse effect and are causing global warming. Global warming describes the enhance of average temperature on the surface of earth in long-term information. It has input as a major part of climate change. According to the present consent of scientist, a large part of this climate transform is caused by human activities and Industrialization.
Climate change concerns the whole planet and various decisions are made to cut the greenhouse gas emissions. The most well-known decision took place when the European Union ratified the Kyoto Protocol to the United Nations Framework [2].

1.2 Desiccant cooling system

The sensible and the latent load are the issue of concern in air conditioning system. An air conditioner must counter stability the two sorts of load in order to preserve the desired indoor temperature . The latent heat is eliminate by, the famous refrigerant vapor compression system (VCS) or the not yet so famous vapor sorption system (VSS), cools the ways air down below its dew point temperature (DBT) in arrange to condense out water vapor contained within. The humidified air is dehumidified then reheated to meet the desired indoor temperature conditions. If the latent load is handled by another means than by this deep cooling, two components of the burden on the conditioner, brought about by the presence of latent load, will be avoided. Those are, namely,
(1) The energy requirement for reheat the air from that temperature up to the supply air temperature.
(2) The energy needed to bring the air from the supply temperature low to the temperature of condensation of water vapor contained in the process air (below the dew point of the air)

When the sensible heat ratio (SHR) of the specific space is low, these two components sum are increases considerably [3]. therefore the VCS are run by current, the production of which involves most often the consumption of fossil fuelled different power plant (thermal power plant ,hydro power plant etc.)with the resultant emissions of carbon dioxide (CO_2) into the environment. Now a day's this carbon dioxide well-known as carbon foot print. Finally, the refrigerants used in this air conditioning technology are more or less CFCs based ones, that many countries are taking steps to make a concern so. The desiccant cooling can be either a perfect substitute to the traditional vapor compression air conditioning technology to prevail over the effects of its drawbacks, or an alternative to it for assuring more easy on the pocket, accessible, and cleaner air conditioning. at rest more significantly, when powered by free energy sources (renewable energy sources)such as waste heat and solar energy, it can considerably reduce the operating costs and increase noticeably the user-friendliness to the air conditioning for the populations in remote areas, particularly in developing countries like as India. The desiccants are natural or artificial substances able of adsorbing or absorbing water vapor due the variation of water vapor pressure between the desiccant surface and the surrounding air. They are encountered in both liquid and solid states. Each of solid and liquid desiccant systems has its own shortcomings and advantages. In addi-

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tion of having low regenerative temperature and flexibility in operation, liquid desiccant have low pressure drop on air side. Solid desiccant are packed together, carryover and less subject to corrosion. Commonly used desiccant materials include silica gels, lithium chloride, aluminum silicates (zeolites or molecular sieves) tri-ethylene glycol, lithium chloride, lithium bromide solution and aluminum oxides solution with water, etc.

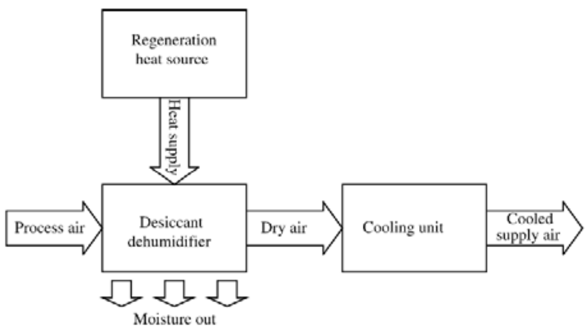

Fig1:- Principles of desiccant cooling [4]

1.3 Principles of desiccant cooling

Desiccant cooling technology consists in dehumidifying the intake air stream by passing it from beginning to end a desiccant material and then drying the air to the desired indoor temperature. To make the system working constantly, water vapor adsorbed/absorbed must be run out of the desiccant material (regeneration) so that it can be dried an adequate amount of air to absorb moisture or water droplets in the next cycle. This has done by raising temperature of the material desiccant to its temperature of regeneration which is dependent upon the nature of the desiccant material used. A desiccant cooling system, therefore, comprises primarily three components, namely the regeneration heat source, the dehumidifier (desiccant material), and the cooling unit. The effectiveness of desiccant system depends powerfully on the Sensible heat Ratio (SHR). The SHR is known as the ratio of the sensible heat gain to the sensible and latent heat gain of the space being conditioned. A lower value of this quantity means that the total cooling load is predominately the latent load, in which situation desiccant cooling is demonstrated to be effective and easy on the pocket [4].

1.4 Open Desiccant Cooling Systems

Open desiccant cooling technology are ventilations arrangement which contain of a sorption based dehumidification unit with sorbents or solid, a heat exchanger and humidifiers on the supply and return air side. In the present work a system with a solid sorbent dehumidification unit in form of desiccant wheel is regarded. In full desiccant mode the intake air is first dried in the desiccant wheel and afterwards pre-cooled in a heat exchanger by the return air which has been humidified before to the maximum to lower its temperature. The pre-cooled and dry supply air is then humidified to the maximum supply air humidity level to further decrease the temperature which increases the sensible cooling power. The humid return air is preheated in the heat exchanger by the dried supply air and then further heated by e.g. a liquid based solar heating system or by solar air collectors.

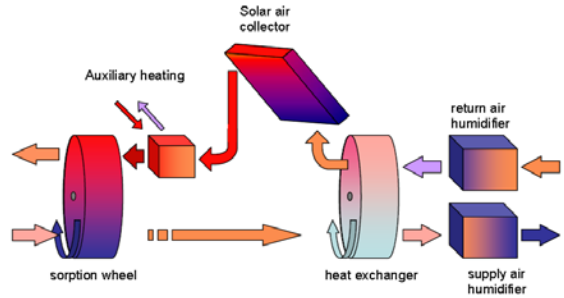

Fig 2:-DEC system scheme with solar air collectors and heating energy supply [5].

1.5 Closed Solar Driven Absorption Cooling Sytem

Closed solar driven absorption cooling systems contains apart from the absorption chiller typically of a liquid based solar system which provides the required driving heat for the set of connections. The solar system consists of solar collectors, a solar heat exchanger and a hot water storage tank. For heat rejection either wet cooling towers or dry heat rejection systems are used. On the cold distribution side most systems run with smaller or larger cold water storage. In case of insufficient solar heat supply an auxiliary heating device is connected to most of the systems. Fig.3 shows a scheme of a solar driven absorption cooling system.

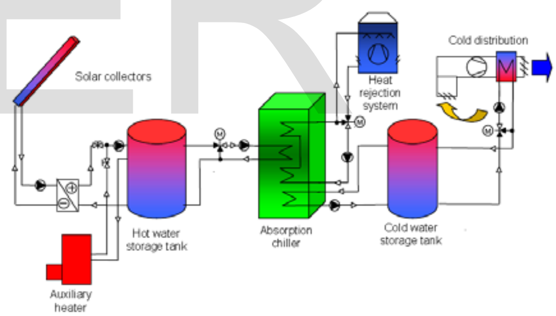

Fig3:- A solar driven absorption cooling System [5].

1.5.1 The regeneration heat source

The regeneration heat source supplies the thermal energy required for pouring out the moisture that the desiccant had in use up for the period of the sorption phase. Because the thermal energy source is required, a variety of promising energy sources can be utilized. Those include solar energy, waste heat, and natural gas heating, and the possibility of energy improvement within the system. In the case of a liquid desiccant cooling being used, the heat of regeneration is furnished to the desiccant solution surrounded by the structure of a regenerator where a scavenger air stream is at the same time as blown to carry away the moisture desorbed under the heating .The scavenger air can also be a hot air stream brought into contact with the dilute desiccant solution inside the regenerator thereby heating it extracting away its humidity.

1.5.2 The desiccant dehumidifier

when the desiccant is functioning in its solid state, the desiccant dehumidifier is normally a little by little revolving desiccant wheel or a periodically regenerated adsorbent bed When the liquid desiccant is working, the dehumidifier (absorber) is the equipment surrounded by which the liquid desiccant is brought into contact with the process air flow. Its possible configurations include coil-type absorber, finned-tube surface, packed tower, and spray tower. The dehumidifier (absorber) and the regenerator are generally referred to as contactors. The packing mode of packed towers can be regular (structured) or random (irregular).

1.5.3 The cooling unit

The cooling unit can be the evaporator of a conventional air conditioner, an evaporative cooler or a cold coil. The function of the cooling unit is the handling of the sensible load while the desiccant removes the latent load. When a desiccant wheel system is implemented, a heat exchanger is normally used in tandem with it to preliminarily cool the dry and warm air stream before its additional cooling by an evaporative cooler or a cold coil, etc. In this case, the heat exchanger simultaneously with the evaporator cooler or the cold coil constitutes the cooling unit[5].

1.6 History and Background

The idea of desiccant cooling was introduces in the 1930s and near the beginning attempts to commercialization the system were so failure. Pennington got his patent the first desiccant cooling cycle (Pennington, 1955), which was then modified by Carl Munters in the 1960s. The most broadly used desiccants are silica gel, lithium chloride or molecular sieves, for example zeolites. Solid desiccants such as silica gel absorb moisture or water in its highly porous structure. Apart from cooling applications with adiabatic humidification, desiccant systems have been proposed for air drying only.. Although the technology is known for decades, there are only a few demonstration plants which are powered by solar energy, so that operational experience from such plants is very less. To introduce the technology into the market, information about the energy performance (heat, electricity consumption and efficiency,), water consumption and maintenance issues need to be studied.

Compared to open cycle system effectiveness can either be related to the taking away cooling load of the system (room air) or to the enthalpy decrease of ambient air, closed cycle cooling systems, where the thermal energy effectiveness is simply known by the ratio of formed cold to the input heat. For the hygienically looked-for fresh air supply, the enthalpy difference between ambient air and room supply air can be measured as useful cooling energy. If the system has higher cooling loads than that can be enclosed by the required fresh air supply, the useful cooling load has to be calculated from the enthalpy difference between room exhaust and supply air, which is more often than not lower. The thermal COP is get from the enthalpy ratio. Related to ambient air, the thermal COP can be near to 1.0, if regeneration temperatures are kept lower, and reduce to 0.5, if the ambient air has to be appreciably dehumidified. Thermal COP's obtained from room exhaust to supply air are lower between 0.35 and 0.55 [6,7].

Under conditions of 35°C ambient air temperature and 40% relative humidity, defined by the American Air conditioning and Refrigeration Institute (so called ARI conditions), reversible thermal COP´s of 2.6 and 3.0 were calculated for recirculation method and ventilation. The genuine procedure ,has highly irreversible features such as adiabatic humidification. Furthermore, the specific heat capacity of the desiccant rotor increases the heat input necessary. Simple models have been used to estimate the working range of desiccant cooling systems, for example to provide room conditions not just for one set point, but for a range of adequate comfort environment. The performance of the desiccant rotor itself can be evaluated by complex heat and mass transfer models based on Navier Stokes equations. This allows the evaluation of the influence of flow channel geometry, sorption material thickness, heat capacity, rotational speed, fluid velocity etc. Different control strategies have been compared to study the influence of air volume flow and regeneration temperature[8]. As the increase of regeneration temperature does not linearly lower the supply air temperature, the study concluded that increased air flow rates are preferable to increased thermal input by auxiliary heaters, if the cooling demand is high.

Mean calculated thermal COP´s for the climatic conditions of Nice were between 0.3 and 0.4. Henning and others also remarked that increasing the air flow is useful in desiccant cooling mode, but that the minimum acceptable flow rate should be used in adiabatic cooling or free ventilation mode to reduce electricity consumption [8.9,10,11]. Common problems of numerous installed DEC systems are very low solar system efficiencies of the installed collector fields [9,10,11,12]. For comparison, standard air handling units with compression chillers attain primary energy efficiencies in the section of one or slightly below one [11]. The low solar system efficiencies of the collector fields of DEC systems are an attribute to the fact that for dry climatic conditions indirect or combined humidification is frequently adequate to cover up the required cooling load, particularly if the system is operated at maximum air flow rate. In significance, the sorption wheel is very hardly ever in operation. In some control strategies, predetermined regeneration temperatures are implemented although often much lower regeneration temperatures would be enough to cover up the essential cooling load [13,14].

The supplementary heater is considered as the last control option to increase the regeneration air temperature if at full desiccant mode and full air flow rate the provided cooling power is still too low to keep the room air conditions within comfort limits. However, common control problems of installed DEC systems mostly result from an unsatisfactory consideration of the inertia of the apparatus particularly of the humidifiers. Representative contact matrix or hybrid humidifiers take about 5 to 10 minutes after activation until they reach their full humidification effectiveness. If they are deactivated after full operation it takes more than 15 minutes until a significant decrease in humidification efficiency becomes visible and more than 45 minutes until they are completely dried. A too fast activation of the components can show the way to uncomfortable supply air conditions which result in several control reactions to increase the supply air temperature again. In consequence the DEC system is operated unproductively at variable operation modes [15,16]. A too slow activation of

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the humidifiers and humidifier stages on the other hand can lead to uncomfortable room air conditions and in significance to an activation of the DEC mode with increased air volume flow although not strictly required.

This considerably increases the quantity of required supplementary heating energy. Systems with primary energy optimized control therefore should function at variable regeneration temperatures between 45°C and 90°C. furthermore, the regeneration mode should be activated with major concern to the increase of the air flow rate if enough solar energy is available and the cooling load cannot be covered with combined humidification at the lowest possible air flow rate. DEC systems are typically controlled by sequence controllers which switch on or off the system components depending on the ambient and room air conditions. In case of a primary energy improved control strategy at cool and dry ambient air conditions first the return air humidifier and the heat exchanger between supply and return air are activated for indirect evaporative cooling. Afterwards the supply air humidifier is switched on and the system operates in combined humidification mode. If the room air temperature still increases, sufficient solar energy is available and the supply air temperature is above the lower limit, the regeneration mode is activated. If this is still not sufficient to cover up the cooling load, as a next control option the air volume flow is increased.

2. Technical Parameters Of Desicant Cooling

2.1. Coefficient of performance (COP)

Coefficient of performance (COP) is the fraction of the cooling capacity(Q_C) to the total input energy Q_{reg}(thermal Q_{th} and electric Q_{el}) needed for the regeneration method as articulated by equation [17]:-

$$COP = \frac{\Delta h}{\Delta h_{reg}} \mathrm{X} \eta_{heater} \mathrm{X} \eta_{solar}$$

where η_{solar} the solar collector's efficiency defined by:

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

where η_0 is the collector's optical efficiency, G is the solar irradiance in the collector plane, C_1 and C_2 are collector heat loss coefficients, t_m is the collector temperature and t_a is the ambient temperature(both in ◦C).Then the cooling process coefficient of performance will be considered as:

$$COP_{cooling} = \frac{Q_C}{Q_{reg} + Q_{evap}} \mathrm{X} \eta_{heater} \mathrm{X} \eta_{solar}$$

$$= \frac{\eta_{heater} \mathrm{X} m_{\mathrm{sup}} \mathrm{X} \Delta h}{(m_{reg} \mathrm{X} \Delta h_{reg}) + Q_{evap} + Q_{el}} \mathrm{X} \eta_{heater} \mathrm{X} \eta_{solar}$$

where Q_{evap} is the energy consumed by the evaporative cooler, heater is regeneration backup heater efficiency, m_{sup} is the mass flow of supply air, m_{reg} is the mass flow of the regeneration air ,h is the enthalpy difference between outside and supply air and h_{reg} is the enthalpy rise in the heater for the regeneration.

2.1. Energy savings and primary energy used

Solar desiccant cooling system energy savings can be calculated based on the difference between primary energy used by the reference stand-alone conventional vapor compression system and primary energy used by the solar desiccant cooling system. The system primary energy is used by the backup heaters, the hot water pump, the cold water pump, the generator pump, the dehumidifier pump, the evaporative cooler pump and the reference conventional HVAC system. The total primary energy used by the desiccant cooling system can be expressed as [18,19]:-

$$W_{el-primary} = \left(\left(\frac{m.C_w (T_{set} - T_{in}) + U_A (T - T_{env})}{\eta_{heater}} \right) + \frac{Q_{evap}}{\eta_e} \right) + Q_{parasitic}$$

where η_e is the evaporative cooler efficiency, Q_{evap} is the evaporative cooler capacity, m is inlet water mass flow rate, T_{set} is the set temperature of the heater internal thermostat in ◦C, T_{in} is water inlet temperature in ◦C, U_A is overall loss coefficient between the backup heater and its surroundings during operation, $\overline{T}$ is $(T_{set} + T_{in})/2$ and T_{env} is temperature of heater surroundings for loss calculations in ◦C and $Q_{parasitic}$ is the total parasitic energy used by the system main and auxiliary components. The system total energy savings to cover a certain cooling load can be expressed as [19].

$$\mathrm{E}_{\mathrm{saved}} = \frac{\left(\frac{W_{conv}}{Q_{cs,conv}} \right) - \left(\frac{W_d}{Q_{CD}} \right)}{\left(\frac{E_{conv}}{Q_{c,conv}} \right)} \mathrm{X} L_{total}$$

where E_{Conv} is conventional system electric power, $Q_{C,Conv}$ is conventional cooling system capacity, E_{Solar} is solar cooling system electric power, $Q_{C,Solar}$ is solar cooling system cooling capacity and L_{total} is the conditioned building total cooling load.

2.3. Solar fraction

Solar fraction is measured as the most important feasibility indicator. Solar fraction is defined as the fraction between energy produced by the solar collectors and the total regeneration energy (solar and primary) [20]. Therefore the solar fraction can be expressed as:

$$SF = \frac{Q_{solar}}{Q_{solar} + W_{el-primary}}$$

2.4 Desiccant efficiency

Desiccant efficiency is defined as the fraction of the achieved

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dehumidification capacity to the maximum desiccant system nominal dehumidification [20]. The dehumidification efficiency depends on the amount of moisture removed from the treated air, Δd , which can be calculated using:

$$\Delta d = d_6 - d_1$$

The desiccant efficiency is expressed as [21,22]:

$$\eta_{deh} = \frac{\Delta d}{\Delta_{\max}}$$

where Δd is the moisture removed by the desiccant wheel and $\Delta_{\max}$ is the nominal dehumidification capacity.

3. Feasibility reports

Mavroudaki et al. [23] and Halliday et al. [24] experimented separately two viability studies of solar driven desiccant cooling in whole European cities on behalf of different climatic zones on the continent. The conclusion shows by the authors revealed that primary energy consumption is low were achieved in all climatic conditions. A decline in energy savings were noticed in highly humid zones. This decline was attributed to the high temperature essential to regenerate the desiccant in the climates of high humidity. Jain et al. [25] installed a setup for an experiment four cycles (the Dunkle cycle ,the recirculation cycle, the ventilation cycle, and the wet surface heat exchangers cycle) for various outdoor conditions (Dry-bulb temperature and wet-bulb temperature) of many cities in India). The study was goal at measured the influence of evaporative coolers on the cooling coefficient of performance (COP) and the effectiveness of heat exchangers as well as on the air volumetric flow rate in different climatic environment. The authors over and done with that the Dunkle cycle to have efficient and improved performance as compared to ventilation and recirculation cycles in all climatic conditions. But the cycle using wet surface featured the finest performance with due respect to all the three other cycles investigated

4. Performance reports

[26] Yadav experiments and simulated a hybrid desiccant cooling system comprising the traditional vapor compression air conditioning system coupled with a liquid desiccant dehumidifier which was regenerated by solar energy. The study suggested that, when the latent load constitutes 90% of the total cooling load, the system can generate up to 80% of energy savings. Alizadeh et al.[27] designed, constructed and optimized an investigational setup of a forced flow solar collector/regenerator. They utilized an aqueous solution of calcium chloride as desiccant and studied the various influence of parameters, such as air and desiccant solution flow rates as well as the climatic (environmental) conditions on the regenerator's performance. The performance of a regenerator was actuated by the rate at which it removed water vapor or moisture from the weak desiccant solution. The conclusion reached in that study was that the efficiency of the regenerator increased as the air flow-rate increased. The solar collector efficiency generally increased with the increase of the air mass flow-rate. The existence of an optimum value of the air flow-rate at which the efficiency is maximal was also predicted. A strong influence of the solar insolation on the collector/regenerator thermal performance was noticed. Shen et al. [28] used the desiccant wheel as adsorbent in a desiccant cooling system and simulated water vapor and carbon dioxide removal from the process air. The authors conducted an optimization study involving the coefficient of performance, the temperature of desorption, the overall number of transfer units, and the adsorption time. Dai et al. [29] conducted a relative study of a standalone VCS, the desiccant-associated VCS, and the desiccant and evaporative cooling associated VCS. The authors found an increase of cold production by 38.8–76% and that of COP by 20–30%. Henning et al. [30] conducted a parametric study of a combined desiccant/chiller solar assisted cooling systems and showed not only their feasibility but also the primary energy savings of up to 50% with a low increased overall expenditure. Mazzei et al.[31] compared the operating costs of the desiccant and traditional systems using the computer simulation tool and predicted operating cost savings of about 35% and a reduction of thermal power up to 52%. In the case were the desiccant would be regenerated by waste heat, the authors expected operating costs savings reaching up to 87%. They also found that cost savings and cooling power reduction increased when the indirect evaporative cooling is used in conjunction with desiccant dehumidification. At this point, it must be pointed out that savings on operating costs are dependent on the local electricity fares, which vary from one country to another, even within the same country. Techajuntaet al. [32] used silica gel as adsorbent and studied its regeneration with simulated solar energy in which glowing electric bulbs were used to simulate solar irradiation. The regeneration rate was found to be strongly dependent on the solar radiation intensity while its dependence on the air-flow rate was found to be weak. Fathalah et al. [33] studied a heat recovery system. The system studied was a solar energy driven LiBr–H2O absorption cooling machine. The heat was recovered from the condenser of the machine and added to the driving solar energy. The coefficient of performance was raised 1.2 times, hence 58% higher than that for the absorption machine alone. The evaporator temperature was raised from 11.5 to 19.3℃. Sanjev et al. [34] studied theoretically and experimentally a liquid desiccant cooling system made of a falling film tubular absorber and a falling film regenerator. For the purpose of performance evaluation, the authors cleared wetness factors to characterize the uniformity of wetting of the surface of the contactors (dehumidifier and regenerator) by the desiccant solution. Their study is of great interest for designing viewpoint, as it can help calculate more accurately the size of the contactors. Shyi-Min et al. [35] reported a standalone solar desiccant cooling system inherited from the concept of desiccant enhanced nocturnal radiation cooling and dehumidification (DESRAD) [32]. The system is a passive desiccant-cooling scheme operating alternately according to the sequence of diurnal and nocturnal natural cycle.

Kadoma et al. [36] investigated the impact of the desiccant wheel speed, air velocity and regeneration temperature on the COP. The authors showed the existence of an optimal speed and established that the COP decreased when the airflow rate increased and, on the contrary, the temperature of regeneration and the cooling capacity had the same development tendency. Arshad [37] undertook the study of a mathematical model of a liquid absorber (dehumidifier). The said study has proved the increase of the performance with the number transfer units

(NTU) of heat transfer between the process air and the desiccant solution. It is worth noting here that the NTU is determined, in part, by the size of the absorber. Adam [38] conducted a simulation study on a desiccant cooling system using with aqueous solution of $CaCl_2$ as liquid desiccant. The impact of certain parameters on the system performance was studied. Those parameters include the desiccant solution's inlet temperature, the space sensible heat ratio (SHR), heat exchanger effectiveness, and the ratio of liquid desiccant flow rate to the air flow rate (GL/Ga).

The authors reached the following conclusions:

(i)The ratio G_L/G_a has been created to have negligible effect on the system performance.

(ii)Increasing the supply inlet temperature of liquid desiccant (up to definite limit) has the results of improving the system performance for lower values of SHR.

(iii)The system coefficient of performance at given breathing space conditions and inlet temperature of the liquid desiccant increased with the decrease in SHR.

(iv)The system performance decreased with the decrease of the heat exchanger effectiveness.

5. Conclusion

This comprehensive assessment, it has been seen that the desiccant cooling is a easy to handle and economical technology which can be unite with other technologies to increase their efficiency. Evaporative and radiant ceiling cooling for case in point, are less effective in climates where the wet-bulb temperature (WBT) is high. Desiccant cooling can enhancement them beneficially by extending their climatic applicability scope. Its potential contribution in improving enclosed air quality, costs and energy savings, as well as environmental protection makes it attractive at a time where depletion of energy resources and environmental dreadful conditions are internationally concerns. This potential is primarily due to the removal of the overcooling and the reheating. One of most important advantages of desiccant cooling systems undoubtedly lies in the possibility of their regeneration by the free energy such as waste and solar without any beforehand adaptation. Here are some examples of Desiccant evaporative cooling system experimented and a developed by other countries likes as Italy and Austria etc [39].

A in depth valuation of monitoring outcome of a solar desiccant evaporative cooling system in south Italy was carried out, and immediate, monthly as well as seasonal performance indicators are performed. The Electric COP during summer function was 2.4 if the total cooling energy produced and the total electricity consumed are considered. The COP was 4.4 if only the electricity consumption and cooling energy related to the DEC process are considered. The use of heat rejected by the chiller to preheat regeneration airflow permitted a reduction of the solar collector region by about 30%. Therefore, due to the heat recovery, a seasonal value of 1.0 for the thermal COP of the system was calculated [40].

The estimation of the Austrian DEC systems in the Energy base office building made clear that solar power driven DEC systems have high primary energy saving potentials compared to a reference system with an air handling unit using compression chillers for air-conditioning. In winter time the highest primary energy savings can be achieved for heating and humidity improvement purposes of fresh air as well as moderate savings during summer time for cooling and humidity control. When the exterior temperature and humidity are close to the set points of the supply air, the primary energy savings compared to a reference system are relatively low, which occurs in locations with moderate climate such as in Vienna during transition time. In 2010 the solar driven DEC system achieved 60.5% primary energy savings compared to a reference system[41].

The utilize of desiccant materials for cooling and dehumidification is an effective, economical, and environmentally safe method for meeting indoor air quality. The current review study was carried out to evaluate the dehumidification rate of air in a dehumidifier-packed tower structure using the liquid desiccant $H_2O/CaCl_2$. The performance evaluation is done by varying the liquid desiccant and airflow rates, and inlet air and desiccant surroundings. it is accomplished that an increase in inlet air temperature helps the desiccant solution to easily catch the moisture from humid fresh air and thus increases the effectiveness. It is also conditional that by increasing the air flow rate, the condensation of moisture enhances and thus the overall moisture removal rate increases. Similarly increased humidity also enhances condensation and thereby increases the moisture removal rate from the room. This technology is gaining acceptance as an option for air-conditioning buildings[42].

6. Overall conclusion

Desiccant cooling systems are appropriate recognized technology in most parts of the world including the India. Solid desiccant is at the present approved as an substitute for the air conditioning segment and developments in the technology are advancing speedily. In Sweden solid desiccant systems are being sold and working in full competition with conventional vapor pressure systems. These systems are try to making in-roads into the Indian market with a number of systems presently in operation at sites in metro cities These comprise both new and restoration systems. This growth has been brought about by the input of refrigerants used in conventional cooling systems to the depletion of the ozone layer and the involvement of both these refrigerants and the fossil fuels used to produce electricity to power them to global warming.

Desiccant systems do good to by using water as the refrigerant and by being able to utilize environmentally cleaner sources of energy such as natural gas, waste heat and solar energy. Indirect benefits are associated with low humidity levels including reduced corrosion and reduced microbial growth. Solid desiccant units have been linked with solar heating in installations in the USA and Europe and the impending benefits of this technology require evaluation for the Indian climate. The upsetting predictions for temperature increase due to global warming are likely to impact upon design strategies and evidence from Europe indicates that solar is increasingly perceived as a realistic energy source to provide the necessary cooling.

Solar desiccant air cooling is a clean technology. It is technically possible to offer a benign solution to the cooling of buildings, in new and refurbished situations, to reduce faith on dangerous refrigerants and to considerably decrease greenhouse gas emissions which result from air conditioning demands. Solar Fractions of 50% are readily achievable based on present performance studies show with reductions of 50% in running costs and CO_2 emissions. The use of full fresh air is also very attractive in relation to indoor health and productivity concerns. Solar thermal energy is presently expensive although further developments of the technology are likely especially in the area of transpired collectors. Other heat sources (such as waste heat) may also be applicable and cost effective. However, at present no reliable information on the extent of parasitic losses is available and insufficient operational data exist to determine the conditions for optimum design and costing and this is a direct consequence of the lack of feedback from desiccant systems. The lack of information also has an implication for limited market competition due to the domination by small numbers of equipment suppliers [43].

7. Next steps for future

This examine to-date has provided a technological review of the prospective, but real benefit would accrue from a demonstration project which reviewed, initially desiccant, and then solar desiccant in detail. It is feasible, and suitable, to develop a cost-effective and practical demonstration project which would significantly enhance present cost and performance issues.

The existing models of solar desiccant cooling will be advanced against real loads and developed together with variations in internal design conditions and climate to develop performance guiding principle. The project will enable an assessment to be made of India options as these relate to dependence on variables such as latitude, internal design conditions and available heat energy and the implications for energy conservation and CO_2 emission reduction. If we are to look for improvement strategies well-matched with financially viable and ecological sustainability then we must create systems which are principally self-sustaining and do not bring with them excessive operational complexity. Passive systems and renewable technologies are the ones to which we must aspire if we are to create a truly sustainable built environment. The development of a collaborative demonstration project represents an effective and appropriate research and development response.

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