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# A Review on Liquid Desiccant Air Cooling Systems

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**ABSTRACT:** This paper overviews liquid desiccant applications, conceptual operation, and experimental analysis of conventional desiccant and hybrid systems used with vapor compression refrigeration systems. This review provides information about various parameters which affect the performance, i.e. COP, of the system. Liquid desiccant air conditioning (LDAC) systems have significant energy savings ranging between 20 to 30% above conventional air cooling systems. Liquid desiccant cooling systems use low-grade energy sources that are sustainable and environment friendly. Dehumidification is a very important variable that helps in maintaining the comfort level in hot as well as humid condition of environment. Desiccant dehumidification system is promising alternative technologies that help in reducing power consumption. Here different parameters and variables are investigated, such as flow rates of desiccant and air, its temperature, concentration, and humidity that can affect the performance of dehumidification and regeneration along with COP of the system. Mix desiccants give the best performance along with flow control of both air and desiccant.

**KEYWORDS:** Liquid desiccant, air conditioning, dehumidification, performance parameters, Regeneration of desiccant

## I. INTRODUCTION

In present world, load of heating, ventilation and air conditioning (HVAC) is rise 6.2% per year is estimated[6]. For human thermal comfort the energy use is nearer to 50% of the building total energy consumed [5]. Also refrigerant use in air conditioning is responsible for increasing the ozone depletion and global warming. For overcome this difficulties desiccant cooling systems are considered as method of controlling moisture content in outdoor process air. The main components of liquid desiccant cooling system are heat exchanger, regenerator, dehumidifier, pump, heater & cooler.

Applications of liquid desiccant

1. Banking and snack food solution
2. Bulk handling solutions
3. Candy and sugar solutions
4. Chemical and cold storage solutions
5. Dairy solutions
6. Film and glass solutions
7. Hospital solutions
8. Plastic solutions

Merits of liquid desiccant cooling system over solid desiccant are as follows:

1. Cooling as well as dehumidification can be achieved using an liquid desiccant system compare to overheating of dry air steam.
2. Moisture carrying capacity of liquid desiccants is high.

3. Desiccant regeneration temperature is low for liquid desiccant.
4. Energy storage is possible in LDAC system because it is possible to store concentrated desiccant in tanks.

### II. BASIC SYSTEMS OF LIQUID DESICCANT AIR COOLING SYSTEMS (LDACS)

As shown in Figure 1[5] simple LDAC system containing regenerator and dehumidifier. Moisture from the outdoor process air at entry is removed in the dehumidifier or in absorber unit, where the water vapor from the process air is absorbed by liquid desiccant. As a result of difference in vapor pressure one can achieve mass transfer. In next process heat is liberated during condensation of water. Also heat exchange takes place because of mixing.

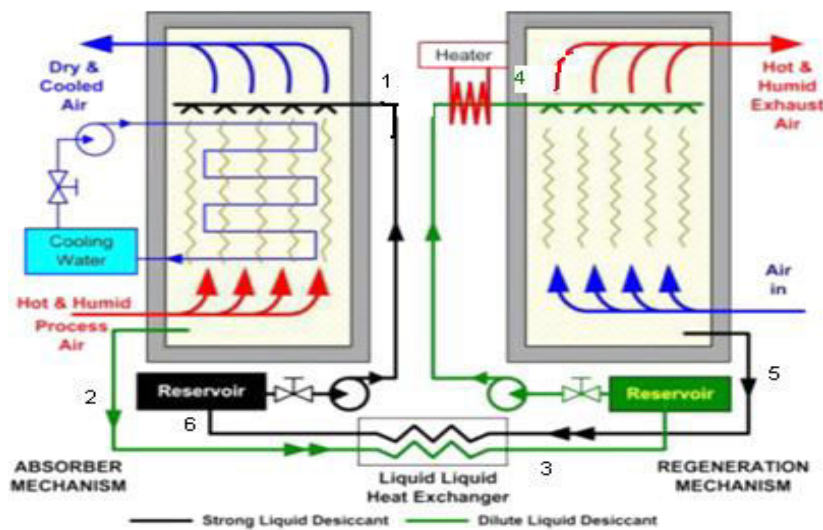


Figure 1: Schematic of liquid desiccant air cooling system [5]

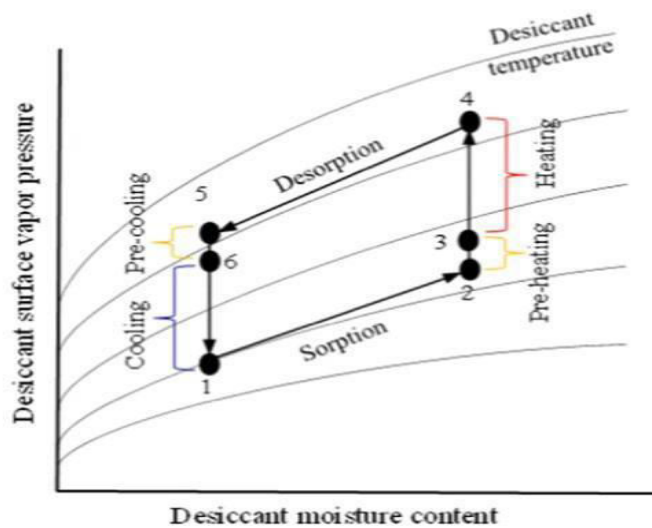


Figure 2 Diagram of desiccant vapor pressure to moisture content [3]

Fig shows the at different pressure, moisture will be present in desiccant solution or to show that desiccant absorb moisture or desorbs. The different processes are as follows

1-2 Dehumidification process: During this process the desiccant absorbs the moisture from incoming air. This is done by direct contact to air which is come to atmosphere.

2-3 Preheating process: This process in done in a heat exchanger by transfer heat between weak desiccants to strong desiccant.

3-4 Heating process: This process is done in heater. This process is done because of increase the temperature of desiccant at a certain limit before it enters the regenerator section.

4-5 Regeneration process:- In this process, desiccant desorbs moisture to the air. This is done by contact between the air and desiccant.

5-6 Pre cooling process:- This process is done in heat exchanger by transferring heat to strong desiccant to weak desiccant

6-1 Cooling process:- This process is done in cooler. This process is done because of decrease the temperature of desiccant to a certain limit before in passes to dehumidifier section.

In dehumidifier section, desiccant is sprayed on top portion of dehumidifier and the air inlet is from bottom portion of dehumidifier. Desiccant absorbs moisture from process air and then this diluted solution is being stored in bottom portion of dehumidifier.

From that diluted solution is passing through heat exchanger to heater and then to regenerator unit. In regenerator unit the dilute desiccant solution removed the moisture to air and this moist air is removed to atmosphere. In heat exchanger heat transfer takes place between hot to cold or cold to hot desiccant.

### III. DIRECT CONTACT TYPE DEHUMIDIFIER OR REGENERATOR

In direct contact dehumidifier-regenerator system, water vapor and heat exchange takes place between the streams of desiccant and air. There are various designs for direct contact dehumidifier- regenerator system like packed bed type, spray tower and falling film type.

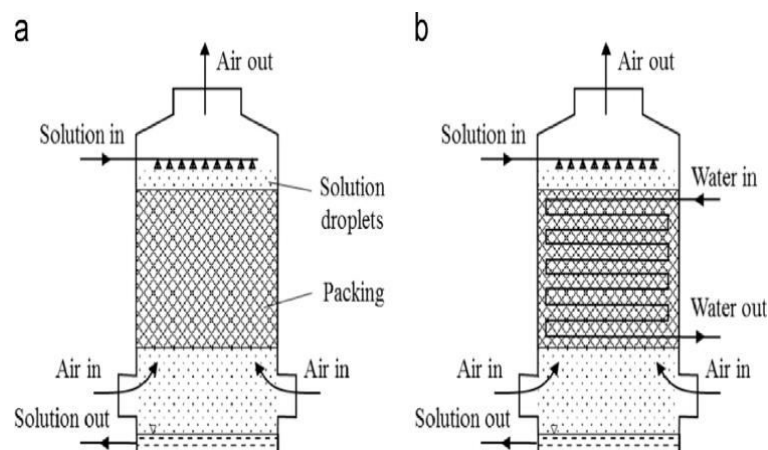


Figure 3: (a) Adiabatic packed bed and (b) Iso-thermal packed bed[3]

Packed bed: Desiccant solution is sprayed with the help of nozzle of any other spraying mechanism from top of packed bed. Then desiccant comes into the direct contact of air. The contacting dehumidifier and regenerator may be of two type, Adiabatic or Isothermal or Internally cooled/heated type as shown in figure 3. [3]

In an adiabatic packed bed, Figure 3(a)[3], as desiccant pass through dehumidifier-regenerator set, its temperature varies because of heat exchange with air stream and phase change. Because of this reason moisture removal or addition takes place. In internally heated/cooled “isothermal” packed bed, shown in Figure 3(b)[3], Water is used as third fluid for continuous heating/cooling of solution.. So solutions' temperature remains almost constant and it has better mass transfer compared to adiabatic type.

#### IV. CONCEPTUAL STUDY OF LDAC SYSTEM

G. Grossman [1] did an extensive review on solar cooling and solar air conditioning system. Different methods have been compared such as liquid desiccant, absorption cycle, solid desiccant, ejector cooling system, heat engine driven VCRC with different refrigerants. In an open type liquid desiccant system, the authors considered four processes: dehumidification, sensible cooling, evaporative cooling, and liquid desiccant systems. Liquid desiccant can be  $\text{CaCl}_2$ , ethylene glycol, LiBr, LiCl. As per researchers, Lithium and Calcium based desiccants are strong and weak respectively. For a very low relative humidity level one can use LiBr or LiCl.

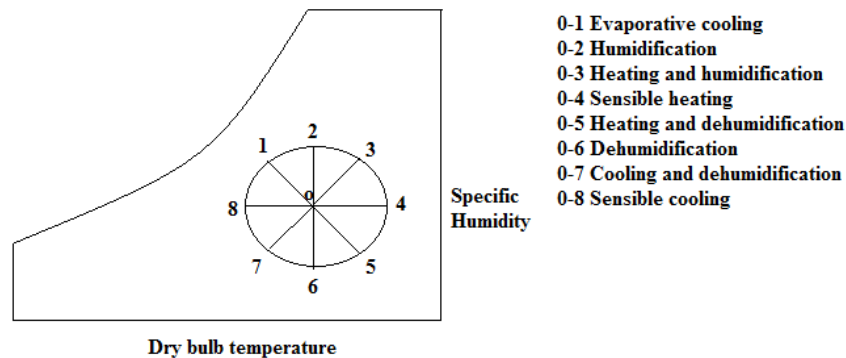


Figure 4 Processes on psychrometric chart

Glycol is example of very mild desiccant. When anyone is using organic desiccant then desiccant condensation is must because during the regeneration process, there is evaporation of desiccant.

D.Waugaman<sup>[2]</sup> has studies and review of desiccant cooling system. He shows design advance in liquid desiccant system like computer modeling and hybrid system that combine with vapor compression system. In advancement of technologies the use of solar energy for regeneration during day time and alternatives are used for night regeneration.

H. Ahmed<sup>[3]</sup> showed carry over problem reduced by indirect contact design like liquid to air membrane energy exchanger. For better performance combination of LDAC and dew point evaporative cooler used.

X.Zhao<sup>[4]</sup> did research on performance evaluation of various mixtures of liquid desiccants to get better performance. Mixture of different liquid desiccants can give better dehumidification efficiency and lower energy consumption as well as lower material cost. They got improvement in COP for various cases in rage of 18% to 27.5 %. They have various group of mixture,

Group 1 pure LiBr

Group 2 is 43% LiBr and 4.8%  $\text{CaCl}_2$

Group 3 is 41% LiBr and 9%  $\text{CaCl}_2$ ,

Group 4 is 39% LiBr and 13%  $\text{CaCl}_2$ ,

Group 5 is 37.5% LiBr and 16.7% CaCl<sub>2</sub>.

Group 5 gives good results in dehumidification efficiency as 18.5% higher as compare to Group 1

M. Mujahid<sup>[5]</sup> did a review on liquid desiccant material and dehumidifiers. They showed liquid desiccants have high moisture absorption capacity, non-corrosive, and non-volatile in nature. LiCl and CaCl<sub>2</sub> mixture are very cost effective. Stability of LiCl is highest among all and has very low vapor pressure. To remove carry-over problem, internally cooled dehumidifier, rotary type dehumidifier and liquid–air membrane exchanger were proposed. Also, the authors have proposed the usage of a high adiabatic flow rate in order to improve the wettability of the surface. Wettability of surface allow the air to come in a contact with liquid desiccant in proper manner and it provides more interaction time to desiccant and air which results in high moisture removal.

M. Mujahid<sup>[6]</sup> showed that in hot and humid climate, evaporative cooling is not so efficient, so author proposed LDAS in combination with evaporative cooling.. Conventional VCRS system is mainly designed to work with latent heat load. This system is good only for sensible heat ratio higher than 0.75. Indirect evaporative cooling and direct evaporating cooling were suggested to improve latent and sensible heat load removal.

V.Desai<sup>[7]</sup> has study about basic process of LDAC system. There are many challenges faced while the system design like which type of material used, carryover & compatibility. He conclude that for LDAC system aluminum & copper is preferable material.

Y. Yin <sup>[8]</sup> had shown that to remove carry-over loss, internally heated regenerators can be used and they found to be more promising than adiabatic regenerator with lower flow rate.

X. Xie<sup>[9]</sup> did experimental analysis and developed mathematical model for LD systems including both sensible and latent heat loads. Surrounding air temperature 29.1°C to 33.6°C and humidity ratio 13.7 to 19.7g/kg. Supply air temperature 23.6°C to 24.2°C and humidity ratio is 7.4 to 8.6 g/kg. COP of the system is 1.3 to 1.8. As shows in above data, they considered cooling and dehumidification process. They compare the+ir mathematical model with their results. Instead of VCRS if we used LD system driven by water than it saves the energy up to 30%, got COP as 4.5.

## V. EXPERIMENTAL INVESTIGATION OF LDAC SYSTEM

M. Bassuoni<sup>[10]</sup> has done experimental analysis with vapor compression refrigeration cycle with liquid desiccant system. Combination of both of these systems increase 54% COP than conventional VCRS with reheating. Energy consumption saved up to 46%.

M.Ali<sup>[11]</sup> explains integrated hybrid cycle between desiccant systems with vapor compression system. The result shows that thermal COP decrease around 35 to 25% than VCRS system. Here desiccant wheel was used along with VCRS.

C.Lin<sup>[12]</sup> explain very important concept of entrancy dissipation. When moisture transfer from one medium to another, there is existence of resistance referred as moisture transfer resistance (MTR). They also co-relate MTR and its performance. To reduce moisture transfer resistance, it is suggested to do pre cooling.

W.Cole<sup>[13]</sup> thermal storage applied for combined heat and power system, solar thermal power station. The result shows that if the thermal energy storage is properly designed, increases system efficiency, flexibility, reduce energy consumption, emission & equipment cost.

Y. Song<sup>[14]</sup> explains requirement of indoor air quality. Energy consumption of various equipments for domestic and industrial is given over here. As shown in below figure, maximum amount of energy consumed by HVAC. Liquid desiccants can be alternate solution to conventional technology.

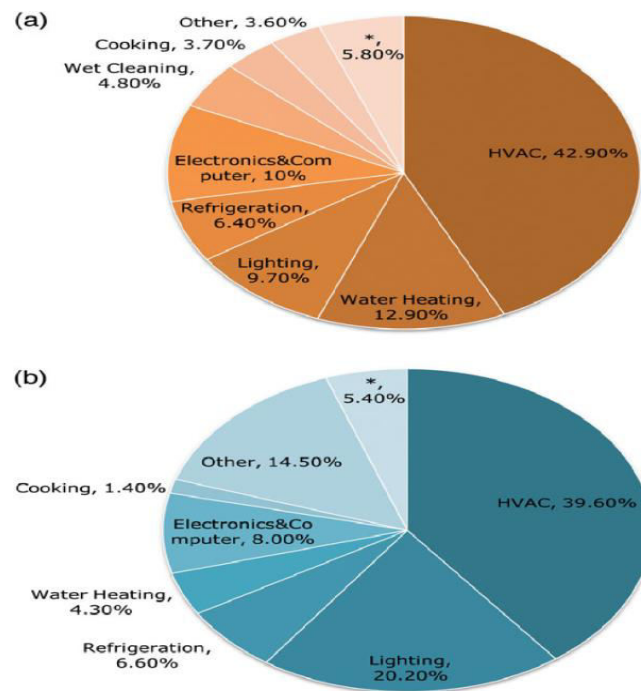


Figure 5: (a) Energy consumption in domestic purpose (b) Energy consumption in Industrial application [14]

R. Qi[15] shows that energy consumption of conventional refrigeration can be reduce by increasing collector area and provide cooling coil to dehumidifier increase the rate of dehumidification. It can save 11-35% of energy consumption during various load condition.

S.Huang[16] has done experiments on cross-flow system for air flow and desiccant flow. On vertical surface, water layer was formed. On that water layer, air flow over it. The flow condition of air was hydro-dynamically and thermally fully developed flow. Afterward governing equations were applied to the system. Validation of Sherwood number and nusselt number were done by experimental result analysis for fully developed flow condition. 2-3% deviation they got because of experimental uncertainty.

J.Park[17] explains empirical analysis for prediction of dehumidification effectiveness. LiCl used as liquid desiccant in the system. 33.3 m<sup>3</sup>/min was flow rate and they obtained various value of dehumidification effectiveness at different operating condition, validate this model with current existed model.

N.Fumo[18] shows that while considering regeneration process, liquid desiccant is more advantageous than solid type. Humidification as well as regeneration rate depend upon flow rate and temperature of both i.e. liquid desiccant and air. To get desire experimental result, Oberg model has been used.

W. Kessling[19] it is the best way to store dissipated energy in the desiccant itself. A Novel dehumidification is designed in which a micro scale flow of liquid desiccant solution was made. Dehumidification of air 5.5 g/kg and storage capacity 700 MJ/m<sup>3</sup> would be gain.

X.Lui[20] experimentally shows that desiccant cooling is far better than air cooling for better dehumidification efficiency. It was suggested to put one more heat exchanger for more heat recovery also proposed to put one more spray section. When air processor ran by heat pump, system's COP becomes 5. COP becomes 1.19 when water driven processor is used. This system can save 20-30% energy. To get good humidification (regenerative), desiccant can be heated.

G.Angrisani[21] the performance of the LDAC system depends upon humidity ratio, regeneration and outdoor air temperature, and flow rate of air. When regeneration temperature increase thermal performance of the system reduces or vice versa. The thermal COP is 0.9 & 1.28 was obtain with regenerative temperature is equal to 55°C & 85°C.

L.Yinglin[22] has done work on performance analysis of combination of VCR and LDAC sytems. The result shows that by small difference of concentration of 1.5% loss of cooling capacity exceeds 10%.

K.Keniar[23] proposed theoretical model which gives nearer result to the experimental result with solar regeneration. It was observed that 10 % of relative humidity decrease indoor air quality.

## VI. EXPERIMENTAL INVESTIGATION OF HYBRID DESICCANT COOLING SYSTEM

K.Gommed[24] proposed the solar powered desiccant system. This is for taking latent load only and there is separate heat pump for sensible load. Humidity of air supplied to conditioned space depends mainly on flow rate of solution also temperature and flow rate of heating/cooling water. Certain condition is discussed for optimum output.

K.Gommed[25] analyses the performance of component theoretically and provide real-time data of heat as well as mass transfer factor or coefficient for system having dehumidification capacity of about 16 KW(average). The data analysis indicates that thermal cop of about 0.8 having plastic losses on the order of 10%.

D.Salimized[26] in this review paper, evaluate cooling water storage for that TRNSYS simulation is use to measure the optimal operating condition of the evaporating cooling tower. Also the TRNSYS simulation is use to measure the performance of the cooling water storage. Result shows that cooling water storage system consuming less energy and increase the performance of the system up to 16% also improve cooling rate about 6%.

S.Bergero[27] the hybrid system is used to achieving higher COP by using heat pump. Advantage of the heat pump is that it operates at the higher evaporation temperature than conventional system. Usage of heat pump increases COP of the system and also the thermal effectiveness of the condenser and evaporator.Result shows that by using the heat pump energy saving increase up to 50%.

I.Karonaki[28] by using counter current flow between desiccant and air to make high dehumidification mass rate, lower mass flow rate of air, lower desiccant and cooling water temperature. For the same inlet condition LiCl humidity ratio is decreased to 31% and the LiBr humidity ratio is reduced to 12%. This results indicate that LiBr is less efficient than LiCl.

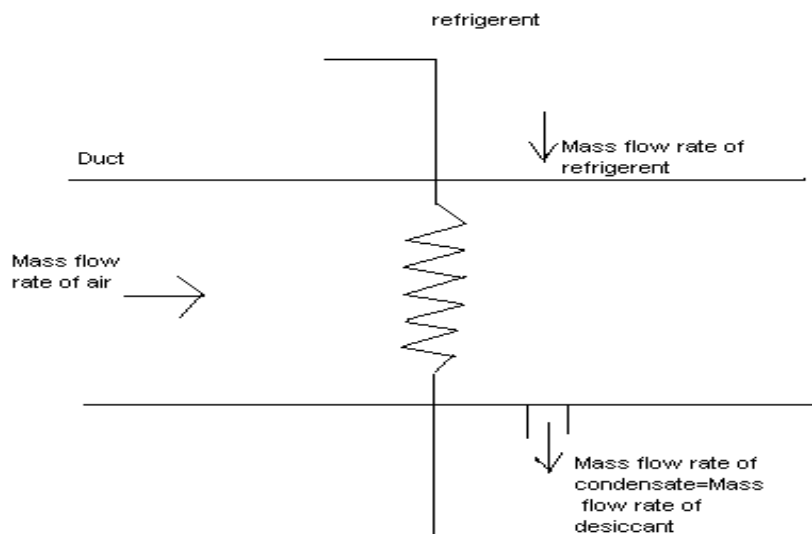


Figure 6: Fluid flow direction (air, desiccant and coolant)





Along with regeneration temperature and coolant temperature, performance of system affected by flow rate of air, desiccant and coolant. By considering energy balance equation in steady state condition, following equation can be derived.

$$m_{air} C_{p_{air}} T_{air,in} + m_{ref} h_{ref,in} = m_{air} C_{p_{air}} T_{air,out} + m_{ref} h_{ref,out} + m_{desiccant} h_{fg}$$

$$m_{air} C_{p_{air}} (T_{air,in} - T_{air,out}) + m_{ref}(h_{ref,in} - h_{ref,out}) = m_{desiccant} h_{fg}$$

$h_{ref,in}$  = enthalpy of refrigerant into the system

$h_{ref,out}$  = enthalpy of refrigerant out of the system

$h_{fg}$  = heat of vaporization

RE = refrigeration effect =  $(h_{ref,in} - h_{ref,out})$

$\Delta T_a$  = temperature drop in air

$$m_{air} C_{p_{air}} \Delta T_a - m_{ref} RE = m_{desiccant} h_{fg}$$

$$m_{desiccant} = \frac{m_{air} C_{p_{air}} \Delta T_a - m_{ref} RE}{h_{fg}}$$

By considering energy balance equation in steady state condition, following equation can be derived.

## VII. CONCLUSIONS

The following conclusions of can be made from the review of recent advance technology LDAC for both system as well as equipment.

- Desiccant reduces humidity of air and temperature is reduced by other components.
- Effectiveness of regeneration and dehumidification process depends on the effect of variable such as air temperature, air and desiccant flow rates, humidity, desiccant concentration and temperature.
- LDAC system save 20% to 30% energy in comparison with conventional AC system.
- The COP of hybrid desiccant system has changed according to climate. The COP of the hybrid desiccant system is 36% and 28% less than the COP of VCS in hot dry or humid condition.
- A concentration of strong solution increases, specific moisture removal rate and COP will increase.
- Thermal performance of hybrid cooling system reduces when temperature of regeneration increase is useful for increasing cooling effect provided by the desiccant cooling system.
- The COP of mixed desiccant i.e. LiBr – CaCl<sub>2</sub> – water can improved to 18% and 27.9% then the pure water system respectively.
- Most design suitable good heat transfer effectiveness obtained acceptable pressure drop 80% effectiveness.
- The mass flow ratio of air to desiccant solution varies in range of 0.15 to 0.25.
- By increasing the flow rates of desiccant and air both solution, the system COP as well as moisture removal rate are increased.

## NOMENCLATURE

C.C.	Cooling Capacity
AC	Air conditioning
LDAS	Liquid desiccant air cooling system



LD	Liquid Desiccant
VCR	Vapor Compression Refrigeration
SMR	Specific moisture removal rate
DCS	Desiccant cooling system
DW	Desiccant wheel
ILADAC	Internally cooled liquid desiccant air conditioning system
ALDAC	Adiabatic liquid desiccant air conditioning system
TES	Thermal energy storage
RSHF	Room sensible heat factor
HVAC	Heating, ventilation & air conditioning
LiBr	Lithium Bromide
LiCl	Lithium Chloride
CaCl <sub>2</sub>	Calcium Chloride
SHR	Sensible heat ratio
$\varepsilon$	Effectiveness

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