LIQUID DESICCANT AIR CONDITIONING SYSTEM: A REVIEW

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Abstract: Due to depletion of ozone layer and greenhouse effect, global warming increases day by day which affects the comfort condition required for the human kind. Thus, to provide a comfort condition to human kind, air-conditioning system is utilized. But conventional air-conditioning system consumes the major part of conventionally generated electricity. Hence, there is an urge to find the efficient way to provide comfort condition to human kind. Liquid desiccant based air-conditioning system is one of the promising system, which supplies clean and dehumidified air to provide comfort condition and can be utilized in buildings and industrial applications. This paper focuses on different new methods applied by researchers to use liquid desiccants in air conditioning like multistage cooling, membrane LDAC, hybrid LDAC and many more augmentations to improve liquid desiccant air conditioning performance.

Introduction

Growing human needs with their increasing population have enforced them to play with nature and natural resources. To fulfill their needless requirement they are less concerned about harm they are causing to nature and using much conventional energy, to live comfort life human kind need air conditioners but conventional air-conditioning system consumes the major part of conventionally generated electricity and have an adverse environmental effect too.

India being a torrid zone, all over year requires air conditioning for comfort working conditions. Sensible heat factor controls the various temperature differences in enclosed space and latent heat factor controls the moisture content of space to be conditioned [1]. In summer, the humidity level is higher and load of air-conditioners increases to maintain comfort condition as temperature to be maintained much below the dew point temperature which requires more conventional energy. So in such case Liquid desiccant air conditioning can replace conventional one with no or less environmental effect.

Desiccants and their properties

Desiccants are used in air conditioning and refrigeration system as these are hydroscopic substances. There are two types of desiccants 1) Solid desiccants 2) Liquid desiccants. The liquid desiccants can be regenerated at temperatures below 80ºC and the concentrated and diluted desiccants can easily be stored to provide a high energy storage capacity for air dehumidification and cooling and having absorption capacity of up to 1000 MJ/m^3 [2].

Properties of good desiccants: [3]

- Large saturation absorption capacity
- Low regeneration temperature
- High heat and mass transfer coefficients
- Low viscosity
- Non- Volatile
- Non-Corrosive
- Odourless
- Non toxic
- Non Flammable

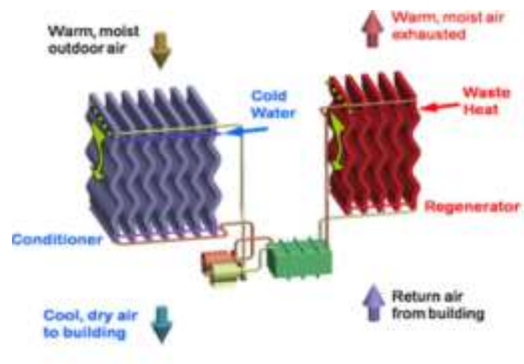

Fig 1. Liquid Desiccant Cooling Air Conditioning [4]

I. LITERATURE REVIEW

Crofoot Lisa et al. [5] have studied a Liquid desiccant air conditioning (LDAC) system driven by solar energy that has been installed in Kingston, Ontario, Canada at a field site. The setup features a low-flow parallel plate liquid desiccant air conditioner, and a 95 m^2 evacuated tube solar collector array. In installed LDAC system a low-flow parallel-plate mass and heat exchangers was used as both the regenerator and conditioner with having desiccant flow down the outside of the plates while internally cooling/heating water was recirculated.

Fig 2. (a) Installation of solar array (b) Liquid desiccant air conditioner (right) at field testing site [5]

A 90kW gas boiler was used to test LDAC and to simulate a solar input. Higher performance obtained with high water heating temperatures. Therefore evacuated tube collectors were chosen for solar array. The average latent cooling power was obtained as 13.2 and cooling power was 12.3kW. Over the days of experiment 0.47 thermal COP was seen. Solar collector efficiency was 56% and solar energy was able to give 63% of the heat to drive the LDAC. Performance improved with hotter and more humid weather. Over the winter the solar array was operated with a dry cooler. 18,800 kWh were collected with an average efficiency of 61%.

Table 1. Operating conditions and Experimental results

	System Parameter	Results
Controlled Parameters	Process Air Flow (L/s)	1200
	Hot Water Flow (L/min)	90
	Cold Water Flow (L/min)	130 L/min
	Desiccant Concentration (%wt)	25.64-42.73
	Conditioner Desiccant Flow (L/min)	5.3
	Regenerator Desiccant Flow (L/min)	6.5
	Heating Water Temperature (°C)	50 - 90
Results	Measured Latent Cooling Capacity (kW)	4.5 – 23.3 (1.3 – 6.6 tons)
	Measured Total Cooling Capacity (kW)	4.8 – 18.1 (1.4 – 5.1 tons)
	Thermal Coefficient of Performance (-)	0.4-0.6

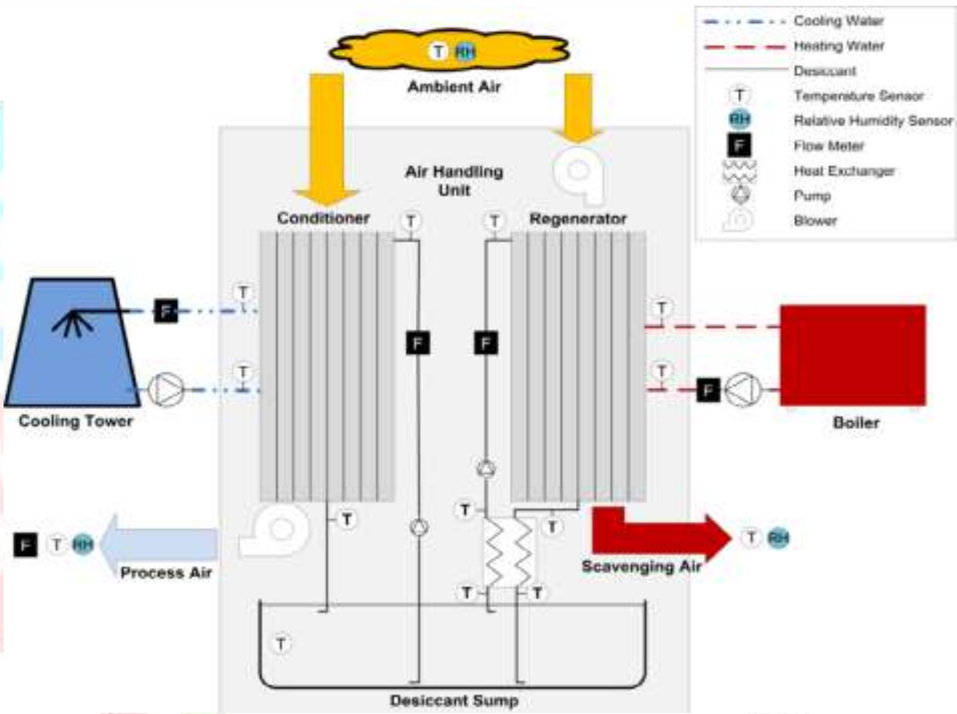

Fig 3.Schematic of liquid desiccant air conditioning equipment and instrumentation used in Phase I testing [5]

Yamguchi seiichi et al. [6] focused on a hybrid liquid desiccant air-conditioning system having a conventional liquid desiccant system and a vapor compression heat pump. The liquid desiccant used in this system is aqueous solution of lithium chloride and the refrigerant of the vapor compression heat pump is R407C. The highlight of the experiment is the absorber and regenerator are integrated with evaporator and condenser. A hybrid system consists mainly of either two source of power or heat or utilize the system for two purpose. Here we can see two systems are integrated to enhance the performance of system. Furthermore mathematical model was developed for the whole system and improved methods for system efficiency was discussed.

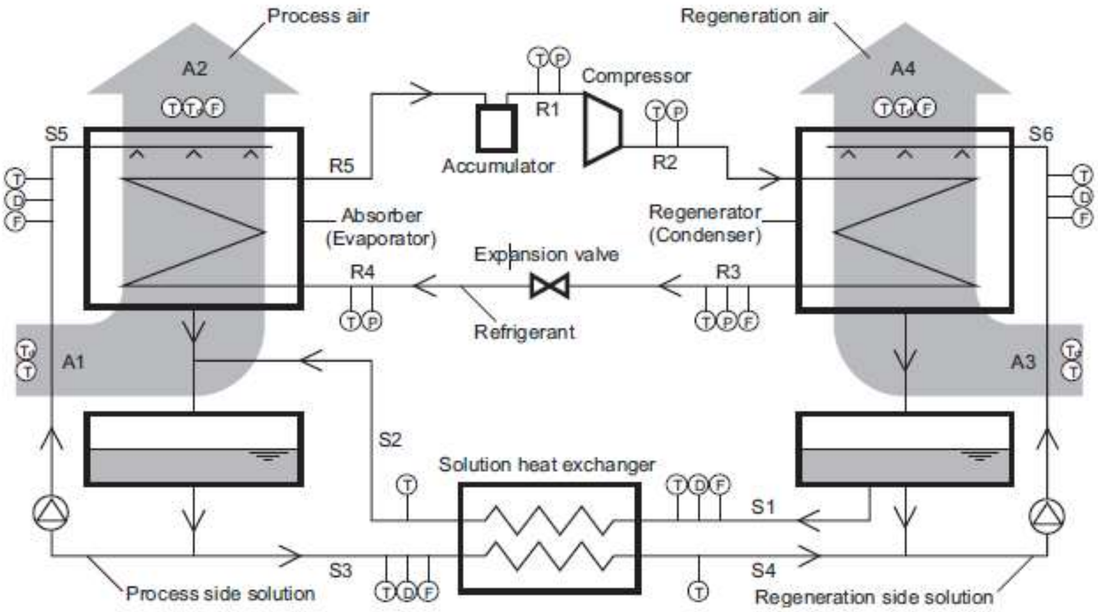

Fig 4. Schematic diagram of hybrid liquid desiccant air-conditioning system [6]

The performance evaluation test was carried out with 4.2 kW rated cooling capacity. The constant air condition generators are equipped to supply stably conditioned air to the process side and regeneration side respectively. The main measuring points are indicated in Fig. 3. T, Td, D, P and F are temperature, dew-point temperature of air, density of solution, pressure of refrigerant and flow rate respectively. In addition, compressor's electric power consumption was also measured.

System's performance was evaluated by two types of coefficient of performance, COP_{sys} and COP_{hp} which are given by following equations: where, COP_{hp} only define compression heat pump cycle.

$$COP_{sys} = \frac{G'_{A1}h_{A1} - G'_{A2}h_{A2}}{G'_{R2}h_{R2} - G'_{R1}h_{R1}}$$

$$COP_{hp} = \frac{G'_{R5}h_{R5} - G'_{R4}G'_{R4}}{G'_{R2}h_{R2} - G'_{R1}h_{R1}}$$

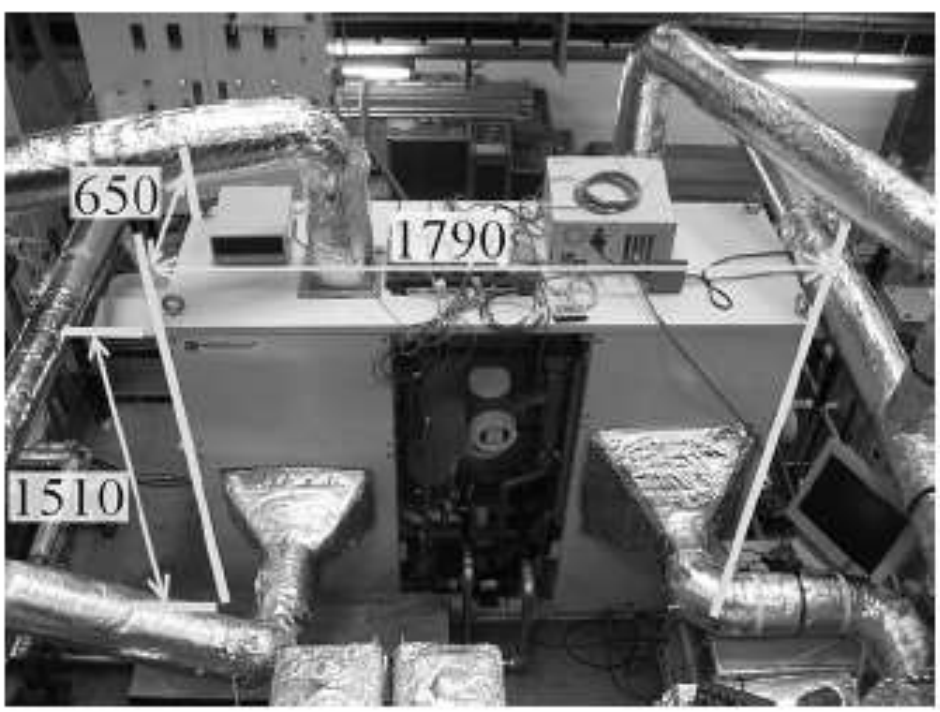

Fig 5. Hybrid liquid desiccant air-conditioning system [6]

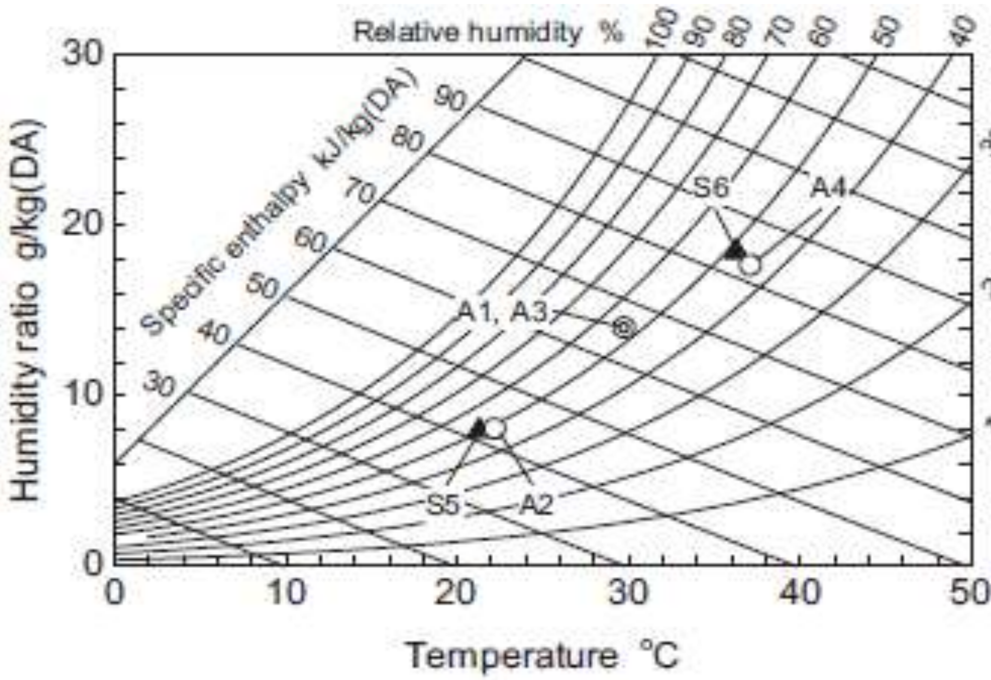

Fig 6. Experimental result of air and solution states on psychrometric chart [6]

In this test there was change in humidity (5.9 g/kg (DA)) as the process air was dehumidified from 14 to 8.1 g/kg (DA) and undergoes cooling from 30 to 22.2ºC. Furthermore, COP_{sys} and COP_{hp} were 2.7 and 3.8 respectively.

Table 2. Experimental results

Parameter (measuring point)	Value
Air	
Temperature at absorber outlet (A2), °C	22.2
Humidity at absorber outlet (A2), g/kg(DA)	8.1
Temperature at regenerator outlet (A4), °C	37.1
Humidity at regenerator outlet (A4), g/kg(DA)	17.7
Solution	
Temperature at absorber inlet (S5), °C	21.3
Temperature at regenerator inlet (S6), °C	36.3
Temperature at heat exchanger inlet (S1), °C	37.1
Temperature at heat exchanger outlet (S2), °C	29.0
Temperature at heat exchanger inlet (S3), °C	21.3
Temperature at heat exchanger outlet (S4), °C	29.0
Concentration at absorber inlet (S5), %	26.9
Concentration at regenerator inlet (S6), %	28.1
Concentration at heat exchanger inlet (S1), %	28.3
Concentration at heat exchanger inlet (S3), %	26.8
Refrigerant	
Temperature at evaporator inlet (R4), oC	6.1
Temperature at evaporator outlet (R5), oC	9.7
Temperature at compressor inlet (R1), oC	13.2
Temperature at compressor outlet (R2), oC	74.6
Temperature at condenser outlet (R3), oC	38.3
Pressure at compressor inlet (R1), MPa	0.64
Pressure at compressor outlet (R2), MPa	1.89
Pressure at condenser outlet (R3), MPa	1.87
Pressure at evaporator inlet (R4), MPa	1.89
Flow rate (R2), kg/s	0.66
Performance indices	
Compressor isentropic efficiency, –	0.63
Temp. efficiency of solution heat exchanger, –	0.50
COP_{sys}	2.71
COP_{hp}	3.82

Abdel-salam H. Ahmed et al. [7] have proposed and investigated a new membrane liquid desiccant air-conditioning (LDAC) system. Dehumidifier and a regenerator in this system was a liquid-to-air membrane energy exchangers (LAMEEs) which can eliminate the desiccant droplets carryover problem occurring in most direct-contact LDAC systems. The system was effective in removing latent load in process that needed controlled humidity. The desiccant used in this system was Lithium chloride (LiCl) due to its low risk of crystallization and lower equilibrium humidity ratio. The performance of the system improves until NTU=10.

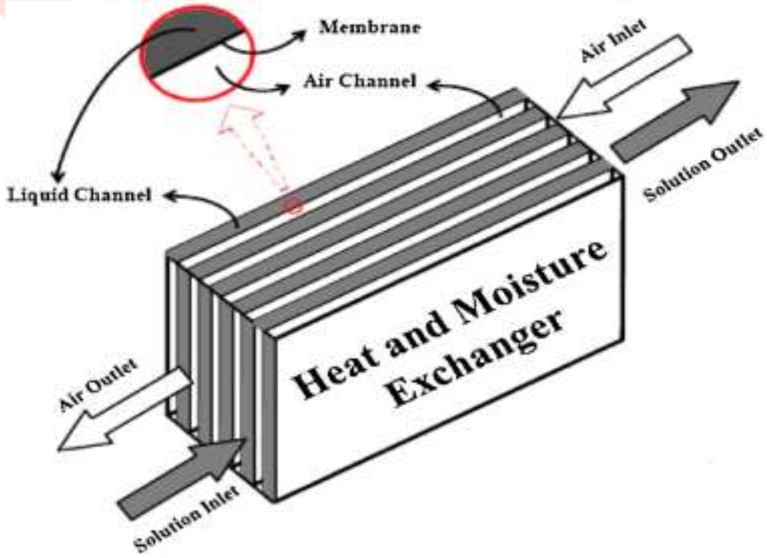

Fig 7. Schematic of a counter-flow LAMEE [7]

The performance parameters in this system are mentioned as follows:

1. Influence of solution inlet temperature to the regenerator ($T_{sol,reg,in}$): It has greater impact on humidity ratio, when $T_{sol,reg,in}$ increases from 40 to 65^{0}C $W_{air,deh,out}$ decreases from 9.5 to 3.8 g/kg.
2. Influence of solution inlet temperature to the dehumidifier ($T_{sol,deh,in}$): Both air outlet temperature and humidity ratio decreases with decrease in the solution inlet temperature. COP and cooling capacity increases by 15% and 53% respectively.
3. Influence of solution-to-solution sensible heat exchanger effectiveness (ε_{shx}): It has greater impact on COP due to effect on cooling capacity and heating equipment. With heat exchanger effectiveness of 0.9 there was rise in electrical coefficient of performance (ECOP) by 14%, thermal coefficient of performance (TCOP) by 38% and COP by 23%.

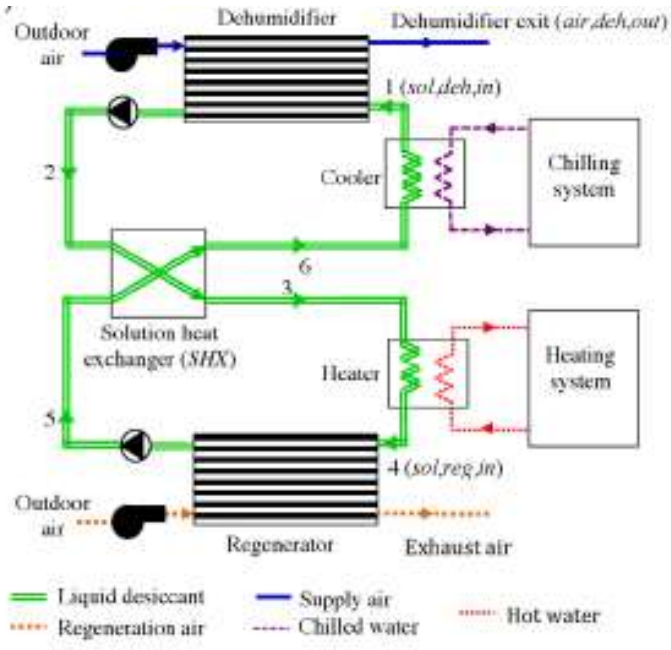

Fig 8. Proposed membrane LDAC system [7]

Wu Qiong et al. [8] presented a study on new desiccant concentration regulation strategy for the dehumidifier of a liquid desiccant air conditioner (LDAC). This technique supplied a strong solution in an intermittent manner to maintain the required working concentration and capable of using multi dehumidifier with single regenerator for many application in buildings.

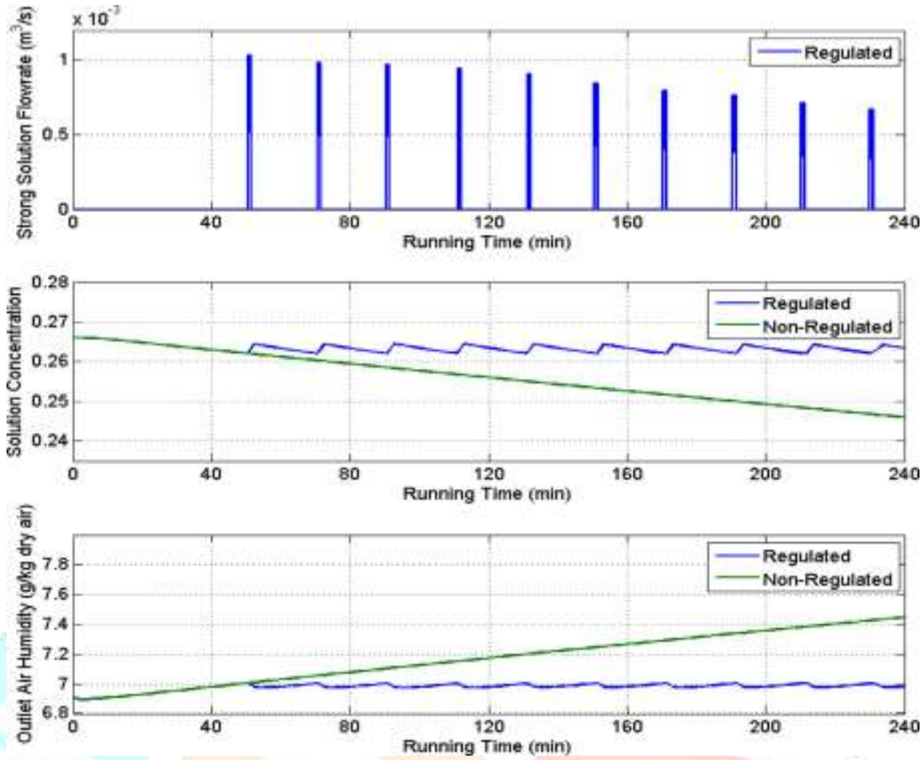

Fig 9. Concentration regulation without disturbances (Case 1). [8]

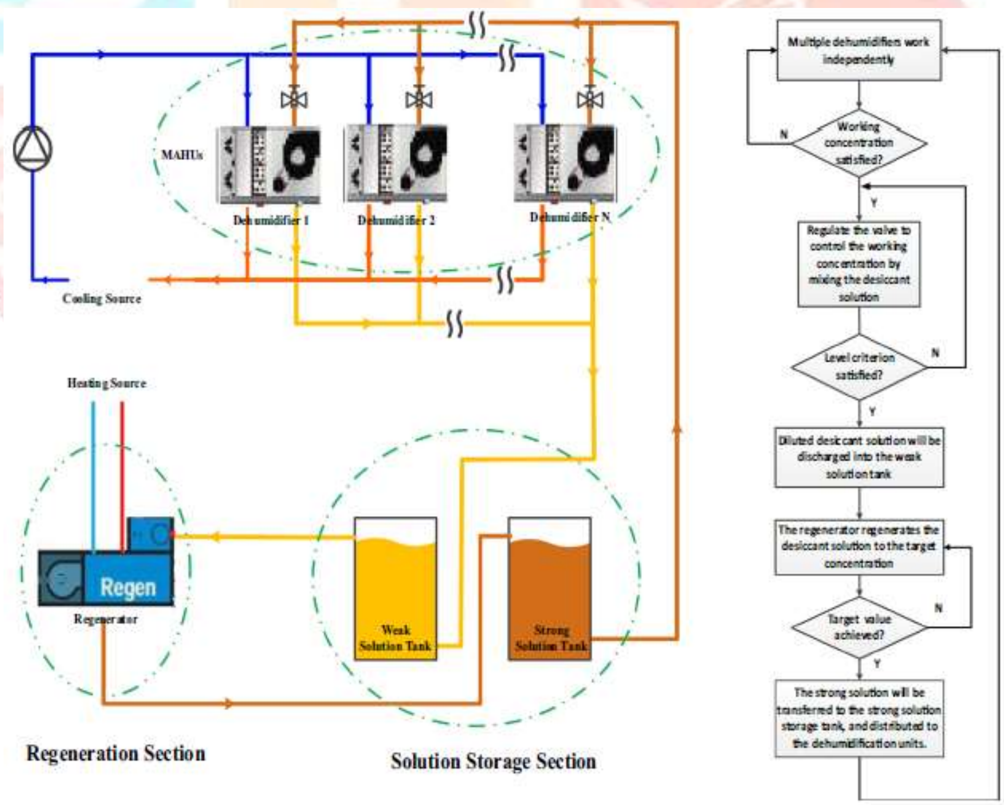

Fig 10. Fig. 9 Diagram and operational process of a distributed LDAC [8]

Strong solution supply rate was determined by the flow rate of strong solution and opening duration of regulating valve by manipulating the opening duration of the valve respect to mass flow rate. The regulation strategy were controlled with and without disturbances, the valve opening time length and frequency were adjusted in controlled manner. This technique leads to use multi dehumidifier with single regenerator for multipurpose in buildings.

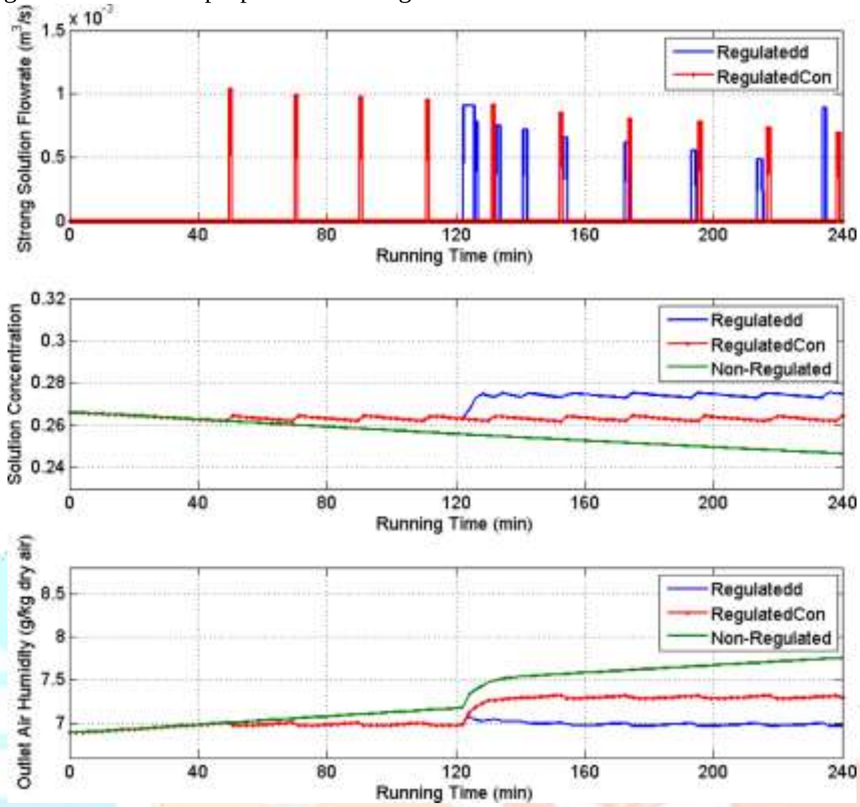

Fig 11. Concentration regulation with solution inlet temperature (Case 2). [8]

Ahmed M. A. et al. [9] developed a conventional liquid desiccant air conditioning with a way to reduce the energy consumption by recovering the heat from the scavenging air using the condenser while also producing freshwater in addition to space cooling. Lithium chloride (LiCl) was used as desiccant in this system.

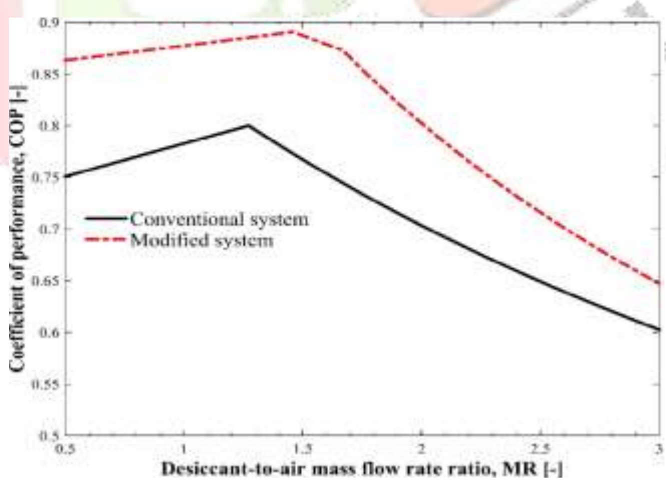

Fig 12. Effect of desiccant-to-air mass flow rate ratio on COP [9]

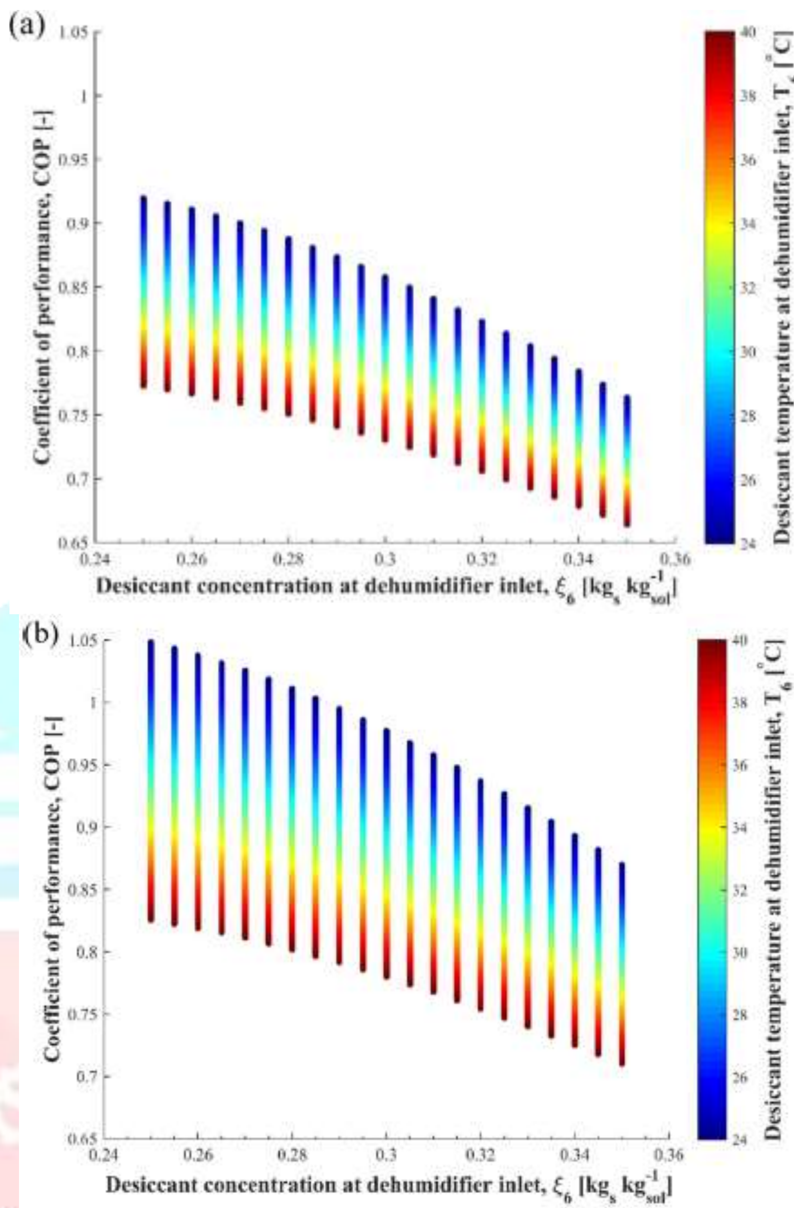

Fig. 13 Effect of desiccant solution condition at dehumidifier inlet on COP. (a) Conventional system. (b) Modified system. [9]

The weak desiccant solution is preheated after the dehumidification process, in the condenser and heat exchanger to states 1 and 2, respectively. Then it is heated to the regeneration temperature (state 3) using the heater with the cycle following the conventional cycle. Hot and humid air leaves the regenerator and enters the condenser where it condenses out. The condensate is produced as fresh water.

The modified system performance was 11.25% better than the conventional one but with limitation that condenser effectiveness should not be less than 0.57. The modified system produces 86.4 kg of fresh water per hour as a by-product.

McNevin Christopher et al. [10] have evaluated novel multi-stage liquid-desiccant air-conditioner with inter-stage flows of heating and cooling water, and flows of desiccant in semi series form. Lithium bromide (LiBr) was used as desiccant with average total cooling rates between 8.4 kW and 19.7 kW, lower cooling water temperatures have given higher cooling rate with 8.8 kW sensible cooling. Thermal coefficient of performance (COP) of 0.58 and electrical COP of 4.7 was achieved.

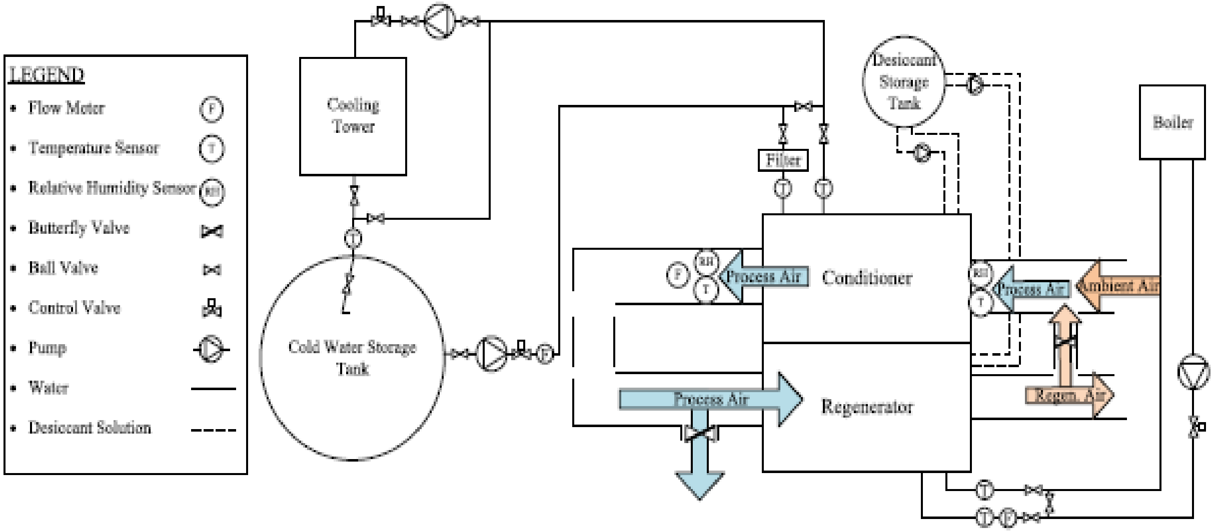

Fig. 14 System Layout showing sensor locations, air flows, and major equipment [10]

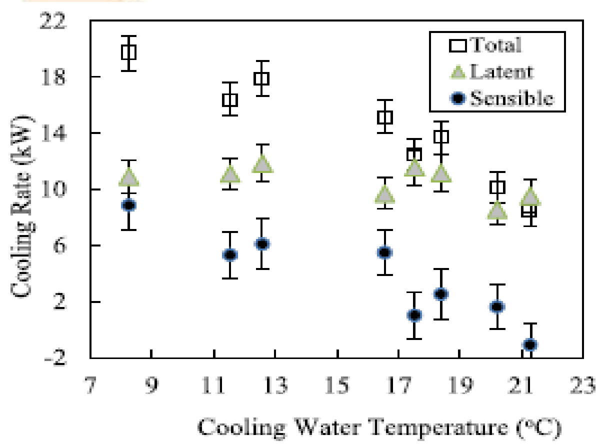

Fig. 15 System's daily average cooling rates effected by cooling water temperature [10]

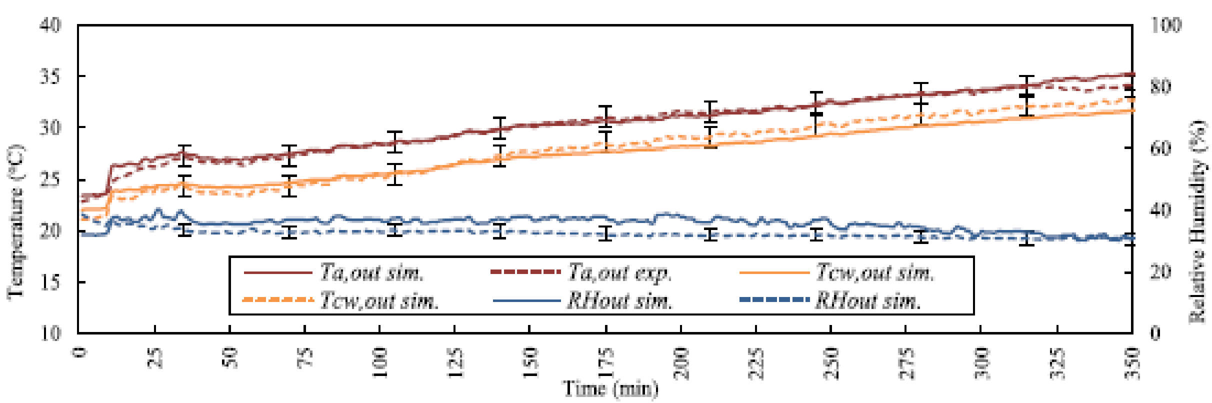

Fig. 16 Simulated conditioner outlets compared to experimental for September 9th [10]

Zhang Fan et al. [11] have combined effective behavior of liquid desiccant and evaporative cooling technology which are highly capable of using low grade heat for regeneration and air conditioning. The results arrived in the form of handling process air to 17.9°C and 9.2 g/kg with COP of 0.56. The effect of solution self-cycle ratio (R_s) discussed and should be kept between 0.6 and 0.7 but under high hot and humid condition this term should be off and regeneration inlet temperature should be increased.

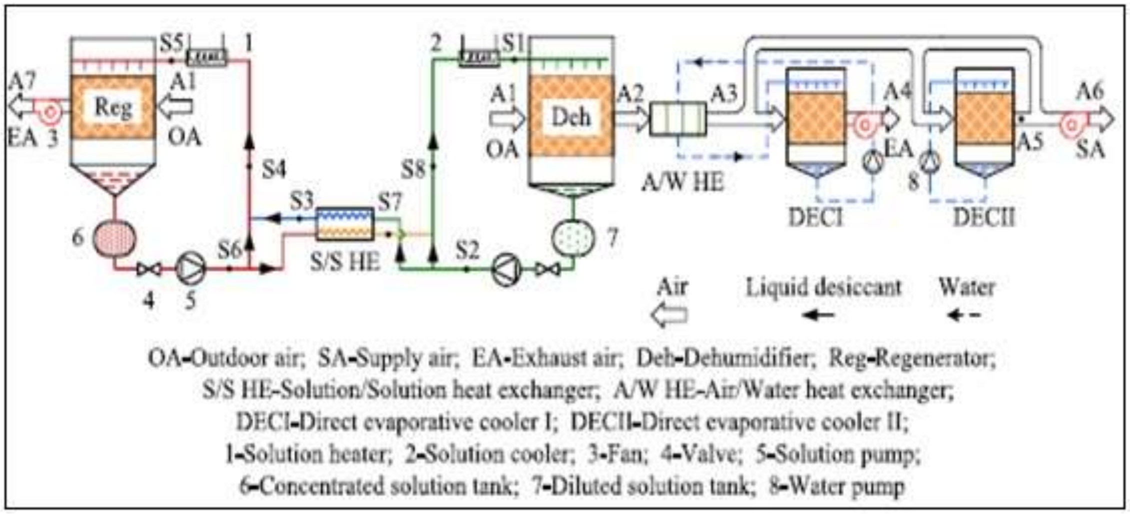

Fig. 17 Schematic diagram of the proposed liquid desiccant evaporative cooling fresh air conditioning system [11]

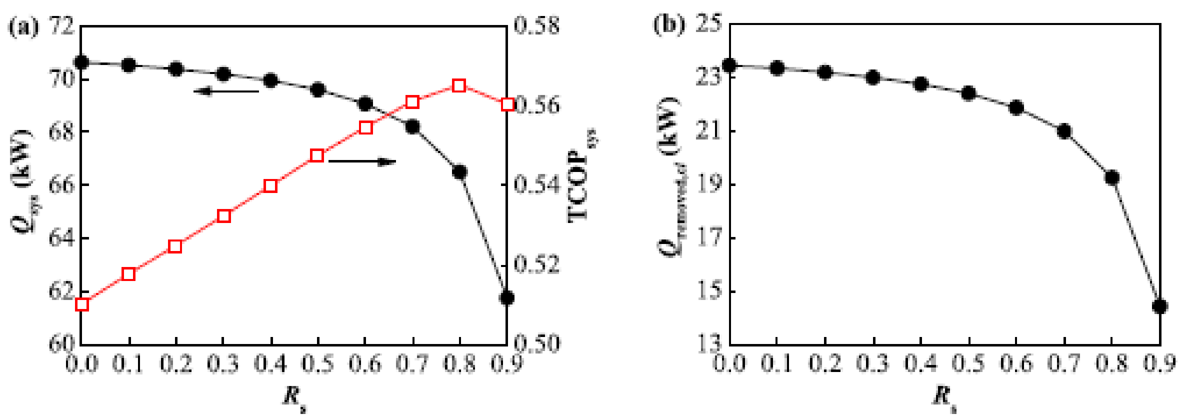

Fig. 18 Effects of solution self-cycle ratio Rs on (a) system cooling capacity Q_{sys} and thermal COP of the whole system and (b) the removed cooling load from the conditioned space $Q_{removed.}$ [11]

II. CONCLUSION

Liquid desiccant air conditioning have great potential and scope to replace the current conventional air conditioning with different new augmentations and techniques along with using low grade heat like solar heat for regeneration and dehumidification that have been discussed in this review paper. New techniques like hybrid LDAC, membrane LDAC, multi stage LDAC, multi dehumidifier, thermodynamics analysis and many more have been studied and compared with conventional air conditioning and given enhanced performance. Lithium chloride have been used in most of the experiments due to its low danger of crystallization. Furthermore advancements needed in terms of regeneration methods for liquid desiccants with their uses and stability as these are highly reliable in humidity control.

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