SOLAR LIQUID DESICCANT SYSTEMS

Fresh Air Dehumidification and Air Conditioning

TERI Workshop on Solar Cooling

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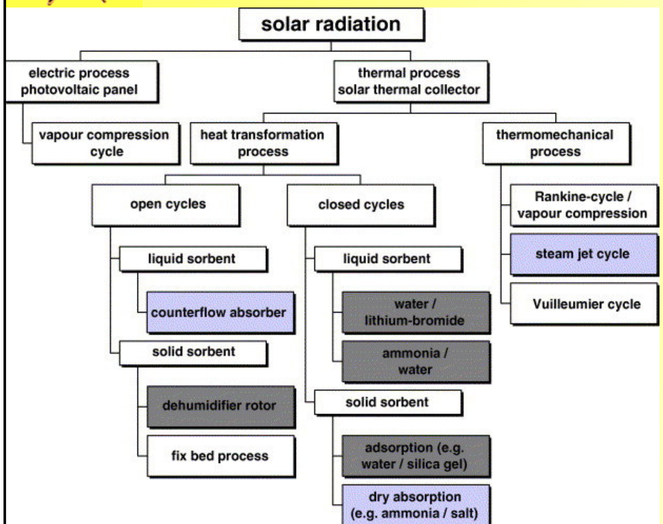
OUTLINE OF PRESENTATION

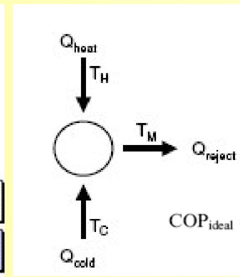
Solar Air Conditioning with focus on Liquid Desiccant Technology

- ***Introduction***
- ***Thermally Driven Cooling Technologies (TDCTs)***
- ***Desiccant based Air Conditioning Systems***
- ***Solar Collectors for AC application***
- ***Recent Developments in the Field***
- ***Conclusion and Future Work***

THERMALLY DRIVEN COOLING TECHNOLOGIES

Source of Energy: Heat





$$COP_{ideal} = \frac{T_C}{T_H} \cdot \frac{T_H - T_M}{T_M - T_C}$$

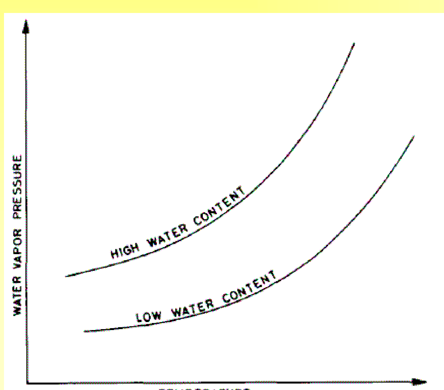
- ***Prevailing Technologies***
  - ✓ Vapor absorption (VAb)
  - ✓ Vapor adsorption (VAd)
  - ✓ Solid desiccant based
  - ✓ Liquid desiccant based
- ***Three Levels of Temperature***
  - ✓ Heat source, heat sink and cold source

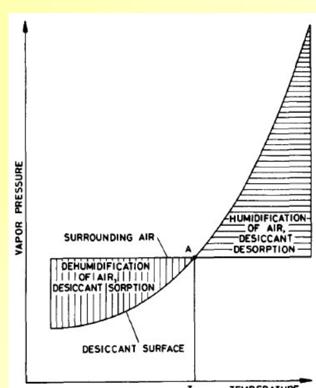
CHARACTERISTICS OF DESICCANTS

Relation of Vapor Pressure with Temperature and Concentration

- ***Vapor Pressure at the Surface of Desiccant***

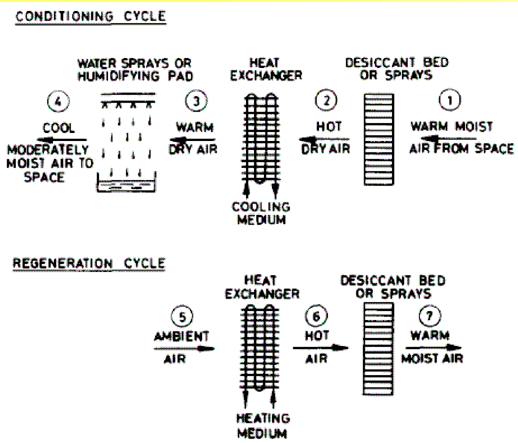
✓ Lower	Low temperature and High concentration	Absorbs water vapor
✓ Higher	High temperature and Low concentration	Desorbs water vapor

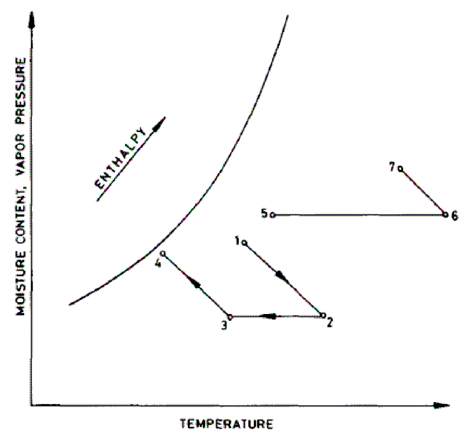




OPEN CYCLE DESICCANT COOLING

Various Schemes





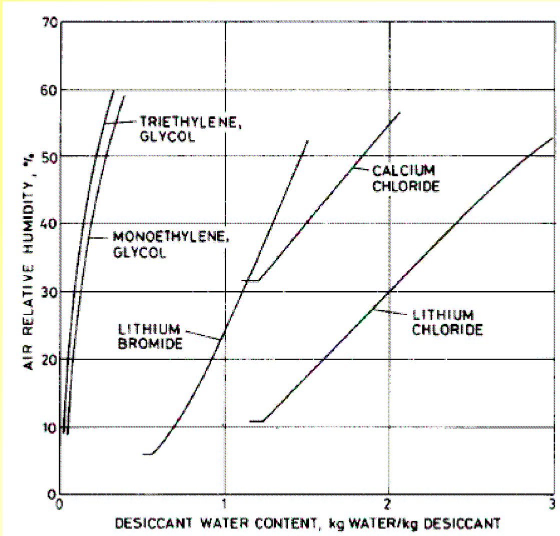
- ***Absorber:*** *Dehumidification of air* — *Cooling before/after*
- ***Regenerator:*** *Moisture removal from desiccant* — *Heating before*

LIQUID DESICCANT MATERIALS

Jain and Bansal, 2007

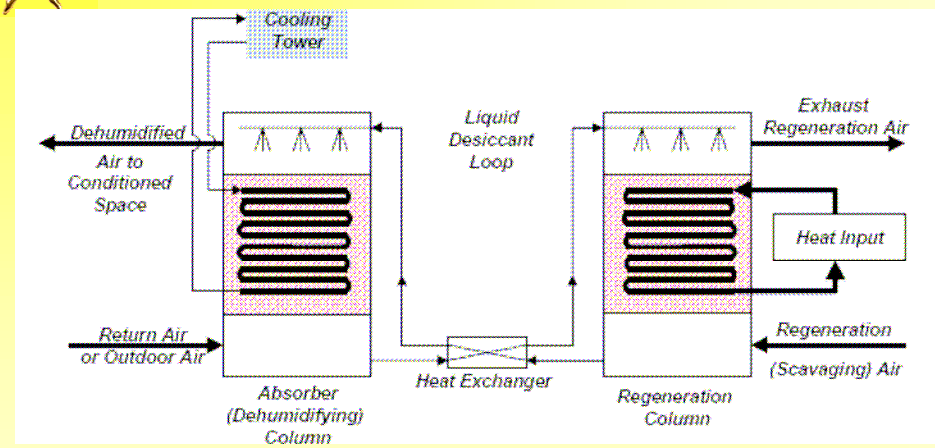
Desirable Properties and Candidates

- ***Triethylene Glycol (TEG)***
  - ✓ Dehumidifies air down to low RH
  - ✓ Higher solution circulation rate
    - *Steeper curve*
  - ✓ Mass loss during regeneration
- ***Calcium Chloride***
  - ✓ Low cost
  - ✓ Moderate corrosion hazard
  - ✓ High crystallization risk
- ***Lithium Chloride***
  - ✓ Dehumidifies air down to low RH
  - ✓ High cost
  - ✓ High corrosion hazard
- ***Cost effective mixture***
  - ✓ $LiCl+CaCl_2$ (50% each)



LIQUID DESICCANT AIR CONDITIONING SYSTEM

Components and Layout

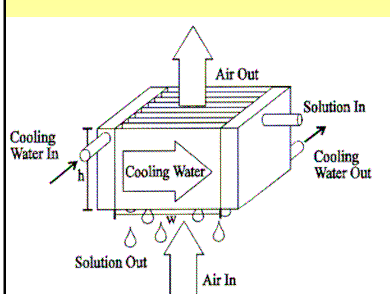


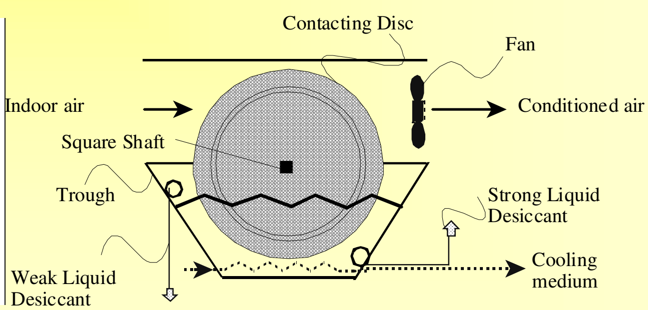
- ***Absorber (Dehumidifying Column):*** ***simultaneous cooling improves performance***
- ***Regeneration Column:*** ***simultaneous heating improves performance***
- ***Liquid-Liquid Heat Exchanger*** ***increases COP***

ABSORBER DESIGNS

Desirable Features and their Need

High mass transfer coefficient	*Effective moisture removal*
High heat transfer coefficient	*Keep desiccant temperature low*
High surface/volume ratio	*Compact design*
Uniform distribution at low flow	*Better contact*
Zero carryover	*No health hazard to occupants*
Low flow resistance	*Reduce pumping and blower power*

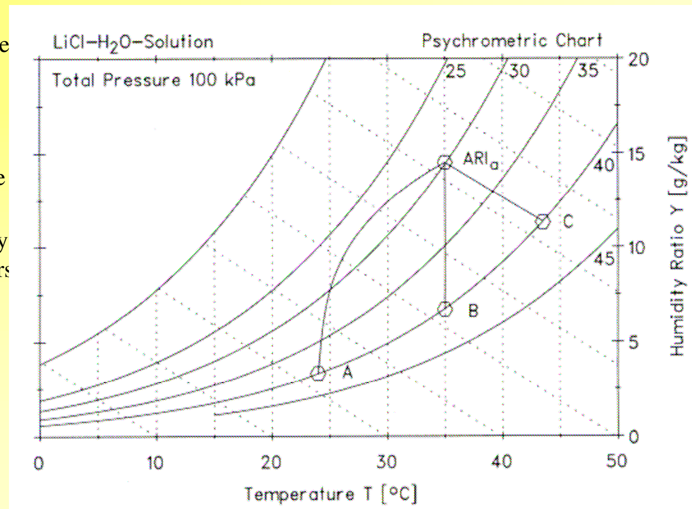




ABSORBER PERFORMANCE

Adiabatic, Isothermal, Internally Cooled

- ***Adiabatic Absorbers***
  - ✓ High humidity ratio in the outlet conditioned air
  - ✓ Precooled LD coupled
- ***Isothermal Absorbers***
  - ✓ Low humidity ratio in the outlet conditioned air
  - ✓ Suitable for evaporatively cooled LD based absorbers
- ***Internallly Cooled Absorbers***
  - ✓ Very low humidity ratio in the outlet conditioned air
  - ✓ Coupled with DX vapour compression system or chilled water loop



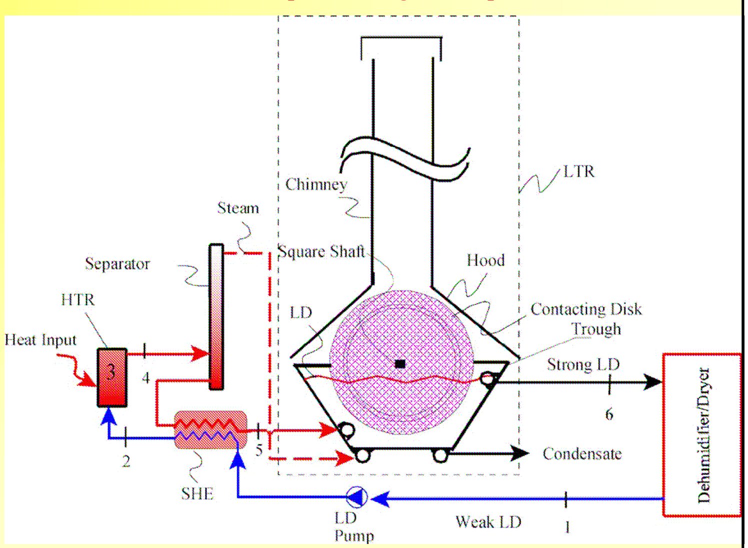
REGENERATOR DESIGNS

Rane et al, 2005

Desirable Features, A Superior Design Example

Two Stage Regeneration

- ***High COP***
- ***Higher concentration difference: Lower flow rate, low parasitic power***
- ***Needs higher heat supply temperature ~150 C***
- ***Disc Type Contacting Device***
- ***Wetting and flow rate decoupled***
- ***High packing density (465-600 m^2/m^3)***
- ***Low pressure drop of air (50 to 100 Pa)***



LIQUID DESICCANT TECHNOLOGY

Advantages and Issues

- ***Advantages***
  - ✓ Work at ambient pressure
    - *No issues related with pressure (low or high)*
  - ✓ Separation of regeneration and absorption processes in time and space
    - *Flexible component layout*
    - *Regeneration time as per heat availability (say from sun)*
    - *High density energy storage (for absorption in off-sunshine hours)*
      - ***Theoretically 1354 MJ/m3 as compared to 360 MJ/m3 for water (Kessling et al., 1998)***
  - ✓ Two stage regeneration advantages

- ***Issues***

✓ Zero carryover of desiccant	Air supplied to occupied space
✓ Uniform distribution	Contacting devices at low flow rate of desiccant
✓ Low cost of components	Compatibility with desiccant
✓ Low parasitic power	Compete with high COP VC system

LIQUID DESICCANT SYSTEM
FOR
FRESH AIR DEHUMIDIFICATION

LDS_FAD for TMC Chhatrapati Shivaji Hospital (TMC_CSH), Kalwa

Based on IIT Bombay Owned
Indian Patent # 203 949 & Indian Patent # 206 320

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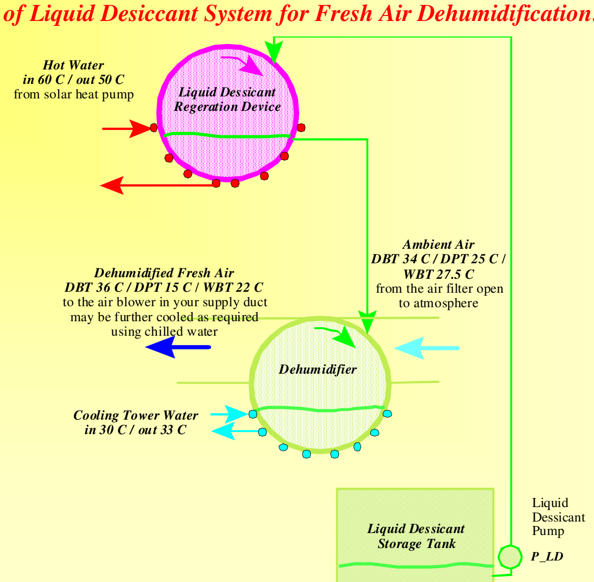
OBJECTIVES

Liquid Desiccant System for Fresh Air Dehumidification: LDS_FAD

- ***Supply Dehumidified Fresh Air using Modular LDS_FAD***
  - ✓ Dehumidifying fresh air before supplying in to the air conditioned spaces at the Chhatrapati Shivaji Hospital (TMC_CSH), Kalwa
- ***Save 10 to 30% Requirement for Chilled Water used for Air Conditioning***
  - ✓ Saving would depend on outdoor weather condition
- ***LDS_FAD Module Size would be 7.5 TR***
  - ✓ Suitable for pairing up with Modular Solar Heat Pump (SHP) of 15 TR cooling capacity
  - ✓ LDS_FAD would be operated using recovered hot water from SHP
    - *Hot water at 60 C from Ammonia/Water based SHP will be used to regenerate the Liquid Desiccant (LD)*
    - *Regenerated LD will be used to dehumidify fresh air while being cooled using water from a cooling tower*
- ***Dehumidified Fresh Air will be Cooled Further before Being Ducted to Various Zones***
  - ✓ Chilled water at 12 to 15 C from Ammonia/Water based SHP will be used

SCHEMATIC REPRESENTATION

Schematic of Liquid Desiccant System for Fresh Air Dehumidification: LDS_FAD



DESIGN CONDITIONS FOR TMC_CSH KALWA

Liquid Desiccant System for Fresh Air Dehumidification: LDS_FAD

- ***LDS_FAD Module Capacity*** — ***7.5 TR (26.4 kW) max***
  - ✓ Air delivery condition DBT / DPT — 36 / 15 C
  - ✓ Air flow rate — ~ 0.75 m^3/s; ~0.9 kg/s
  - ✓ Moisture removal capacity — ~ 10 g/s; 36 kg/h
  - ✓ Air side pressure drop (excluding inlet air filter) — < 15 mm H_2O
- ***Cooling Tower Capacity*** — ***9 TR (32 kW_h)***
  - ✓ Water temperature In/Out — 33 / 30 C
  - ✓ Water flow rate — 1.26 lps; 75 lpm; 4500 lph
- ***Hot Water Requirement*** — ***45 kW_h***
  - ✓ Water temperature In/Out — 60 / 50 C
  - ✓ Water flow rate — 1.08 lps; 65 lpm; 3900 lph
  - ✓ Water side pressure drop through the LDS_FAD — < 10 m H_2O

Note: Heat required is about 50% of the heat recovered from the absorber of a 15 TR SHP

*15 TR x 3.52 kW/TR / 0.6 x 50% = 52.8 kW / 0.6 x 50% = 88 kW x 0.50 = **44** kW*

SCOPE OF SUPPLY

NOTE: ANALYSIS LISTED IS FOR 7 X 7.5 TR LDS_FAD BASED ON SWH

Liquid Desiccant System for Fresh Air Dehumidification: LDS_FAD

- ***LDS_FAD Module*** — ***7.5 TR (26.4 kW) max***
  - ✓ LD storage tank, circulation pump and piping
  - ✓ Hot water and cooling tower water piping
  - ✓ Hot water and cooling tower circulation pumps
  - ✓ Controller with instrumentation
- ***Cooling Tower Capacity*** — ***9 TR (32 kW_h)***
- ***Delivery at TMC_CSH, Kalwa***
- ***Supervision of Installation and Commissioning***
  - ✓ A skid mounted system, 1500 L x 2000 W x 2000 H, will be tested and shipped from ADITTYA/HPL_IITB
  - ✓ A cooling tower, footprint less than 1200 L x 1200 W, may be separately shipped and may have to be coupled to this skid mounted system at site by locating it next to it.

<u>Note:</u> ***Following items/activities are not included in ADITTYA's scope***

Air blowers to draw air through the LDS_FAD, cool it further and blow through the ducts and associated installation

Foundation for the skid, the cooling tower and all the associated civil and electrical work

SOLAR COLLECTORS

Kalogirou 2004

Suitable for Sorption based Air Conditioning

Solar energy collectors

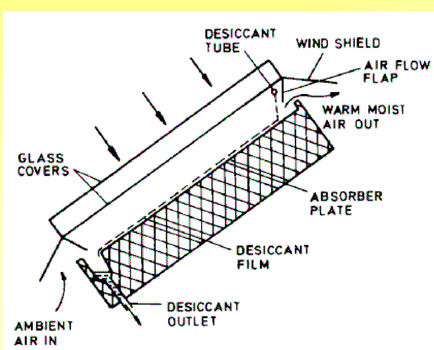
Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

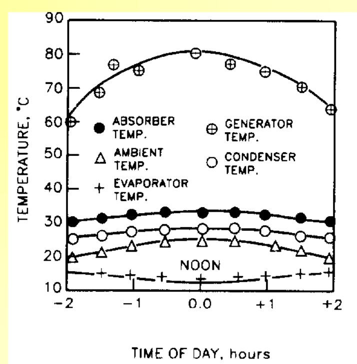
- ***Flate Plate Collectors (FPC)***
  - ✓ Direct regeneration — Liquid desiccant regeneration
  - ✓ Air heater — Solid desiccant regeneration
  - ✓ Water heater — Adsorption chiller
- ***Evacuated Tube and Compound Parabolic Collector (EGT and CPC)***
  - ✓ Single/Double effect absorption chiller
  - ✓ Two stage liquid desiccant regeneration

FLAT PLATE SOLAR COLLECTOR

Liquid Desiccant / Absorption System

- ***Direct Regeneration of $CaCl_2$*** *(Mullick and Gupta, 1974)*
  - ✓ Max temp/efficiency/collector area — 68 C/ 40% / 8.75 m² per kW
- ***Hot Water for Vapor Absorption System*** ***(Hommad and Zurigat, 1998)***
  - ✓ Collector area/Duty period — 14 m² for 1.5 TR system / 4 to 5 h/day

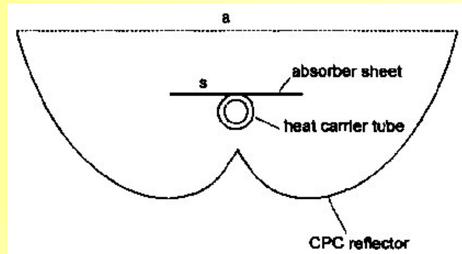




COMPOUND PARABOLIC COLLECTOR

Liquid Desiccant / Absorption System

- ***Features*** *(Lamp 1998)*
  - ✓ Non-imaging reflector
  - ✓ Higher acceptance angle
  - ✓ Fixed, Long axis E-W
    - *Min acceptance angle>23.5 x2*
    - *>47 to collect diffuse radiation*
  - ✓ Better performance features
    - *Temperature* 150 C
    - *Efficiency* 50%
      - ***800 W/m2 insolation***
- ***Application***
  - ✓ Double effect absorption system
    - *At high insolation (Da Silva, 2005)*
  - ✓ Two stage regeneration
    - *Liquid desiccant*



PLASTIC SOLAR AIR HEATER

COST RS 4,100/M², WEIGHT 5 TO 7 KG/M², AIR IN/OUT 29 / 90 TO 104 C

HEAT DUTY 0.45 TO 0.72 KW/M², AIR FLOW 390 LPM/M² EFFICIENCY 60 TO 65%, ISOLATION 0.75 TO 1.2 KW/M²

EVACUUATED GLASS TUBE SOLAR AIR HEATER

FIXED PARABOLIC REFLECTOR: COST RS 5,000/M^2, WEIGHT 5 TO 7 KG/M^2

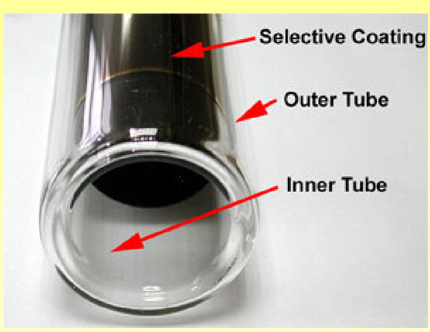
AIR IN/OUT 29/150 TO 298 C, HEAT DUTY 0.3 TO 0.375 KW/M^2, AIR FLOW 100 LPM/M^2, EFFICIENCY 40 TO 60%

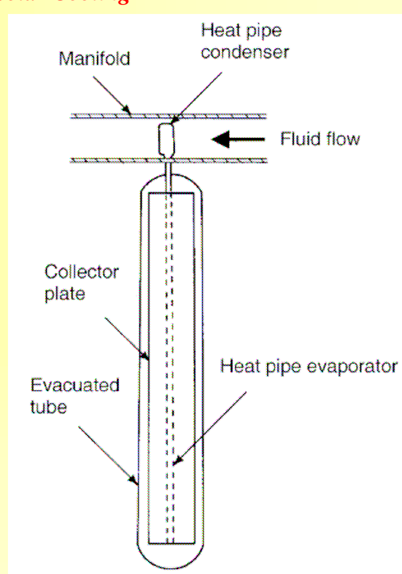
ISOLATION 0.75 TO 1.2 KW/M^2

EVACUATED GLASS TUBE COLLECTOR

Favorable Features for Solar Cooling

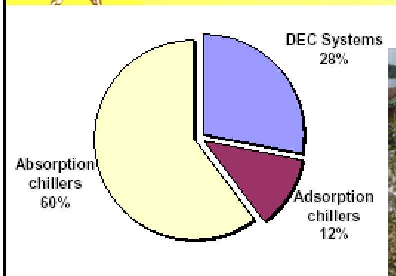
- *Suppression of convection loss*
- *Captures diffuse radiation*
- *Higher efficiency at high incidence angle*
- *Higher efficiency at high collector temperature*
- *Combination with CPC*
- *All glass EGTs are more economical*

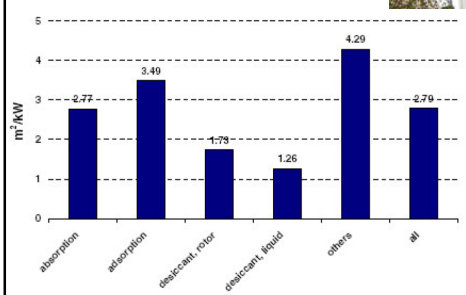




MARKET SHARE AND SPECIFIC COLLECTOR AREA

Solar Sorption Cooling Technologies





- Example
  - ✓ H_2O/LiBr EAW Wegracal SE15 in Rimsting, Germany
  - ✓ Office space cooling and heating
  - ✓ 37 m² flat plate and 34 m² vacuum tube collectors & oil burner Back-up

VAPOR ADSORPTION AC SYSTEM

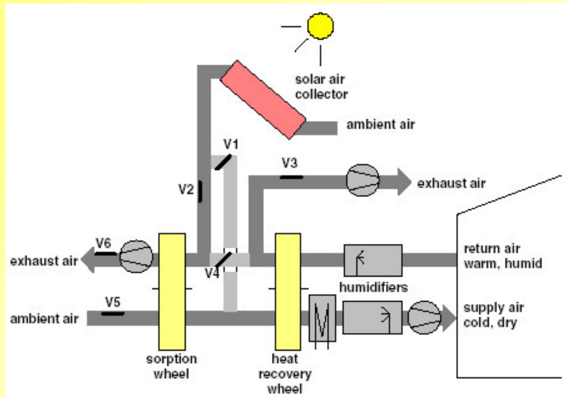
Advantages and Limitations

- ***Advantages***
  - ✓ Dry cooling tower
  - ✓ Low heat supply temperature
  - ✓ No risk of crystallization
  - No wastage of water
  - Low collector cost
  - Less controls
- ***Limitations***
  - ✓ Higher initial cost
  - ✓ Larger construction volume and mass
- ***SolarNext chillii® STC6 unit***
  - ✓ Average COP~0.5
  - ✓ 5.5 kW cooling, 24 m² flat plate collectors

SOLID DESICCANT AC SYSTEM

Chamber of Trade and Commerce, Freiberg, Germany

- ***Features*** ***(Henning, 2007)***
  - ✓ 10,200 m^3/h of nominal air flow rate
  - ✓ 100 m^2 of solar air collector
  - ✓ Indoor conditions are satisfactory
  - ✓ COP values are rather low



LIQUID DESICCANT AC SYSTEM

CONDE 2007

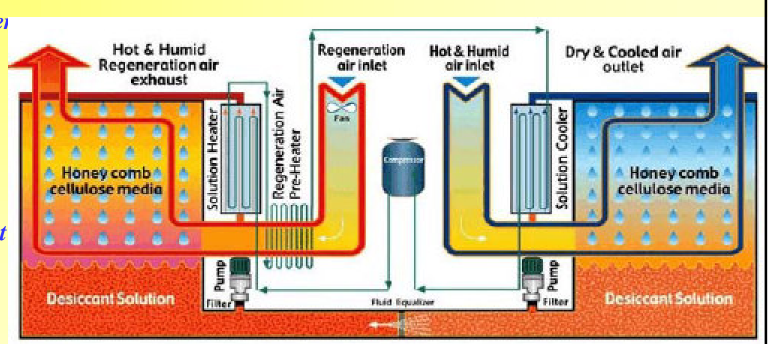
Features of Hybrid Commercial Systems

Kathabar Inc. Hybrid system

- ***Cooling from VC system***
- ***Cooling before absorber***
- ***Heat supply by natural gas***
- ***Heating before regeneration***
- ***Desiccant: Kathene***

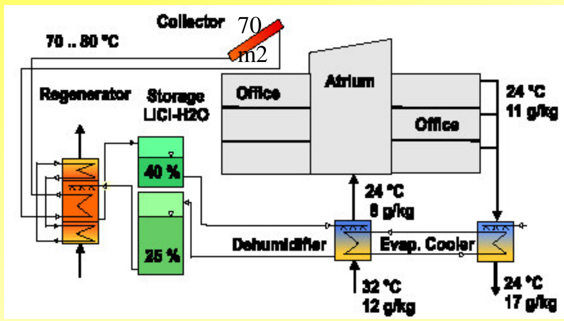
Drycor Corp.

- ***Heat pump use for heat supply and cooling***
- ***Cellulose contacting pads for air-desiccant contact***
- ***Desiccant: LiCl***
- ***Stopped manufacturing due to corrosion problem***



SOLAR DRIVEN LIQUID DESICCANT AC SYSTEM

Features of Commercial Systems

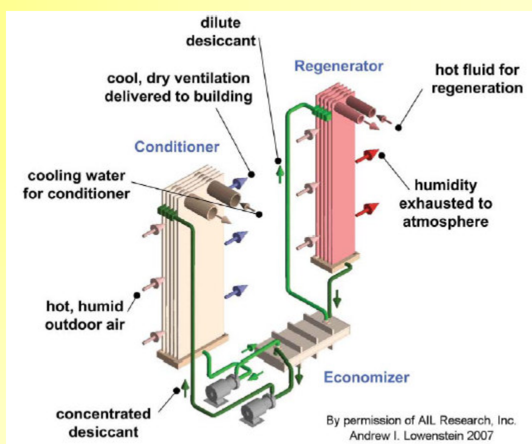


- *L-DCS, Germany*
  - ✓ Cooling capacity: 40 kW
  - ✓ Hot water at 70 to 80 C
  - ✓ Centralized regeneration and energy storage (350 kWh/m3)
  - ✓ Patented contacting devices
  - ✓ Predicted COP : 1.2 to 2
    - *Less in hot, humid climate*
  - ✓ Direct Air-LiCl contact
    - *Bacteriostaticity*
    - *Probabiliy of LiCl generated aerosol, causing corrosion* *(Conde 2007)*

SOLAR DRIVEN LIQUID DESICCANT AC SYSTEM

Features of Commercial Systems

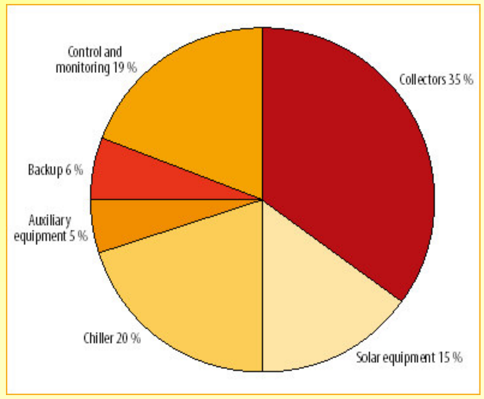
- *AIL Research Unit*
  - ✓ All plastic contactors and heat exchanger
  - ✓ Internal cooling and heating in contacting devices
  - ✓ Intended to handle only latent load
  - ✓ With aging carryover problem may pop-up (Conde 2007)



SOLAR DRIVEN AC SYSTEMS

Economy

- ***Economic Viability***
  - ✓ Cost of Ab/Adsortion Unit/kW cooling
    - *€ 5,000 and 7,000 (Rs 3.2 to 4.5 lakh)!*
    - *2 to 4 m^2 collector area/kWcooling*
  - ✓ Cost of DEC system/kW cooling
    - *1,300 € (Rs 83000)*
    - *0.8 to 1.5 m^2 collector area/kW cooling*
  - ✓ Figures show need for cost effective solar collectors



CONCLUSION

Fresh Air Dehumidification and Air Conditioning

- ***Making Solar Cooling Techno-Ecnomically Viable is Still a Challenge***
  - ✓ Collector costs need to be lowered almost to half their present value, Rs/kW heat delivered specially in the mid temperature range
- ***Liquid Desiccant Systems can be Simpler, Reliable, Cost Competitive***
  - ✓ in the entire range of capacities
  - ✓ COP of 0.8 to 1 for small and 1 to 1.5 for large capacity two stage systems is possible
  - ✓ Energy storage capability ~1300 MJ/m^3
- ***Problems to Overcome***
  - ✓ Carryover
  - ✓ Parasitic power
  - ✓ Corrosive nature of liquid desiccant
- ***Development of Cost-effective Solar Collector***
  - ✓ Around 50% efficiency ~150 C temperature
  - ✓ EGT based collectors hold promise!

REFERENCES

1. *ASHRAE Fundamentals, 2005*
2. *ASHRAE Standard 62, 1989*
3. *Besana F, Troi A, Sparber W; Solar Combi-plus System for Residential and Small Commercial Application; March 2006*
4. *Conde M R; Properties of Aqueous Solutions of Lithium and Calcium Chlorides: Formulations for Use in Air Conditioning Equipment Design International Journal of Thermal Sciences 43 (2004) 367–382*
5. *Conde M; Liquid Desiccant base Air Conditioning Systems – LDACS; 1st European Conference on Polygeneration; Spain, 2007*
6. *Coronas A et al; Sorption Cooling Technologies for Solar Air Conditioning Applications – An Overview; Proceedings ACRECONF 2007*
7. *Da Silva M ; Solar Air Conditioning Potential for Offices in Lisbon; M Sc thesis, 2005*
8. *Forkosh et al, US patent 6976365 B2*
9. *Fumo N, Goswami D Y; Study of an Aqueous Lithium Chloride Desiccant System: Air Dehumidification and Desiccant Regeneration; Solar Energy Vol. 72, No. 4, pp. 351–361, 2002*
10. *Grossman G, Johannsen A; Solar Cooling and Air Conditioning; Prog. Energy Combust. Sci., Vol. 7 (1981), pp. 185-228.*
11. *Henning Hans-Martin; Solar Assisted Air Conditioning of Buildings – An Overview; Applied Thermal Engineering 27 (2007) 1734–1749*
12. *Hommad M and Zurigat Y, Performance of a Second Generation Solar Cooling Unit; Solar Energy, Vol 62(2), 79-84, 1998*
13. *http://www.eere.energy.gov/de/pdfs/conf-03_der_pr/lowenstein.pdf last visited on 20/11/2008*
14. *http://www.kathabar.com/products/dehumidifiers/spdesiccant.html*
15. *http://www.solarnext.eu/pdf/ger/publications/jakob/SWE_0801_076-85_Solar_Cooling.pdf*

REFERENCES

Continued

16. *Jacob, Uli; IEA HPP Annex 34 Kick-off meeting; Thermally driven heat pumps; Netherlands, 2007*
17. *Jain S, Kumar M, Asati A K, Dhar P L, Drift and wetting characteristics of falling film absorber and regenerator, Proceedings of ACRECONF, Allied Publishers, New Delhi, 2003, pp. 16-25*
18. *Jain S and Bansal P K; Performance Analysis of Liquid Desiccant Dehumidification Systems; International Journal of Refrigeration; 30 (2007), 861-872*
19. *Johannsen A, Grossman G, Performance simulation of regenerating type solar collectors, Solar Energy. Vol. 30. No. 2. pp. 87-92, 1983*
20. *Kalogirou S A; Solar Thermal Collectors and Applications; Progress in Energy and Combustion Science 30 (2004) 231–295*
21. *Kessling W et al; Energy Storage for Desiccant Cooling Systems Component Development; Solar Energy Vol. 64, Nos 4–6, pp. 209–221, 1998*
22. *Kessling W et al; Energy Storage in Open Cycle Liquid Desiccant Cooling systems; lnt J. Refrig. Vol. 21, No. 2, pp. 150-156, 1998*
23. *Kopko W L, US patent no. US 6513339 B1, February 2003.*
24. *Lowenstein et al; A Zero Carryover Liquid-Desiccant Air Conditioner for Solar Applications; ASME International Solar Energy Conference (ISEC2006)*
25. *Mingheng et al., Investigation on Regeneration and Energy Storage Characteristics of a Solar Liquid Desiccant Air-Conditioning System; Front. Energy Power Eng. China 2007, 1(1): 85–90*
26. *Mullick S C and Gupta M C; Solar Desorption of Absorbent Solutions; Solar Energy, Vol. 16(1974), pp. 19-24*
27. *P. Gandhidasan; Quick Performance Prediction of Liquid Desiccant Regeneration in a Packed Bed; Solar Energy 2004*
28. *Rane et al, Indian Patent # 203949*
29. *Rane M V and Meena P M; Evacuated Glass Tube Solar Air Heater – Low Cost Light Weight Design; International Conference on 'Advances in Energy Research, (ICAER) 2007*

VAPOR ABSORPTION BASED AC SYSTEM

Features and Issues

Number of cycles	1	2
Solvent	LiBr	LiBr
Refrigerent	H_2O	H_2O
Driving temperature	80°C - 110°C	140°C - 160°C
Driven by	hot water steam	hot water steam directly burned
COP	0,6 - 0,8	0,9 - 1,2
Power range market available	few producers 20 to 100 kW many producers more than 100 kW	few producers 50 to 100 kW more producers more than 100 kW
Producer	Broad, Carrier, Century, EAW, Ebara, Enropie, LG Machinery, Sanyo-McQuay, Sulzer-Escher Wyss, Trane, Dunham-Bush, Yazaki, York	

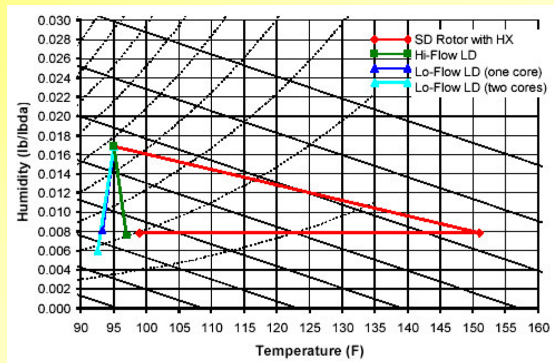
Manufacturer	Capacity [kW]	Type of machine	COP_{th}	Website
Climatewell AB	10	absorption H_2O/LiCl	0.68	www.climatewell.com
EAW Energieanlagenbau Westenfeld GmbH	15	absorption H_2O/LiBr	0.75	www.eaw-energieanlagenbau.de
Solarnext AG	10	absorption NH_3/H_2O	0.64	www.solarnext.de
Sonnenklima GmbH	10	absorption H_2O/LiBr	0.75	www.sonnenklima.de
Sortech AG	5.5	adsorption H_2O/silica gel	0.6	www.sortech.de
Rotartica	5	absorption H_2O/LiBr	0.7	www.rotartica.com
Yasaki Europe Ltd.	17.5	absorption H_2O/LiBr	0.7	www.yazaki-airconditioning.com

- ***Solar Combi-plus Systems*** *(Besana F, 2006)*
  - ✓ Developed under IEA Task 38
  - ✓ Co-generation of hot water, heat in winter/cold in summer
  - ✓ Improves overall economy
- ***Issues***
  - ✓ Mainly intended for large-scale applications
    - ▪ *Demand for solar based systems is at smaller scale*
  - ✓ Cooling tower increases cost
  - ✓ Small capacity and efficiency at low driving temperature
  - ✓ Elaborate instrumentation and control

REFERENCES

Continued

30. *Rane M V, Reddy S V K, Easow R R, Energy Efficient Liquid Desiccant-based Dryer, Applied Thermal Engineering, 25, pp 769–781 (2005).*
31. *Roth K W et al; Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume III: Energy Savings Potential; July 2002*
32. *Sabatelli V et al; Technical status report on solar desalination and solar cooling; NEGST, 2005*
33. *Sparber W, et al.; Overview on World-wide Installed Solar Cooling Systems; 2nd International Conference Solar Air Conditioning, 2007*
34. *Tamainot-Telto Z and Critoph R E; Solar Sorption Refrigerator using a CPC Collector; Renewable Energy 16 (1999), 735-738*
35. *Sun & Wind energy 1/2008*



CONTACTING DEVICES

JAIN AND BANSAL, 2007

Advantages and Limitations

Contacting Device	**Advantages**	***Limitations***
1. Spray Tower	Simple construction, low pressure drop on air side, low cost and compact size	***Higher pressure drop on water side, Low effectiveness in absorption, Fair chances of liquid carryover***
2. Packed Bed Tower	Compact, higher efficiency, large contact area and contact time	
2a. Random packing	Good contact between air and liquid	***Higher flow rate of liquid is required and air pressure drop is high***
2b. Structured packing	Used in recent designs	***Unable to provide internal cooling***
3. Wetted Wall (Falling Film) Column 3a. Tube type 3b. Plate type	Low pressure drop, Low initial cost, High contact area for unit volume	***Difficult to achieve a thin film over complete cross section of large towers***