Ionic liquid absorption system for dehumidification and IAQ enhancement in built environment

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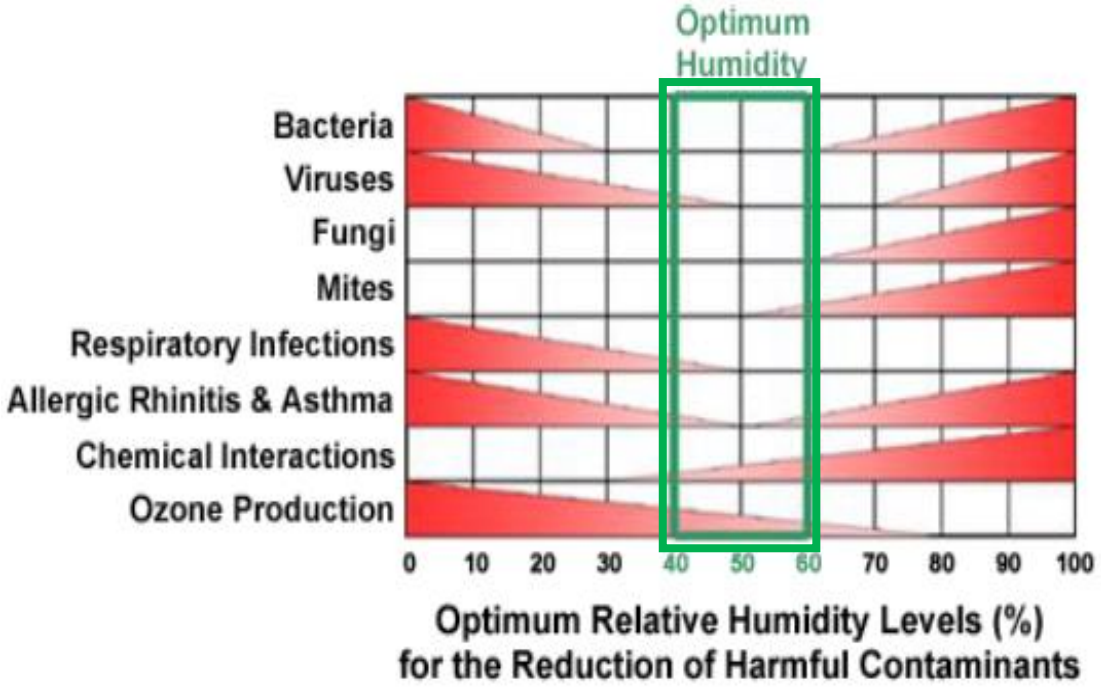
Motivation

- High humidity in built environment
  - ➢ Fogging and condensation
  - ➢ Uncomfortably muggy climate
  - ➢ Damage to surface and structures

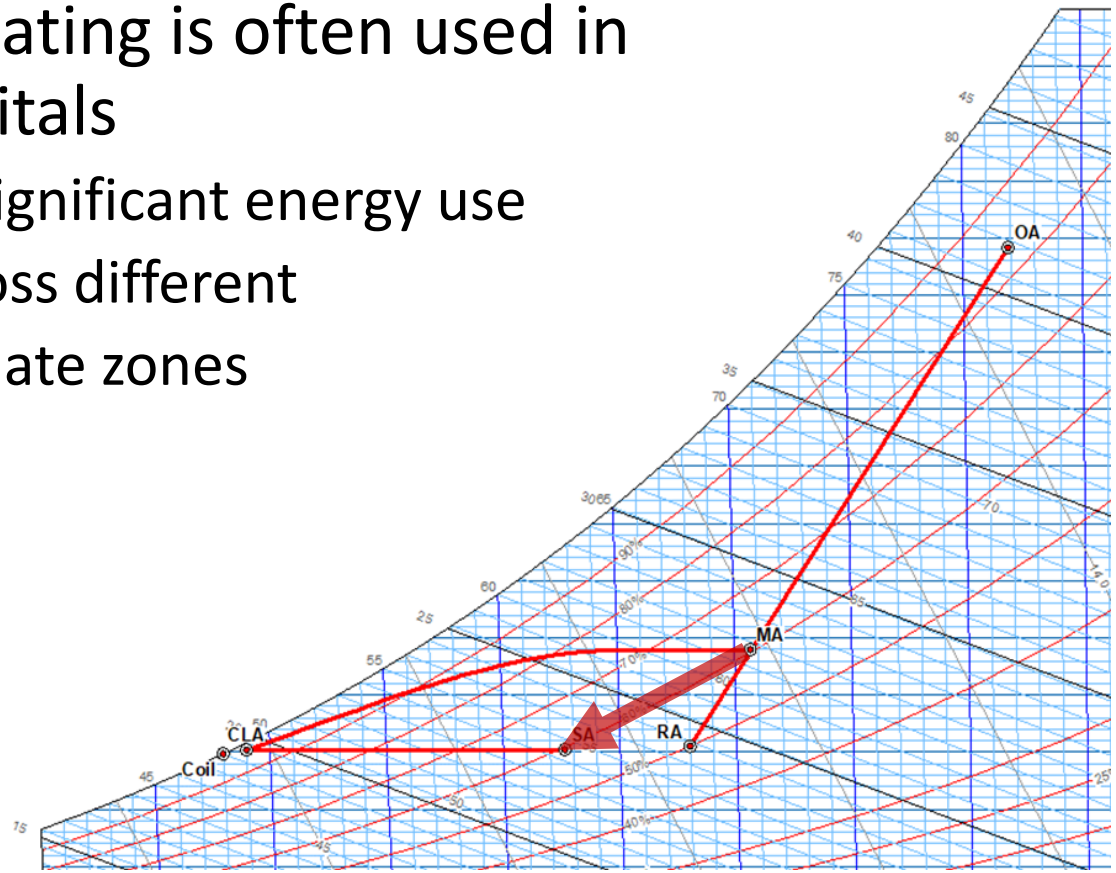
Motivation

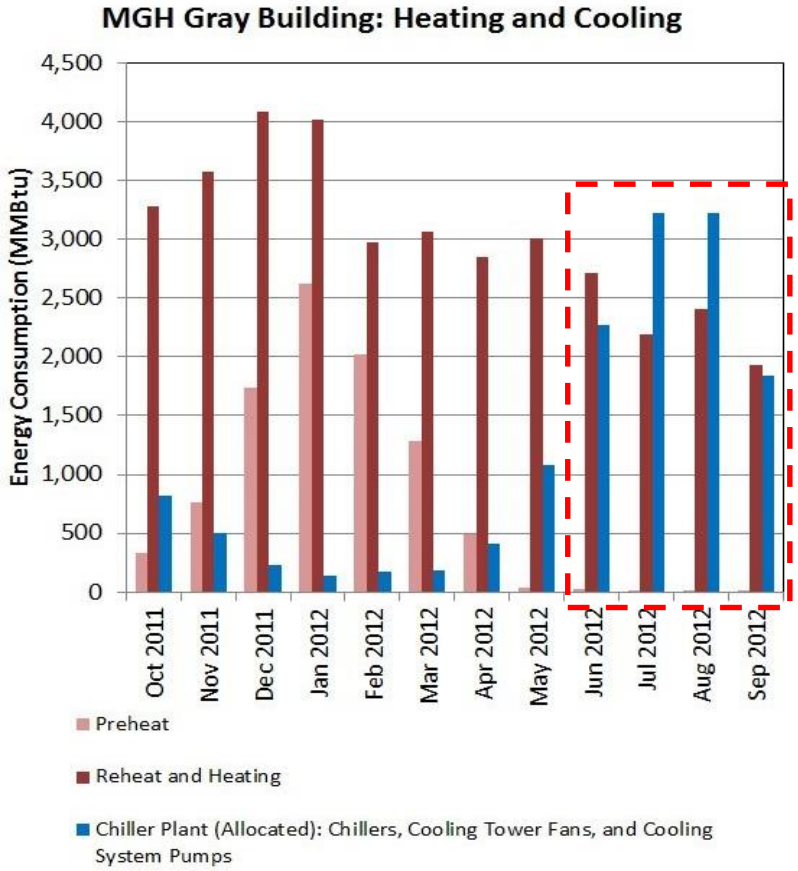
- Health and hygiene
  - ➢ Specially in health care facilities



Controlling Humidity

- Reheating is often used in hospitals
  - ➢ Significant energy use across different climate zones



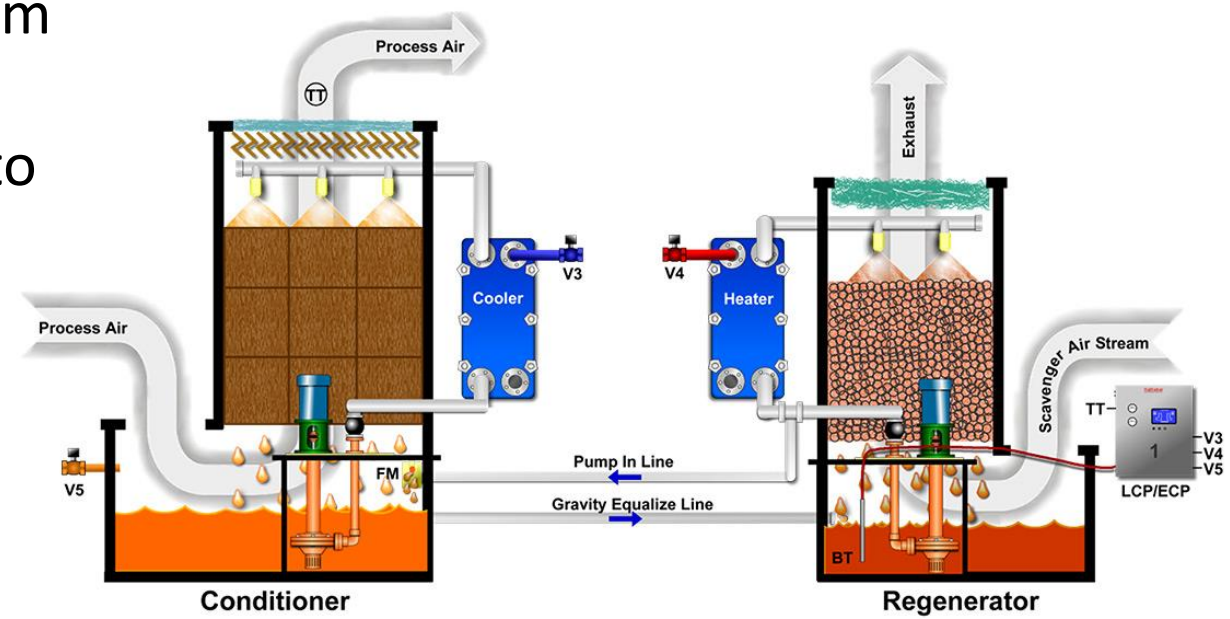


https://www.energy.gov/eere/buildings/healthcare-energy-spotlight-reheat-and-heating

Liquid Desiccants: State-of-the-Art (SOA)

Adiabatic absorber

- High flow rate lowers the system efficiency
- Limited ability to lower the dew point



Alfa Laval Kathabar liquid desiccant dehumidification system

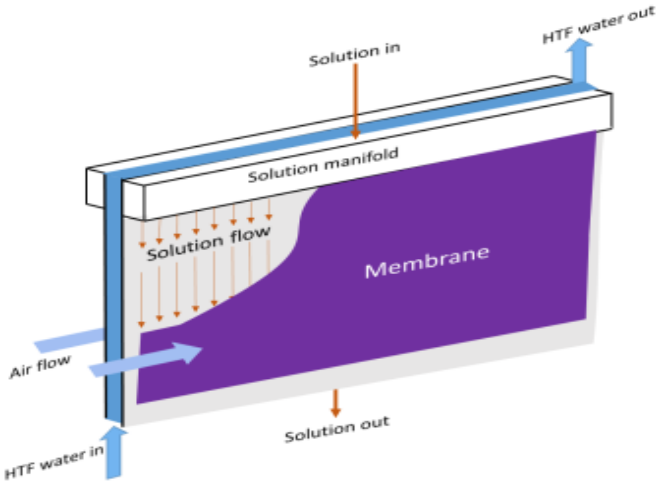
Use of "scavenging air"

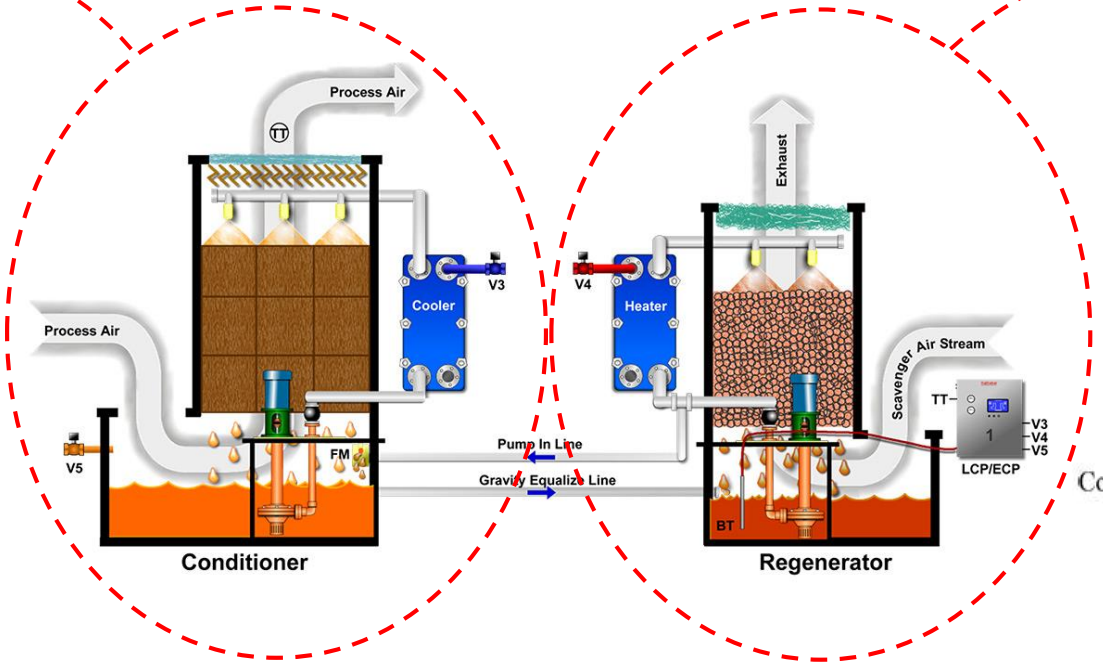
- Requires ducting air to mechanical room
- Heat loss from the desorber to air

(additional recovery HX is needed)

- Outdoor RH impacts the performance

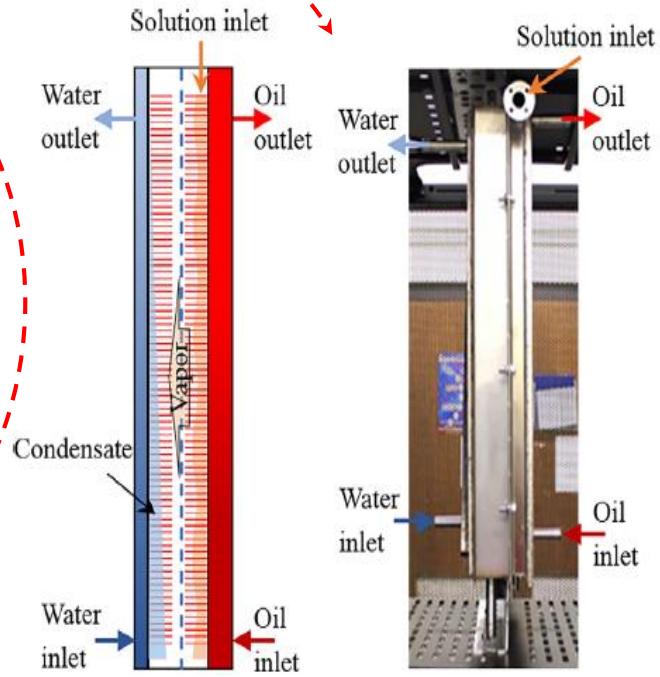
Enhancing Robustness and Performance





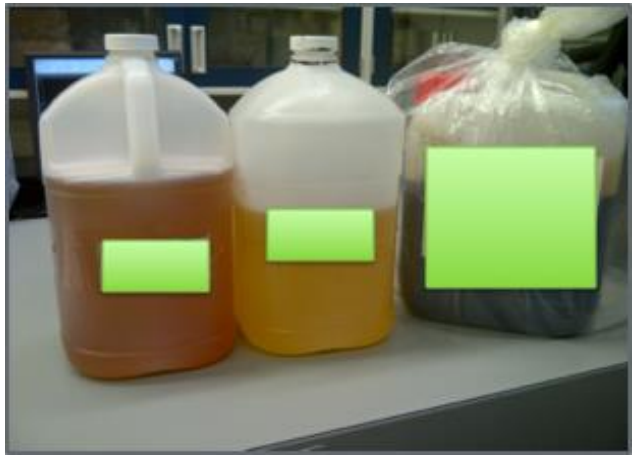
Current liquid desiccant dehumidification system

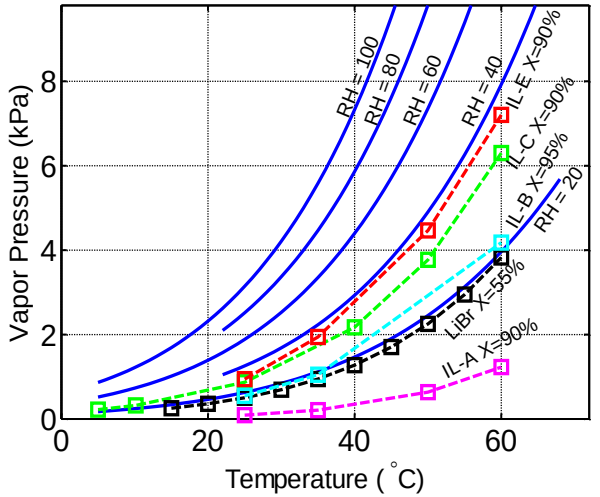
COP ~ 0.4



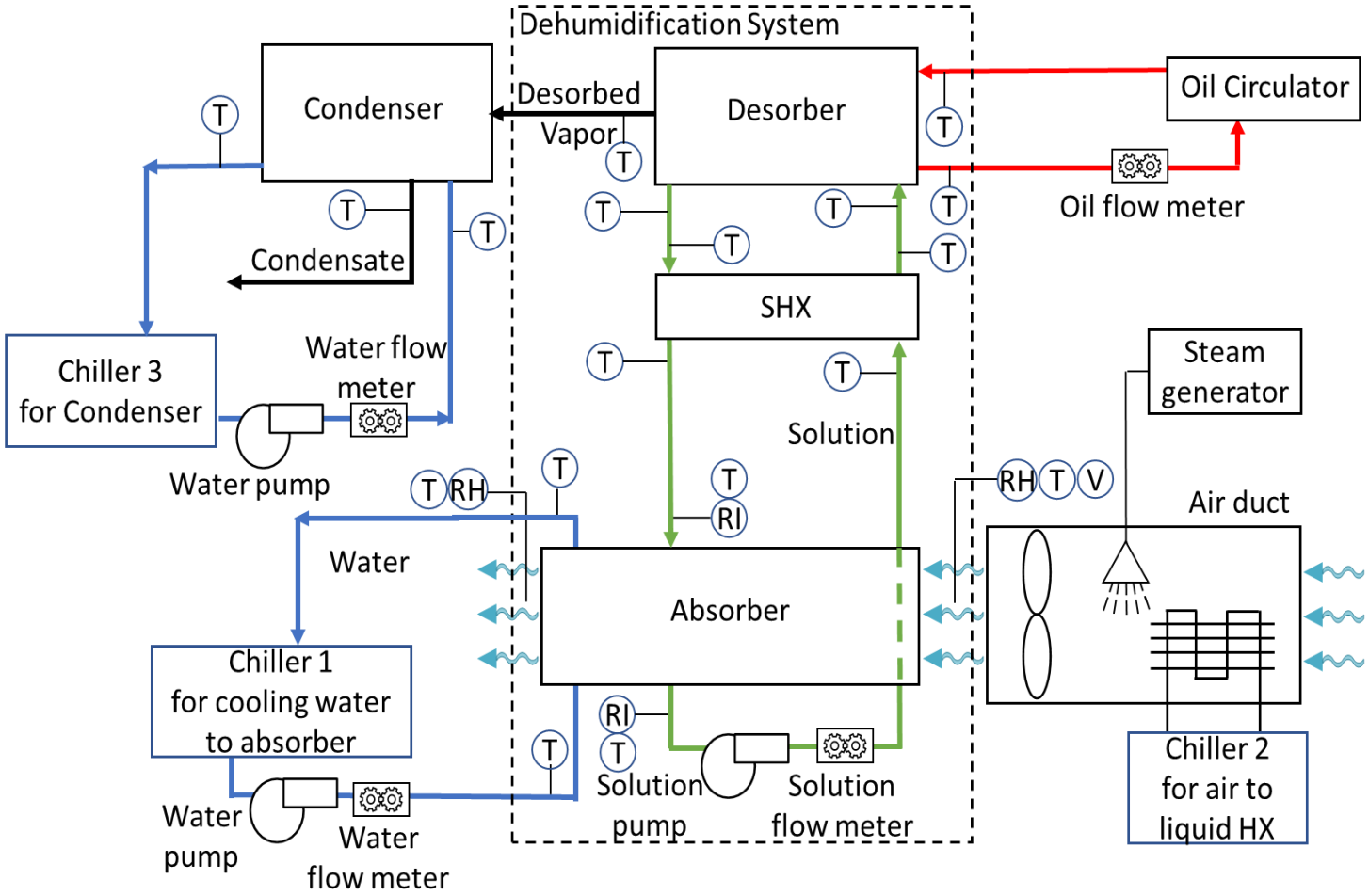
Ionic Liquid (IL) Absorbents

- Allow higher operating temperature
  - More efficient cycles
- Crystallization issue is addressed
- Environment friendly
- Low corrosion





Test Suite Overview

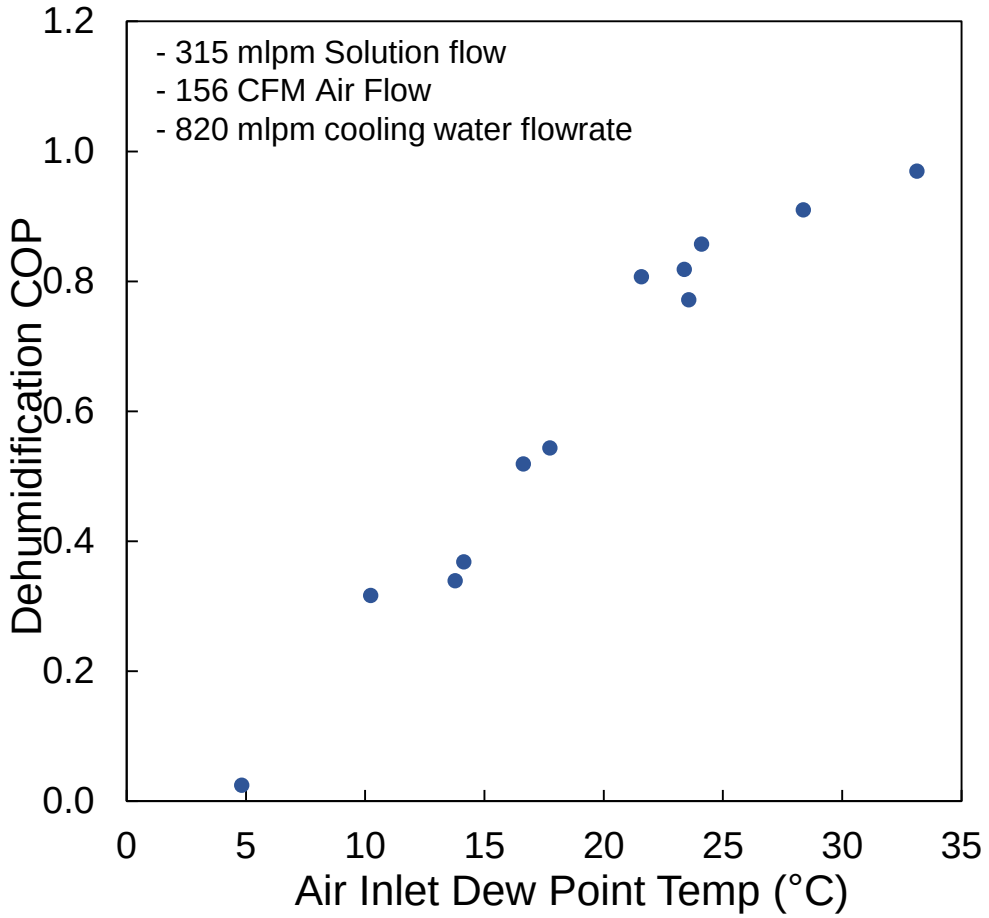


- Three primary flow loops
  - Desiccant solution
  - Process air
  - Process water
- Three secondary loops
  - Heating oil
  - Cooling water and steam generation loop to control the inlet air condition
  - Condensing water

Test Conditions

Test condition	Inlet Air Conditions			
	Dry Bulb Temp (°C)	Dew Point Temp (°C)	Relative Humidity (%)	
1	35.0	22.1	47.29	ISMRE A (AHRI 920)
2	26.7	21.2	72.03	ISMRE B (AHRI 920)
3	21.1	17.8	81.36	ISMRE C (AHRI 920)
4	17.2	13.6	79.41	ISMRE D (AHRI 920)
5	26.7	15.8	51.14	IEER Condition
6	26.8	24.0	84.48	1% Gainesville, FL, USA
7	35.0	33.1	90.00	
8	30.0	23.9	70.00	
9	20.6	5.6	38.85	
10	32.0	28.1	80.00	

Parametric Study: Effect of DP



$$\text{Dehumidification COP} = \frac{\text{Latent Capacity (watts)}}{\text{Heat input (watts)}}$$

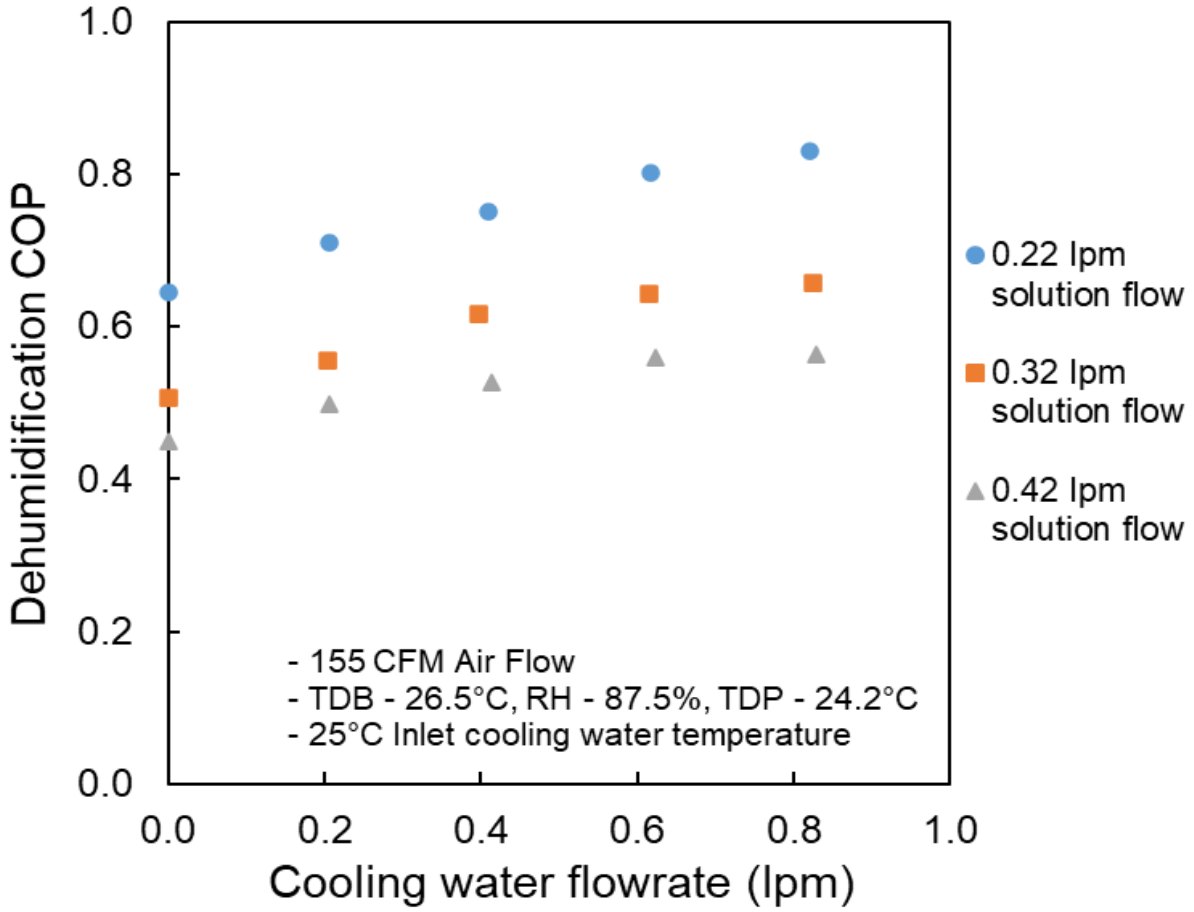
- Dew point temperature is the measure of the moisture content in air

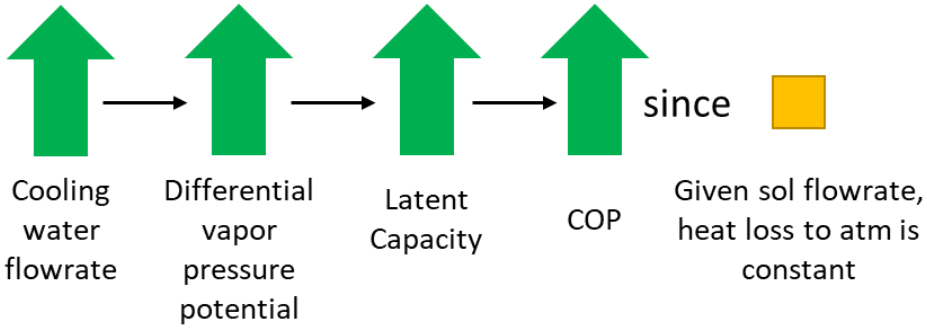
Dew point temp → Differential vapor pressure potential → Dehumidification Capacity

- Whereas,

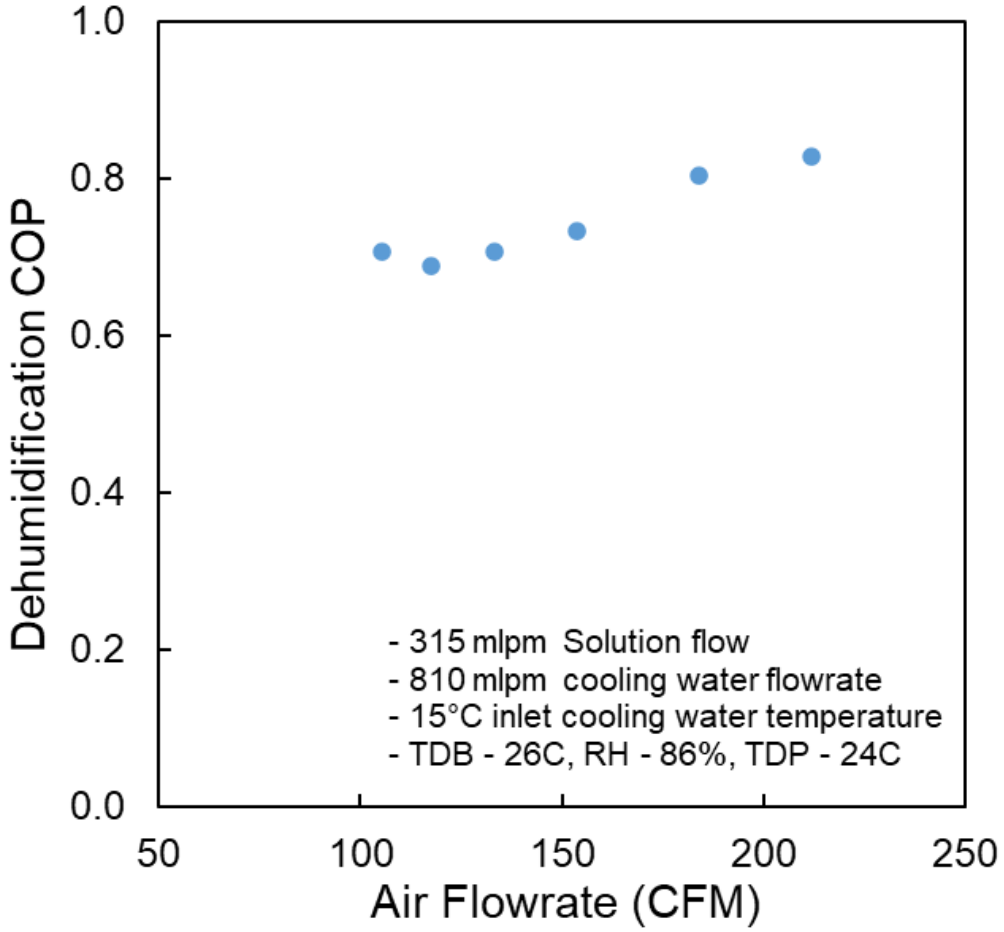
Dehumidification Capacity → COP since Constant solution flowrate leads to constant heat loss to atm

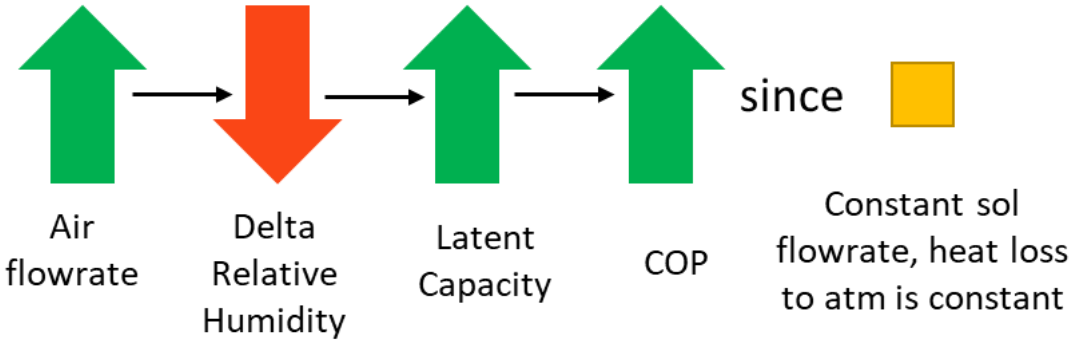
Solution & Cooling Water Flow Rates



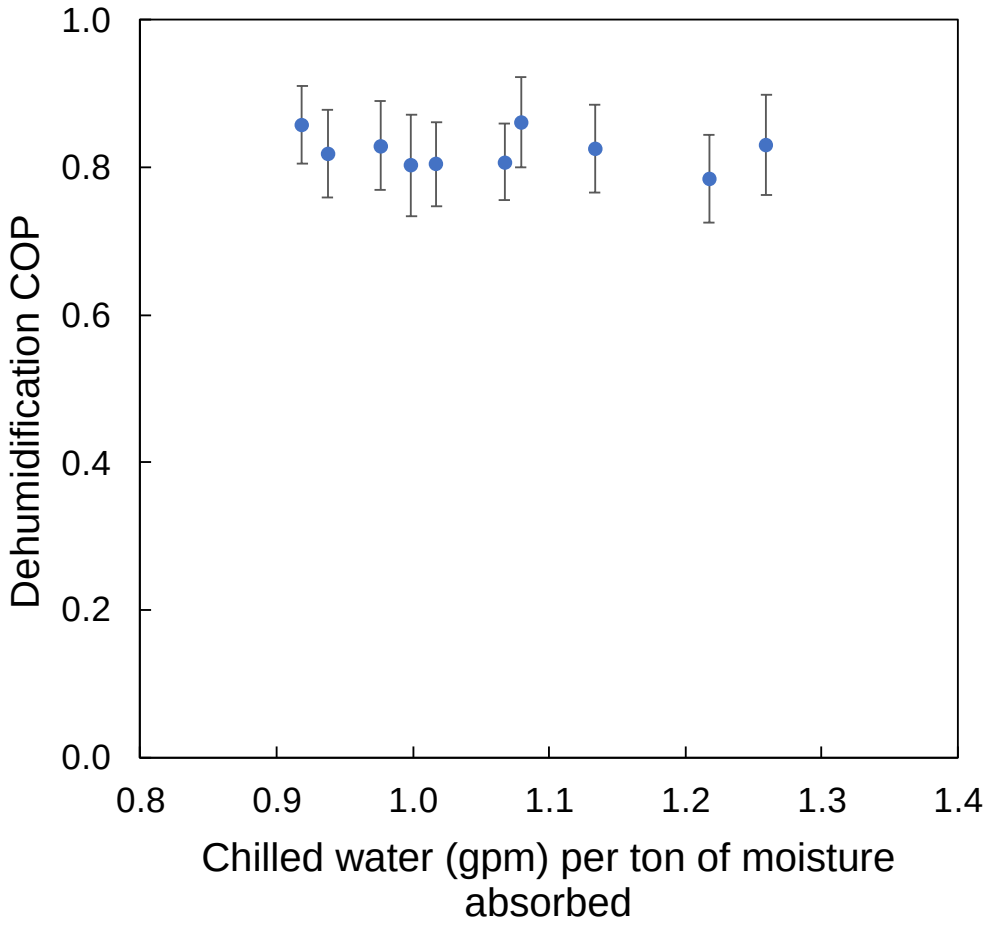


Airflow Rate





Objective Optimization



- Maximizing COP
- Variables
  - Climate (1% Gainesville, FL, ISMRE A, B)
  - Air flow rate
  - Solution flow rate

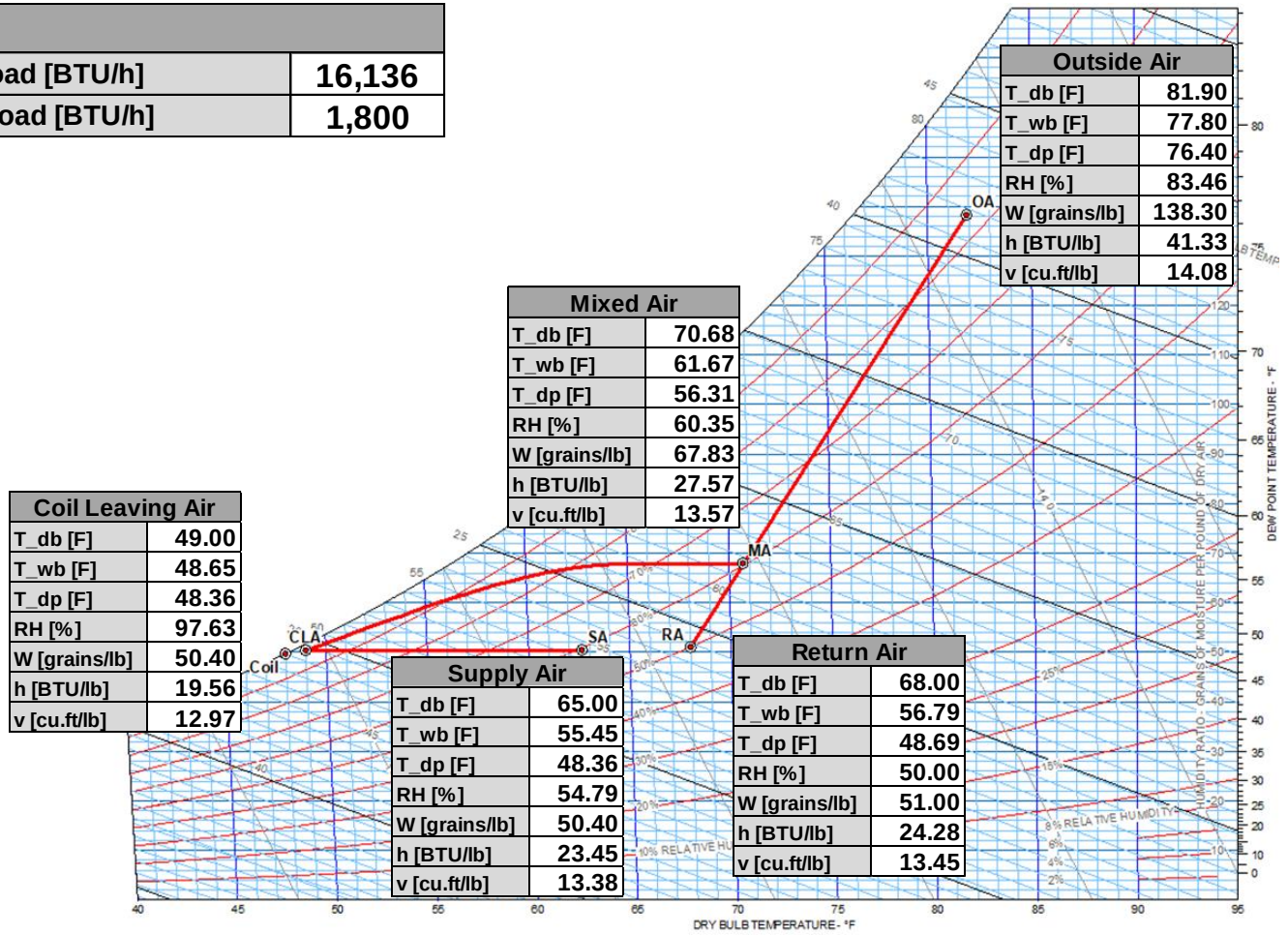
Example Application: DX-based

ROOM CONDITIONS					
T_DB [F]	68	Airflow [CFM]	5000	Total internal Sensible Load [BTU/h]	16,136
RH [%]	50	Outside Air [CFM]	1000	Total interrrrrnal Latent Load [BTU/h]	1,800

Load Calculations (ABS + Cooling Coil)			
Absorber Total Load [BTU/hr]	69340.246	Cooling Coil Total Load [BTU/hr]	21684.459
Absorber Sensible Load [BTU/hr]	8833.179	Cooling Coil Total Sensible Load [BTU/hr]	21684.459
Absorber Latent Load [BTU/hr]	60507.066	Cooling Coil Total Latent Load [BTU/hr]	0.000
Absorber cooling water Load [kW]	69040.246		

Total Load on chiller [kW]	26.589

Internal Load	
Equipment Sensible Load [BTU/hr]	14600
Per Person Sensible Load [BTU/hr]	256
Per Person Latent Load [BTU/hr]	300
of people	6



Example Application: DX+Desiccant

ROOM CONDITIONS					
T_DB [F]	68	Airflow [CFM]	5000	Total internal Sensible Load [BTU/h]	16,136
RH [%]	50	Outside Air [CFM]	1000	Total interrrrrnal Latent Load [BTU/h]	1,800

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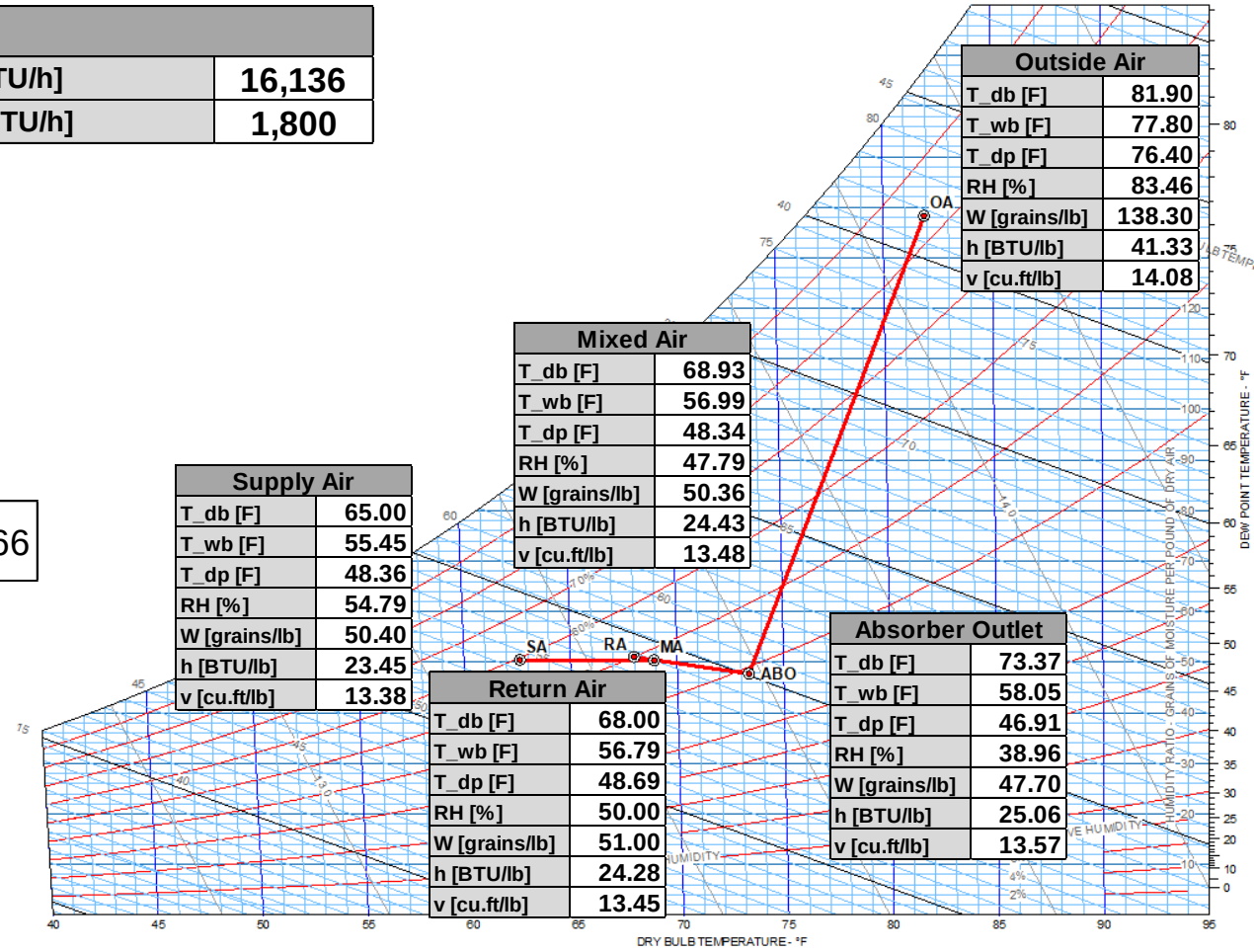
Absorber Latent Load [BTU/hr]	60507.066	Cooling Coil Total Latent Load [BTU/hr]	0.000
Absorber cooling water Load [kW]	69040.246		

Total Load on chiller [kW]	26.589	Absorber Total Heat Input [kW] (@ 0.8 COP)	22.166

Internal Load	
Equipment Sensible Load [BTU/hr]	14600
Per Person Sensible Load [BTU/hr]	256
Per Person Latent Load [BTU/hr]	300
of people	6



Energy Saving Potential

	Psychrometric calculations		Equipment energy consumption		Primary energy		
System	Coil Cooling load (Chiller) (kW)	Reheat load (kW)	Chiller load (kW)[1] (Electric)	Heat Input (kW)[2,3]	Energy for Cooling (kW)[4]	Heat Input (kW)[5]	Total Primary energy (kW)
VCS + Reheat	51.87	25.20	12.97	31.11	36.31	40.83	77.14
SSLC (Abs + Coil)	26.83	0.00	6.71	22.16	18.78	29.09	47.86

1. The chiller COP is taken as 4 for the VCS system as well as for SSLC system
2. For VCS+Reheat system the efficiency of the steam to water heat exchanger and efficiency of water to air heat exchanger are both assumed to be 90%
3. For SSLC system the dehumidification COP for the Absorption system is taken as 0.8
4. The site to source ratio for electricity in US is 2.8
5. The Natural gas boiler steam generation efficiency is taken as 80% and the site to source ratio for natural gas in US is 1.05

Conclusions

- Experimental demonstration of high-performance membrane-based absorption system
- Liquid desiccant absorption system can greatly reduce the energy requirement of air handling systems
  - Eliminate the requirement for Reheating.
  - Provides better humidity control and helps in improving the IAQ in an energy efficient way
  - Provides independent sensible (temperature) and latent (humidity) control
  - Reduces the coil size and eliminates wet coils

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THANK YOU

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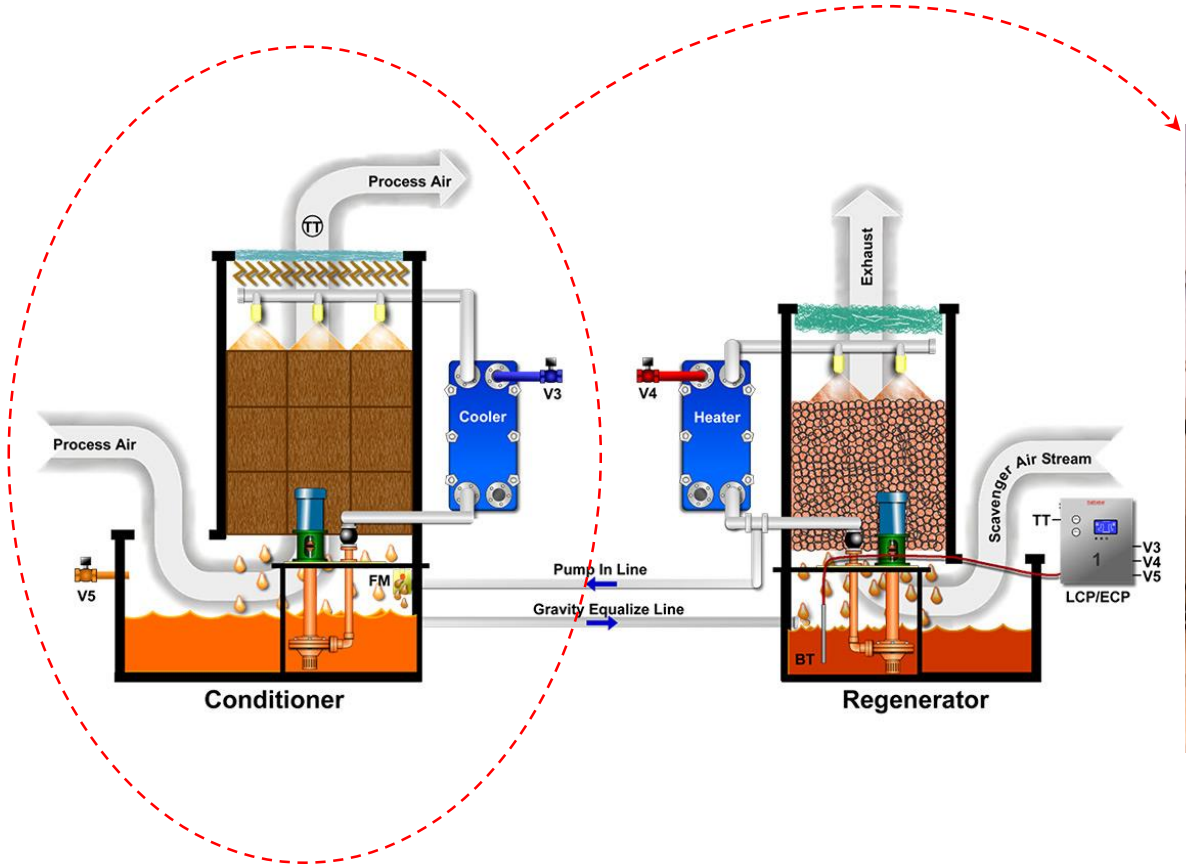
Background

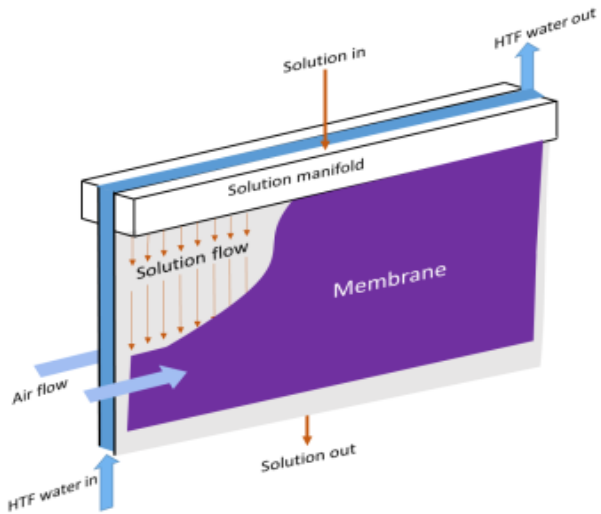
- Significance of controlling humidity

Outline/Agenda

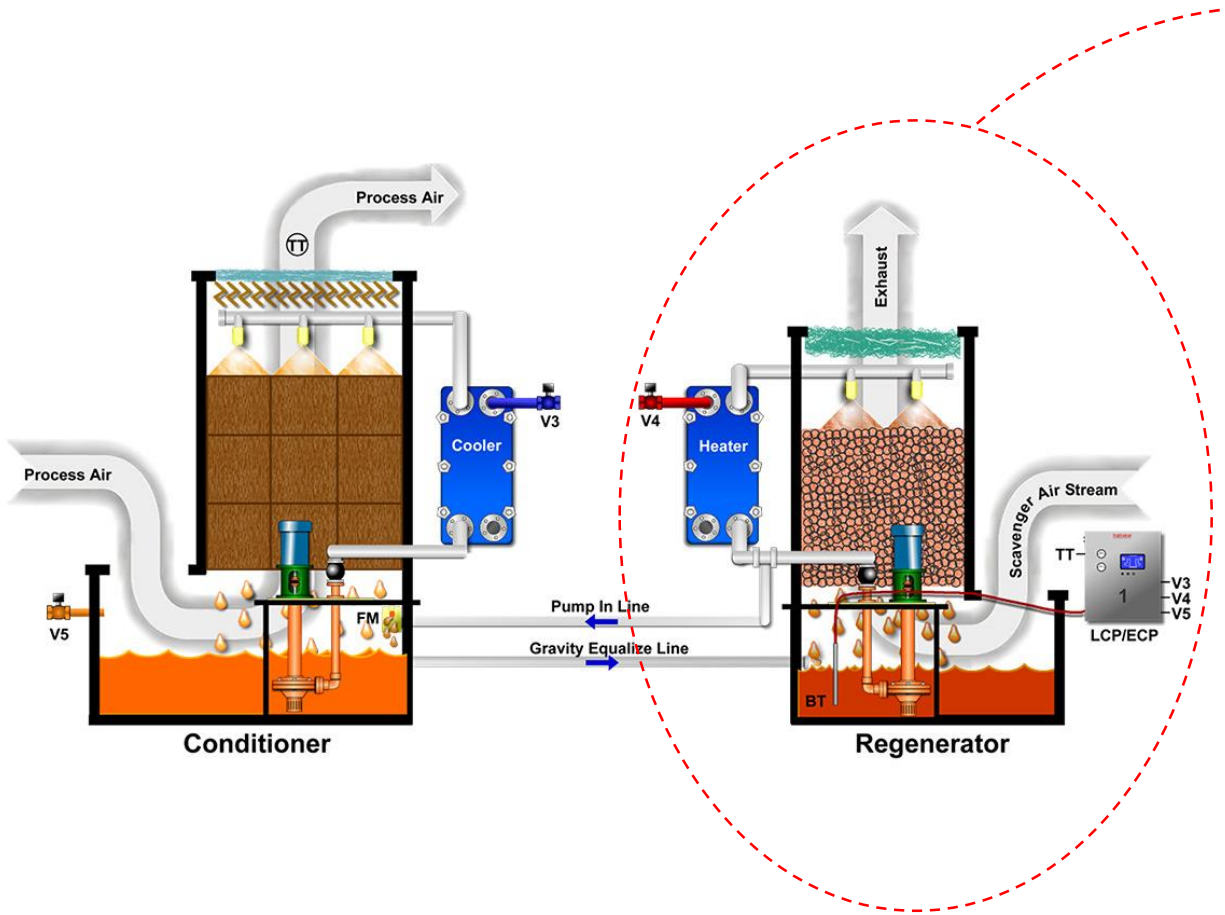
- Background and motivation
- Liquid desiccant systems
- Recent advancements
  - Ionic liquids as alternative absorbents
- Overview of the test setup
- Results
- Load calculation for typical Operation Room
- Concluding Remarks
- Bibliography

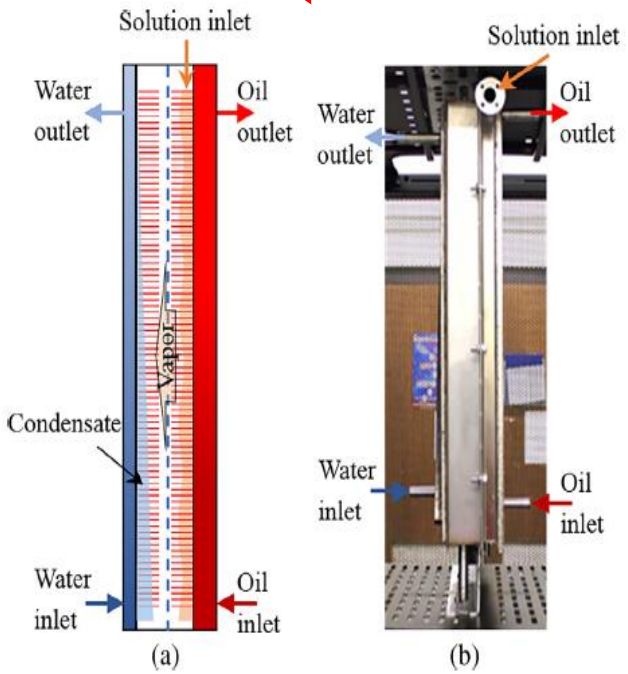
Robustness, Scalability, and Cost





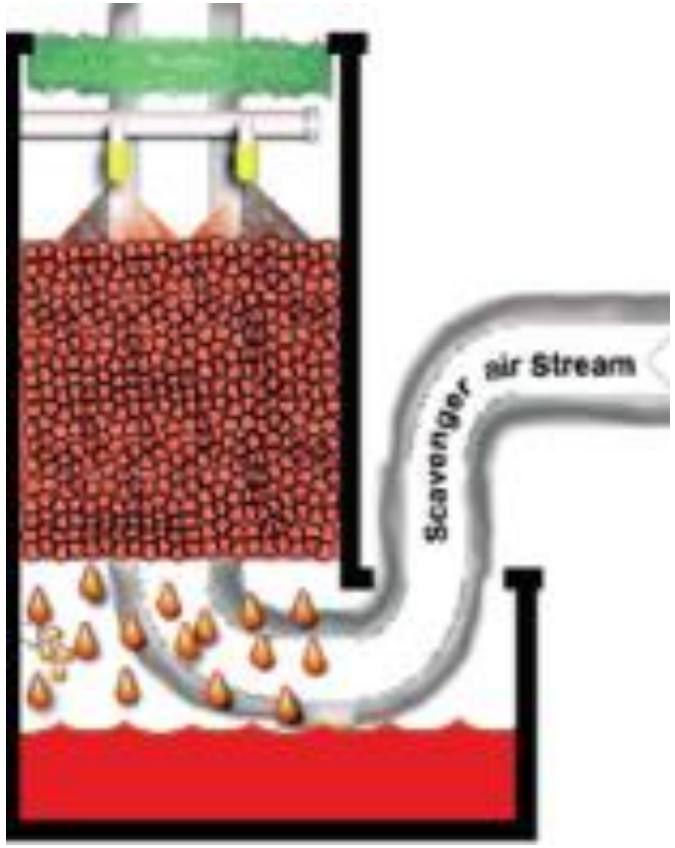
Robustness, Scalability, and Cost

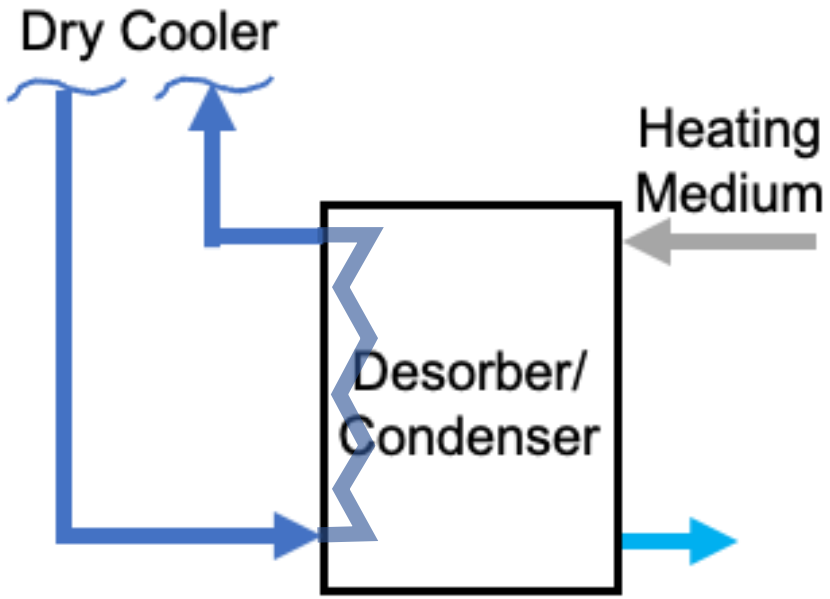




Compact Desorber/Condenser Module

Retrofit and Control Advantages

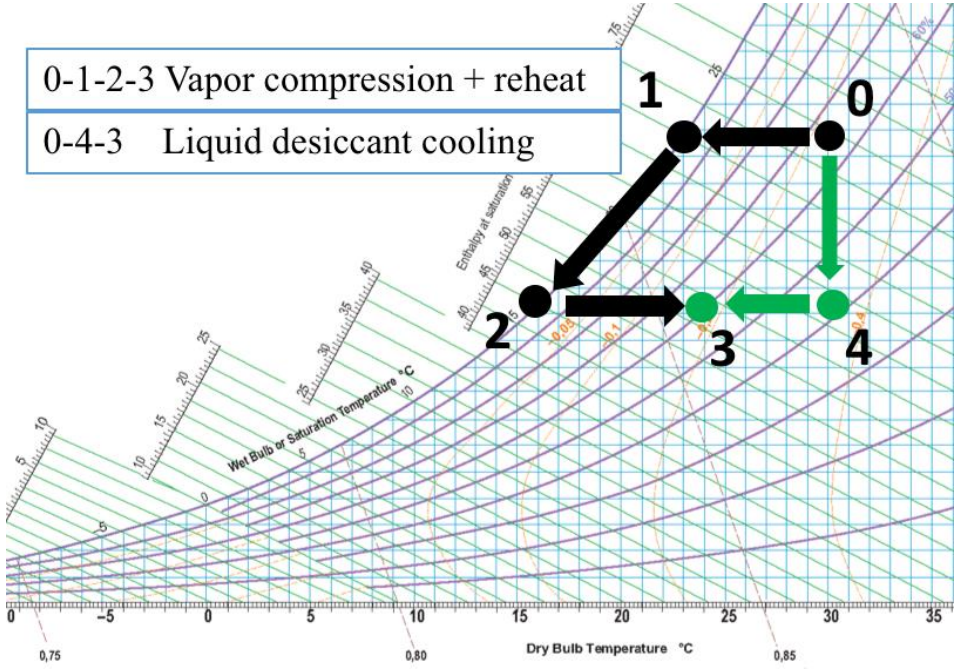




Background

- Opportunity: liquid desiccant systems can
  - ➢ control humidity (improve IAQ, etc.)
  - ➢ enable separate sensible and latent cooling
  - ➢ save energy (it depends!)

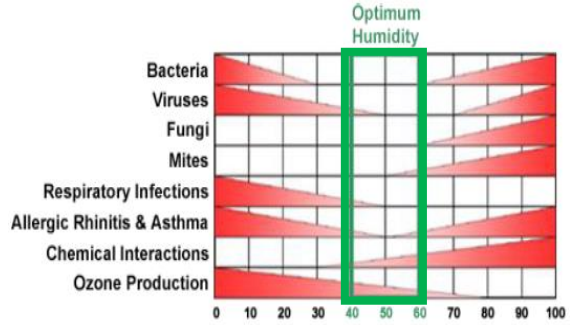
- Challenges:
  - ➢ have

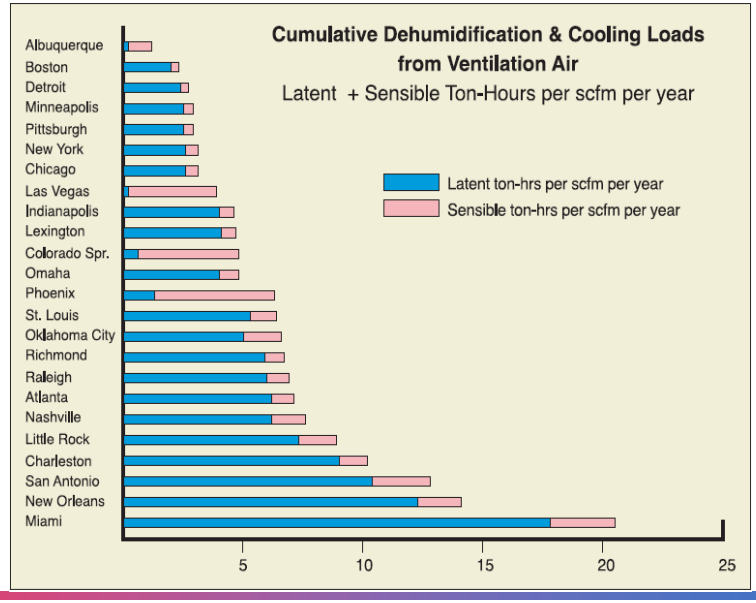


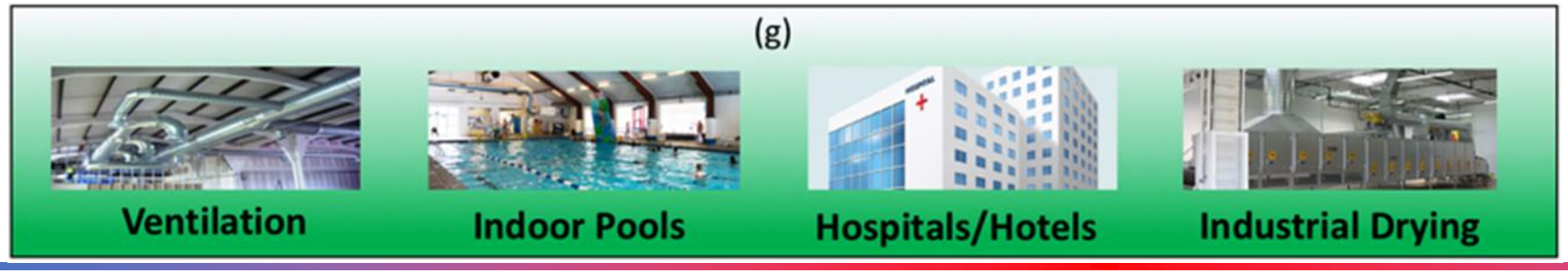
Ionic Liquid (IL) Absorbents

Background and Motivation

- High humidity levels leads to decrease in indoor air quality and comfort
  - It promotes growth of bacteria and mold
  - It leads to health issues
- ➢ One of the major sources of moisture/latent load in a building is from the ventilation air
- ➢ Some applications such as hospitals, museums, art galleries, indoor swimming pools have high latent loads and require precise control on humidity levels

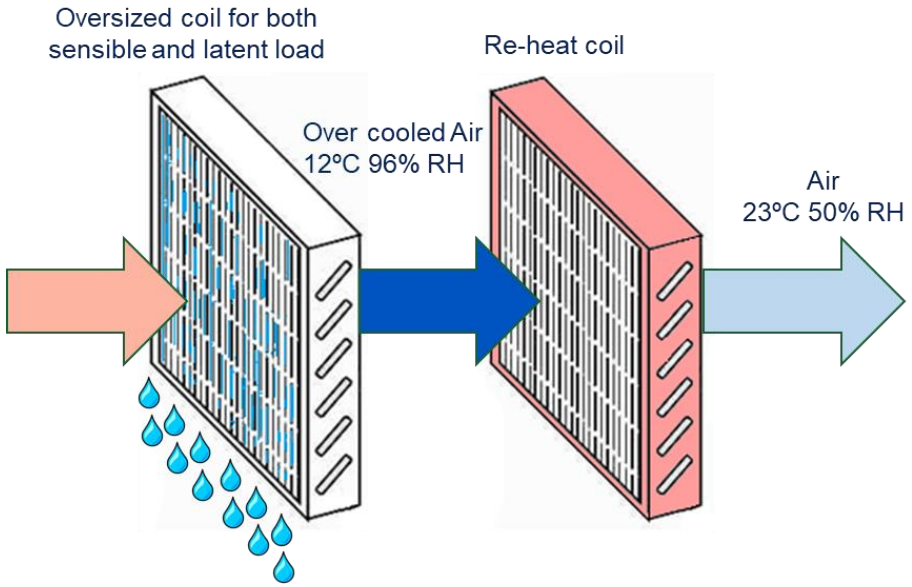






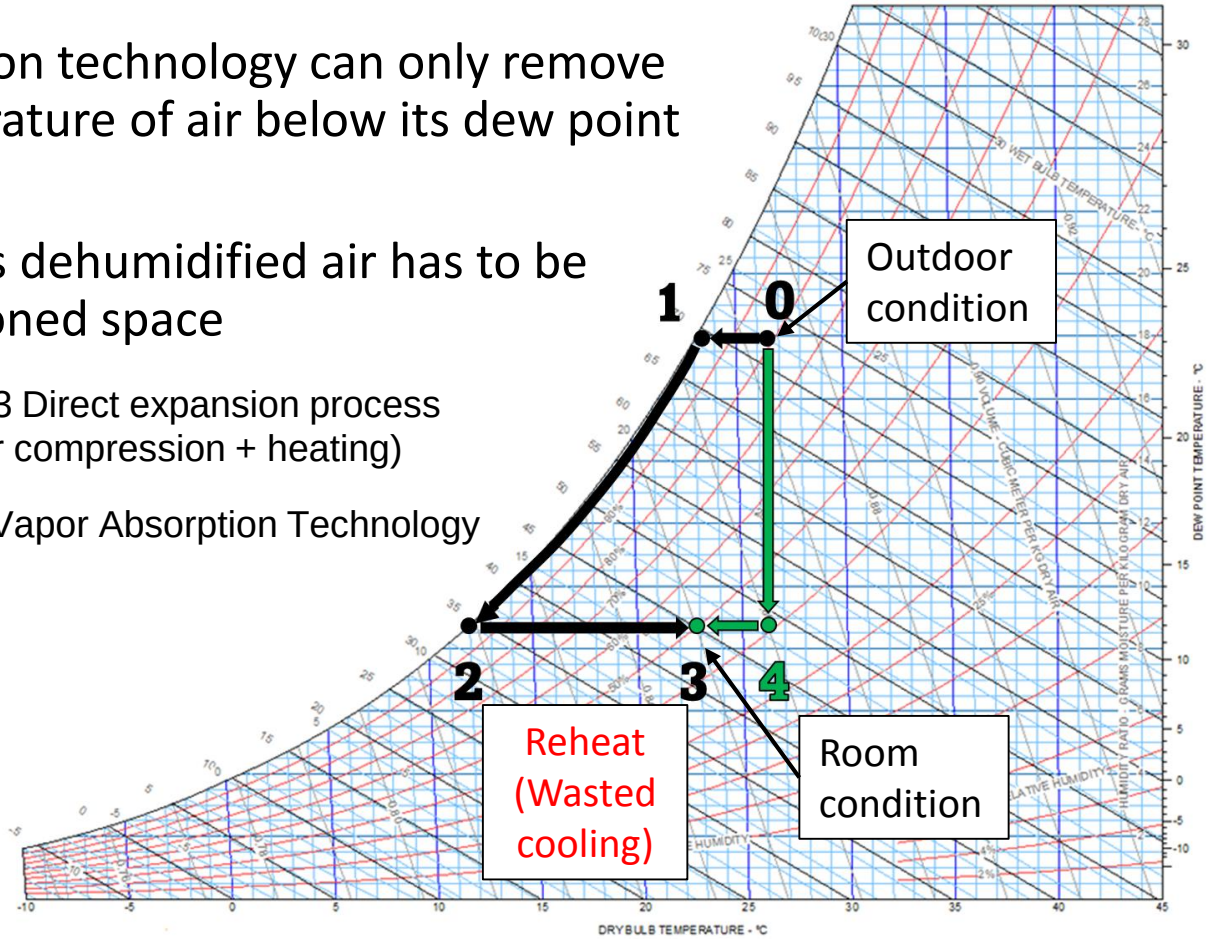
Vapor Compression Systems

- The current HVAC systems using vapor compression technology can only remove moisture (dehumidify air) by reducing the temperature of air below its dew point and condense out the moisture.
- In some cases (such as commercial buildings), this dehumidified air has to be heated back up before supplying it to the conditioned space



0-1-2-3 Direct expansion process (Vapor compression + heating)

0-4-3 Vapor Absorption Technology

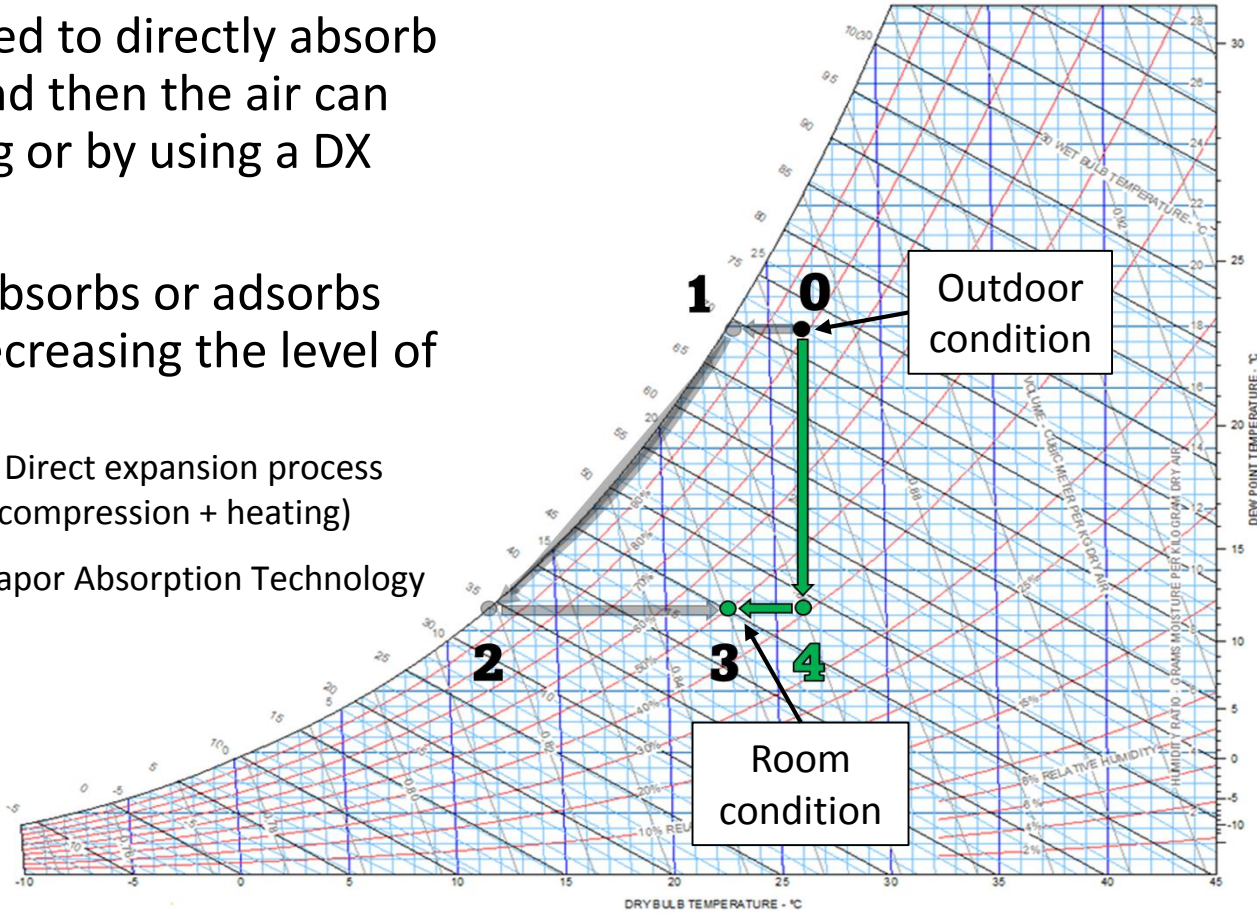


Liquid Desiccant Systems

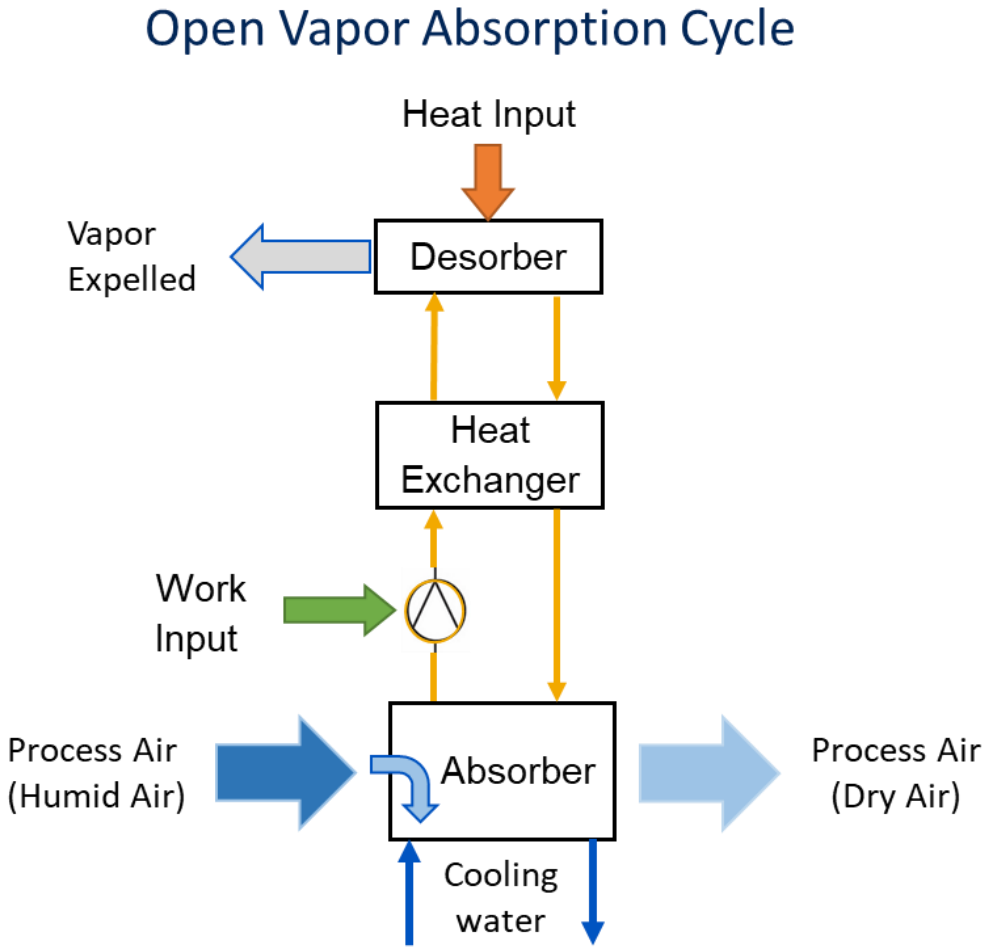
- Alternatively, a liquid desiccant system can be used to directly absorb moisture from the air at atmospheric pressure and then the air can be subsequently cooled using evaporative cooling or by using a DX system.
- A desiccant is any hygroscopic substance which absorbs or adsorbs water molecules from its surrounding air, thus decreasing the level of moisture.

0-1-2-3 Direct expansion process (Vapor compression + heating)

0-4-3 Vapor Absorption Technology

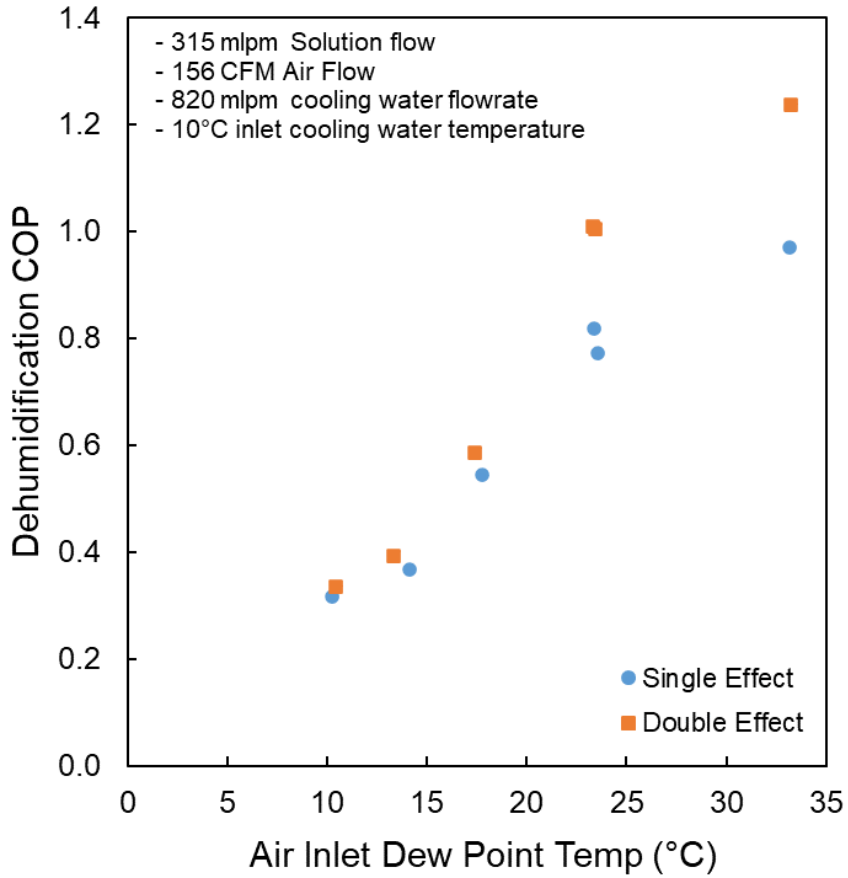


Single Effect Absorption Cycle



- Works at Atmospheric pressure
- Allows low-cost polymer design

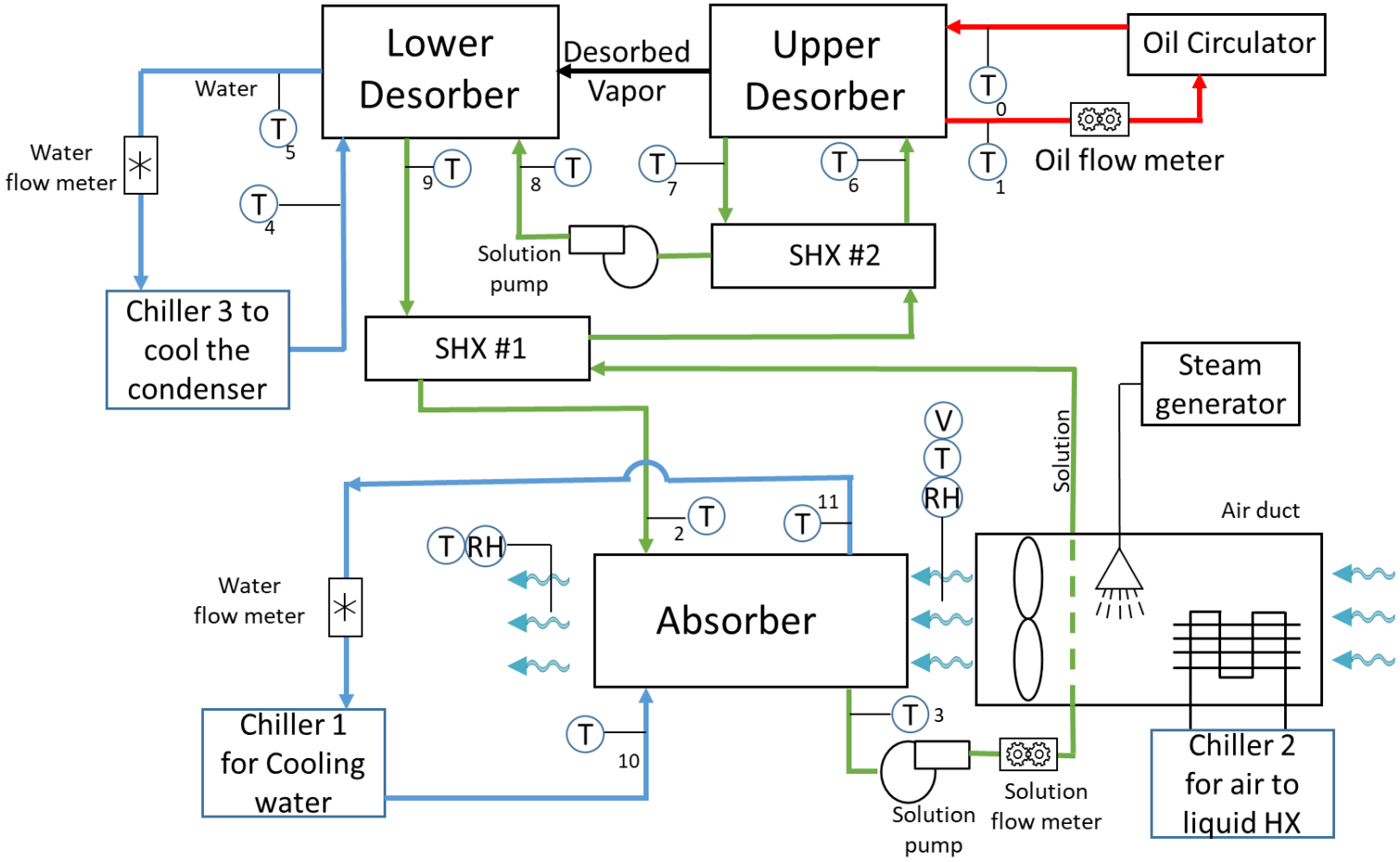
Single/Double Effect Comparison

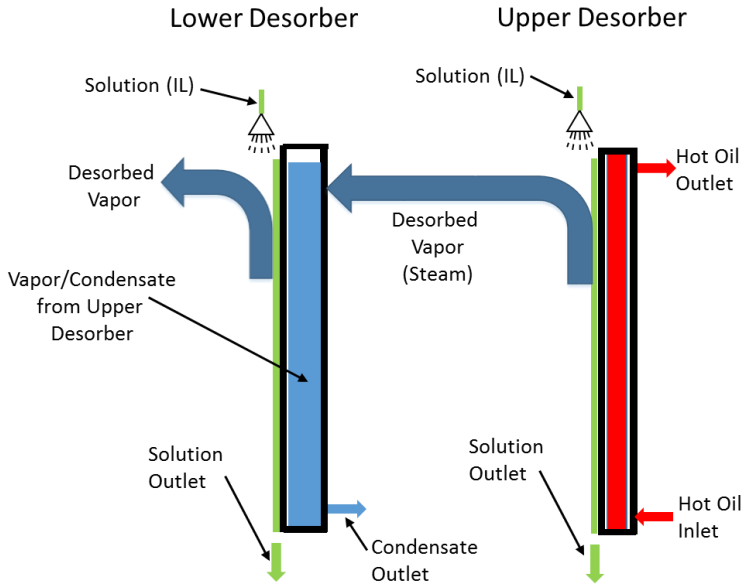


$$\text{Dehumidification COP} = \frac{\text{Latent Capacity (watts)}}{\text{Heat input (watts)}}$$

- As the COP of a double effect system is higher than that of a single effect system, a double effect system requires less input heat energy for the same amount of dehumidification

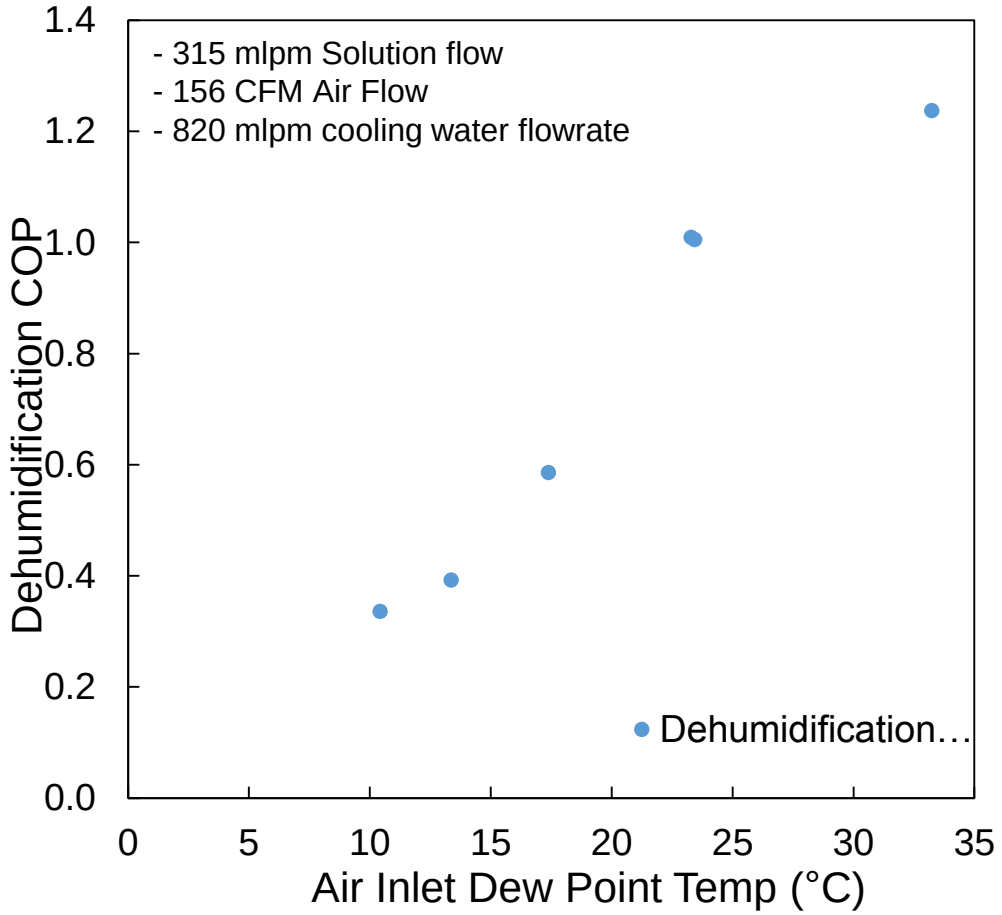
Double effect absorption cycle

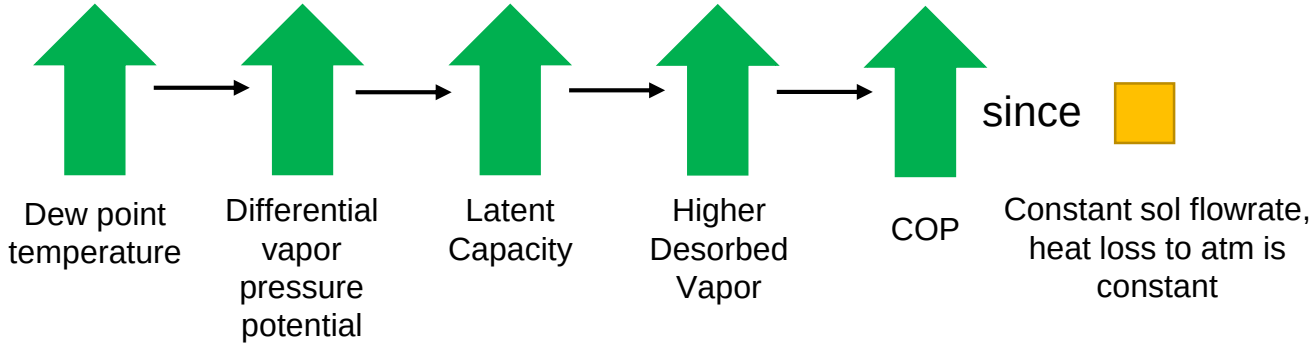




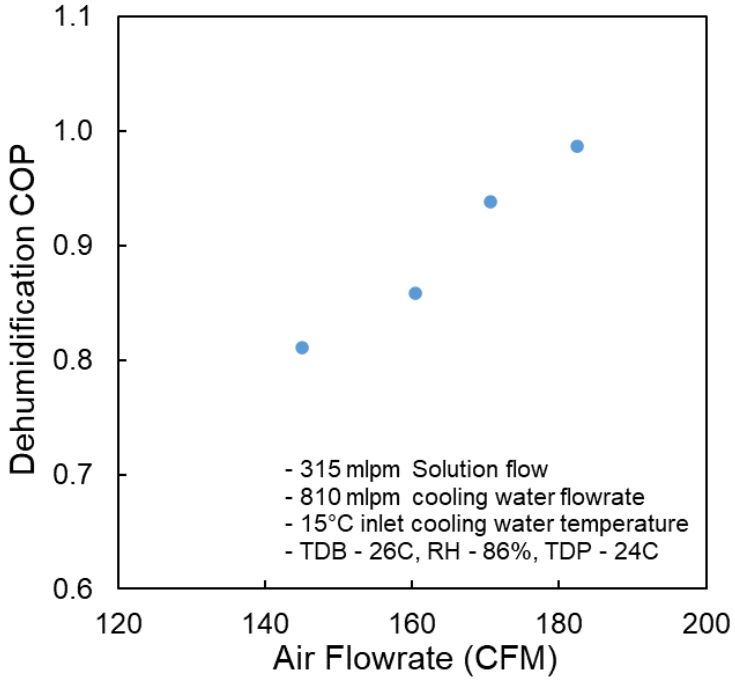
- Double effect system makes use of the desorbed steam from the High Temp Desorber to heat the solution in the Low Temp Desorber

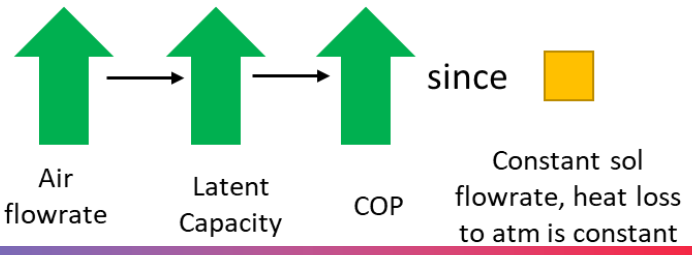
Double Effect Water Cooled Results

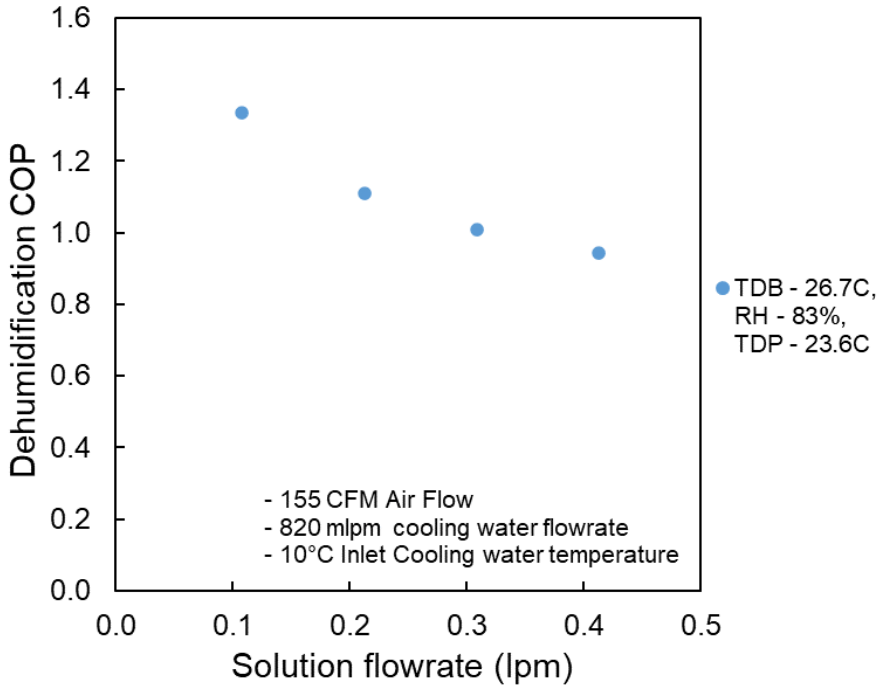


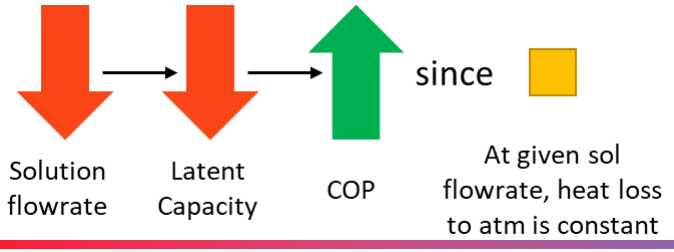


Effect of Air/solution flowrates









Comparison of DX-only and DX + Desiccant

- Hospital operating room (OR)