LIQUID DESICCANT BASED COOLING SYSTEM

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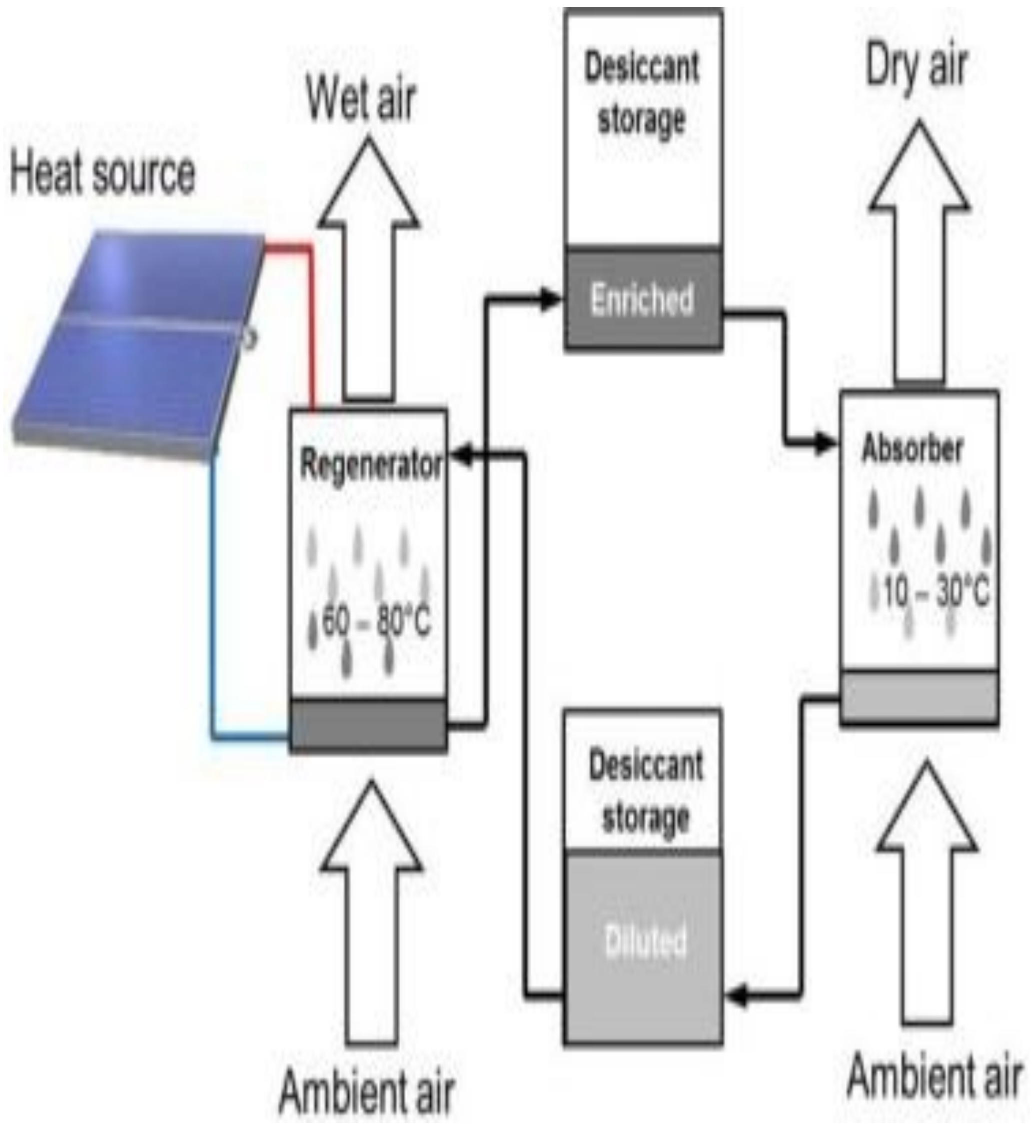
Relevance and basic idea of the project

- The U.S. Department of Energy (DOE) has found that about 40% of energy costs for the average commercial building are spent on heating, cooling and ventilation. This equates to about 7.5% of total costs for the average office building, since 19% of total costs are energy costs.
- A study shows that commercial building owners could save an average of 38% on heating and cooling costs if they install an energy efficient HVAC control system.
- The refrigerants that are used in air conditioners are responsible for ozone depletion as they release CFCs which also are potential greenhouse gases which eventually contribute to global warming.
- Evaporative Coolers if optimised can be a solution.
- Our project aims at optimising these coolers
- The main objective being reducing the humidity of the inlet air using a chemical reagent called desiccant.
- There are two major units in LDS : Dehumidifier and Regenerator

Dehumidification Evaporation

- In the dehumidification chamber, the air which needs to be cooled and the desiccant, flows.
- This desiccant absorbs the moisture from the air and thus the air becomes dehumidified. This air is transported to the evaporative column, to further cool the air.
- The desiccant solution becomes concentrated in water and so, in order to make this process cyclic and continuous, the desiccant is sent to the regeneration chamber where it's original concentration is restored.

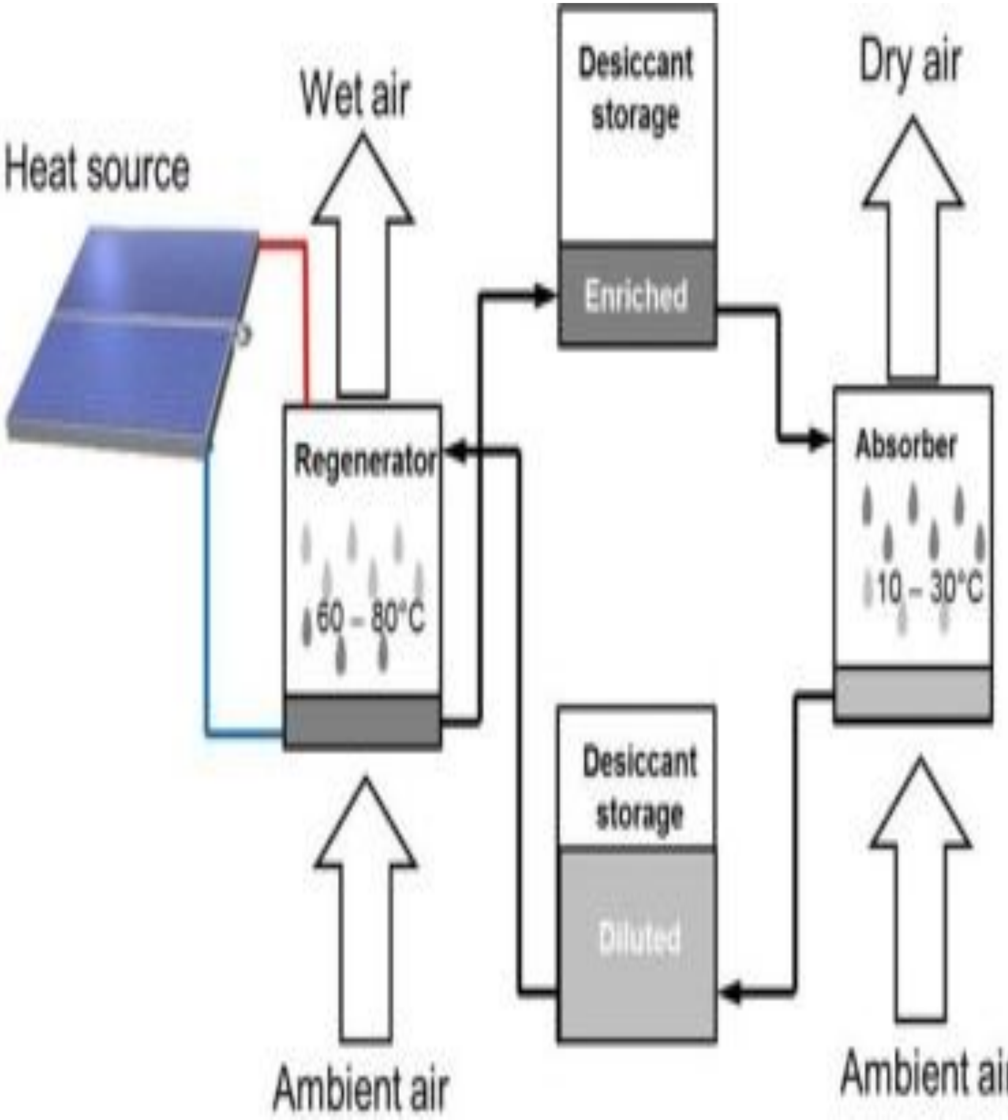


Regeneration Chamber

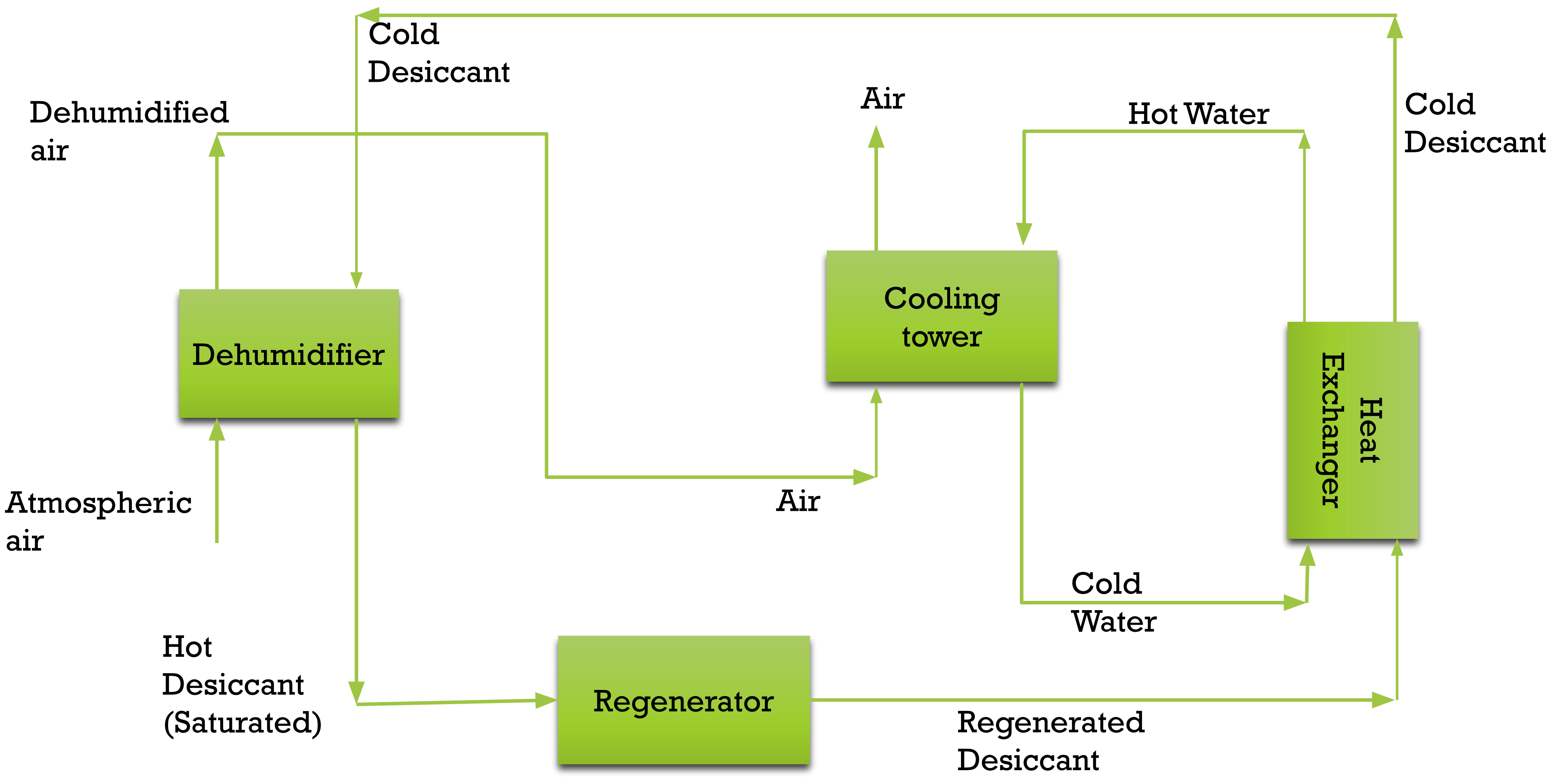
- For the regeneration step, the standard procedure is to heat the desiccant solution resulting in desorption of water molecules from the desiccant.

- But this is not very cost effective method as heating requires a huge amount of energy.

- In order to overcome this problem, we have come up with a different method which is, reverse osmosis, as it does not require much energy, it can be quite cheaper than the vapour compression air conditioners.



Process Flow diagram



Nomenclature

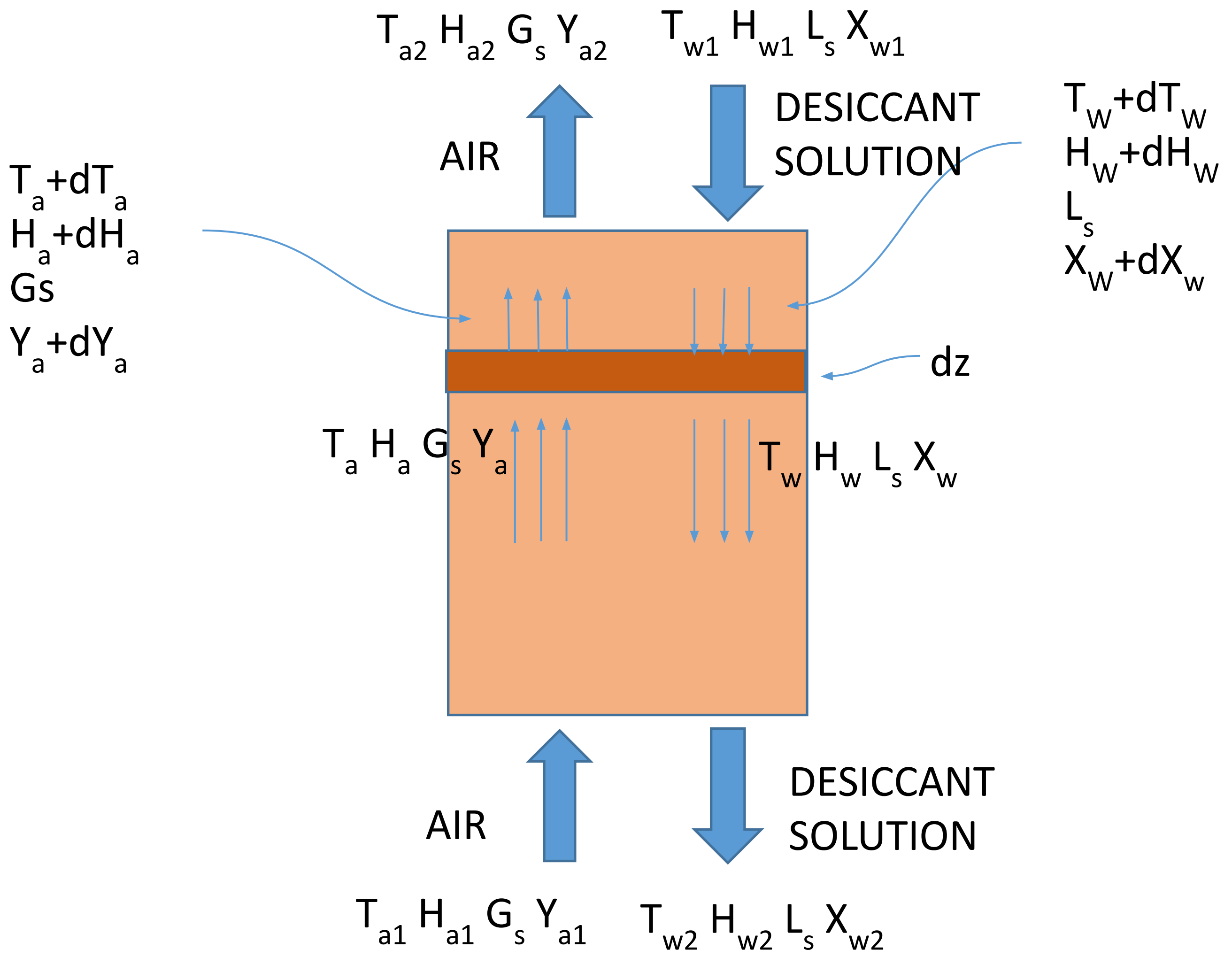
- T (temperature in degree K)
- H (Enthalpy) (KJ/kg)
- L_s (Solution flow rate water free basis) (kg/sec)
- G (Air flow rate water free basis)
- X (mass ratio) = mass of water in kg/mass of desiccant in kg
- Y (absolute humidity of air)
- h_s = heat transfer coefficient
- a = specific surface area per unit volume
- C_{ps} = heat capacity of desiccant solution
- C_{pa} = heat capacity of air
- λ = enthalpy of vaporisation
- Z = height of dehumidifier

L_1' = Total flow rate of solution in kg/sec

Subscripts:

- a = air
- d = desiccant
- w = desiccant solution

Dehumidifier balances



Overall Mass balance for dehumidifier:

$$G_s(Y_{a1} - Y_{a2}) = L_s (X_{w1} - X_{w2}) \quad - 1$$

Required equations for energy balance:

1. Enthalpy of air:

$$H_a = C_{pa} T_a + Y_a (C_{ps} T_a + \lambda) \quad - 2$$

2. Differentiation of eq. 2

$$dH_a = (C_{pa} + Y_a C_{ps}) dT_a + dY_a (C_{ps} T_a + \lambda) - 3$$

Dehumidifier energy balances

- Doing energy balance across a small element of height dz

$G_s\, dH_a = h_s a(T_w - T_a)dz + G_s\, dY_a(C_{ps}T_a + \lambda)$ - 4

Using equation - 3 and combining with 4 final equation obtained is:

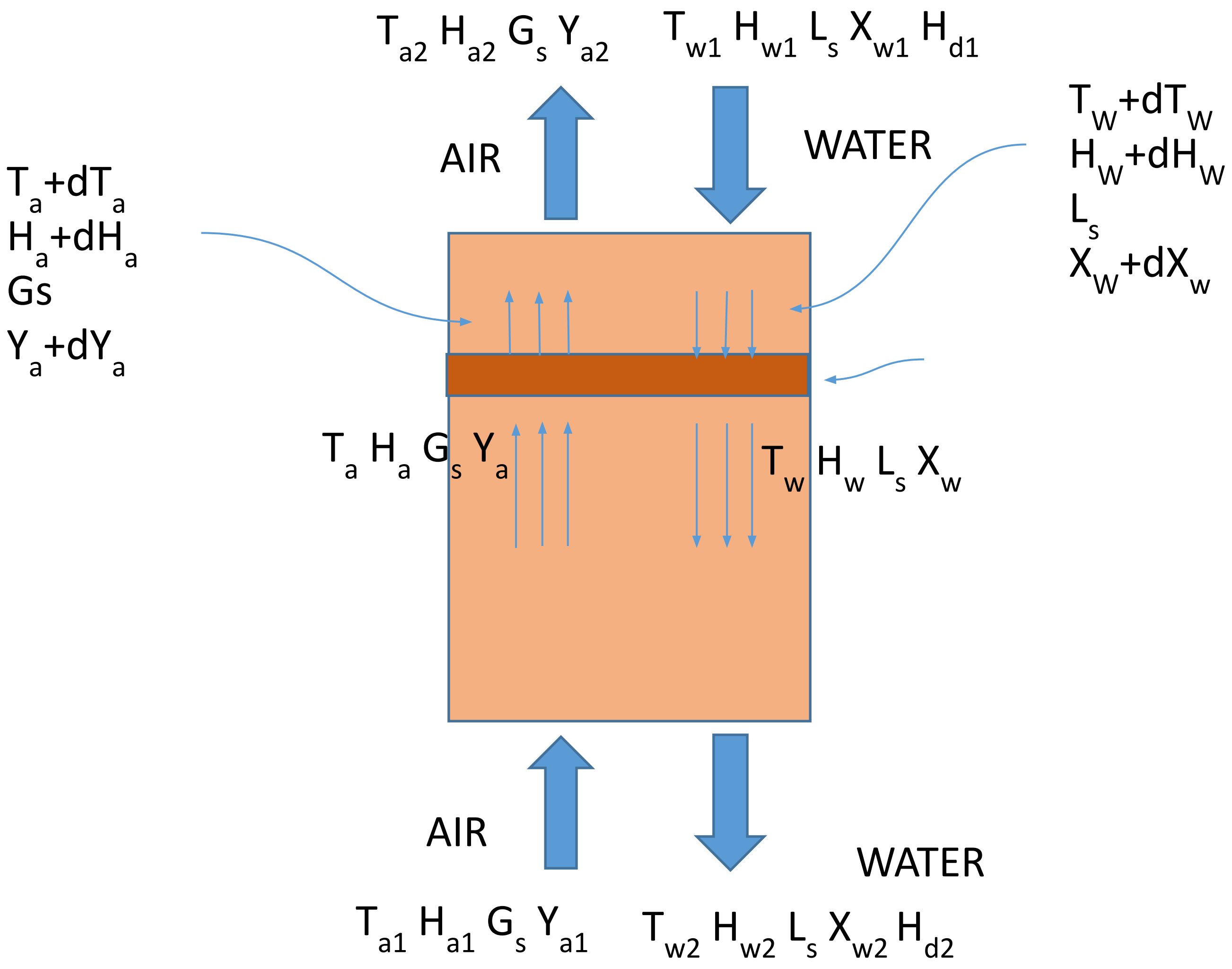
$\frac{dT}{dz} = h_s a(T_s - T_a)/(G_s(C_{pa} + Y_a C_{ps}))$ - 5

Final equation obtained by integrating the equation- 5

$(Ta1 - Ta2)/_{(Ta1 - Tw1)} = 1 - \exp(^{-hs\, a\, z}/_{Gs(Cpa+Ya\, Cps)})$ - 6

In eq 6, all variable are known except T_{a2}

Dehumidifier total energy balances



Here we are doing overall energy balance between inlet and outlet:

$$G_s\,(H_{a1} - H_{a2}) = L_1^{'}\, x_{w1}\, H_{w1} - L_2^{'}\, x_{w2}\, H_{w2} + L_1^{'}\,(1-x_{w1})\, H_{d1} - L_2^{'}\,(1-x_{w2}) H_{d2}$$

Here:

$L_{1,}^{'} = L_s / (1- x_{w1})$

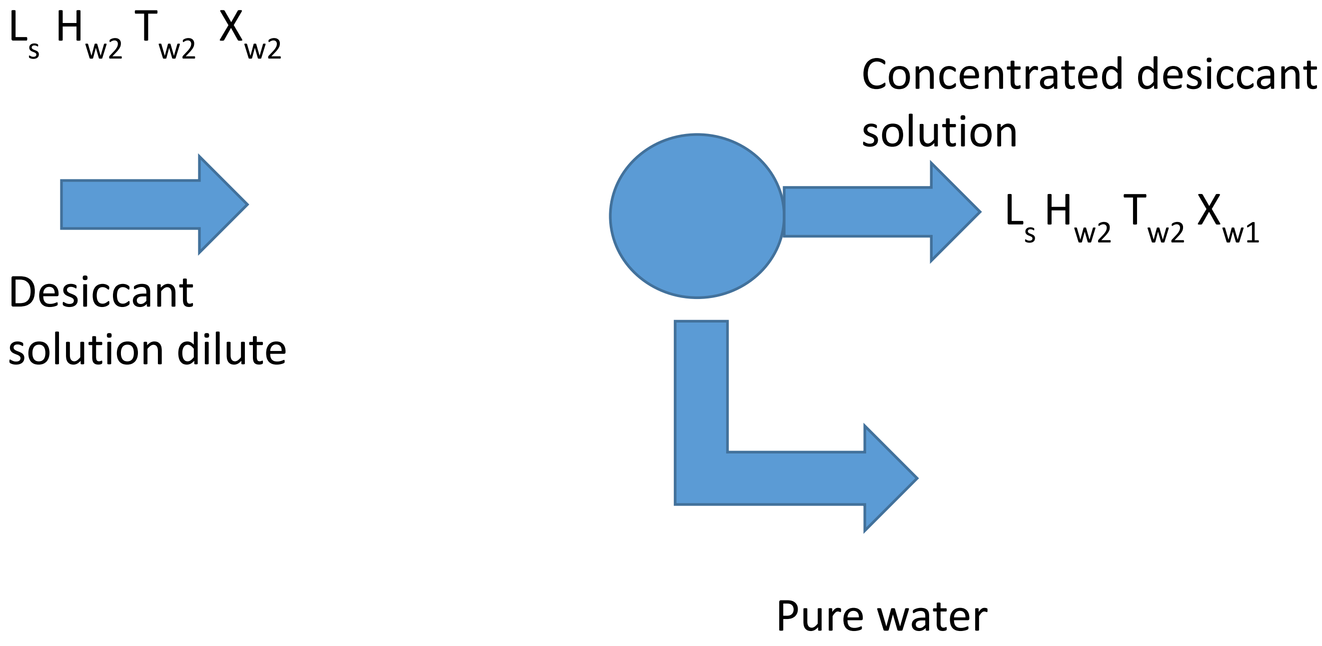
$L_2^{'} = L_s / (1- x_{w2})$

x_{w1} = mass fraction of water in inlet

X_{w2} = mass fraction of water in outlet

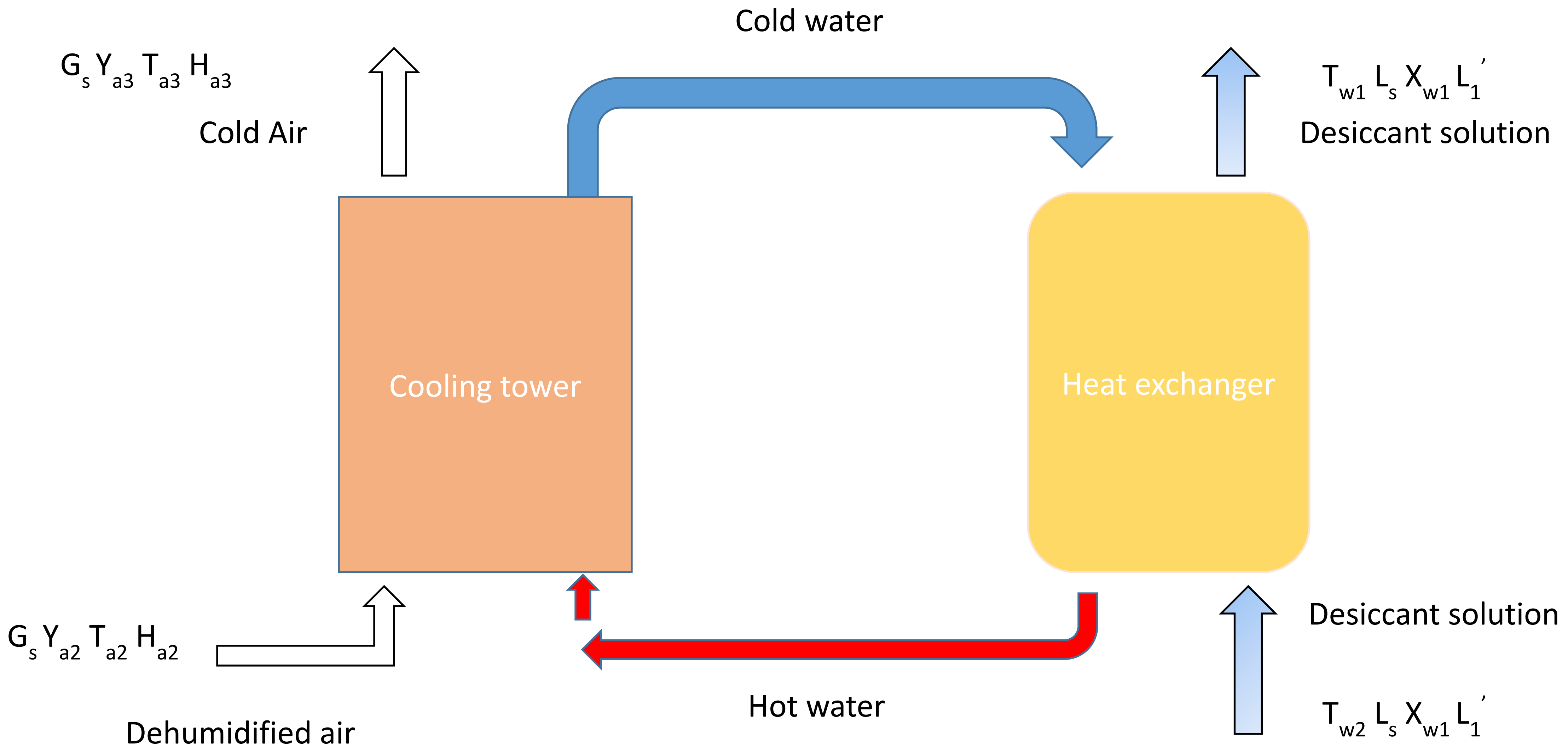
Using this eq. T_{w2} can be known

Regenerator



- ❖ Here we have assumed that there is no change in temperature.
- ❖ Finally the desiccant solution is getting regenerated to the initial inlet condition.

Cooling tower and heat exchanger



Overall energy balance across heat exchanger and Cooling tower

- We are using heat exchanger to bring desiccant solution to initial temperatures.
- The same water is cooled using the cooling tower.
- So energy exchange between air and water, also the energy exchange between water and desiccant solution will be equal.

Following is the energy balance equation obtained:

$$L_1' C_{ps} (T_{w2} - T_{w1}) = G_s (H_{a2} - H_{a3})$$

Where

C_s = heat capacity of desiccant solution

H_{a2} = Enthalpy of air at T_{a2} Temperature and Y_{a2} humidity

$H_{a2} = f(T_{a2}, Y_{a2})$

T_{a3} is known as it is the target variable while in this only T_{w2} and Y_{a3} are unknowns rest all other variables are known or can be calculated.

COP Calculations

The **coefficient of performance** or **COP** of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work (energy) required. Higher COPs equate to higher efficiency, lower energy (power) consumption and thus lower operating costs. Mathematically it can be expressed as:

COP = Q / W

- Q is the useful heat supplied or removed by the considered system.
- W is the work required by the considered system.

Typical range of COP for other existing cooling systems:

- Air Conditioners : 2-5
- Evaporative Coolers : 16-25

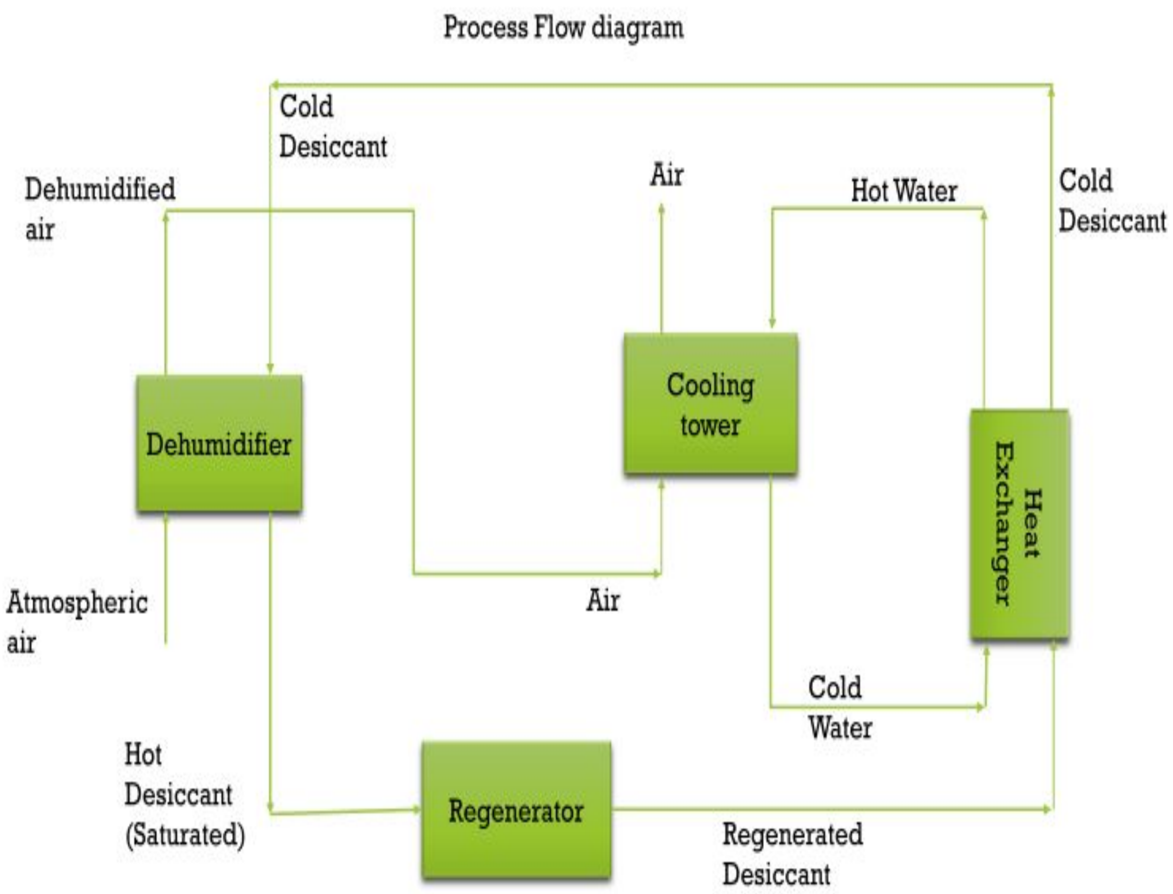
Equipments Required

- As it can be seen in the adjoining figure, we need pumps and fans all over the set up to circulate desiccant solution, water and air through all the equipments.

- So the positions at which we'll require pumps are:

    - Inlet of regenerator- To pump desiccant solution through the RO membrane.
    - Outlet of cooling tower - To circulate cold water through the heat exchanger.
    - Outlet of Heat exchanger - To pump cold desiccant solution back to the dehumidifier.

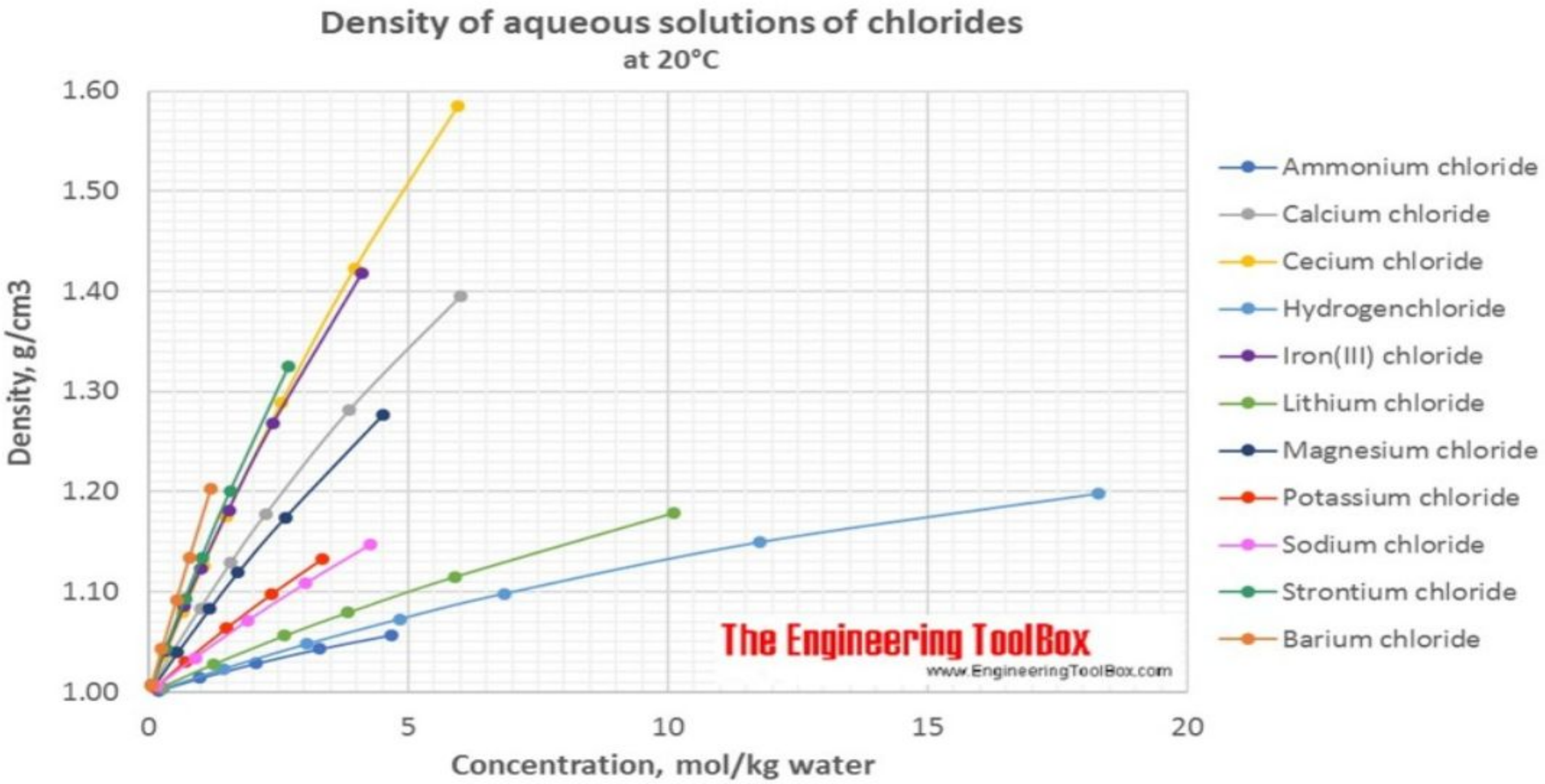
- Location of fans:
    - In dehumidifier
    - In cooling tower



Conditions Assumed

- $T_{air\text{-}inlet}$ (inlet to dehumidifier) = 35 °C
- Density of air = 1.225 kg/m^3
- Flow rate of air = 150 L/sec = 0.18375 kg/sec
- Radius of inlet pipe (r) = 5 cm = 0.05 m
- Cross-sectional area of inlet pipe = π*(r)^2 = 0.00758 m^2
- Velocity of air = 19.79 m/sec
- Absolute humidity, Ya(inlet air) = 11 g/kg
- Desiccant solution conc = 4 mol/L
- Desiccant solution temperature = 20 °C

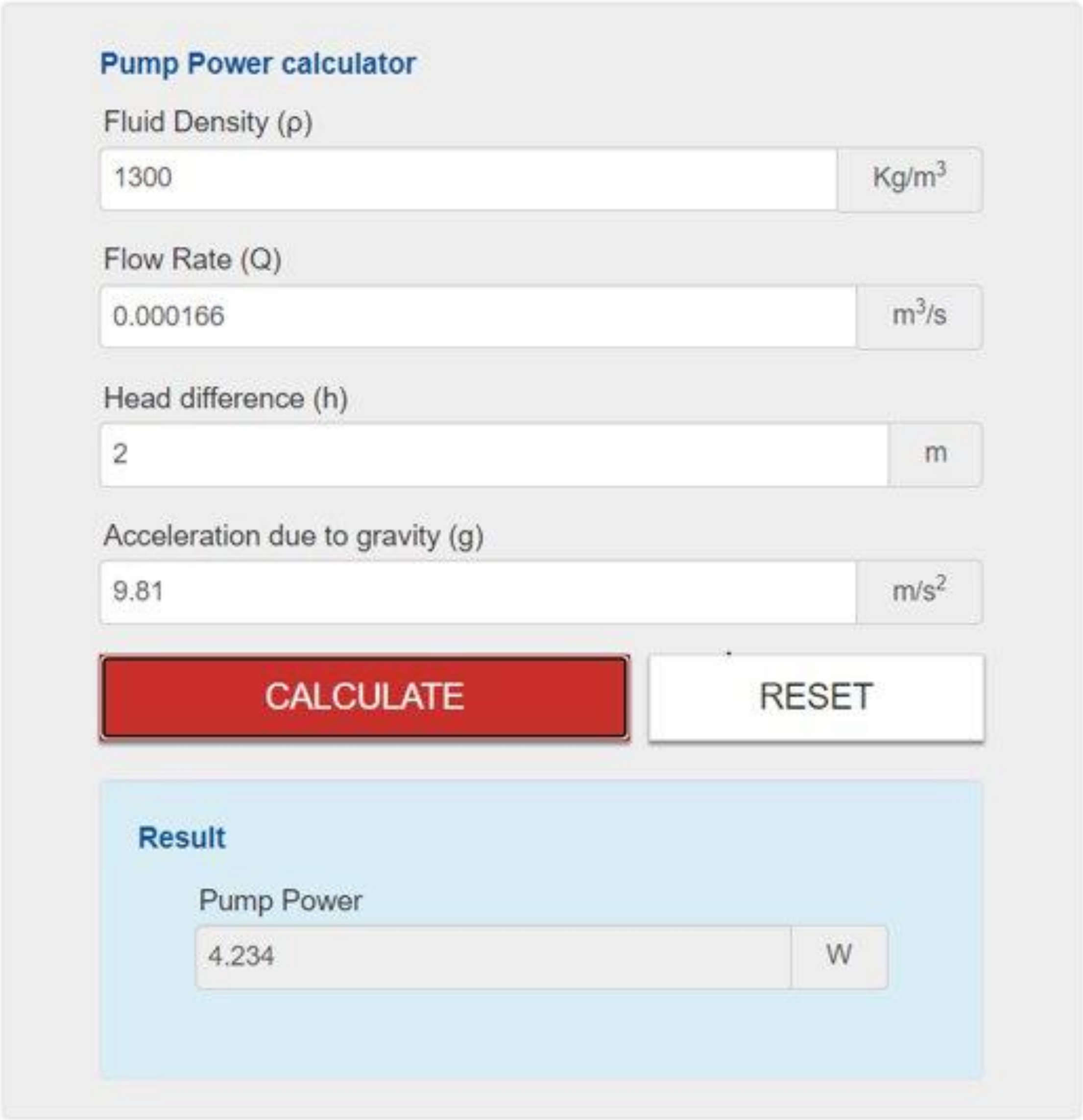
Graph of Density vs Concentration



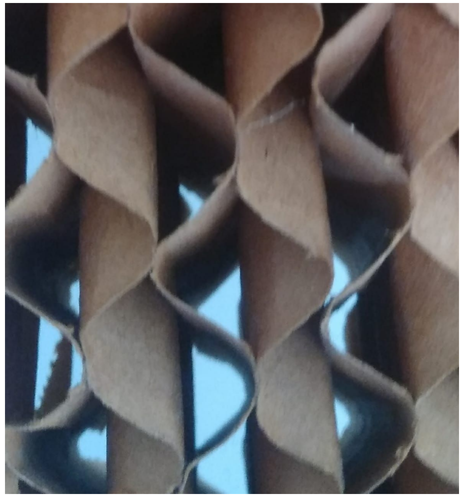
Pump Power Calculation

- Density of desiccant soln. (*ρ*) = 1.3 g/cm^3
- Flow rate of desiccant soln. = 10 L/min
- Flow rate of desiccant soln.(*q*) = 0.000166 m3/sec
- Differential head (h) = 2 m

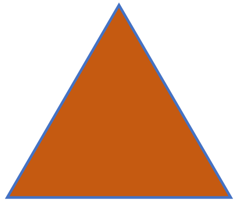
- Hydraulic power = 4.234 W
- Assuming, pump efficiency = 0.8
- Shaft power = 4.234/0.8 = 5.29 W



Hydraulic diameter



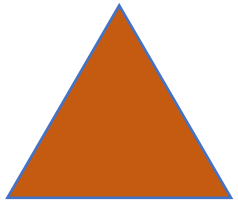
Packing specifications:
L = 85 cm , B = 20 cm.
2240 air channels.



H = 0.9 cm, sides length = 1,1,1.6
Hydraulic dia = 4A/P .
A = 0.8 cm^2
P = 3.6 cm
Hydraulic diameter: = 0.23 cm

Calculation of effective cross sectional area in packed column.

1. From measurements of a single triangular channel the area of single channel can be determined
2. $A_{channel}$ = 0.8 cm^2 (cross section area)
3. No of channels = 2240 (85 x 20 cm cross section of packing)
4. Effective available area for air flow = 0.8*2240 = 0.1792 m^2
5. Assuming 20 % area is available for desiccant.
6. Effective available area for liquid desiccant flow = 0.2*(0.1792) = 0.03584 m^2



Calculation of flow speed

- Assuming desiccant is flowing in the 20% of the area of packing.
- Area of cross section available (A) = 0.1792 m^2
- Velocity of air calculated, $u_a = m_a/(\rho_a A)$
- u_a = 0.83 m/sec
- $u_d = V_d/(0.2*A)$
- u_d = 4.67 x 10^(-3) m/sec.
- Further Reynold's no. is determined which are required for calculations of transfer coefficients.

Heat transfer coefficient calculation in dehumidifier.

$K_h (d_h / \lambda_a) = 0.0295 (Re_a^{0.7117} Re_d^{0.1339})$ - [1]

$\rho_a = 1.225\ kg/m^3$, $\rho_d = 1300\ kg/m^3$

$\mu_a = 0.018$ mPa-sec , $\mu_d = 4$ mPa-sec

$D_h = 0.23$ cm, $u_a = 0.83$ m/sec, $u_d = 4.67 \times 10$^(-3) m/sec

Re_a (Reynold's no. for air) = $\rho_a u_a D_h / \mu_a = 129.918$

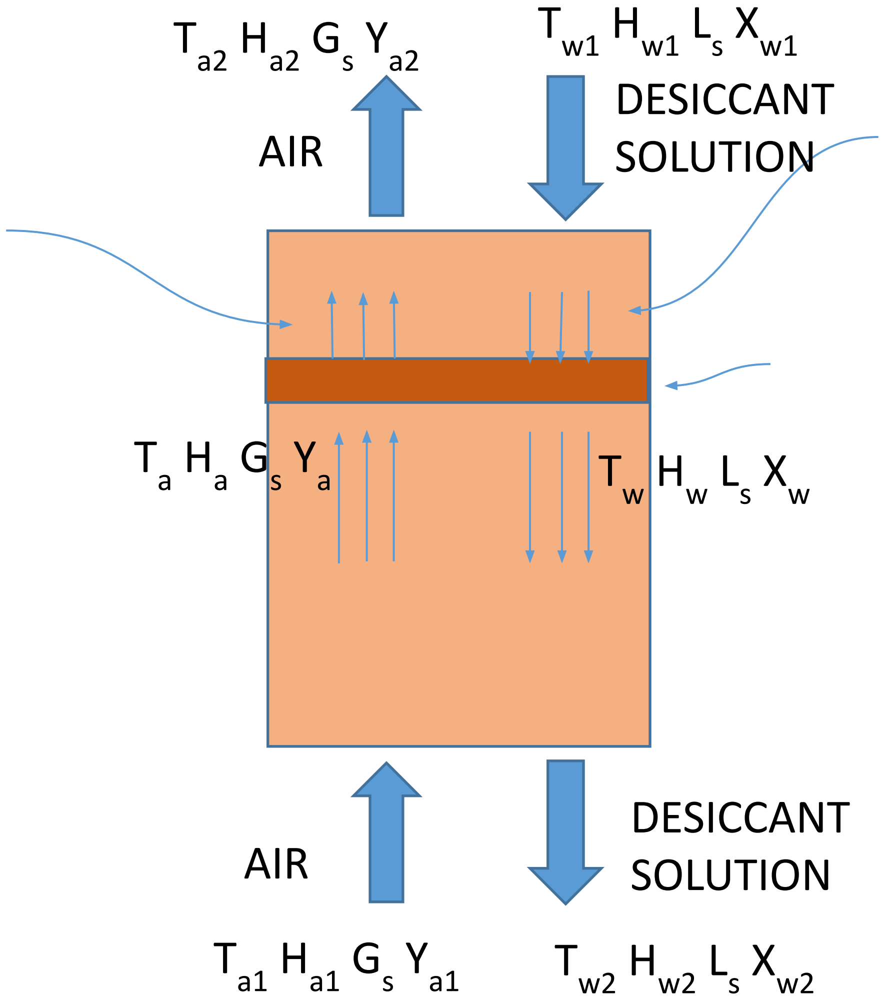
Re_d (Reynold's no. for desiccant) = $\rho_d u_d D_h / \mu_d = 69.81$

λ_a (thermal conductivity of air) = 26.62×10^{-3} W/m-K

$K_h = 19.25\ W/m^2$-K (reference :

https://www.sciencedirect.com/science/article/pii/S001793101634193X#t0005)

Outlet air temperature calculation



$$(Ta1 - Ta2)/_{(Ta1 - Tw1)} = \ 1 - \exp(^{-hs\, a\, z}/_{Gs(Cpa + Ya\, Cps)}) \ \text{-}$$

Hs = heat transfer coefficient = 19.25 W/m^2-K

T_{a1} = 35 ^{o} C

T_{w1} = 30 ^{o} C

a (area of contact/ vol) = 460 $m^2/\ m^3$

z = 0.7 meters

Gs = 0.18 kg/ m^3

Ya = 0.01

Putting all these values in the above equations:

T_{a2} = 30 ^{o} C

Final temperature of cooled air

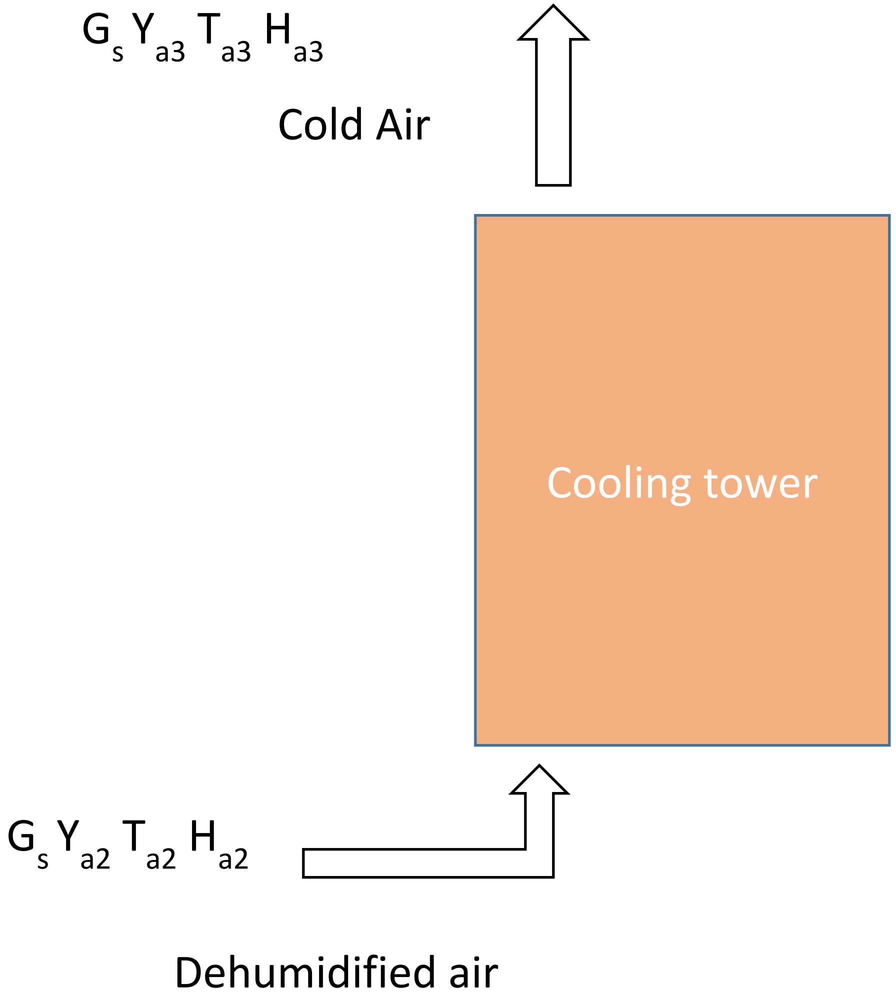
Saturation efficiency = 85 %

Saturation efficiency = $(T_{a2} - T_{a3})/(T_{a2} - T_{wet})$

$T_{wet} = 20\ ^{o}C$

$T_{a2} = 30\ ^{o}C$

$T_{a3} = 21.5\ ^{o}C$



COP CALCULATION

- Power consumed by different equipments :

  - RO booster pump – 96 W
  - Water Pump(2) – 4 W
  - Cooling tower fan – 80 W

- So total power = 96+4+4+80 = 184 W

- Heat Extracted by the system:
  - Temperature of the air at the outlet of cooling tower: 21.5 ℃
  - Temperature at the inlet of dehumidifier : 35 ℃
  - Cp of air(kJ/(kg*k)) = 1
  - Mass flow rate = 0.18375 kg/s

- So heat extracted = M*Cp*(T2 –T1) = 2480.625 W

- Hence **COP = 2480.625/184 = 13.5**
- while the COP of AC is 4, This implies that, **the running cost of our system is 1/3rd of AC.**

References

1. https://www.sciencedirect.com/science/article/pii/S001793101634193X#t0005
2. Shahab Alizadeh, 2008, A Feasibility Study of Using Solar Liquid-Desiccant Air Conditioner, Queensland, Australia
3. Calcium Chloride Water Solution (engineeringtoolbox.com)
4. Richard Jayson Varela, Seiichi Yamaguchi, Niccolo Giannetti, Kiyoshi Saito, , 2018, General correlations in an air-solution contactor of a liquid desiccant system and an experimental case application, International Journal of Heat and Mass Transfer, 120, 851-860.
5.

THANK YOU