Cooling Tower Experiments

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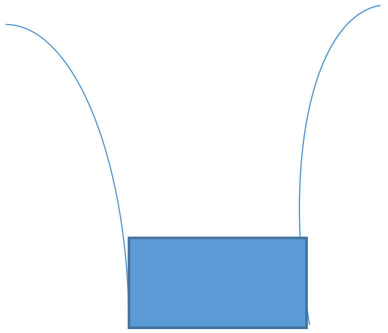
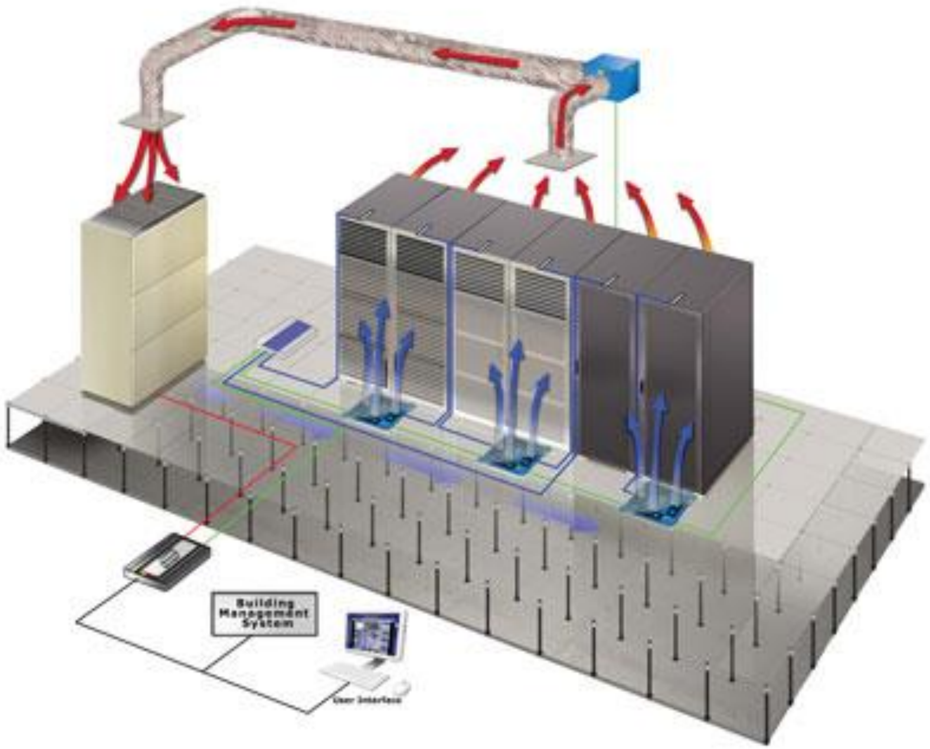
Cooling Tower

Introduction

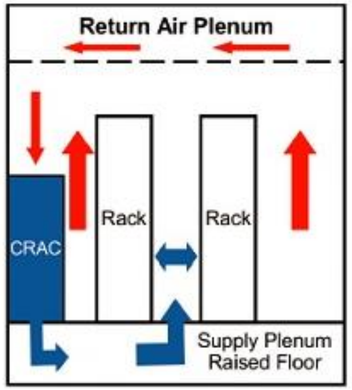
- What is it?
- Applications: powerplants, refrigeration cycles, process industries…
- Types
  - Atmospheric (aspirated flows, hyperbolic towers)
  - Mechanical draft (forced, induced)
  - Hybrid
- Counterflow, crossflow, coflow…
- Shapes

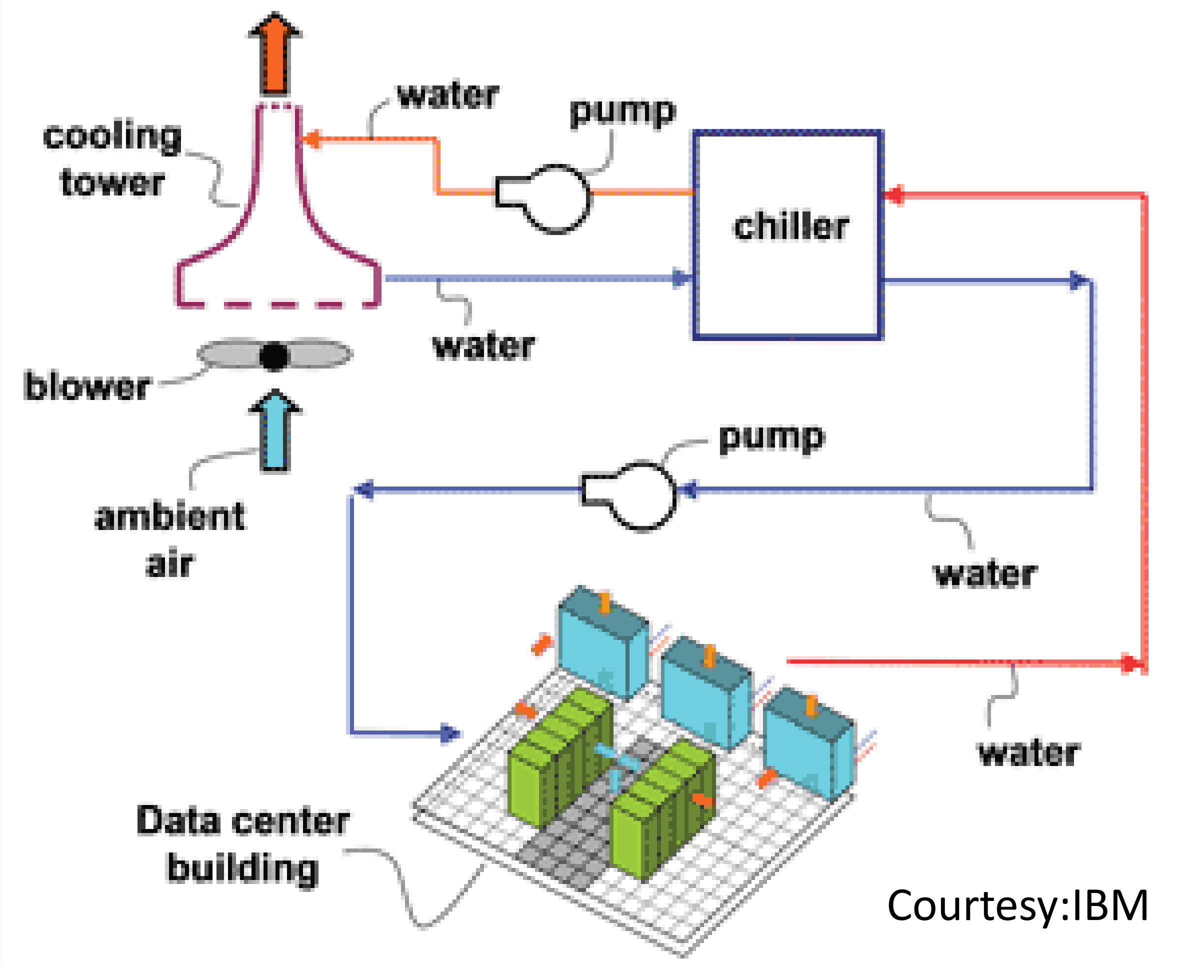


(1) Datacenter Cooling



Courtesy:eecnet.com



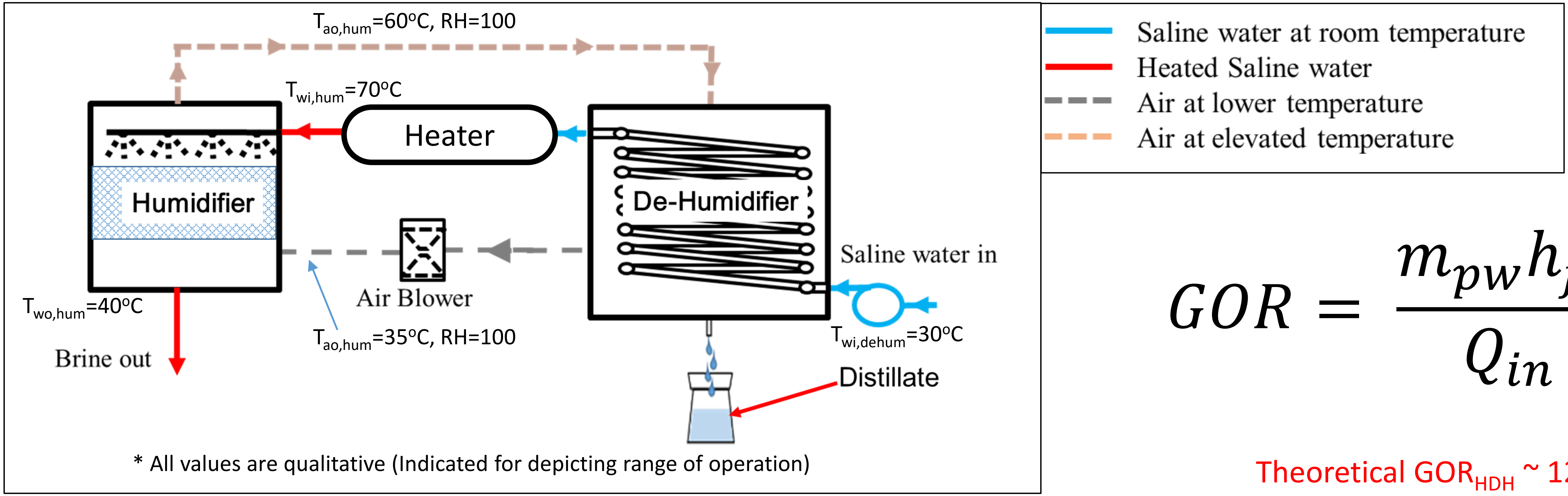


Courtesy:IBM

An Example Air-Cooled Datacenter

(2) Concept of HDH Desalination

Decentralized drinking water technology



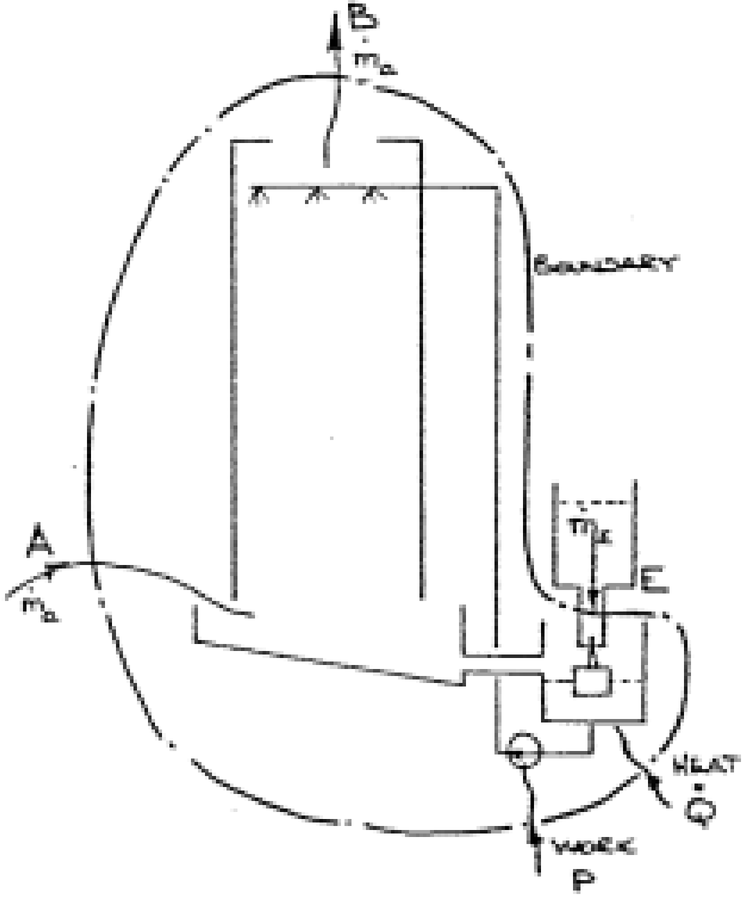
$$GOR = \frac{m_{pw} h_{fg}}{Q_{in}}$$

Theoretical GOR_{HDH} ~ 122

Advantageous features of HDH desalination

- Wide range of low grade thermal waste heat and solar energy can be used to run HDH system
- Simple and low-cost construction
- Non/low skilled operation requirement
- Membrane free (low maintenance construction)
- Robust under high TDS
- Sub-boiling temperature operation (approx. 60 °C - 80°C)

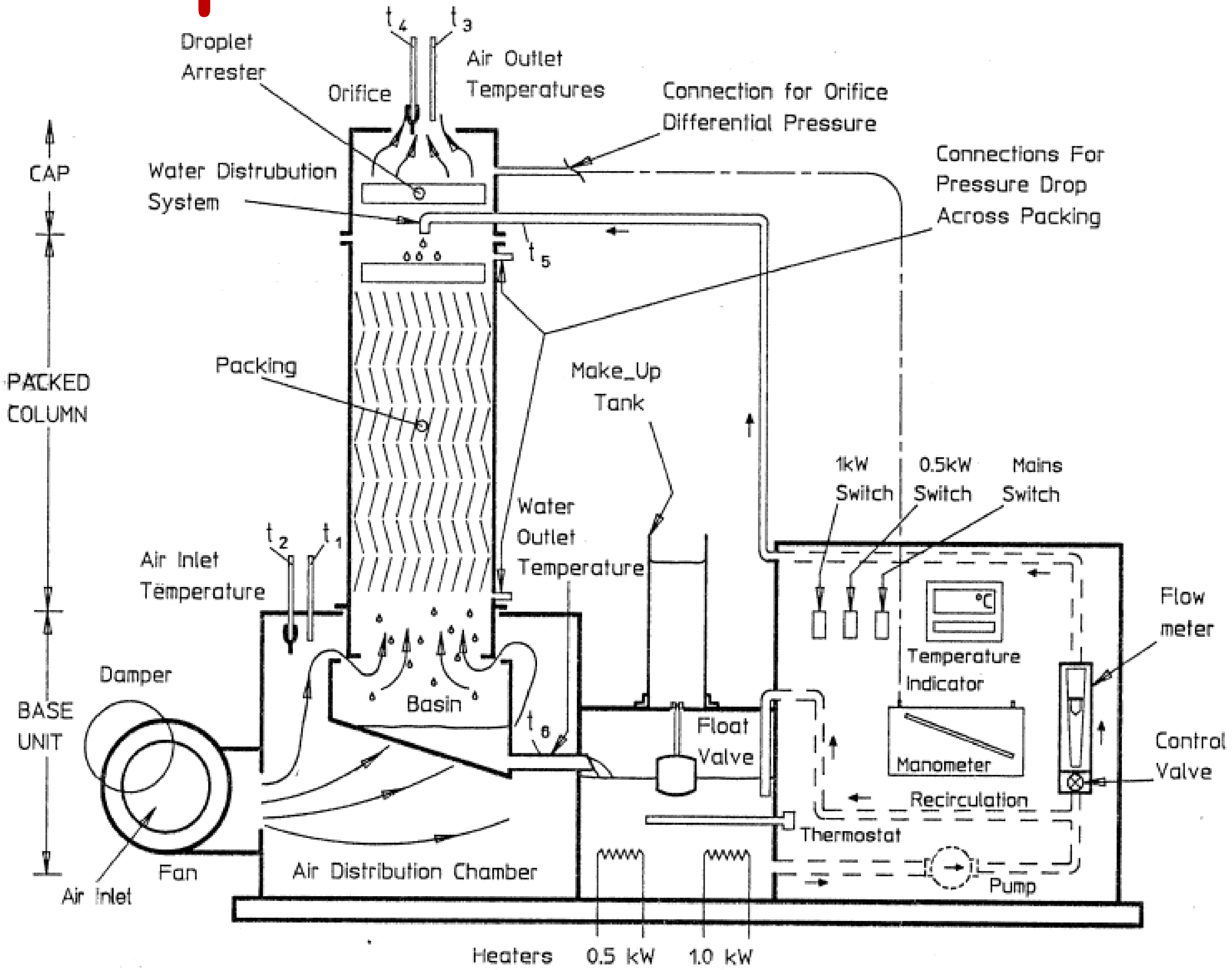
Experimental Setup



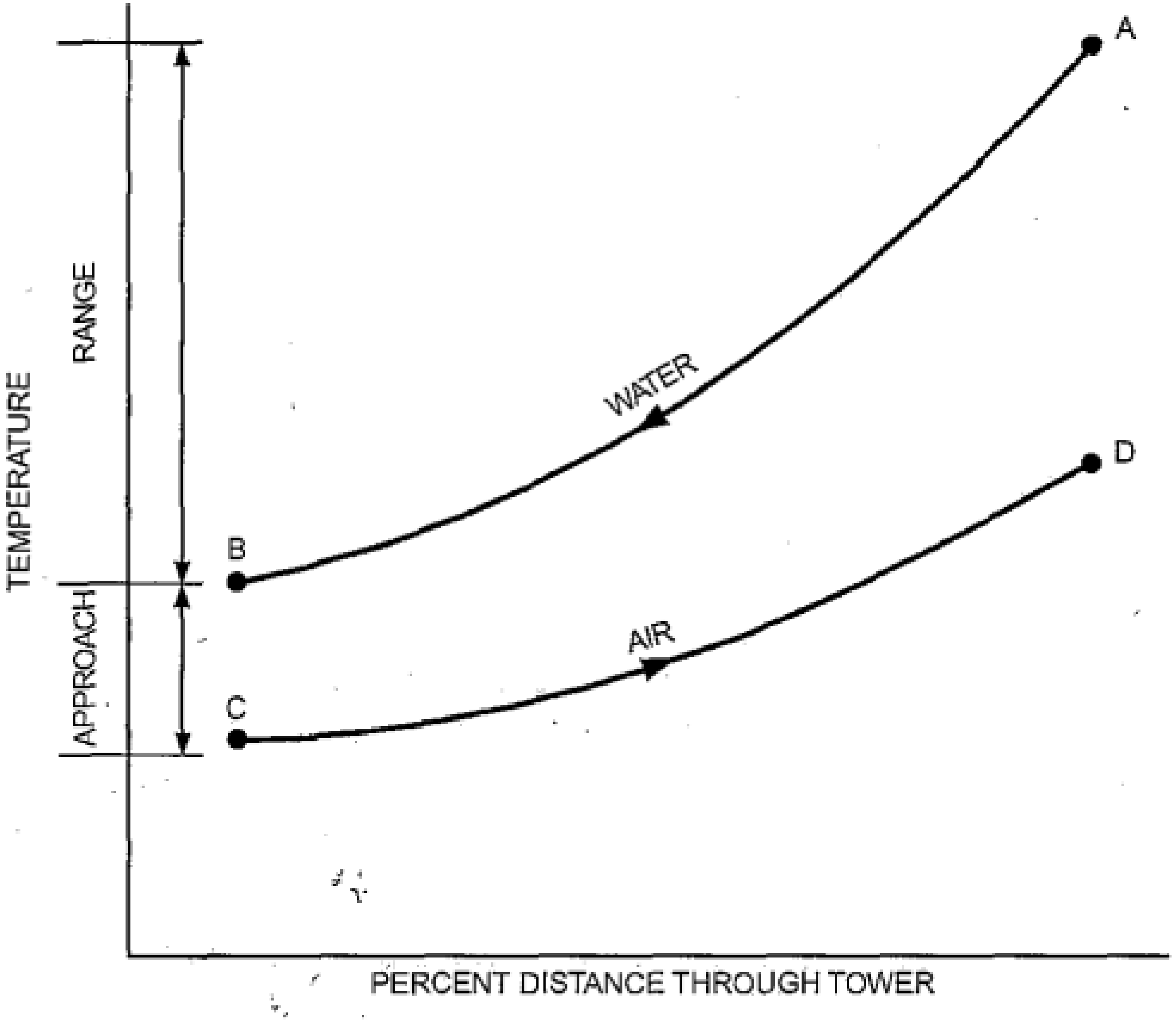
$$\dot{Q} - P = \dot{H}_{Exit} - \dot{H}_{Entry}$$

$$\dot{Q} - P = (\dot{m}_a h_{da} + \dot{m}_s h_s)_B - (\dot{m}_a h_{da} + \dot{m}_s h_s)_A - \dot{m}_E h_E$$

$$\dot{Q} - P = \dot{m}_a (h_B - h_A) - \dot{m}_E h_E$$



Cooling Tower Basics



Specific humidity: mass of water vapor to total mass of moist air

Relative humidity: mole fraction of water vapor in moist air to that of saturated air

Humidity ratio: ratio of mass of water vapor to dry air

Parameters of Cooling Towers

A number of parameters describe the performance of a cooling tower.

- **Range** is the temperature difference between the hot water entering the cooling tower and the cold water leaving.
  - Note that the range is not determined by performance of the tower, but is determined by the heat loading.
- **Approach** is the difference between the temperature of the water leaving the tower and the wet bulb temperature of the entering air.
  - The approach is affected by the cooling tower capability.
  - For a given heat loading, water flow rate, and entering air conditions, a larger tower will produce a smaller approach; i.e., the water leaving the tower will be colder.
- **Water/Air Ratio (m_w/m_a)** is the mass ratio of water (Liquid) flowing through the tower to the air (Gas) flow.
  - Each tower will have a designed water/air ratio.
  - An increase in this ratio will result in an increase of the approach, that is, warmer water will be leaving the tower.

Thermodynamics of Air Water Systems

Humidity Ratio $\omega = \dfrac{\text{Mass Flow of Water Vapour}}{\text{Mass Flow of Dry Air}} = \dfrac{\dot{m}_v}{\dot{m}_a}$

$$p_a\dot{V} = \dot{m}_a R_a T = \frac{\dot{m}_a R_u T}{M_a} \qquad p_v\dot{V} = \dot{m}_v R_v T = \frac{\dot{m}_v R_u T}{M_v}$$

$$\omega = \frac{\dfrac{M_v p_v \dot{V}}{R_u T}}{\dfrac{M_a p_a \dot{V}}{R_u T}} = \left(\frac{M_v}{M_a}\right) \times \left(\frac{p_v}{p_a}\right) = 0.622\left(\frac{p_v}{p_a}\right)$$

Model for Cooling Tower

Conservation of Mass for dry air:

$$\dot{m}_{air,in} = \dot{m}_{air,out} = \dot{m}_{air}$$

Conservation of Mass for water:

$$\dot{m}_{water,in} + \omega_{air,in}\dot{m}_{air,in} = \dot{m}_{water,out} + \omega_{air,out}\dot{m}_{air,out}$$

First Law Analysis:

Specific enthalpy, h = h_{air} + ω h_{vapor}

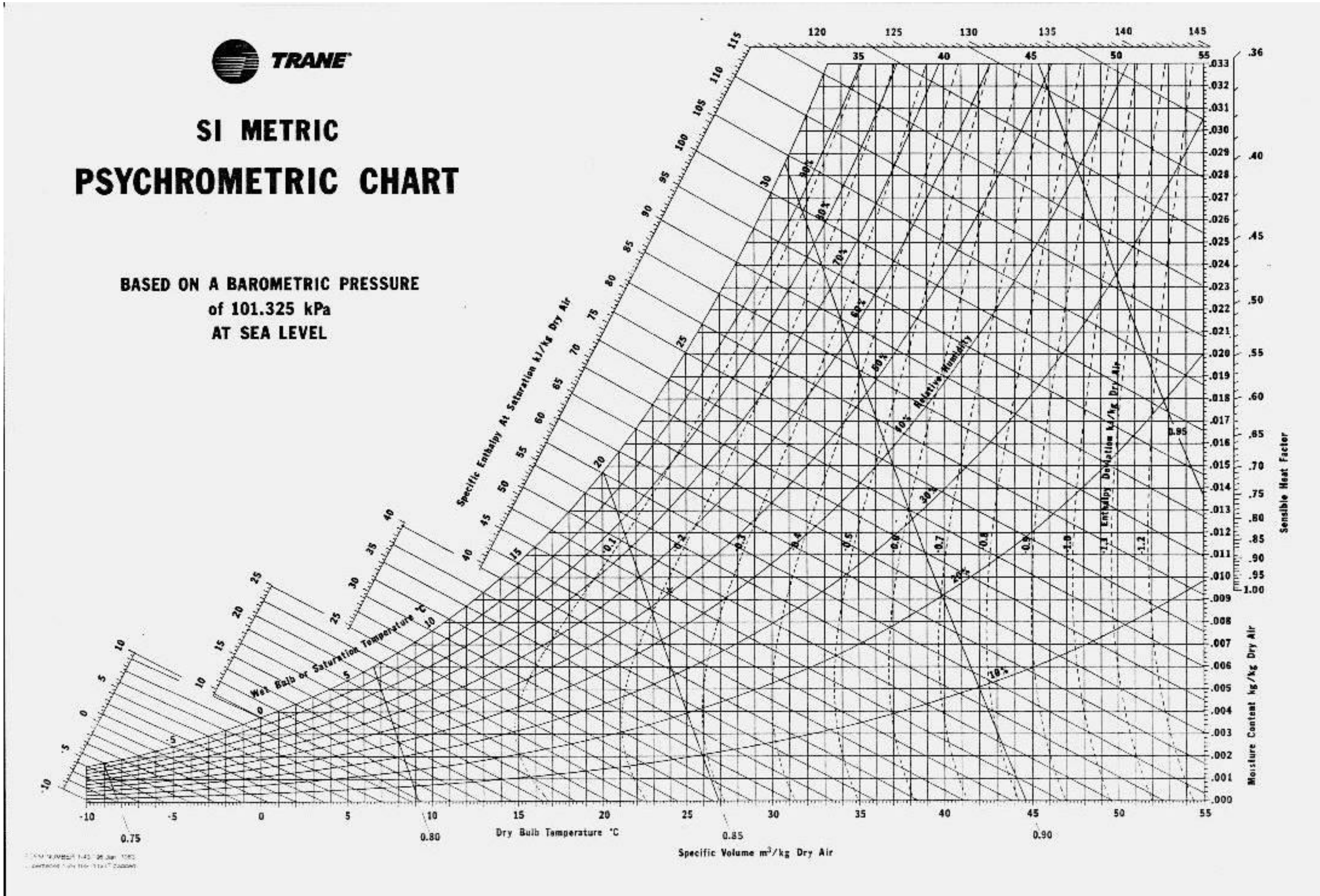
$$\dot{m}_{CWi}\, C_W T_{Wi} - \dot{m}_{CWe}\, C_W T_{We} =$$

$$\dot{m}_{air}\left\{\boxed{\left(C_{p,air} + \omega_e C_{p,steam}\right)\times T_{air,e} - \left(C_{p,air} + \omega_i C_{p,steam}\right)\times T_{air,i}} + \boxed{\left(\omega_e - \omega_i\right)\left(h_{fg}\right)}\right\}$$

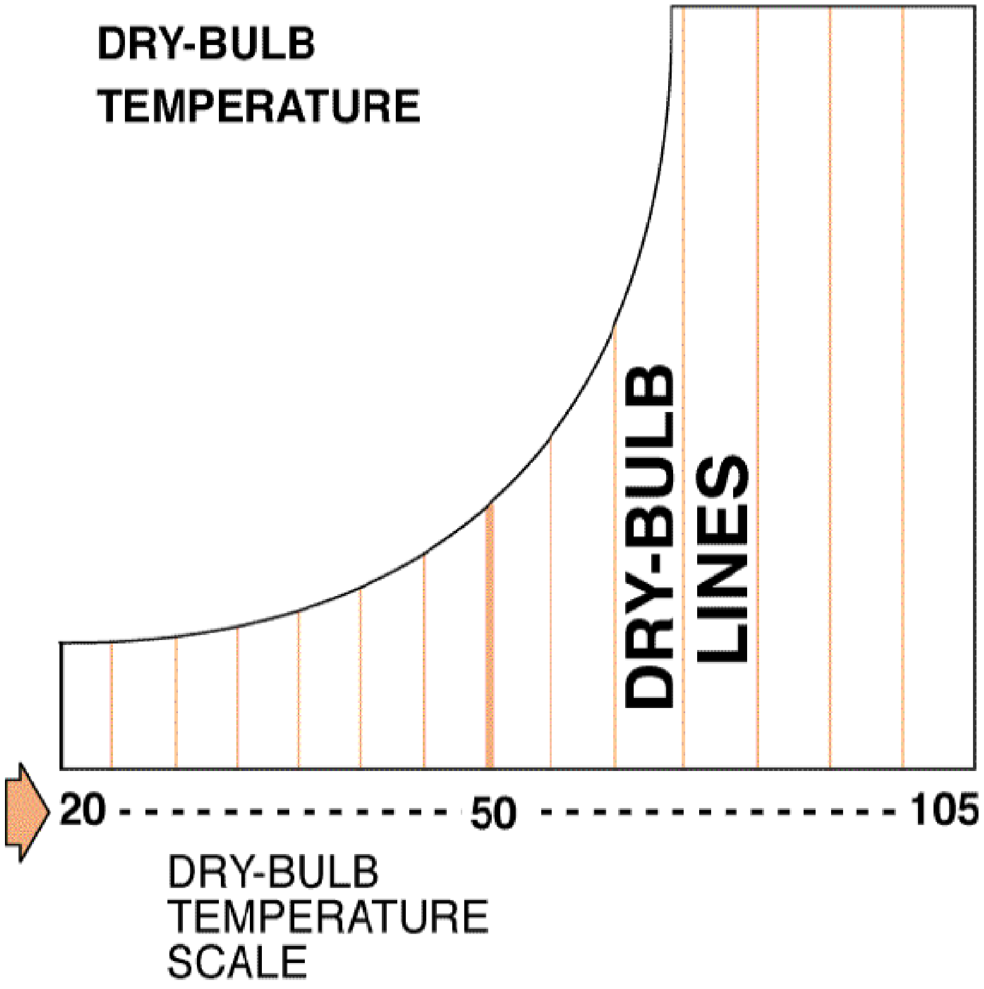
Sensible Heat

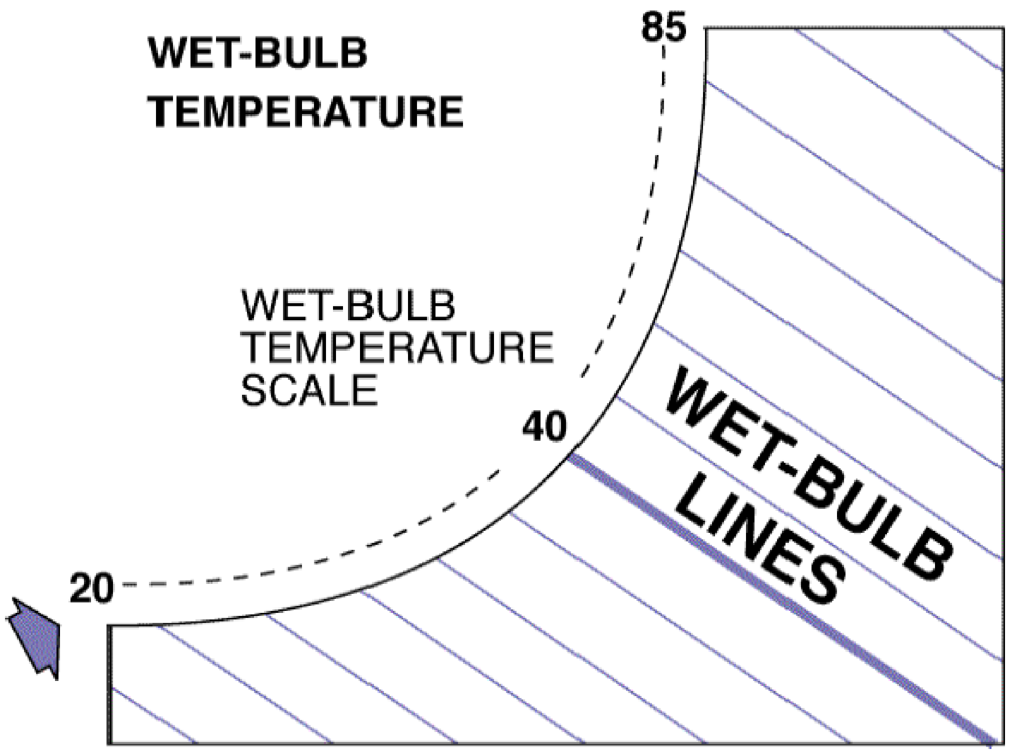
Latent Heat

Psychrometric Chart

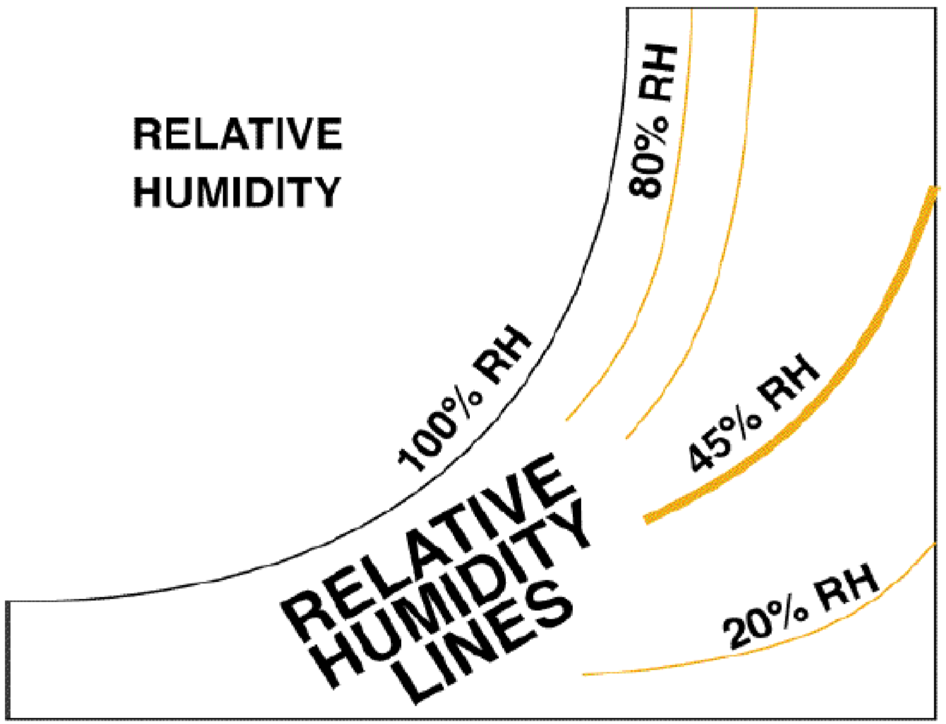


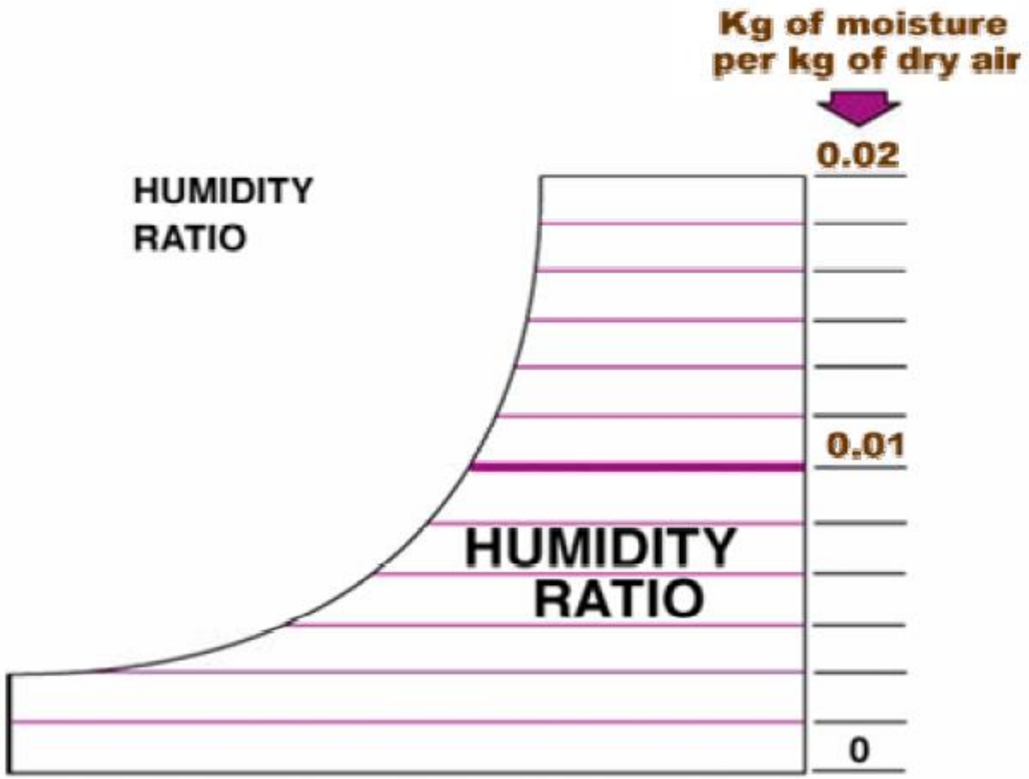
Dry Bulb vs. Wet Bulb



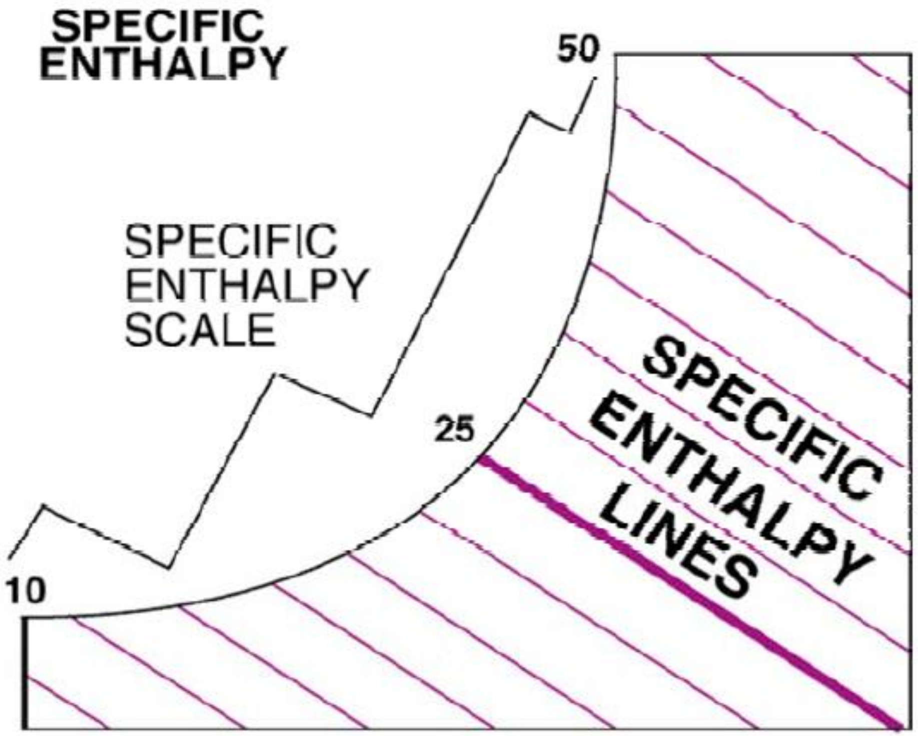


RH vs. Humidity Ratio

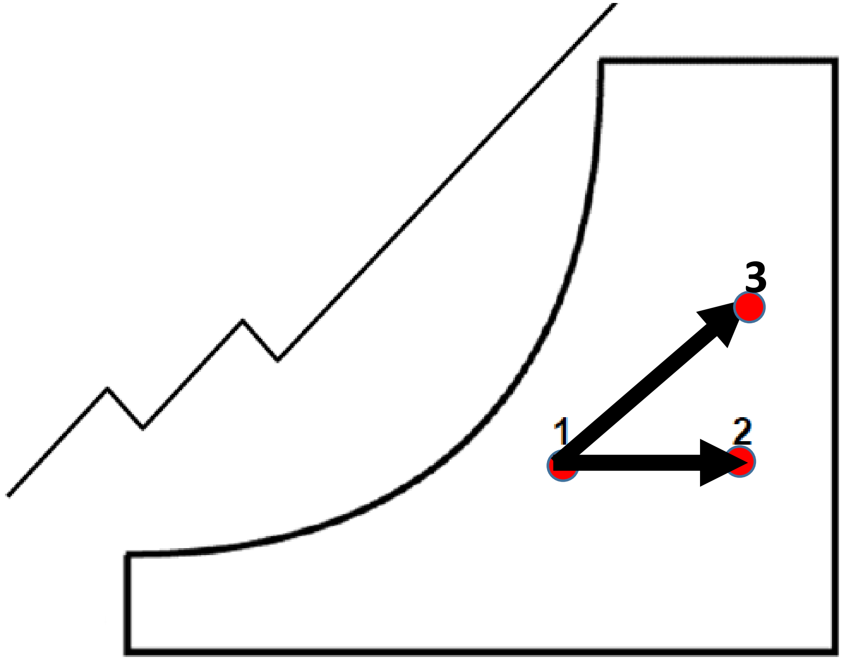




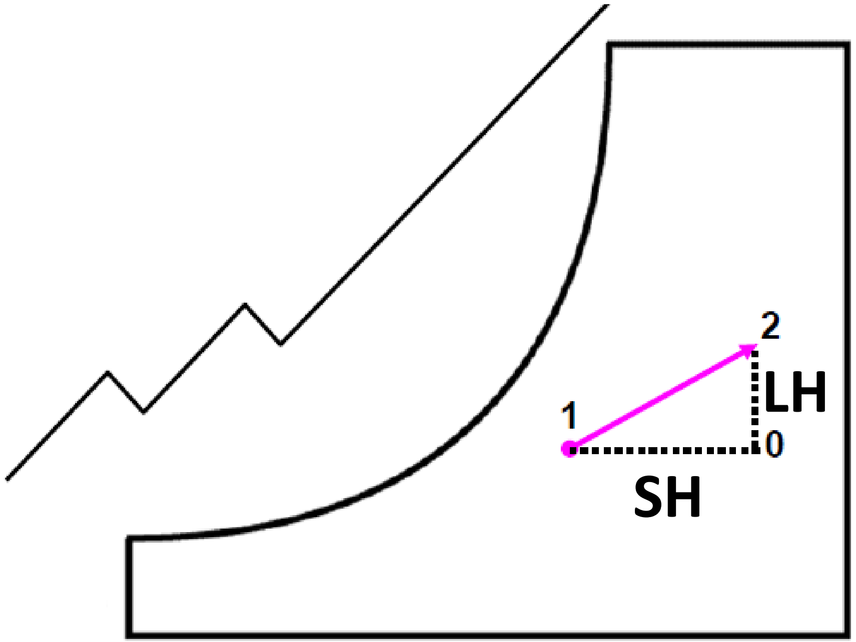
Specific Enthalpy



Sensible Heating/Cooling vs. Humidification

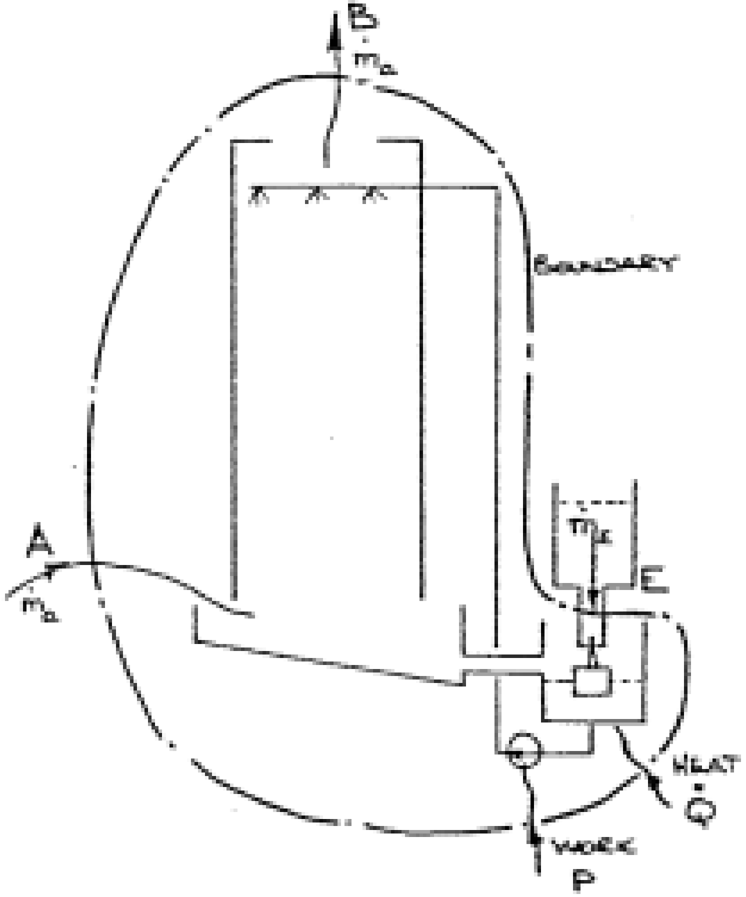


Sensible Heating



Heating and Humidification

Experimental Setup



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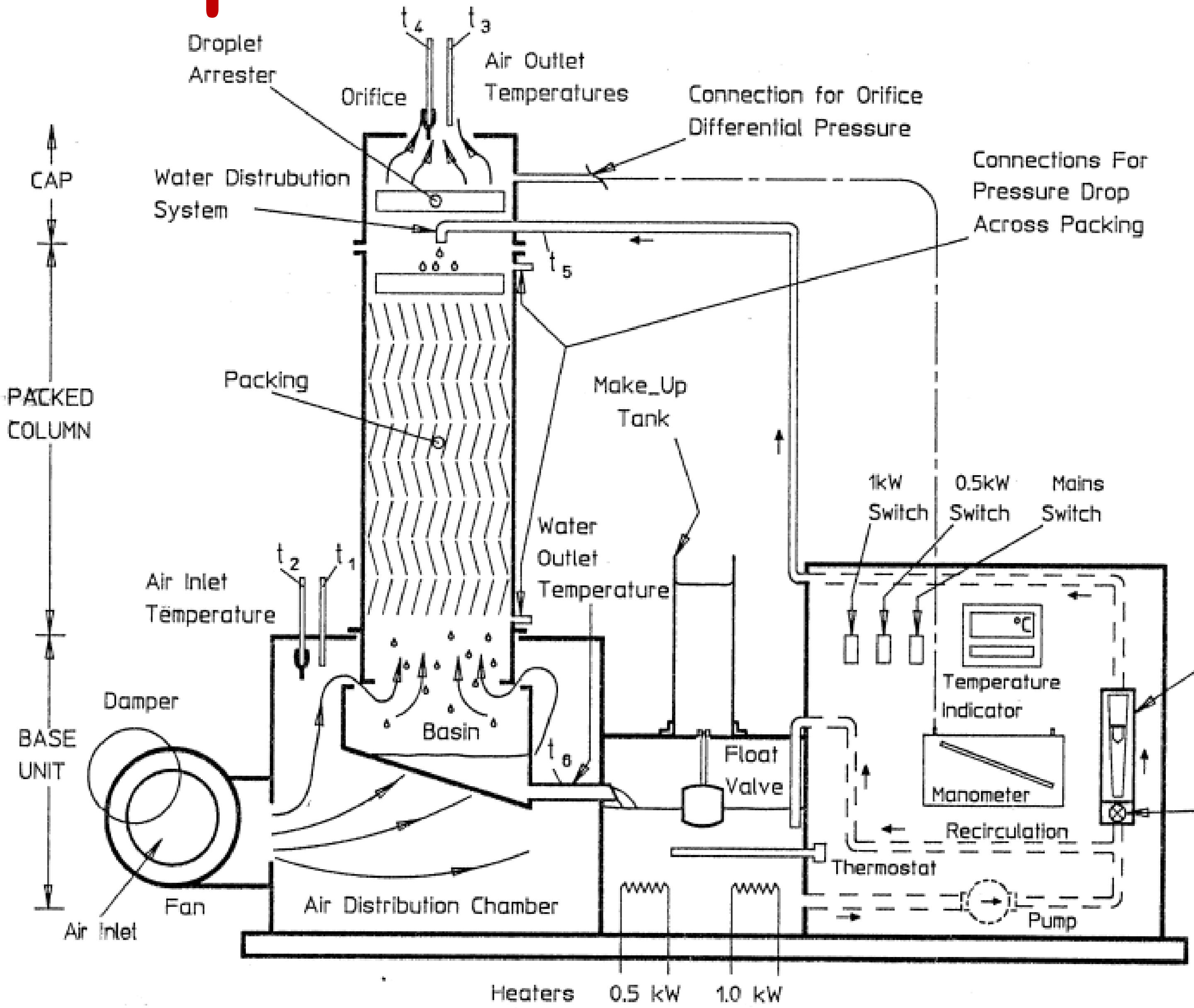
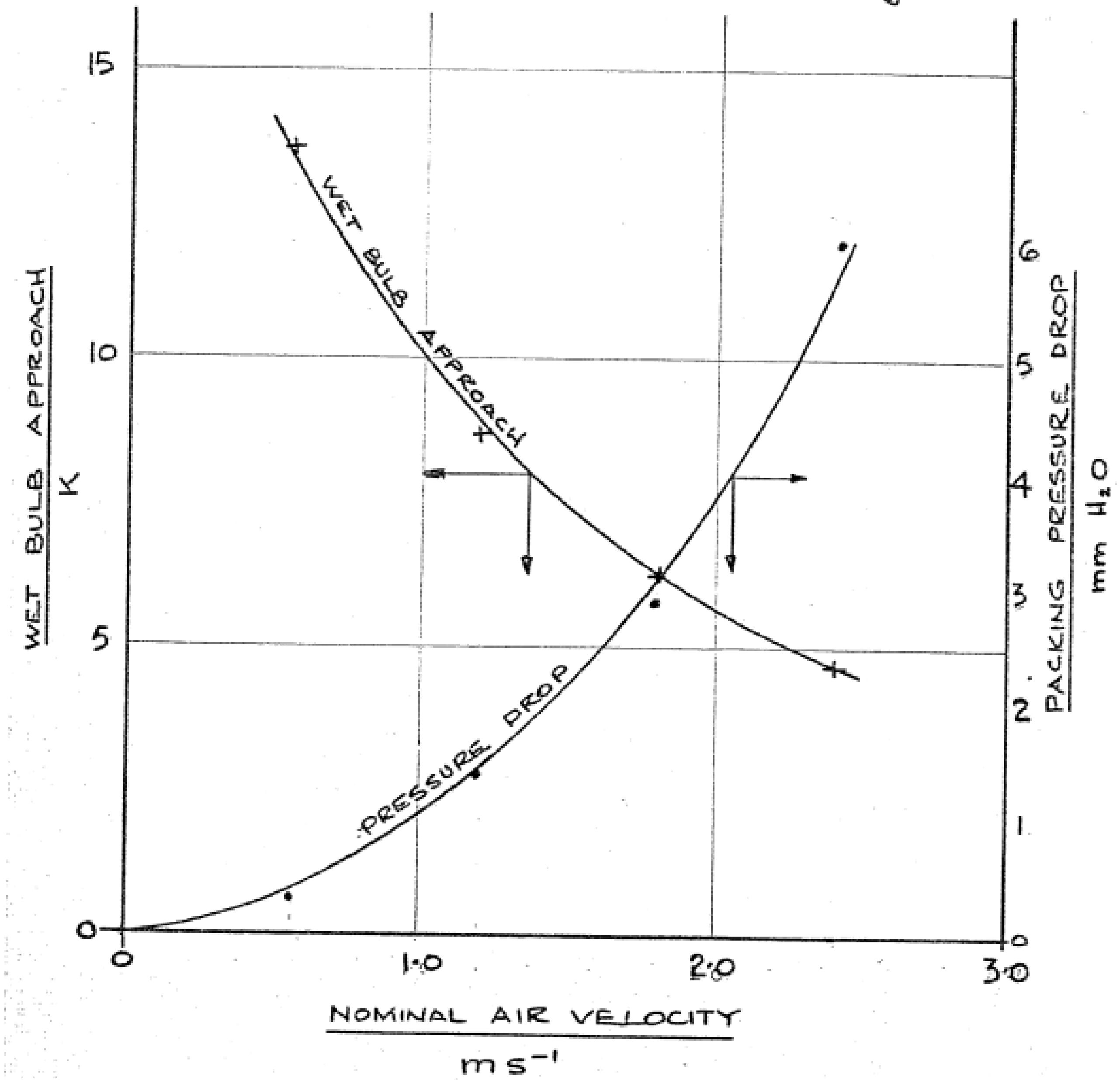
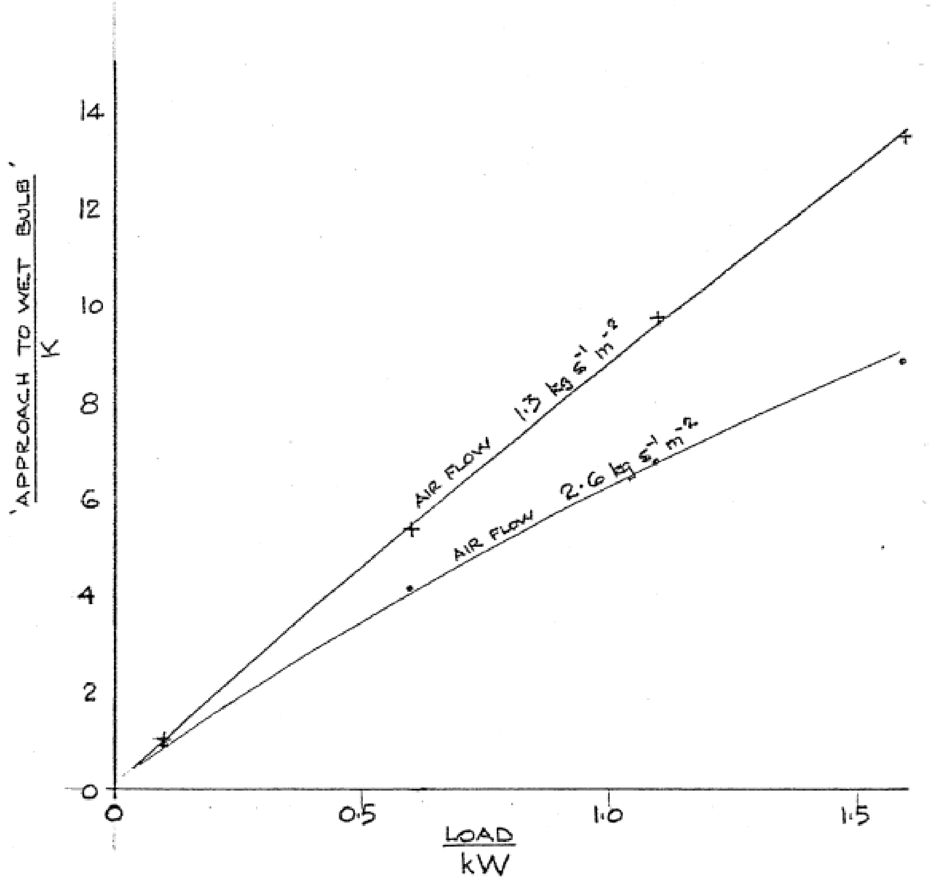


DATA :- INLET WET BULB TEMPERATURE 18°C
COOLING LOAD 1·1 kW
PACKING INSTALLED C ($200 m^{-1}$)
WATER FLOW RATE $40 gm\ s^{-1}$





DATA :- AIR FLOW RATE $\doteq$ 0·058 kg s^{-1}
PACKING B
WATER FLOW RATE 40 gm s^{-1}