Air Conditioning

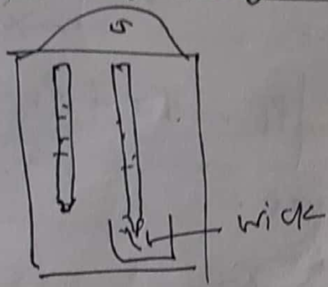
Psychrometry

Summer A/c, winter A/c, year round A/c

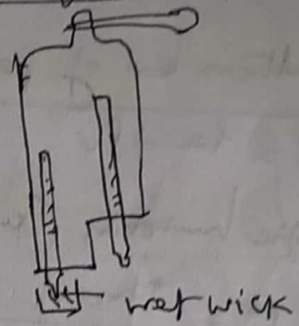
Psychrometry. Study of properties of air,

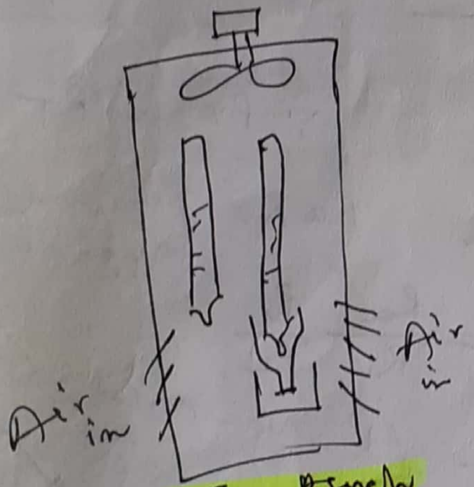
dry air, Moist air, water vapour, DBT, WBT

① Laboratory Psychrometer



② Sling Psychrometer





4) Continuous recording Type

③ Aspirating Psych

Dew pt Temp :- When Temp. of air is reduced by continuous cooling, water vap will start condg at a particular Temp which is DPT.

Specific humidity (humidity ratio)

= Mass of water vap per kg of dry air, kg / kg of dry air, gm / kg of dry air

Absolute humidity :

= wt of water vap. present in unit vol of air

Degree of Saturation . = $\frac{\text{ratio of actual Mass of water vap in unit mass of dry air}}{\text{Mass of water vap in unit mass of dry air}}$

8) **Relative Humidity :**

$= \frac{\text{Actual Mass of water vap in given vol}}{\text{Mass of water vap if the air is saturated at same Temp.}}$

Sensible Heat, L.H, Total heat.

Humid. Specific vol = vol of mixture / kg of dry air in the mixture

Dalton's law of partial pr : $[P_t = P_a + P_b + P_c$ 3 gases$]$

$P_t = P_a + P_v$, a = air, v = water vap.

Specific humidity (ω)

$\omega = \frac{\text{Mass of water vap in mixture}}{\text{Mass of dry air}}$

$= \frac{m_v}{m_a}$ $\because P_v = m R T$

$m_a = \frac{P_a V}{R_a T}$, $m_v = \frac{P_v . V}{R_v . T}$ R_a, R_v gas constant, M_v, M_a = Mole wts

V = Volume of mixture

$\omega = \frac{P_v . V}{R_v . T} \cdot \frac{R_a . T}{P_a . V} = \frac{R_a}{R_v} \frac{P_v}{P_a}$

$\frac{R_a}{R_v} = \frac{M_v}{M_a} \leftarrow R_a = \frac{R}{M_a}$, $R_v = \frac{R}{M_v}$, R = universal gas const

Sp. humidity $\omega = \frac{M_v}{M_a} \cdot \frac{P_v}{P_a} = \frac{18}{29} \frac{P_v}{P_a} = 0.622 \frac{P_v}{P_a} \rightarrow 0.622 \frac{P_v}{P_t - P_v}$; $P_v = \frac{P_a . \omega}{0.622}$ ★

$\frac{Vol}{m_a} = v_a$ $m_a = \frac{V}{v_a}$, $m_v = \frac{V}{v_v}$, $\omega = \frac{m_v}{m_a}$ by definition

$\frac{vol}{m_v} = v_v$ v_a, v_v are sp. volumes of dry air, water vapour

$\omega = \frac{v_a}{v_v}$ $m_a = \frac{V}{v_a}$, $m_v = \frac{V}{v_v}$, v_a, v_v = specific vol

Degree of saturation $\mu = \frac{\text{Mass of water vap per unit mass of dry air}}{\text{Mass of water vap per saturated unit mass of dry air}}$

(ω = sp. humidity, ω_s = sp. humidity when saturated).

$= \frac{\omega}{\omega_s}$.

Scanned with CamScanner

$$\mu = \frac{0.622\left(\frac{p_v}{p_t - p_v}\right)}{0.622\left(\frac{p_{vs}}{p_t - p_{vs}}\right)} = \frac{p_v}{p_{vs}} \frac{(p_t - p_{vs})}{(p_t - p_v)} = \left(\frac{p_v}{p_{vs}}\right)\left[\frac{1 - \frac{p_{vs}}{p_t}}{1 - \frac{p_v}{p_t}}\right]$$

RH = (ϕ) = Mass of water vap in given vol / Mass of " " in same vol ~~...~~ being saturated

$$\phi = \frac{m_v}{m_{vs}} = \frac{p_v \cdot V}{R_v \cdot T} \Big/ \frac{p_{vs} \cdot V}{R_v \cdot T} = \frac{p_v}{p_{vs}}, \quad p_v = \phi \cdot p_{vs}$$

$$\boxed{\phi = p_v / p_{vs}}$$

ϕ = RH = ratio of partial pr. of water vap in a given vol / Partial pr. of water vap when saturated.

By ~~...~~ substituting

$$\mu = \phi \left[\frac{1 - \frac{p_{vs}}{p_t}}{1 - \frac{p_v}{p_t}}\right] = \phi\left[\frac{1 - \frac{p_{vs}}{p_t}}{1 - \frac{\phi \cdot p_{vs}}{p_t}}\right]$$

$$= \phi\left[\frac{p_t - p_{vs}}{p_t - \phi \cdot p_{vs}}\right]$$

$p_{vs} << p_t$, so $\mu = \phi$, $\boxed{\phi = \frac{p_v}{p_{vs}}}$

$$\phi = \left(\frac{p_a \cdot w}{0.622}\right) \cdot \frac{1}{p_{vs}} = 1.6\, w \cdot \frac{p_a}{p_{vs}}$$

enthalpy of Moistair

$h = h_a + w \cdot h_v$ ie (enthalpy of dry air + enthalpy of vapour)

h_a = enthalpy of dry air (1kg)

$w \cdot h_v$ = enthalpy of water vap associated with 1kg of dry air.

$w = \frac{\text{mass of water vap in mixture}}{\text{mass of dry air in mixture}}$

Q) (4)

C_{pa} = sp. ht of dry air (1 KJ/kg K
C_{pw} = " water
T_{db} = DBT , T_{dp} = DPT
$(h_{fg})_{dp}$ = L.H. ~~at DPT~~ of vaporization at DPT
C_{pv} = sp. ht of superheated vap
C_{pw} = 4.18 KJ/kg K (Cp of water)
C_{pv} = 1.88 KJ/kg K (sp. ht of superheated vap)

$$h = C_{pa}(T_{db} - 0) + w[C_{pw} \cdot T_{dp} + (h_{fg})_{dp} + C_{pv}(T_{db} - T_{dp})]$$

ok

$$= 1(T_{db} - 0) + w[4.18\, T_{dp} + (h_{fg})_{dp} + 1.88(T_{db} - T_{dp})]$$

$$h = T_{db} + w[(h_{fg})_{dp} + 1.88\, T_{db} + 2.3\, T_{dp}]$$

$$= T_{db} + w[(h_{fg})_{dp} + 1.88\, T_{db}]$$

4.18
1.88
2.30

$$h = T_{db} + w[2500 + 1.88\, T_{db}] \text{ KJ/Kg of dry air.}$$

not reqd

$$h = T_{db} \times 1 + w(1.88\, T_{db}) + w[(h_{fg})_{dp} + 2.3\, T_{dp}]$$

$$= (1 + 1.88w)T_{db} + w[(h_{fg})_{dp} + 2.3 \cdot T_{dp}]$$

$$= C_{pma} \cdot T_{db} + w[(h_{fg})_{dp} + 2.3\, T_{dp}]$$

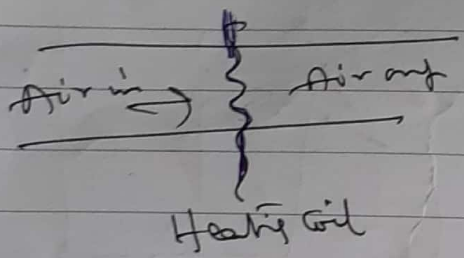
C_{pma} = Mean humid specific heat of air.
$1.88w << 1$
$C_{pma} = 1.01216$ KJ/kg K

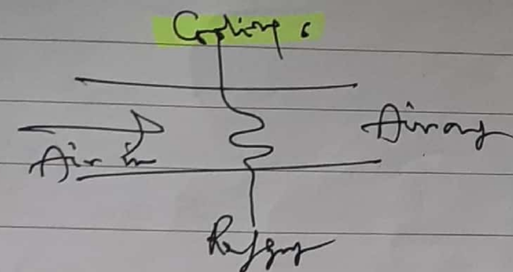
$$h = 1.0216\, T_{db} + w[(h_{fg})_{dp} + 2.3\, T_{dp}]$$

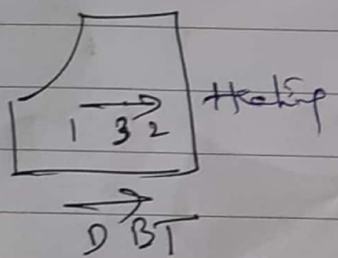
$P_a = 101325\ N/m^2$, barometric pr = 76 cm of Hg.
1 mm of Hg = 133.5 N/m², $m_a = \frac{(P_t - P_v)V}{RT}$

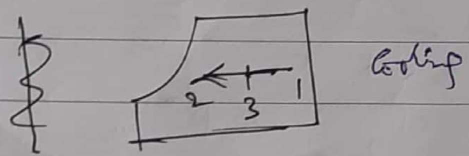
Psychrometric Processes

Sensible Heating





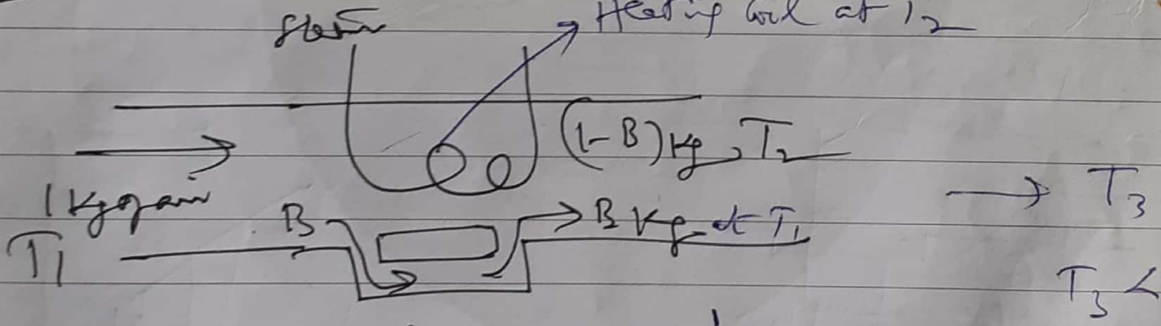




$Q_s = C_{pm}(T_2 - T_1)$

$C_{pm} = 1.0216$

By pass factor



$T_3 < T_2$

$B \cdot C_{pm} \cdot T_1 + (1-B) C_{pm} T_2 = 1 \times C_{pm}(T_3)$

$B \cdot T_1 + (1-B) T_2 = T_3$

$B T_1 + T_2 - B T_2 = T_3$

$T_2 - T_3 = B(T_2 - T_1)$

$$B = \frac{T_2 - T_3}{T_2 - T_1}$$

B = Bypass factor

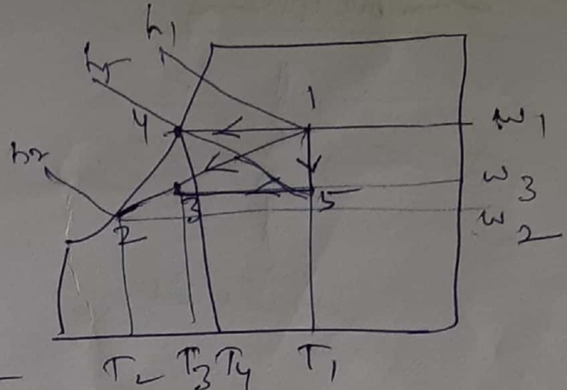
$$B = \frac{\text{Dist } 2\text{-}3}{\text{Dist } 2\text{-}1}$$ in the Psychro Chart

Cooling with dehumidification

T_1 = Temp of air entering coil

T_2 = Coil Surface Temp.

T_4 = Dewpt Temp of air.



$$B = \frac{h_3 - h_2}{h_1 - h_2} = \frac{w_3 - w_2}{w_1 - w_2} = \frac{T_3 - T_2}{T_1 - T_2}$$

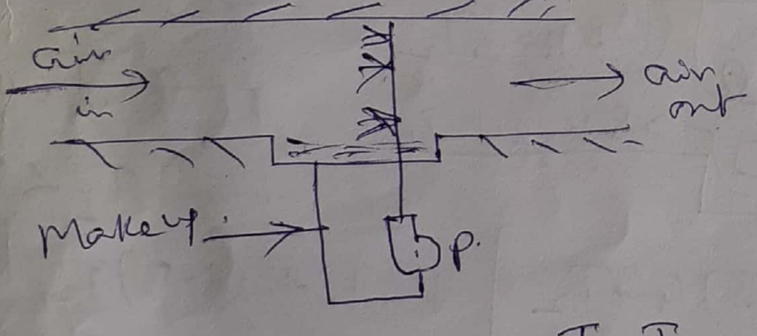
T_2 = ADP ∴ Apparatus dew pt.

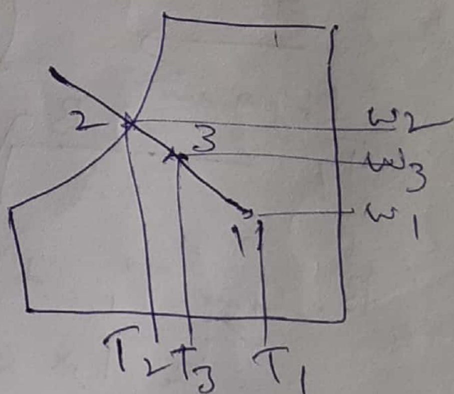
SHR.

$$SHR = \frac{Q_s}{Q_t} = \frac{Q_s}{Q_s + Q_L}$$

$$\text{Capacity in Tons} = \frac{\dot{m}_a (h_1 - h_3)}{3.5}$$

Cooling with adiabatic humidification

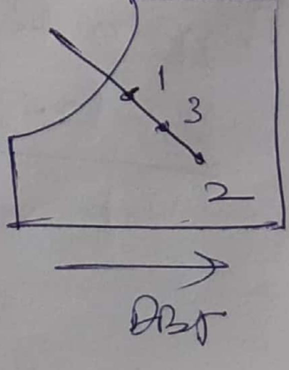




$$\varepsilon = \text{effectiveness} = \frac{T_1 - T_3}{T_1 - T_2}$$

Adiabatic chemical dehumidification

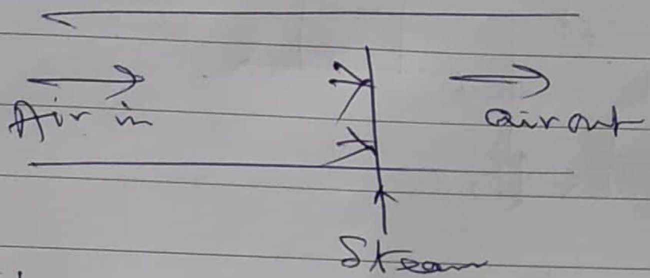
air is passed through Solid absorbent (Silica gel) or Liquid absorbent spray.

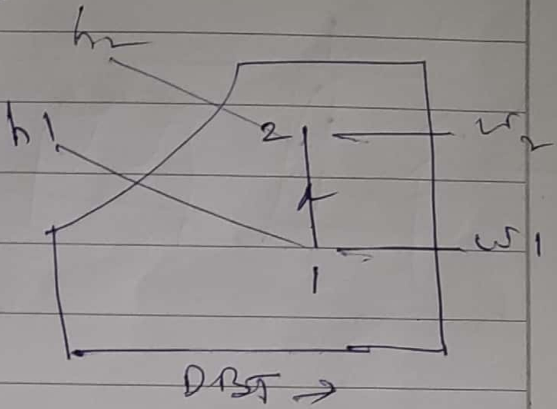


T_2 = Max^m possible temp.

$$\varepsilon = \frac{T_3 - T_1}{T_2 - T_1} = \frac{w_1 - w_3}{w_1 - w_2}$$

Humidification by Steam injection





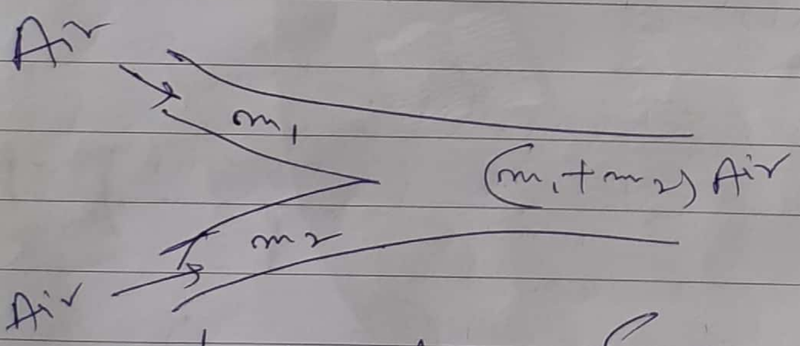
$h_2 = h_1 + m_s h_s$

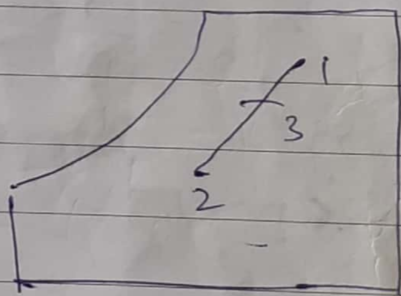
h_s = enthalpy of steam / kg of steam injected

$w_2 = w_1 + m_s$

m_s = qty of steam added per kg of dry air

Mixing of air stream





$m_1 h_1 + m_2 h_2 = (m_1 + m_2) h_3$

$m_1 w_1 + m_2 w_2 = (m_1 + m_2) w_3$

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{w_3 - w_2}{w_1 - w_3} = \frac{\text{dist } 2-3}{\text{dist } 3-1}$$

$\rightarrow m_1 (h_1 - h_3) = m_2 (h_3 - h_2)$

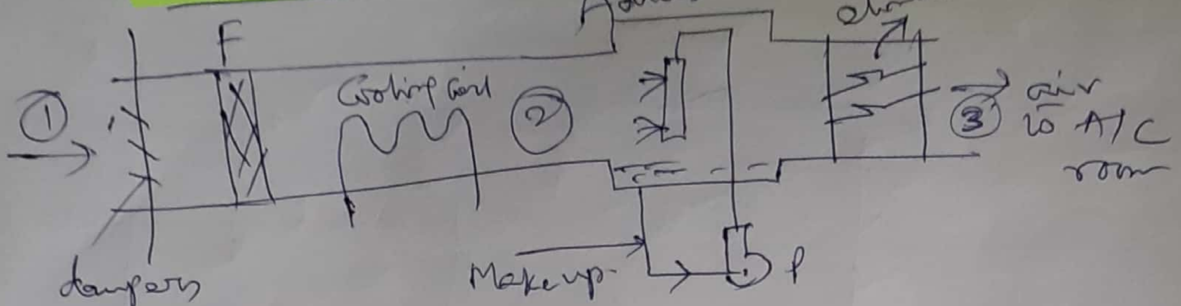
$\rightarrow m_1 (w_1 - w_3) = m_2 (w_3 - w_2)$

P.T.O

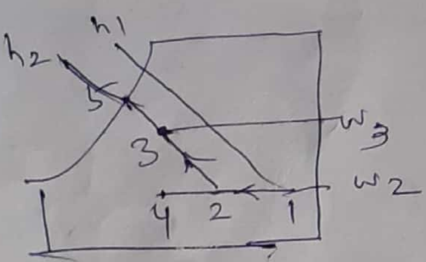
Q5

Summer A/C Systems

① For hot & dry out door Condition



1 = Atmospheric Condition
3 = Reqd room Condition



B of Cooling Coil

$$B = \frac{\text{Dist } 4-2}{\text{Dist } 4-1}$$

$$\eta_h = \frac{T_2 - T_3}{T_2 - T_5} \times 100.$$

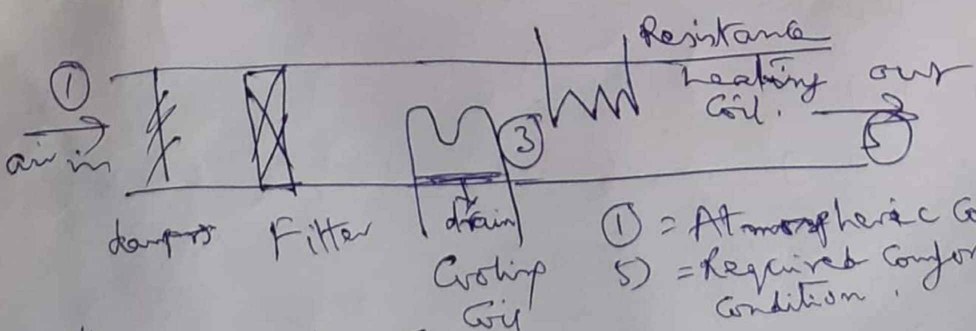
If V = qty of air supplied (cub.m /sec)

$$\text{Capacity of Cooling Coil} = \frac{V}{V_s}\left(\frac{h_2 - h_1}{3.5}\right) \text{ TR}$$

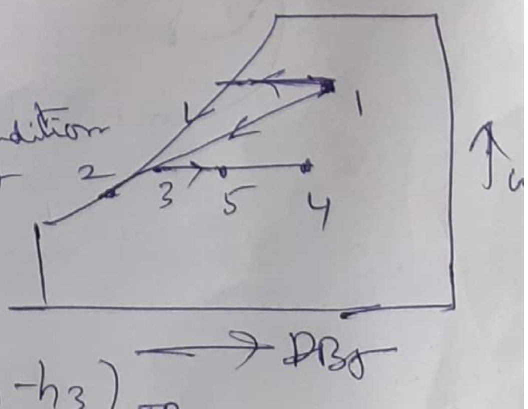
V_s = sp. vol.

$$\text{Capacity of humidifier} = \frac{V}{V_s}\left(\frac{w_3 - w_2}{1000}\right) \text{ kg/sec.}$$

② For hot & humid out door



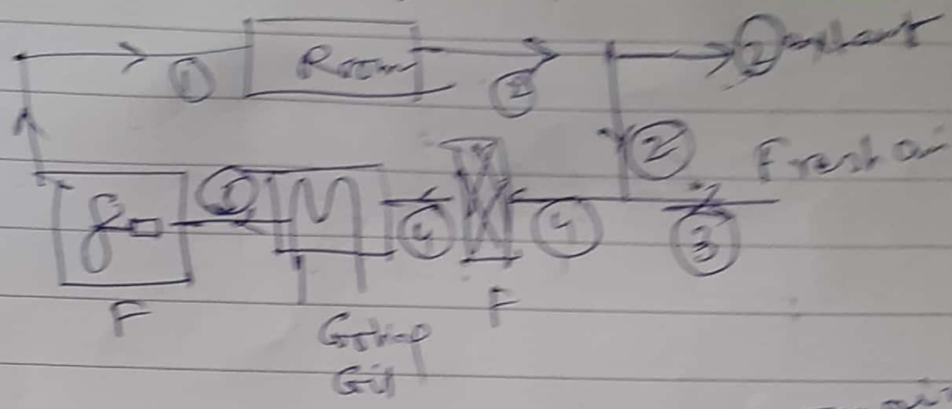
① = Atmospheric Condition
5) = Required Comfort Condition.

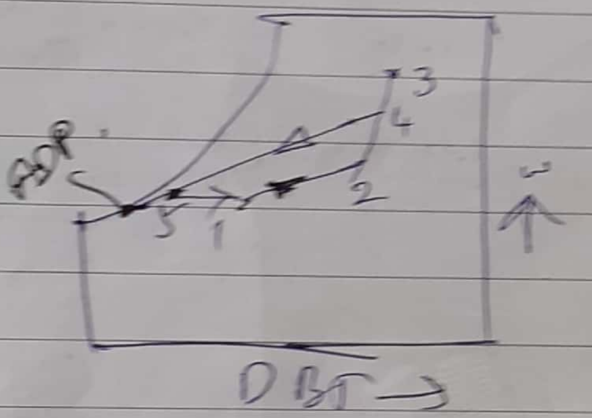


Cooling Coil $B_c = \dfrac{\text{dist } (2-3)}{\text{dist } 2-1}$, Capacity of Cooling Coil $= \dfrac{V}{V_s}\dfrac{(h_1 - h_3)}{3.5}$ TR

Heating Coil $B_h = \dfrac{\text{dist } 5-4}{\text{dist } 3-4}$, Capacity $= \dfrac{V}{V_s}(h_5 - h_3)$ KJ/sec

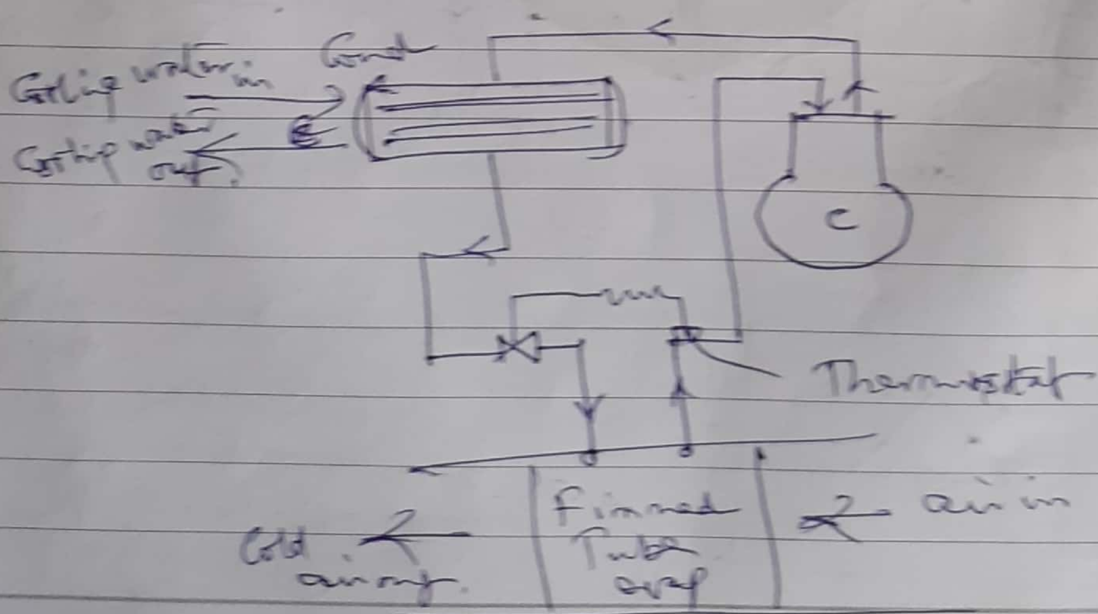
(3) Summer A/C with Single Cooling Coil & Mixing.



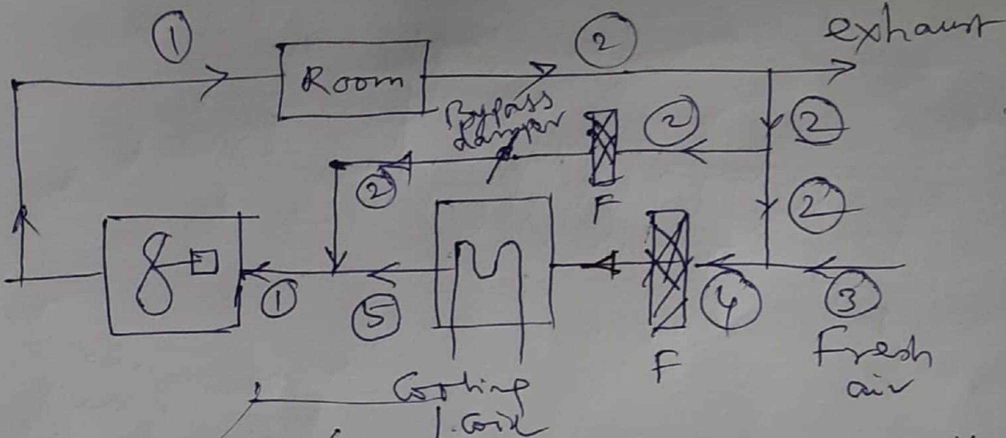


2 = room air
3 = Fresh air
4 = Mixed air
5 = Condition of air leaving Cooling coil
5-1 = Heating due to blower & friction
1-2 = load gaining in the room.

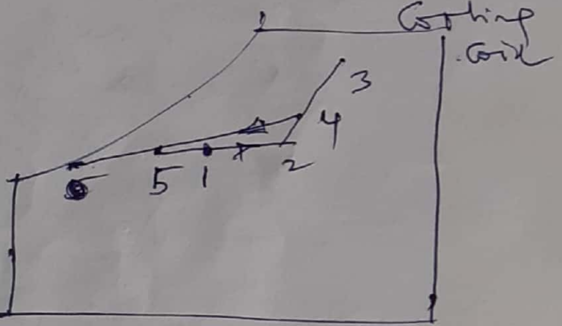
Direct Expan System for Cooling & dehumidifying. (only fig)



(4) Summer A/C with single Cooling Coil & Bypass Mixer



2 = room air out
3 = fresh air
4 = Mixture
4–5 = Cooling
2 = Bypassed air.

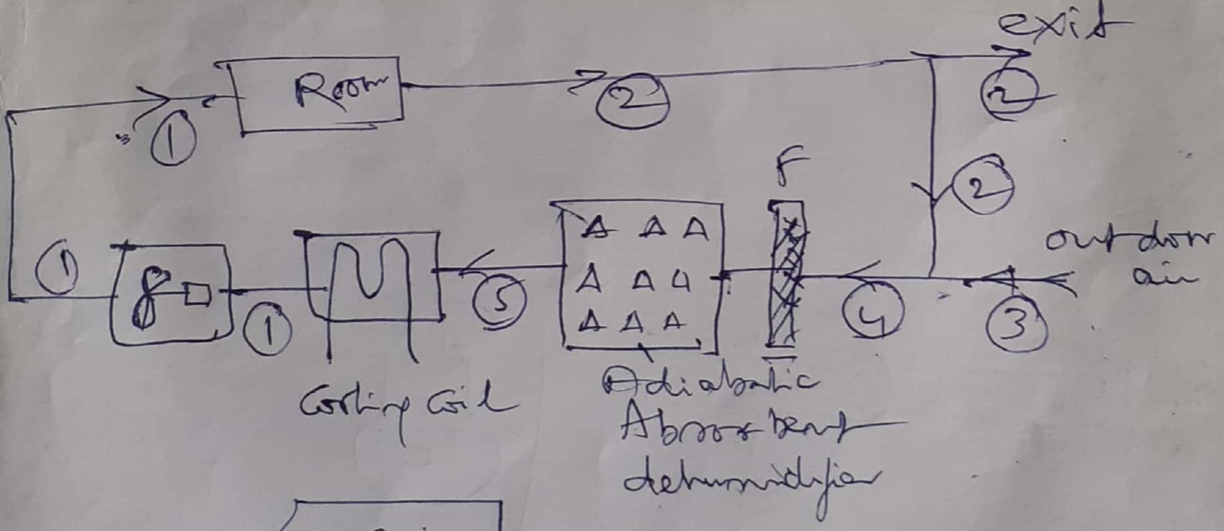


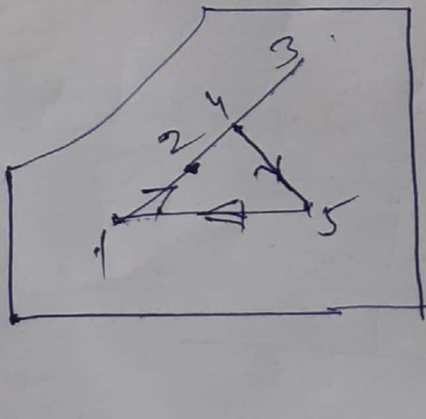
4 to 5 → Cooling & dehumidifying through Coil

1 to 2 → passes through room & takes load

1 = outlet after (5) & (2) bypass mixed.

(5) Summer A/C with Single Cooling Coil & Absorbent dehumidifier

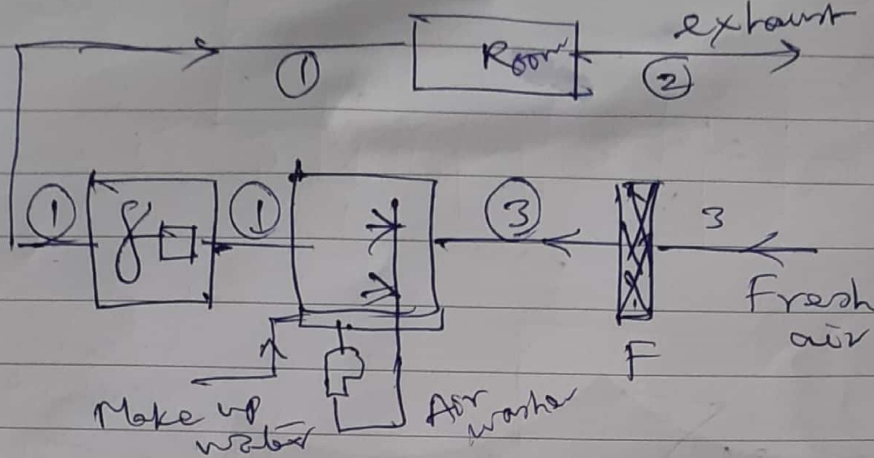




5 to 1 = Sensible Cooling.

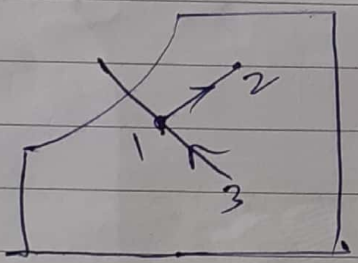
2 = room outlet
3 = outdoor air
4 = Mixture
4–5 = Adiabatic dehumidification
5–1 = Cooling.
1–2 = gaining load from room

6) Summer A/C with evaporative cooling.



less costly.

3 = fresh air
3 to 1 = evap cooling.
1 to 2 = gaining heat load from room

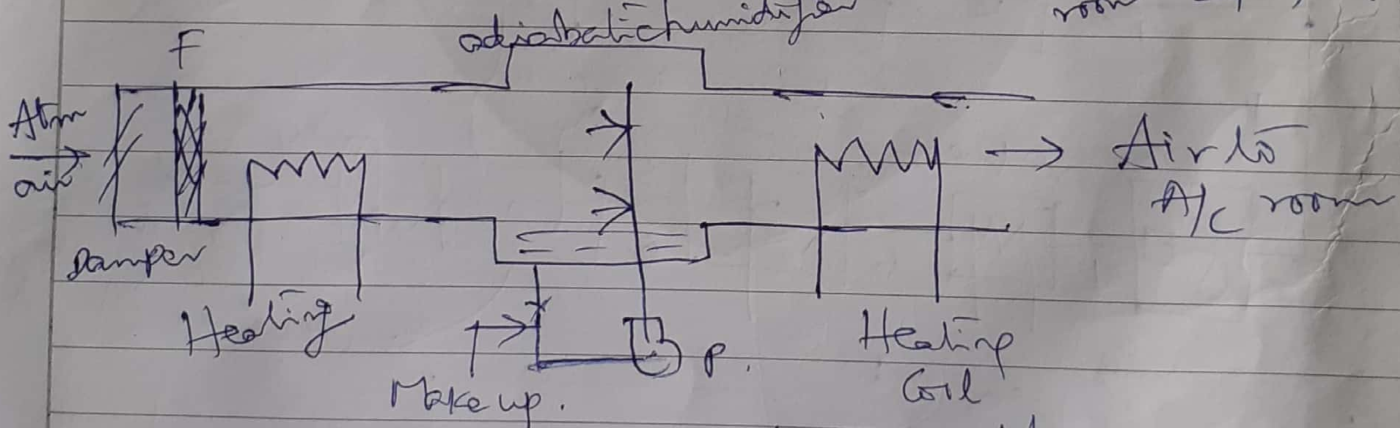


All fresh air.

Winter A/C system

1) For mild cold weather

winter 15°C, 80% RH
room 24°C, 60% RH



By pass preheating coil $= \frac{2-3 \text{ dist}}{1-3}$

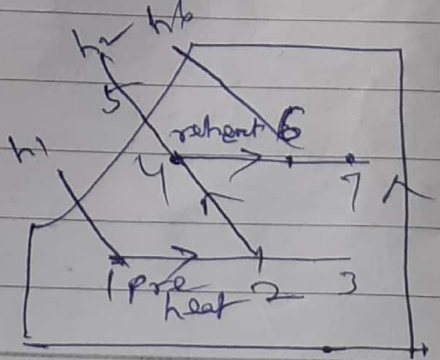
Bypass of reheating $= \frac{6-7}{4-7}$

$\eta_{humid} = \frac{2-4}{2-5} \times 100$

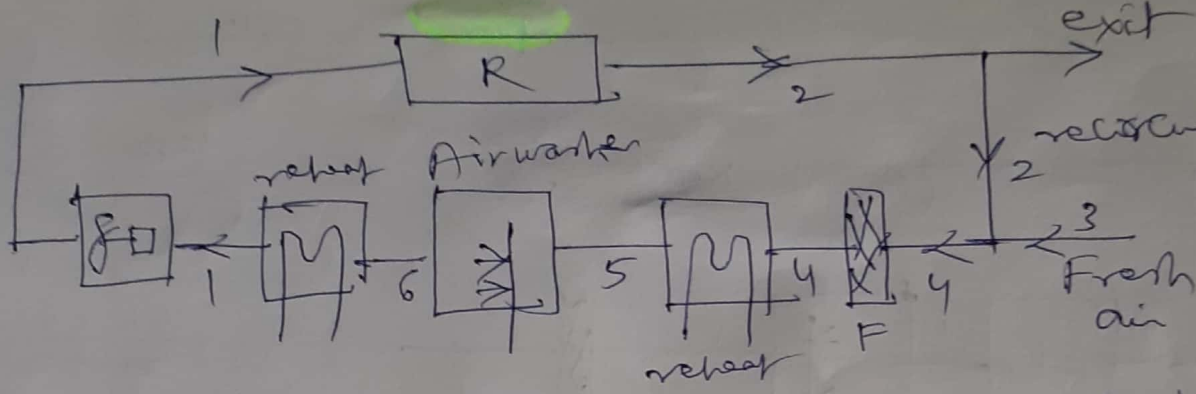
Capacity of preheat $= \frac{V}{v_s}(h_2 - h_1)$

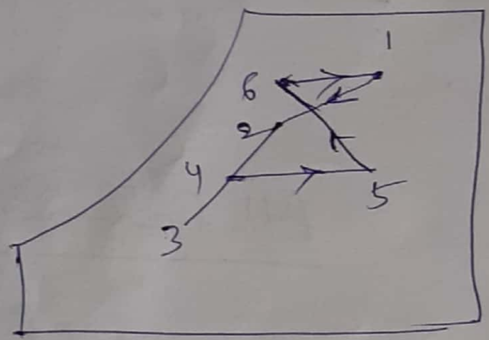
" reheat $= \frac{V}{v_s}(h_6 - h_4)$

" humidifier $= \frac{V}{v_s}\left(\frac{w_4 - w_2}{1000}\right)$ kg/sec



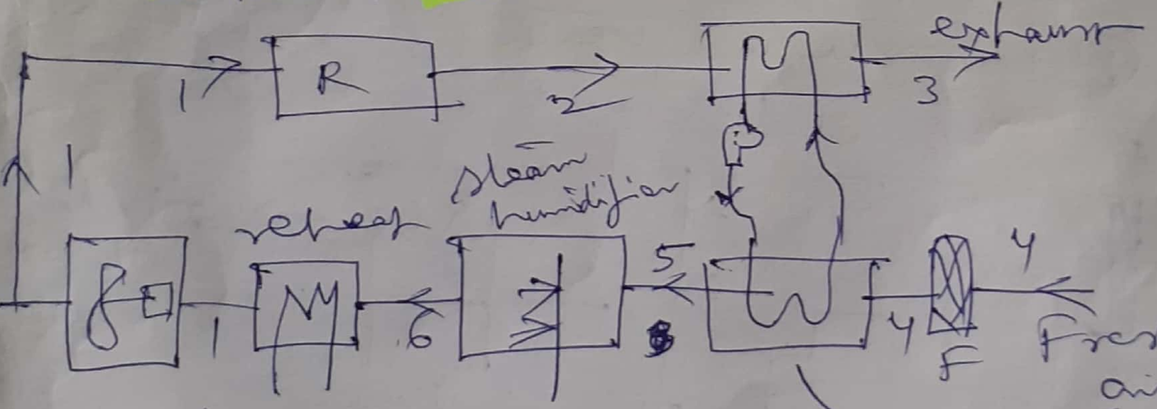
(2) winter A/C with double reheat coil & air washer





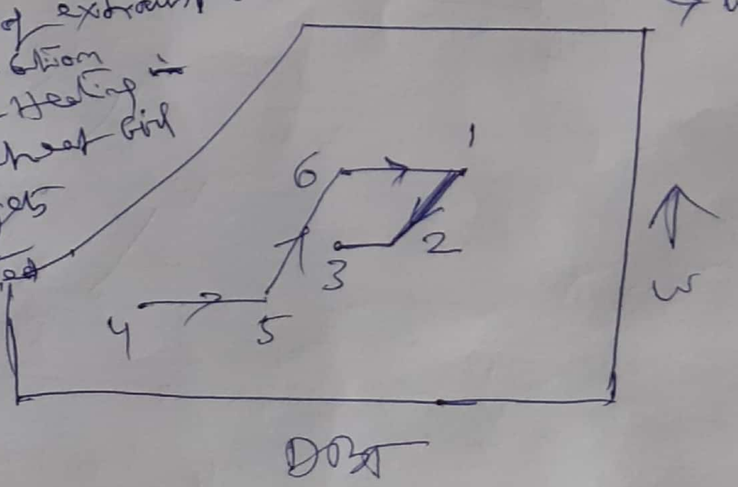
3 = fresh air
2 = recirculated air,
4 = Mixture,
4 to 5 = reheat
5 to 6 = adiabatic humidification
6 to 1 = reheat
1 to 2 = air becomes cooled & dehumidified

(3) winter A/C using 100% out door air with preheating by waste heat from exhaust air.

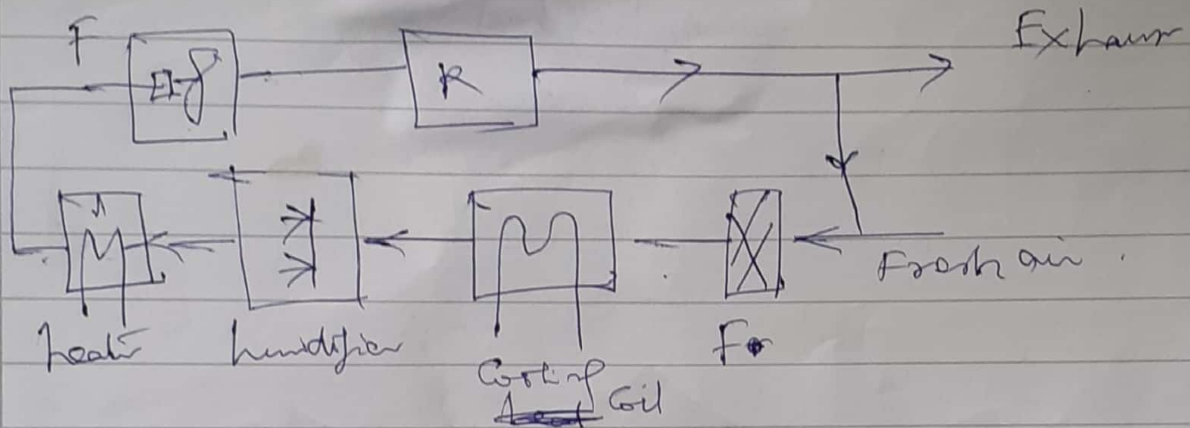


4-5 – Preheat
2-3 – Cooling of exhaust air
5-6 – Humidification
6-1 – Sensible Heating by reheat Coil
1-2 – air gets Cooled & dehumidified

3 = exhaust



year round A/C



with humidistat & thermostat controls.

Formulae

$$RH = \phi = \frac{P_v}{P_{vs}} = 1.6 \cdot w \cdot \frac{P_a}{P_{vs}}$$

$$w = \frac{0.622 P_v}{P_t - P_v} \text{ kg/kg of dry air}$$

$$h_a = \left[T_{db} + w(2500 + 1.88 T_{db})\right] \text{ KJ/kg of dry air}$$

$P_a = 101325 \text{ N/m}^2$ barometer reads $= 76$ cm of Hg

$1 \text{ mm of Hg} = 133.5 \text{ N/m}^2$

$$m_a = \frac{(P_t - P_v)V}{RT}$$

Prob 16.1, 16.2, 16.4, 16.10, 16.23, 16.25, 16)

Requirements of Comfort A/c

Requirements of Comfort A/c

1) Supply of O_2, removal of CO_2
2) Removal of body heat dissipated by occupants
3) " " moisture " "
4) Sufficient Air movement, & distribution.
5) Purity of air by removing odour & dust.

1) **Oxygen supply** :- Human body requires O_2 to sustain combustion (food digestion), & dissipates CO_2.

2) **Heat removal** :- Human body can be considered like an engine which converts thermal energy into mechanical work & remaining amount of heat is dissipated to atmosphere.

When man is not doing any external work, still he does sufficient internal work as pumping of blood through body & muscular work required for respiration.

3) **Moisture removal** :- As air humidity increases, the human body's ability to dispose of heat by evaporation of sweat decreases.

4). **Air motion** :-

Increased velocity reduces the thickness of the layer of the saturated vapour near the body surface & helps for evaporation.

5) **Purity of air** :-

odour, dust, toxic gases & bacteria limits are considered for purity of air.

Biological requirement of the air supplied for Comfort A/c

Now a days as more time is spent indoors in the corporate offices & elegant buildings; indoor air quality is very important. Contamination of indoor air happens by growth of bacteria, fungi, mold, viruses & mildews (collectively termed micro organisms) spread through circulation of exhaled air, as well as food material etc.

Condensate drain pan is a major source for such micro organisms. Care is to be taken

Outdoor environment

1) Climatic factors :- Radiation, temp, Humidity wind velocity, evaporation rate effect the outdoor environment

2) Edaphic factors : Type of soil & soil conditions like soil Temp., Minerals, etc

3) Biotic factors :-
Human beings, & animals – Their habits, life style, Food habits, population etc

Prime factors that affect the indoor environment are
human population & density, working area, degree of ventilation, Hygienic conditions of occupants etc.

Indoor parameters

ASHRAE defines the parameters to be considered for indoor environment

1) Indoor air Temp (IAT) &
   Mean Radiant Temp (MRT)
2) Indoor R.H (IRH)
3) outdoor ventilation rate provided
4) Air cleanliness 5) air path, movement
6) Sound level.

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The following are to be considered.
Dust, Smoke, Fumes, Fog, Mist,
Microbes, Bacteria, Fungal Spores.

Air Purification Methods

Air filters.

1) High efficient Particulate Air Filters (HEPA)
Made of glass Fibres & ~~[illegible]~~ formed into pleated paper mats.
2) Ultra low penetration Air Filters (ULPA)
Similar to HEPA but more efficient.
3) Activated Carbon Filters.
odours & vapours are adsorbed.
4) Plasma Air Purifier:-
Smallest germs, bacteria, odours, microbes, viruses are removed easily.
Life Time use.

Thermodynamics of Human body:

The phenomena of heat loss from the body can be represented by the following eqn

$H_m - W = H_e \pm H_c \pm H_r \pm H_s$.

H_m = Metabolic Heat produced in the body
W = useful rate of working
$H_m - W$ = Heat to be dissipated
H_e = Heat lost by evaporation
H_c = Heat lost or gained by convection
H_r = Heat lost or gained by radiation
H_s = Heat ~~lost in~~ stored in the body.

H_m depends on food consumption.

$H_c = UA(T_b - T_a)$

U = overall heat tr coeff on body surface
A = Body surface area = 1.8 m²
T_b = body surface Temp. T_a = air Temp.

$H_r = \sigma (T_b^4 - T_a^4)$.

Role of Clothing:

Hot climate — loose, thin fittings, white, light colours.

humid & hot climate — light, porous, loose fittings.

Body Temp = 37°C.

Body Temp ≯ 40.5°C, ≮ 36.5° — dangerous.

Body mechanism tries to keep body at 37°C.

He, Hc, Hr dependent on environment conditions like DBT, RH, Air velocity.

Rate of heat gain from occupants in A/c Space

Activity	Application	SHL KJ/hr	LHL KJ/hr	Total Heat load
Seated at rest	Theatre	210	160	370
Heavy work	Blowing Factory	480	1070	1550

Increase in LHL is more pronounced when metabolic rate increases.

Body defense

Human control systems to keep body at 37°C.

1) **Vasomotor control**: — By this the blood supply to skin is controlled. The convective heat transfer is controlled

2) **Sudomotor control**: Sweat production is regulated.

When heat loss by radiation & convection becomes negative, only mode of heat for to dissipate is by ...

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efficiency of performance decreases with increase in ambient Temp.
Important variables are air Temp, mean radiant Temp, air vel, humidity, activity level, thermal resistance of clothing.

effect of heat on work performance

After exposure to extreme heat & work, loss of consciousness occurs.
Heat exhaustion :- Shortage of water in the body & Salt deficiency.
dryness of mouth, giddyness, etc.
Heat Stroke occurs suddenly when body temp rises above 40.5°C & is accompanied by loss of consciousness.

i) Heat exhaustion — fatigue
ii) Heat syncope — For sun, man becomes pale, B.P. falls & he collapses but recovers within 5 to 10'. if he is made to lie in shade.
iii) Heat Cramp or Shock —
experiences pain in calf & thigh muscles. (Cramps). Muscular weakness occurs.
iv) Heat stroke — delirium, convulsion. Can be fatal. To be taken to Hospital

Comfort & Comfort Chart

Feeling of comfort depends on many factors. habits of eating, clothing, duration of stay, age, rate of activity etc.
It defers from individual to individual.

ASHRAE made exhaustive lists on differing kinds of people subjected to wide variations in Temp, RH, air motion.

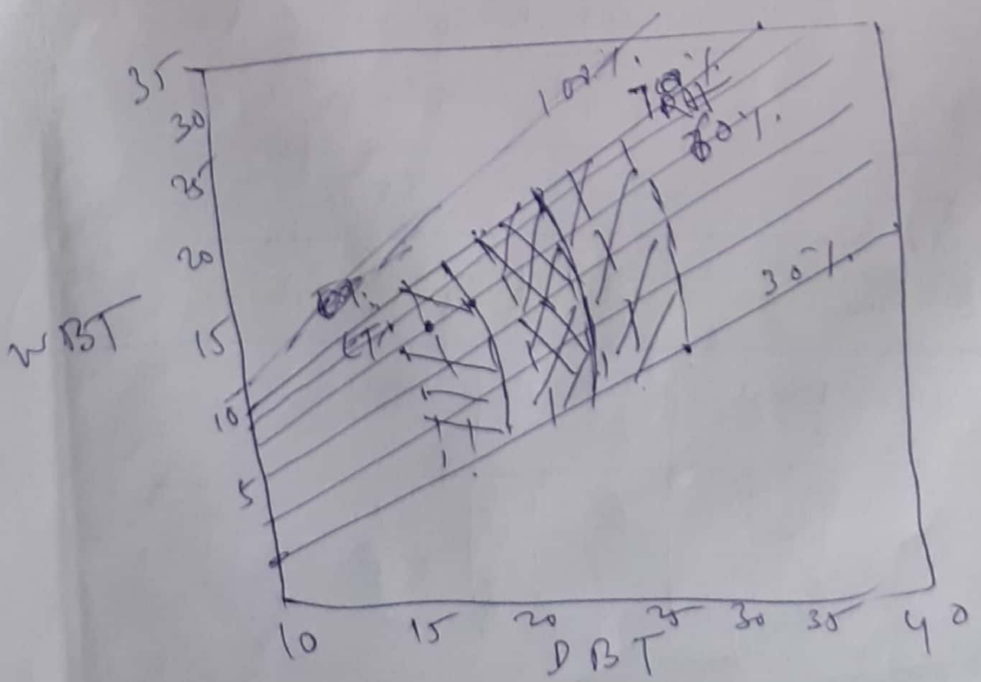
Effective Temp:

Table I

DBT	RH	% of people feeling comfort	ET
21	100%	90%	21
23	88%		
25	76%		
27	64%		
29	52%		

Table II

DBT	RH	% of people feeling comfort	E.T
25	100	80%	25
27	90		
29	80		
31	70%		
32	60%		



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Combinations of DBT & RH in Table 1 carries the same qty of heat from body. Then 21°C at 100% RH is the E.T. Similarly at Table 2, 25°C is the E.T

Finally comfort zone is 20 to 25 DBT & 30 to 70% RH.

A/c design calculation & Tables

Desirable inside design condition for diff buildings (Summer A/c)

Type of bldg		DBT	RH
Residences	living room	20-30	55 to 65%
	others	15-20	"
Factories	Heavy work	15	50%
Restaurants		26°C	50%

Desirable condition for industrial purpose

Ind	DBT	RH
Brewing	5-10	30-50
Printing	20-30	45-80
Leather	32-50	95%

Outside summer design conditions

City	DBT	WBT	RH
Hyd	39.5	26.6	37
Bombay	32.8	26.7	64
Puri	32	27.8	75

Recommended inside conditions for Summer.

outside DBT	occupancy over 40+ minutes				occupancy below 40 minutes			
	DBT	WBT	RH	ET	DBT	WBT	RH	ET
26.5	23.8	18.3	60	21.7	24.4	18.9	61	22.2
	25	17.2	47	21.7	25.6	17.8	47	22.2
	26	16.2	35	21.7	26.6	16.6	36	22.2

Ventilation study

Application	Smoking	Air in m^3/person/min Rec	Minimum
Apartment	Some	0.54	0.4
Bars	Heavy	0.81	0.68
Hospital (operation room)	None	1.2	1.0

Probable bldg air changes by natural effects/hr.

bldg	winter Min	winter Max	Summer Min	Summer Max
Shops	1/2	1	1/2	1
Factory	1/2	2	2	2

on the basis of floor area

0.015 to 1.2 cum/m^2/min.

depending on Application