Fundamental Design Requirements of HVAC System for Buildings

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1. What is HVAC Systems

1.1 HVAC System

- Air conditioning is the generic terms that people impressed to provide cooling to a place in achieving a comfort environment.

- Heating, Ventilation and Air Conditioning (HVAC) is a more suitable terms for representing the system being provided.

- The following figure is showing a typical HVAC system in a residential unit:
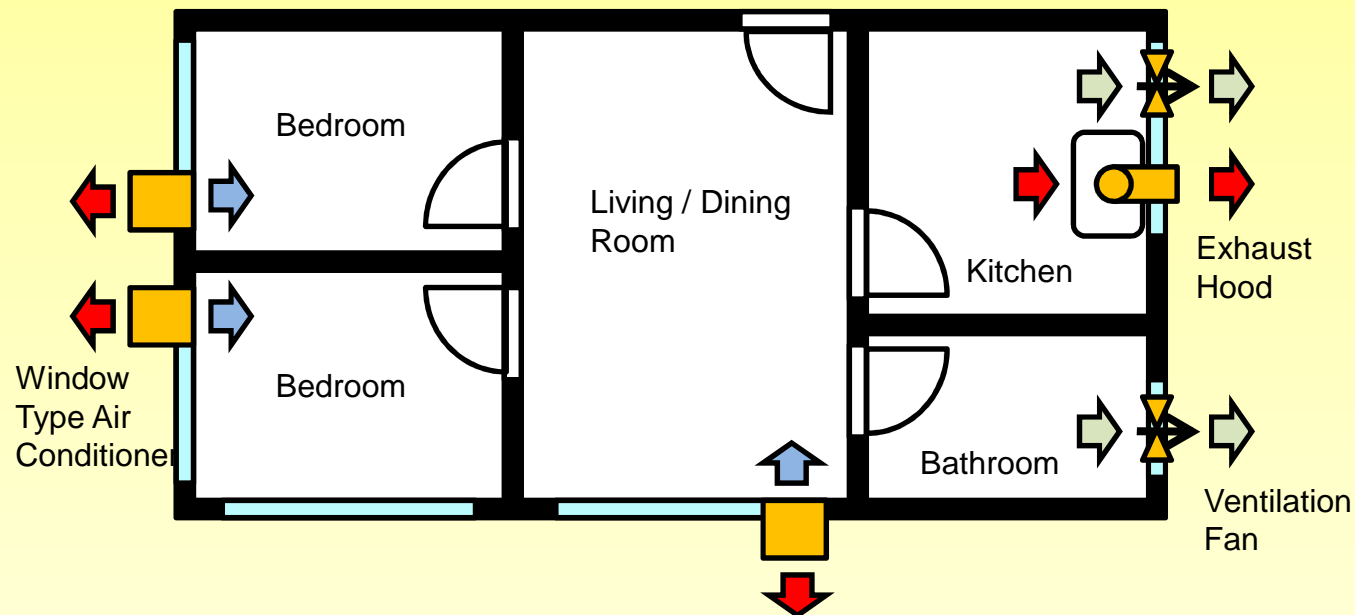
1. What is HVAC Systems

1.1 HVAC System

- The HVAC system in the residential unit composed of

  a) Mechanical ventilation for Bath Room and Kitchen for moisture and odours removal.

  b) Exhaust hood over the cooker inside Kitchen for heat and pollutant removal.

  c) Air-conditioners for Living / Dining Room and Bedrooms.

- This shows how comprehensive of the HVAC system covers.

1. What is HVAC Systems

1.2 Design Criteria

Typical design conditions adopted in Hong Kong are

Location

Latitude	22°18'N
Longitude	114°10'E

Outdoor Design Conditions

Summer	33°C Dry Bulb and 92% RH
Winter	7°C Dry Bulb and unspecified RH

Indoor Design Conditions

Summer	24°C Dry Bulb and 55% RH
Winter	20°C Dry Bulb

1. What is HVAC Systems

1.2   Design Criteria

Typical design conditions adopted in Hong Kong are

Noise Criteria

    Office   NC-40

Fresh Air Supply

    5 – 10L/s-person

Chilled Water Temperature

    Supply / Return   7°C / 12 °C   [5°C ΔT]
    Supply / Return   6.5°C / 12.5 °C   [6°C ΔT]

1. What is HVAC Systems

1.3   Unit

Unit for Air Conditioning Capacity

- Tonnage (Ton)

- Kilo Watt (kW)

- British Thermal Unit (BTU)

- Horse Power (HP)

- Units Conversion

    1 Ton   = 3.52kW   = 12,000BTU

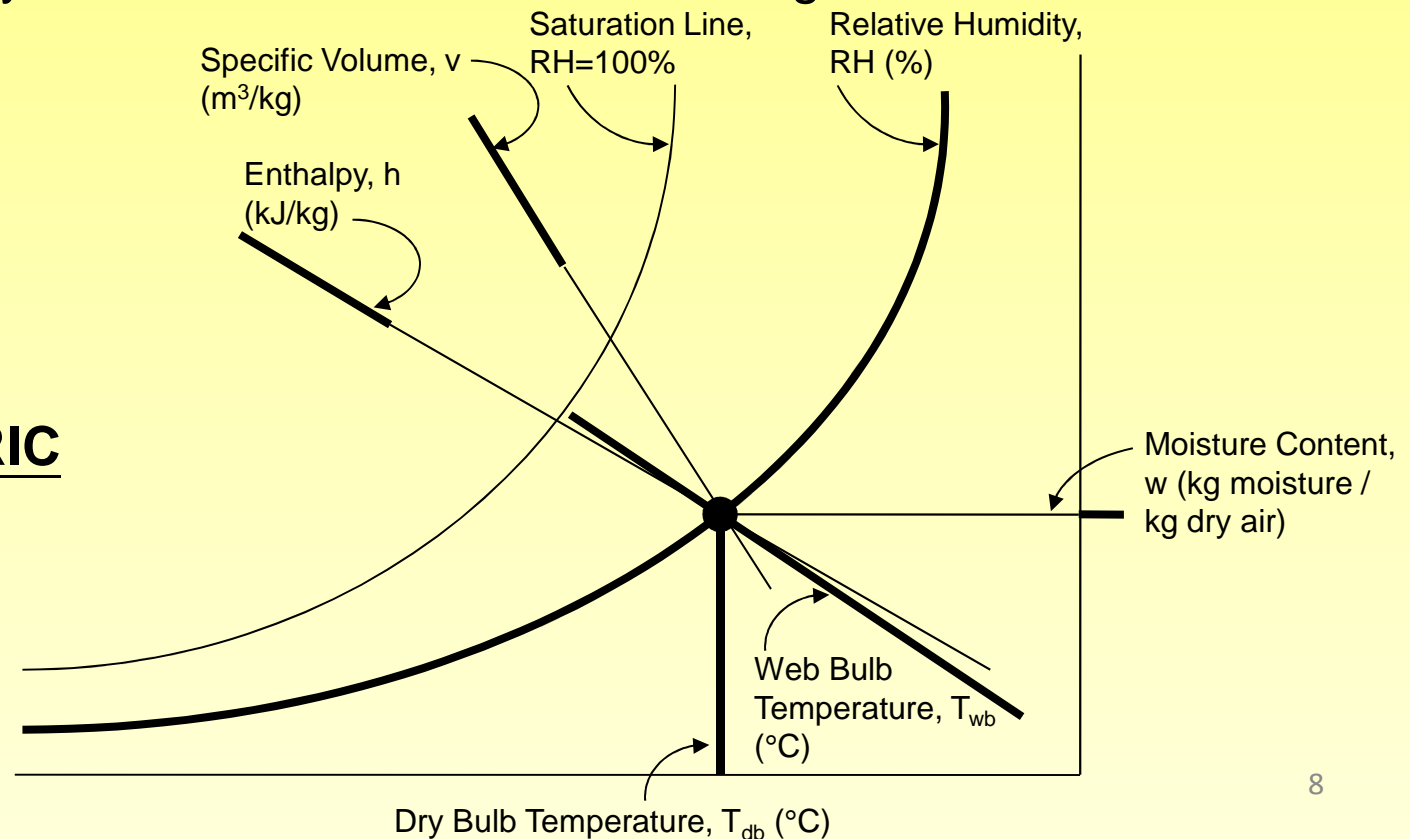   1 HP $\cong$ 9,000BTU

1. What is HVAC Systems

1.4 Psychrometry and Psychrometric Chart

- Psychrometry is analyzing the state of air-moisture mixture in an air conditioning process takes place or a physical change occurs.

- Psychrometric chart gives the state conditions of air-moisture mixture if one know any two conditions that the remaining can be determined graphically.

Specific Volume, v (m^3/kg)

Saturation Line, RH=100%

Relative Humidity, RH (%)

Enthalpy, h (kJ/kg)

PSYCHROMETRIC CHART

Moisture Content, w (kg moisture / kg dry air)

Web Bulb Temperature, T$_{wb}$ (°C)

Dry Bulb Temperature, T$_{db}$ (°C)

1. What is HVAC Systems

1.5 Sensible Cooling or Heating

- Sensible cooling, process from 1 to 2 that the cooling coil temperature must be smaller than the air stream dew point temperature that no condensation takes place.

Cooling / Heating Coil

- Sensible heating, process from 2 to 1.

- In both cases, moisture content remain unchanged.
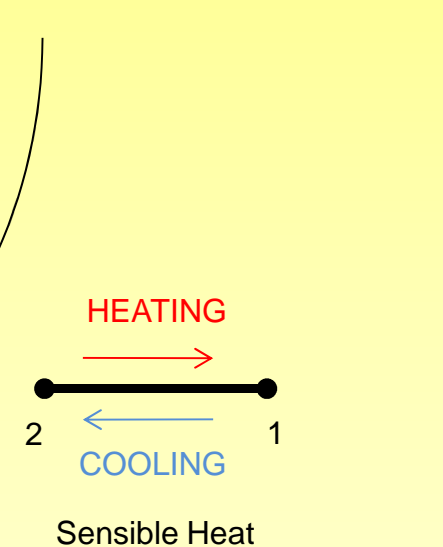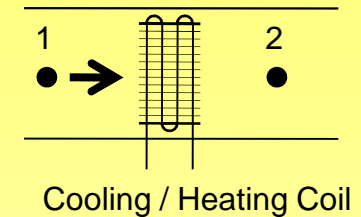
    $$w_1 = w_2$$

- Only sensible heat transfer takes place.

    $$Q = m_a C_{pa}(T_1 - T_2)$$

where,

m_a is mass flow rate of air (kg/s)

C_{pa} is specific heat of air (kJ/kgK)

HEATING

COOLING

Sensible Heat
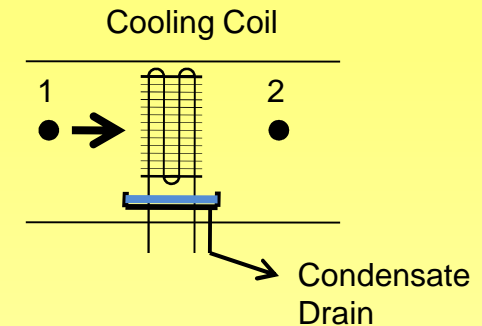
1. What is HVAC Systems

1.6   Cooling and Dehumidification

- Process from 1 to 2 is the arbitrary line for cooling and dehumidification take place.

- In reality, air stream will undergo a sensible cooling from point 1 to 1' and then followed by cooling and dehumidification processes from point 1' to 2.

- Theoretically, point 2 should rest on line with RH=100% if perfect mixing takes place that air will be treated to homogenous temperature.

- In reality, when air stream pass through the cooling coil, it is reasonable to assume the off-coil condition is RH=95%

Cooling Coil

1 → 2

Condensate Drain

1'

COOLING

1

Latent Heat

COOLING & DEHUMIDIFICATION

2

Sensible Heat
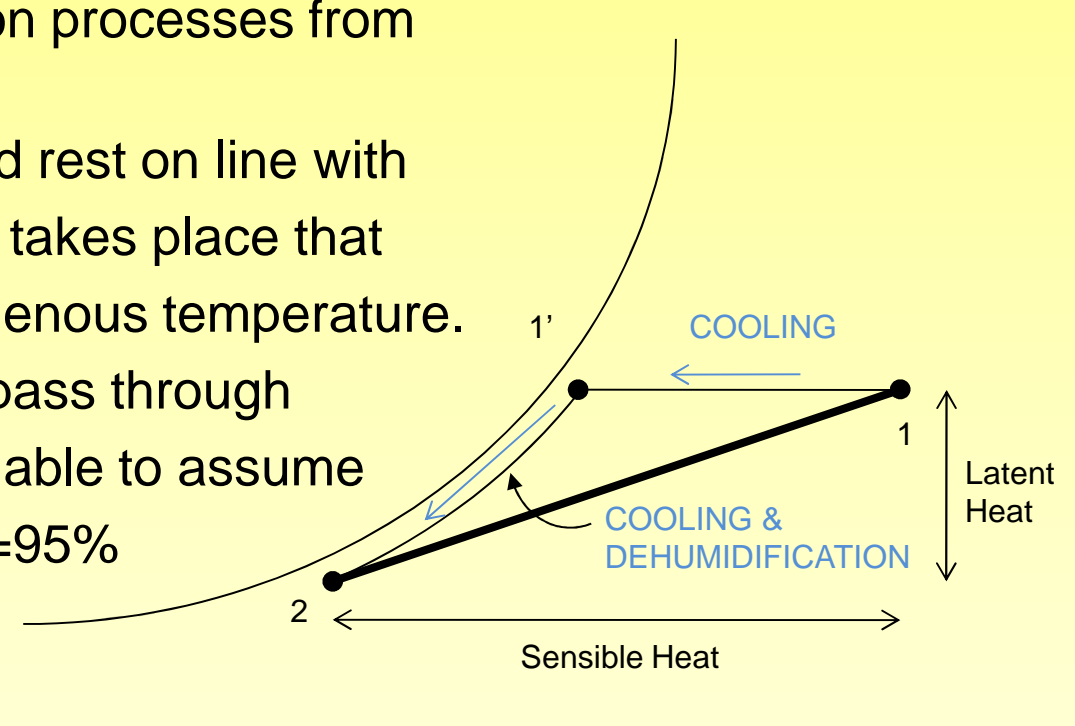
1. What is HVAC Systems

1.7 Humidification

- Water spray into the air stream directly and the process following the constant web bulb temperature line provided that it is an adiabatic process.

$$T_{wb1} = T_{wb2}$$

- The change in enthalpy from point 1 to 2 is small and negligible.

Water Mist Sprayer

1   2

Circulation
Pump

h_2

2

h_1

HUMIDIFICATION

1

Constant Web Bulb
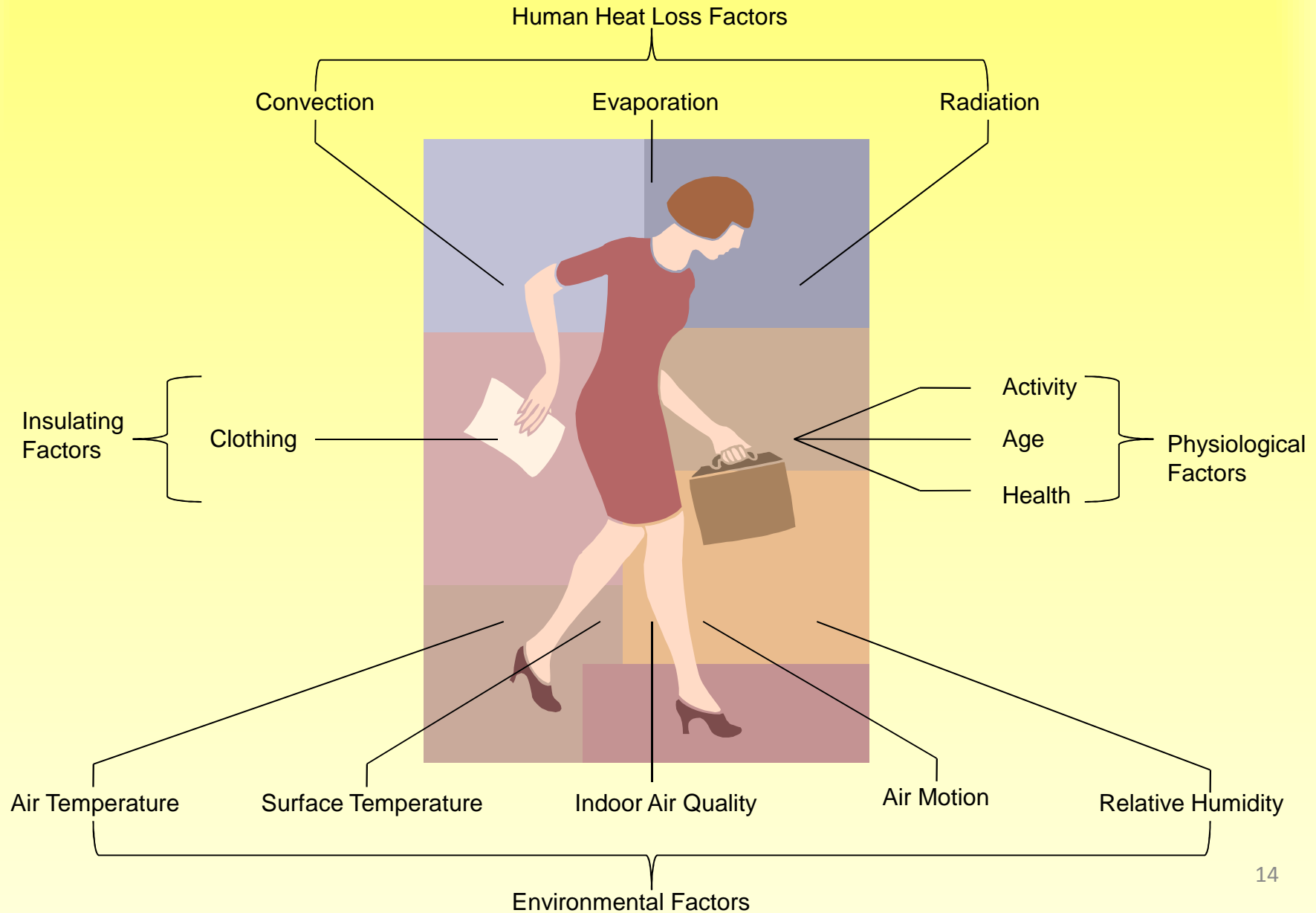Temperature
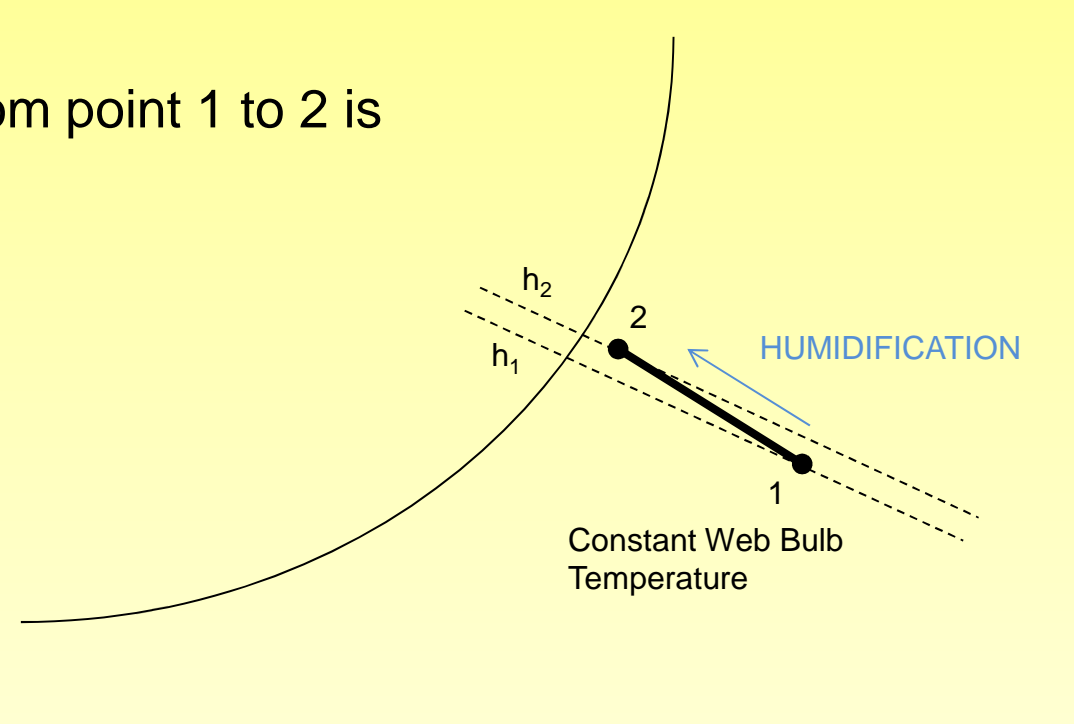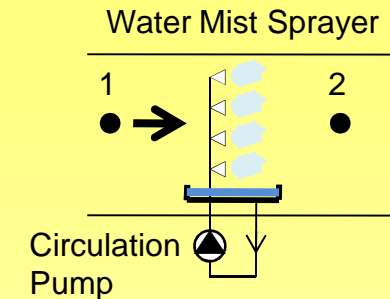
1. What is HVAC Systems

1.8 Ventilation

- To dilute the pollutant concentration within the space at desired level.

- The design condition normally base on the pollutant concentration for system design.

- Outdoor pollutant concentration will be used as the reference level for design provided that it must be lower than the indoor design condition otherwise dilution cannot be achieved and air treatment is further required.

1. What is HVAC Systems

1.9 Air Filtration

- When ventilation system cannot achieve the design concentration of pollutant in space by means of dilution, filtration equipment shall be employed to achieve the design requirements.

- It involves physical removal of pollutant in the air stream supplied into the space.

- Sometimes, it will be assisted by additional equipment to increase the filtration efficiency.

- System pressure drop is a prime concern on filter selection that could lead to impose high capital and operating cost.

2. Thermal Comfort

Human Heat Loss Factors

Convection   Evaporation   Radiation

Insulating Factors   Clothing

Activity

Age

Health

Physiological Factors

Air Temperature   Surface Temperature   Indoor Air Quality   Air Motion   Relative Humidity

Environmental Factors

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2. Thermal Comfort

2.1 Metabolism

- Metabolism is a process which the body uses to convert energy in food into heat and work.

- A person can convert food energy into work with an efficiency as high as 15 to 20% for a short period and for light activity can be of the order of 1%.

- The steady-state heat balance of heat energy produced by metabolism of a body is expressed by:

    $$M = E + R + C + B + S$$

  where,

  M is metabolism rate (W)

  E is heat loss by evaporation (W)

  R is heat transfer by radiation (W)

  C is heat transfer by convection (W)

  B is heat loss by respiration (W)

  S is rate of change of heat storage in body (W)

2. Thermal Comfort

2.1 Metabolism

- For a normally clothed, healthy human being in a comfortable environment and engaged in general activity, S is zero and the thermo-regulatory system of a body is able to modify R and C to maintain a stable and satisfactory temperature.

- Total heat rejection rate of a body (Q_{people} = E + R + C + B) in a conditioned space is ranging from 120W to 440W for light to vigorous activities respectively.

2. Thermal Comfort

2.2 Clothing

- The loss of heat from the body and his comfort in a given environment is much affected by the clothing worn.

- In a room with mixed population of men and women wearing different cloth, comfort for everyone may be almost impossible to achieve.

- The cloth worn by people will have a seasonal pattern that less thermal insulation value will be worn in summer.

- The unit used to describe the thermal insulating quality if the clothing worn is "clo" and has a physical value of $0.155 m^2 K/W$

- The clo-value for men and women can be determined by:

    clo-value(men) $= 0.727\Sigma(\text{individual clo-value}) + 0.113$
    clo-value (women) $= 0.770\Sigma(\text{individual clo-value}) + 0.050$

2. Thermal Comfort

2.2 Clothing

- Thermal resistances of some typical clothing

Men	clo	Women	clo
Sleeveless singlet	0.06	Bra and pants	0.05
T-shirt	0.09	Half slip	0.13
Underpants	0.05	Full slip	0.19
Shirt, light-weight, short sleeves	0.14	Blouse, light-weight	0.20
		Blouse, heavy-weight	0.29
Shirt, light-weight, long sleeves	0.22	Dress, light-weight	0.22
		Dress, heavy-weight	0.70
Waistcoat, light-weight	0.15	Skirt, light-weight	0.10
Waistcoat, heavy-weight	0.29	Skirt, heavy-weight	0.22
Trousers, light-weight	0.26	Slacks, light-weight	0.26
Trousers, heavy-weight	0.32	Slacks, heavy-weight	0.44
Sweater, light-weight	0.20	Sweater, light-weight	0.17
Sweater, heavy-weight	0.37	Sweater, heavy-weight	0.37
Jacket, light-weight	0.22	Jacket, light-weight	0.17
Jacket, heavy-weight	0.49	Jacket, heavy-weight	0.37
Ankle socks	0.04	Stockings or tights	0.01
Knee socks	0.10	Sandals	0.02
Shoes	0.04	Shoes	0.04
Boots	0.08	Boots	0.08

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2. Thermal Comfort

2.2 Clothing

- Average clothing for man and woman is about 0.9 and 0.7 respectively.

- It proves of achieving the satisfactory conditions of comfort for an air conditioned room with mixed population is difficult.

- The comfort of a clothed individual corresponds to a decrease of 0.5°C in dry-bulb temperature for each clothing increase of 0.1clo but this can only be true over a limited range of temperature.

2. Thermal Comfort

2.3 Environmental Influences

- Body maintains a thermal equilibrium with the environment by three modes of heat exchanges involving approximately 25% by evaporation, 45% by radiation and 30% by convection.

- There are four properties of the environment that influence comfort by modifying the contribution of the three mode of heat transfer in a body:

  a) Air dry bulb temperature –

  Affecting evaporation and convection.

  b) Relative humidity –

  Affecting evaporation.

  c) Air velocity –

  Affecting evaporation and convection.

  d) Surface temperature –

  Affecting radiation only.

2. Thermal Comfort

2.3   Environmental Influences

Air Pollutants

- Air pollution may be defined as the presence in the space of substance(s) added directly or indirectly in such amounts as to affect living and non-living things adversely.

- What is classified as a pollutant therefore depends upon recognition of which substances cause adverse effects. It is an ever-changing definition.

- Centuries ago only soot or odoured gases may have been considered air pollutant. Now we recognize that pollutants can cause more subtle effects than producing unpleasants smells. Even CO_2 is now considered a pollutant.

- CO_2 is the space with concentration normally maintained at level not exceeding 0.1%
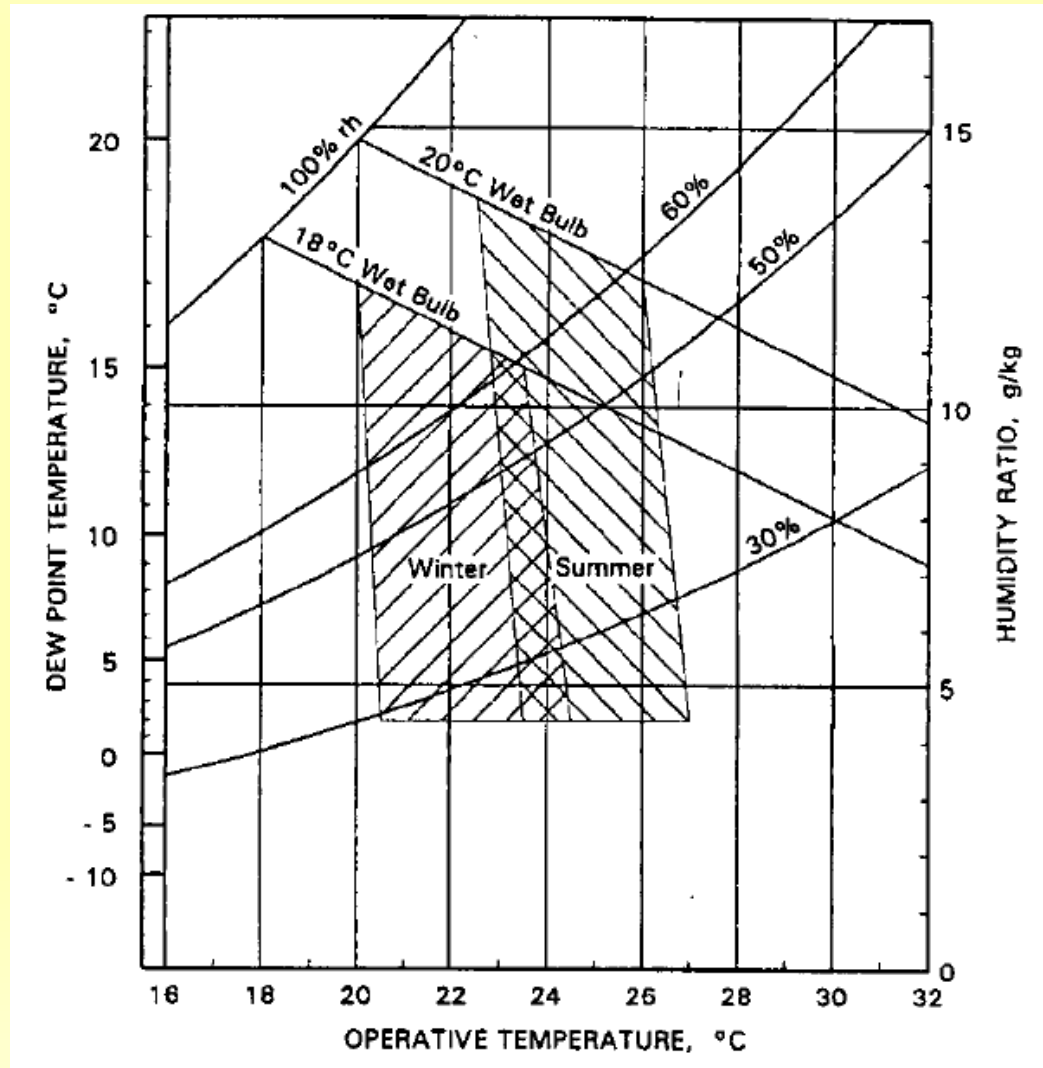
2. Thermal Comfort

2.4   Other Influences

Physiological Factors

- Age –

  Elderly people are less active and implies higher space temperatures are needed.

- Activity –

  People with vigorous activity that generates more heat thus lower space temperature is desired to maintain the steady state heat balance equation.

- Health –

  People got sick that his feeling on comfort is total difference from normal condition.

2. Thermal Comfort
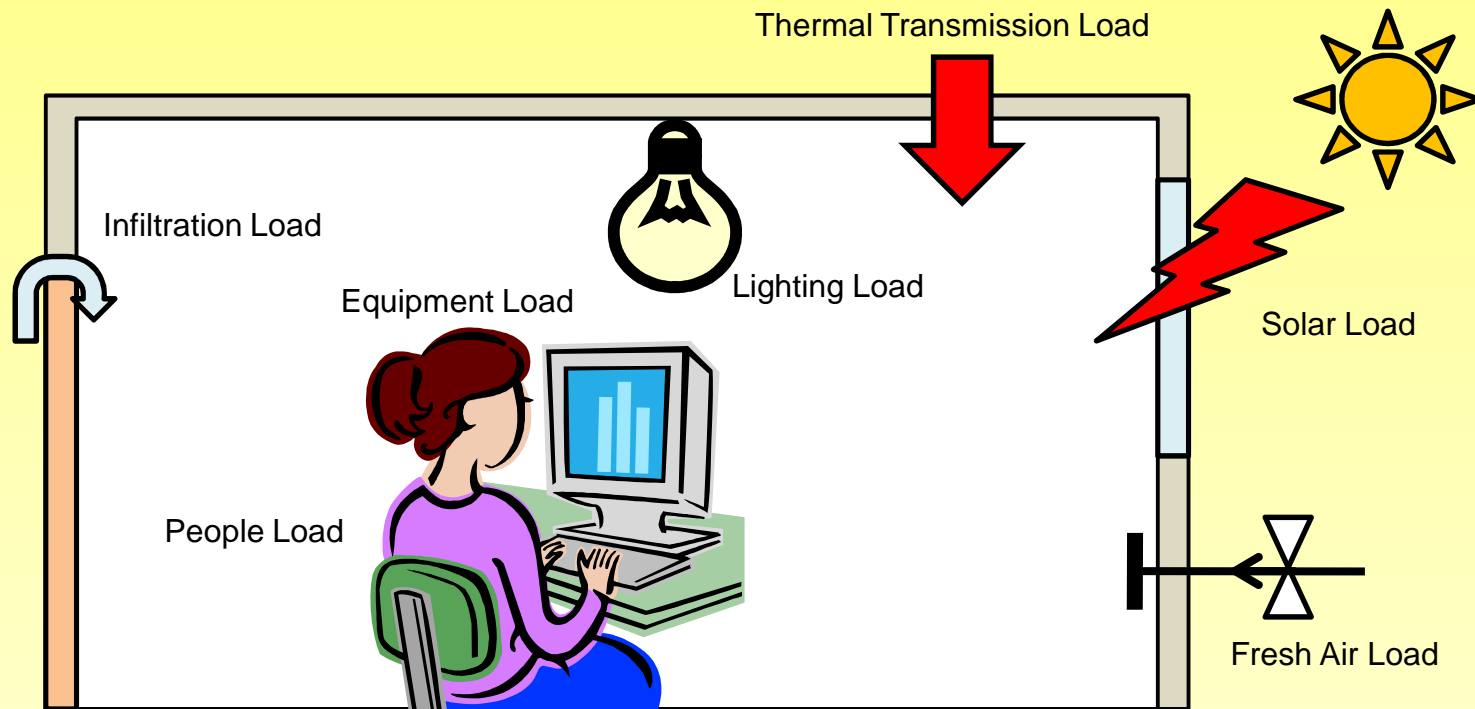
2.5 Design Conditions

(ASHARE Fundamentals Handbook Figure 5 – ASHARE Summer and Winter Comfort Zone)

2. Thermal Comfort

2.5 Design Conditions

- The comfort zone specified in ASHARE with the space conditions likely to be thermally acceptable to at least 80% of people occupied inside.

- The control of dry bulb temperature is not sufficient to maintain a comfort environment whereas the relative humidity is also important because it contributes significance in evaporative heat balance of a body.

- Relative humidity should be maintained between 20% to 60%.

- Desired dry bulb temperature maintain at 24°C and 22°C for summer and winter respectively but higher temperature is acceptable subject to increase in supply air velocity that can achieve comfort criteria of Effective Draft Temperature can be maintained.

3. Cooling Load

Thermal Transmission Load

Infiltration Load

Equipment Load

Lighting Load

Solar Load

People Load

Fresh Air Load

3. Cooling Load

5.1 Thermal Transmission Load

- The heat gain or heat loss by thermal transmission load through the building or zone envelop can be determined by

$$Q = \frac{(T_o - T_i)}{R_T} = \frac{1}{R_{TOT}} A(T_o - T_i) = UA(T_o - T_i)$$

- where,

- R_{TOT} is the thermal resistance per unit area (m^{2}K/W)

- Typical thermal resistance per unit area of selected building materials at 24°C mean temperature is listed in the following table.

Material	1/k, (mK/W)	R, (m^{2}K/W)
Face Brick	0.76	
Sheathing, Fiberboard, Regular Density, 13mm		0.23
Insulation, Mineral Fiber, 75-90mm		1.94
Gypsum board, 15mm		0.08
Air Space, Vertical		0.17
Surface, Still Air, Vertical, Heat Flow Horizontal		0.12
Surface, Moving Air, Heat Season, 6.7m/s		0.029

3. Cooling Load

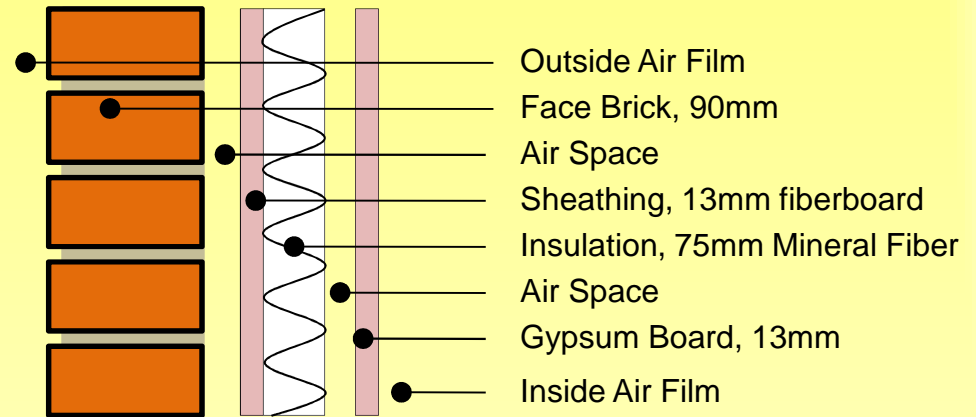3.1   Thermal Transmission Load

Example

Wall surface area is 450m^2

Outside temperature is 35°C

Inside temperature is 24°C

Determine the total thermal resistance of the adjacent wall system, U-Value and the heat gain due to thermal transmission.

Repeat the calculation for omission of 13mm fiberboard sheathing, 75mm mineral insulation.

Outside Air Film

Face Brick, 90mm

Air Space

Sheathing, 13mm fiberboard

Insulation, 75mm Mineral Fiber

Air Space

Gypsum Board, 13mm

Inside Air Film

3. Cooling Load

3.1 Thermal Transmission Load

Solution

$A = 450m^2$, $\qquad T_o = 35°C$, $\qquad T_i = 24°C$

Material	1/k, (mK/W)	R, (m^{2}K/W)
Outside Air Film		0.029
Face Brick, 90mm	0.76	0.068
Air Space		0.170
Sheathing, 13mm fiberboard		0.230
Insulation, 75mm Mineral Fiber		1.940
Air Space		0.170
Gypsum Board, 13mm		0.080
Inside Air Film		0.120
	R$_{TOT}$	2.807

U-Value, $U = 1 / R_{TOT} = 1 / 2.807 = 0.356 W/m^2K$

Heat gain due to Thermal Transmission,

$\qquad q_T = UA(T_o - T_i) = 0.356 \times 450 \times (35 - 24) = 1.76kW$

3. Cooling Load

3.1   Thermal Transmission Load

Solution

Omission of 13mm fiberboard sheathing, 75mm mineral insulation

Material	1/k, (mK/W)	R, (m²K/W)
Outside Air Film		0.029
Face Brick, 90mm	0.76	0.068
Air Space		0.170
Gypsum Board, 13mm		0.080
Inside Air Film		0.120
R_{TOT}		0.467

U-Value, $U = 1 / R_{TOT} = 1 / 0.467 = 2.141 W/m^2K$

Heat gain due to Thermal Transmission,

$q_T = UA(To - Ti) = 2.141 \times 450 \times (35 - 24) = 10.60 kW$

Omission of insulation layer that will increase the heat gain by 6 times that contribute significant in cooling load.
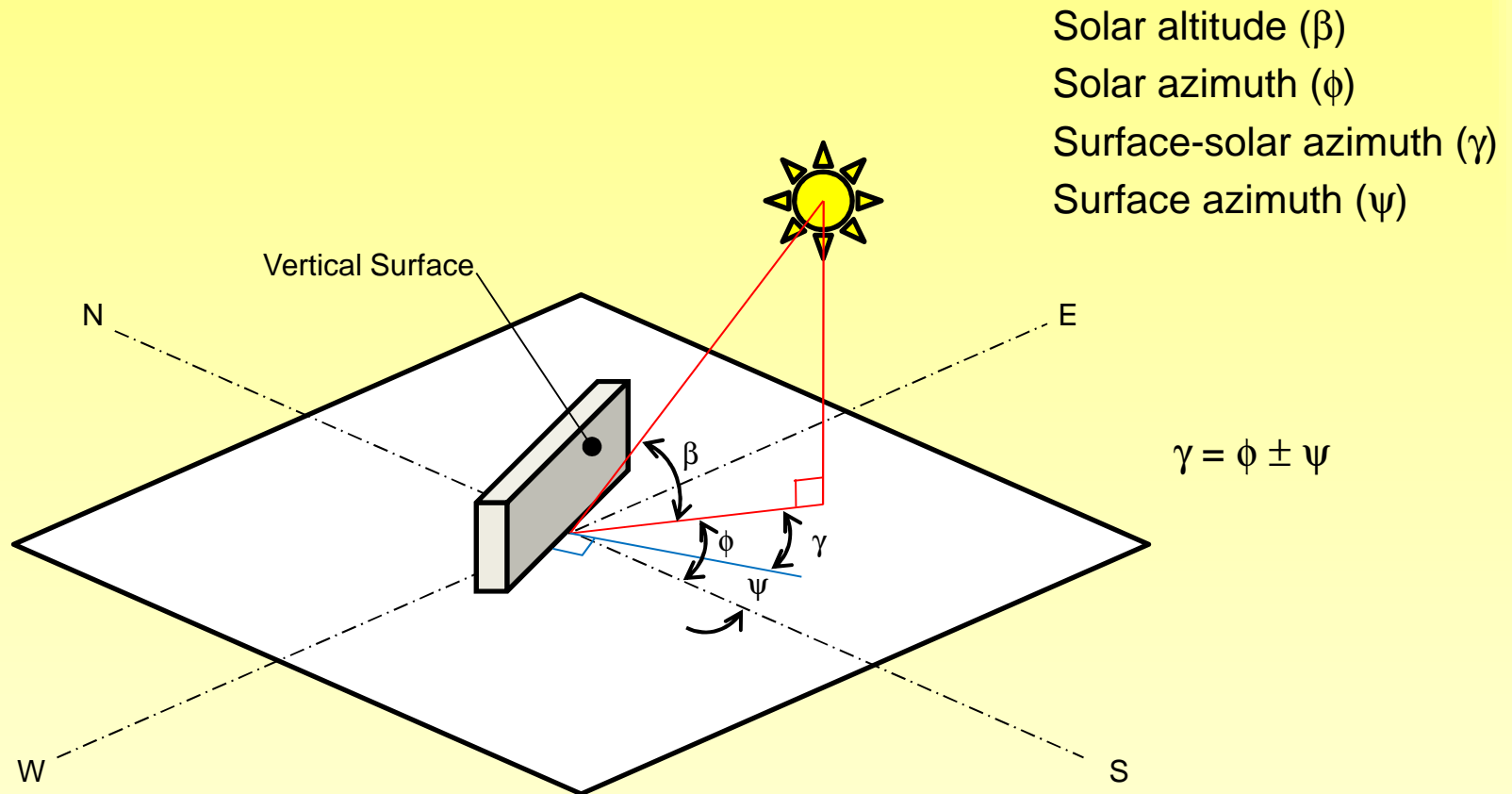
3. Cooling Load

3.2 Solar Load

Latitude

- Latitude (L) is the angle of line join from the residence place (Point P) to the center of the earth (Point O) and the Equator plane.

Artic circle 66.5°
23.5°
Tropic of cancer 23.5°
Equator
Sun's rays
Orbit plane
Earth-sun line
23.5°
Tropic of Capricorn 23.5°
Antarctic circle 66.5°

L-latitude   S-declination angle   H-hour angle

3. Cooling Load

3.2 Solar Load
Solar Angles

Solar altitude (β)
Solar azimuth (ϕ)
Surface-solar azimuth (γ)
Surface azimuth (ψ)

$$\gamma = \phi \pm \psi$$

Vertical Surface

N

E

β

ϕ

γ

ψ

W
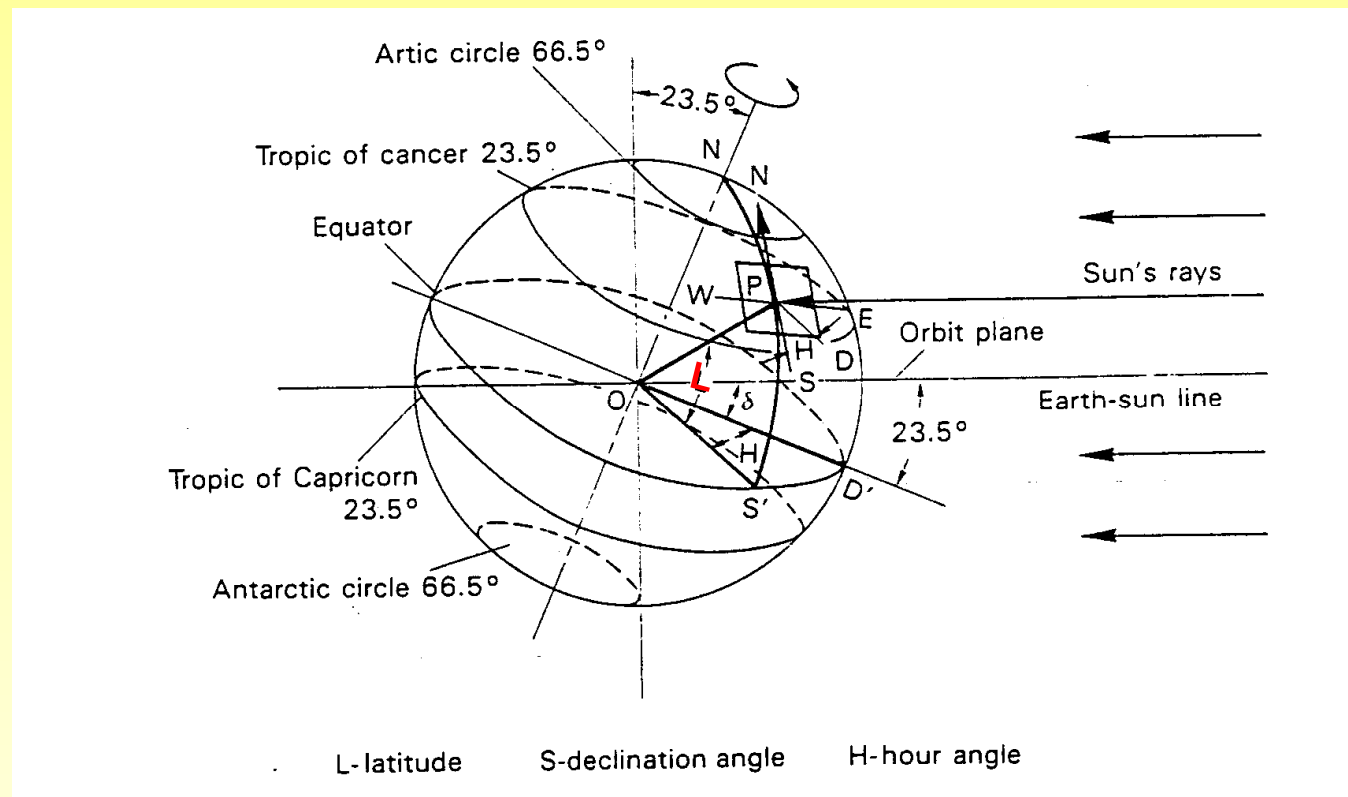
S

3. Cooling Load

3.2 Solar Load

Solar Angles

- Solar altitude (β) is the angle on a vertical plan between the sun ray and the horizontal plane on the earth surface.

- Solar azimuth (ϕ) is the angle on a horizontal plane between the due south direction and the horizontal projection of the sun ray.

- Surface-solar azimuth (γ) is the angle on a horizontal plane between the normal to a vertical surface and the horizontal projection of the sun ray.

- Surface azimuth (ψ) is the angle on a horizontal between the normal to a vertical surface and the north-south direction line.

3. Cooling Load

3.2 Solar Load

Solar Radiation

- Heat gain due to solar radiation will depend on the physical characteristics of the surface.

- Solar irradiation on a surface and it will be reflected, absorbed and transmitted that will depends on the optical properties of the surface.

$$\rho + \alpha + \tau = 1$$

Absorbed α

Glass

Irradiation, I_t

Reflected ρ
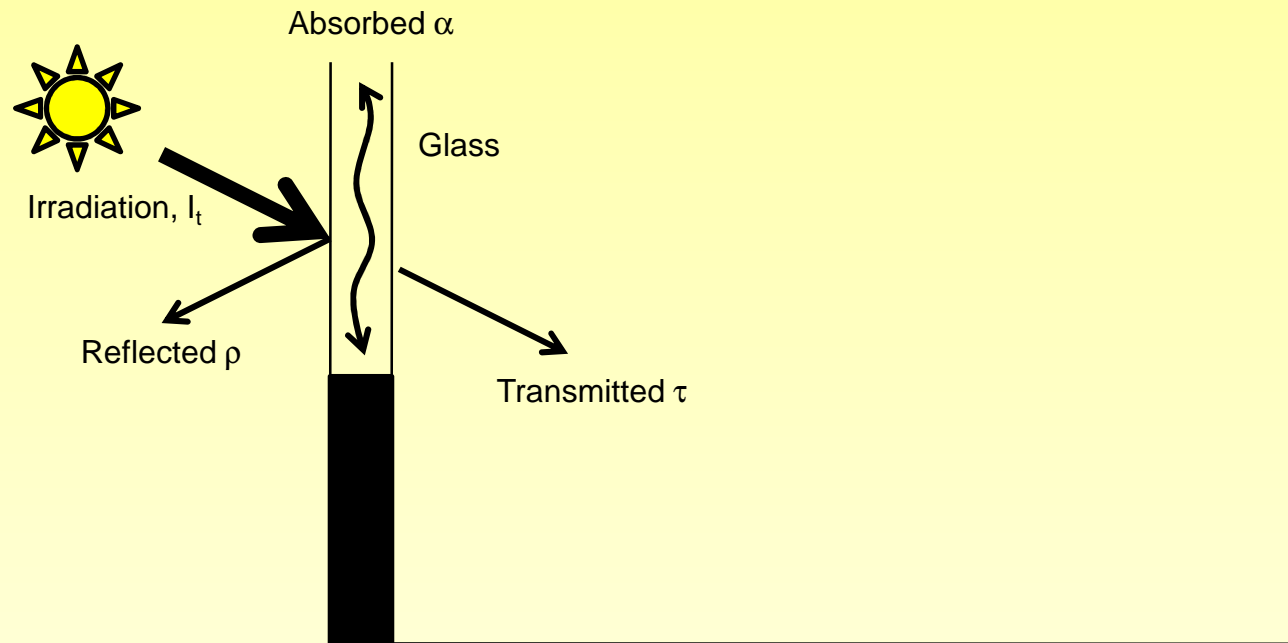
Transmitted τ

3. Cooling Load

3.3   Solar Load Through Glass

- Glass is transparent to short wave solar radiation (wavelength from 0.2 to 3.5μm) and opaque to long wave radiation (wavelength greater than 5μm).

- Short wave solar radiation transmit through the glass and being absorbed by opaque surface thus long wave radiation reradiated out from the hot surface being trapped inside the conditioned space.

3. Cooling Load

3.3   Solar Load Through Glass

External Shading

- Shading from overhangs or other projection shall be take into consideration when determine the sunlit area over the glass panel.
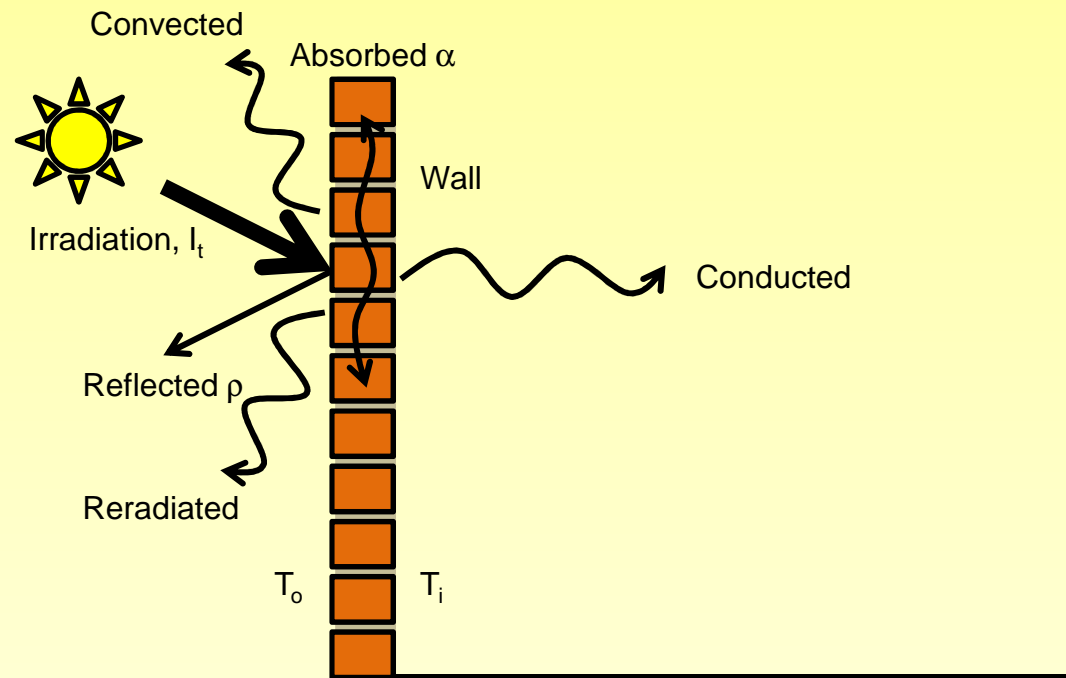

β

γ

d

y

x

Sunlit Area

Projection
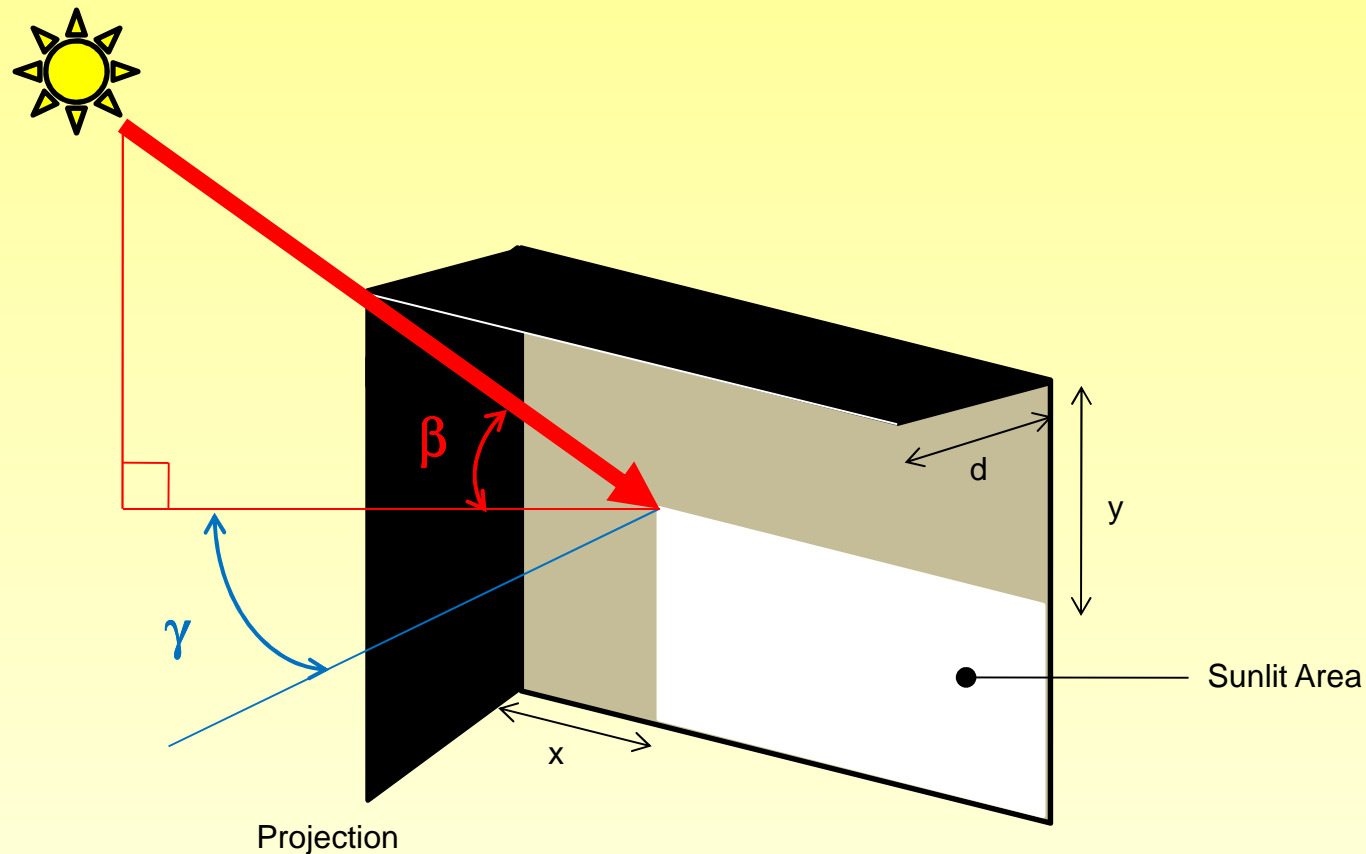
3. Cooling Load

3.4   Solar Load on Opaque Surface

- Transmissivity (τ) is zero for opaque surface and $\rho + \alpha = 1$

- Solar heat gain through opaque surface,

$$q_{sw} = \frac{U_w \alpha}{h_o} I_t A$$

Convected

Absorbed α

Wall

Irradiation, I_t

Conducted

Reflected ρ

Reradiated

T_o T_i

3. Cooling Load

3.5   Infiltration Load and Fresh Air Load

   Infiltration Load

- Outside air ingress into air conditioned space and imposed a cooling load to the system is called infiltration load.

- It is due to:

   a) Wind pressure and particularly on tall building.

   b) Stack effect.

   c) The entry of occupants of the building.

- Maintain the air conditioned space slightly pressure could help on reduction of the infiltration load.

- Infiltration load is difficult to predict because of allocating all air leakage paths and its geometry is very time consuming and impractical.

3. Cooling Load

3.5   Infiltration Load and Fresh Air Load

Fresh Air Load

- Fresh air supply rate can be divided into two categories and cater for

    a) People aspiration.

    b) Pollutant removal.

- For people aspiration, fresh air supply rate can be chosen as 5L/s/person minimum to maximum of 10.

    For heavily smoking area, it can be increased to 15L/s/person.

    The population of the air conditioned space must be known.

3. Cooling Load

3.6 Internal Load

- The source of internal load within a space is from the occupants, lighting and equipment operating inside.

  People Load

- Under the heat balance equation of metabolism, the heat gain from people is equal to

  $$q_{people} = E + R + C + B$$

- People load classified by its activity is listed as follows for cooling load estimate:

Activity	Sensible Heat Gain (W/person)	Latent Heat Gain (W/person)
Sleeping	52.5	17.5
Standing	75	75
Office Work	82.5	67.5
Industrial – Light	105	195
Industrial - Heavy	210	390

3. Cooling Load

3.6   Internal Load

Lighting Load

- Lamp wattage will be used as the base for determining the heat gain and the heat dissipate from the ballast shall be taken into consideration as well.

- Heat gain from lighting is

$$q_{light} = P_{lamp} \times F_u \times F_b$$

    where,

    P_{lamp} is the lamp wattage (W)

    F_u is the utilization factor or fraction of lamps in use.

    F_b is the ballast factor (= 1.2 for typical fluorescent lamp)

- Cooling load from lighting can be determined by multiplying the heat gain by a CLF

$$CL_{light} = P_{lamp} \times F_u \times F_b \times CLF$$

3. Cooling Load

3.6 Internal Load

Lighting Load

- Cooling Load Factor added in the heat gain from lamp to cater for the delay and time lag effect when turn on and turn off the lighting respectively.

- CLF = 1 if lighting is operating 24 hours continuously.

- CLF of lighting switch ON at 0:00 and switch OFF at 10:00

CLF

Hour
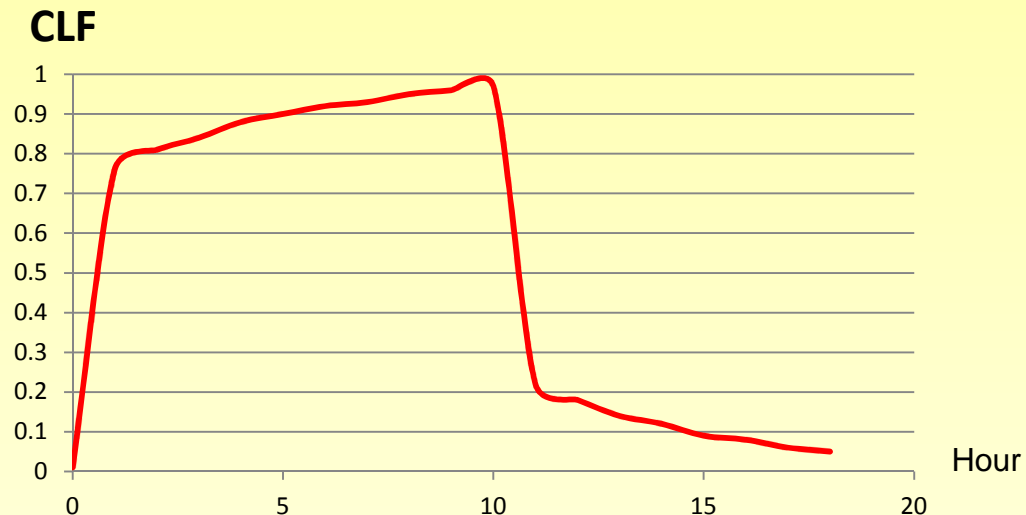
3. Cooling Load

3.6 Internal Load

Equipment Load

- It is required to understand the dynamic response of the heat release from the equipment and the easiest way is getting the information from the manufacturer.

- Cooling Load Factor should be applied to cater for delay and time lag effect same as that in lighting load.

$$CL_{equip} = q_{equip} \times CLF$$

where,

Heat gain from equipment, $q_{equip} = P_{equip} \times (1 - \eta) \times DF$

P_{equip} is rated power of equipment (W)

η is efficiency of equipment (Assuming power not contributed to useful work all convert to heat)

DF is diversity factor of operation.

4. Type of HVAC Systems

4.1 Unitary System

- Provide air conditioning to a room or a zone with its system configuration and operation as an individual.

- Packaged equipment is adopted where either window type or split type air conditioner is available.

- Cooling only or heat pump unit is available in the market.

    Remark:

- Heat pump means refrigeration equipment that utilizes the condenser heat exchange for space heating and the evaporator extract heat from atmosphere.

- Heat pump unit is using a 4-ways valve to change the refrigerant flow such that the coil facing the conditioned space will change to condenser.

4. Type of HVAC Systems

4.1 Unitary System

Heat Pump

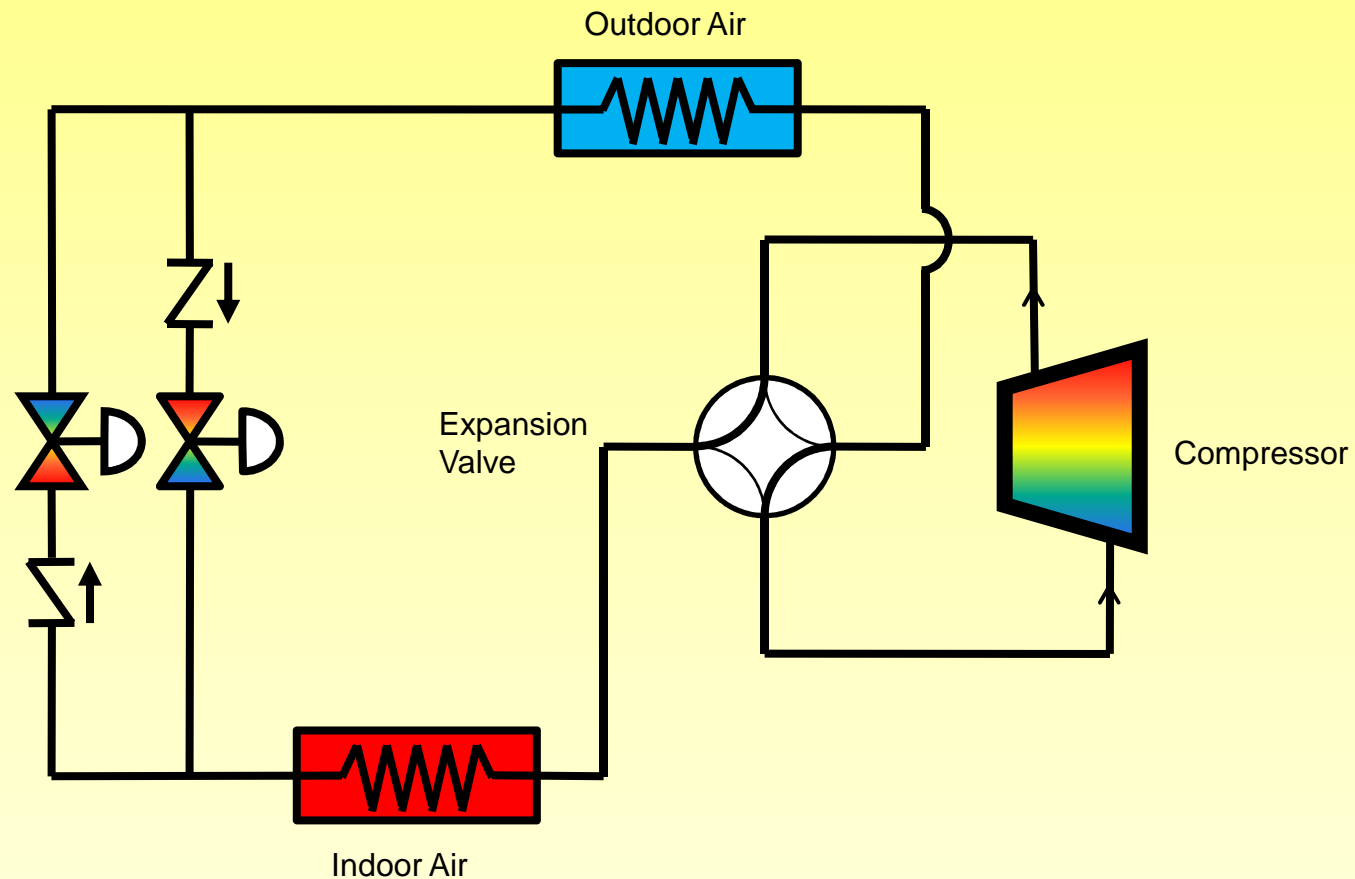- Schematic diagram of refrigerant circuit – **COOLING MODE**.
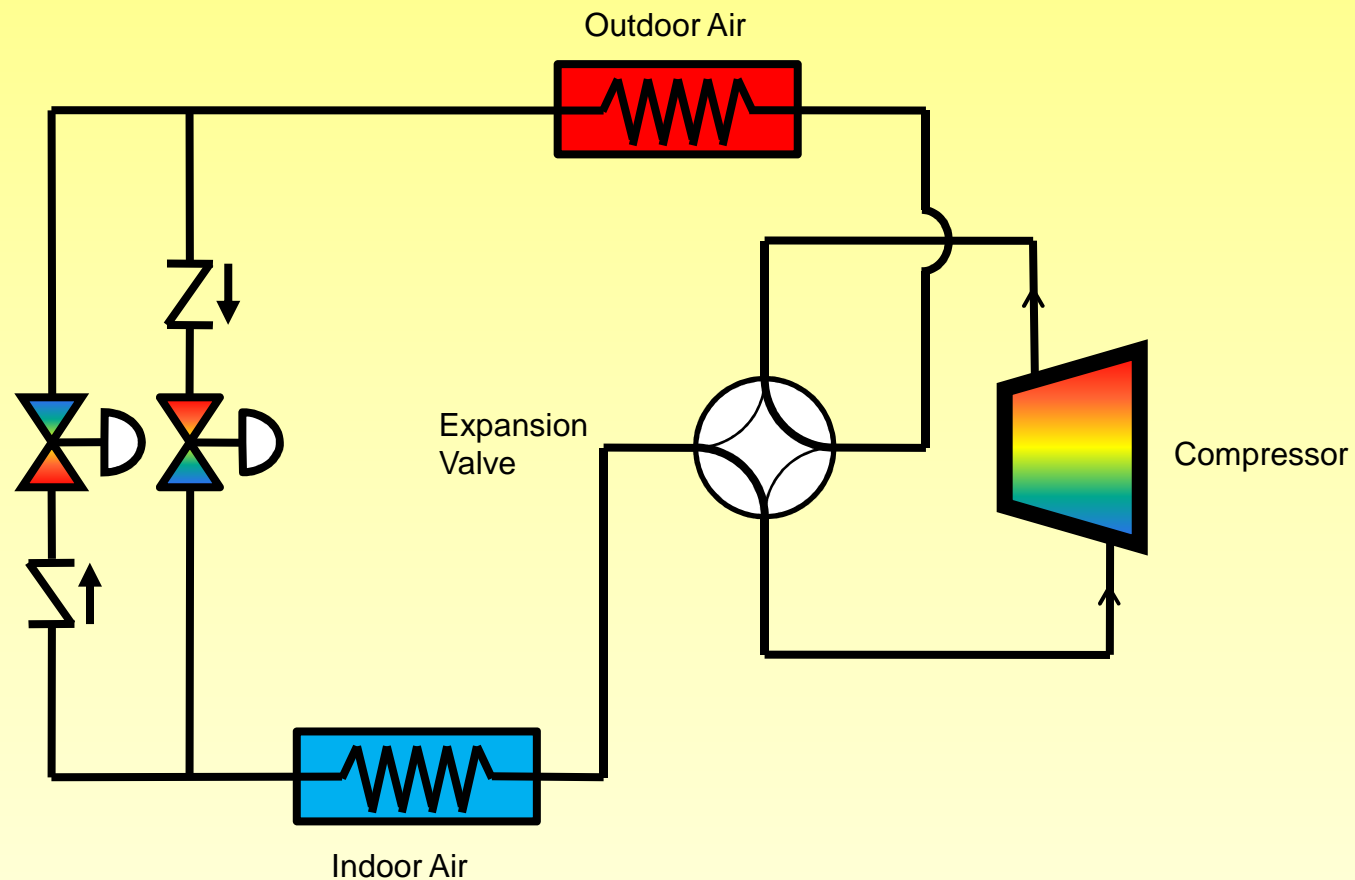
Outdoor Air

Expansion
Valve

Compressor

Indoor Air

4. Type of HVAC Systems

4.1   Unitary System

Heat Pump

- Schematic diagram of refrigerant circuit – **HEATING MODE**.

Outdoor Air

Expansion
Valve

Compressor

Indoor Air

4. Type of HVAC Systems

4.1 Unitary System

Window Type Air Conditioner

- It is a packaged unit that the refrigeration equipment is integrated in a single unit with the evaporator extract heat from space for air conditioning and the condenser reject heat to atmosphere.
- Air is circulating across the condenser and evaporator for heat exchange.
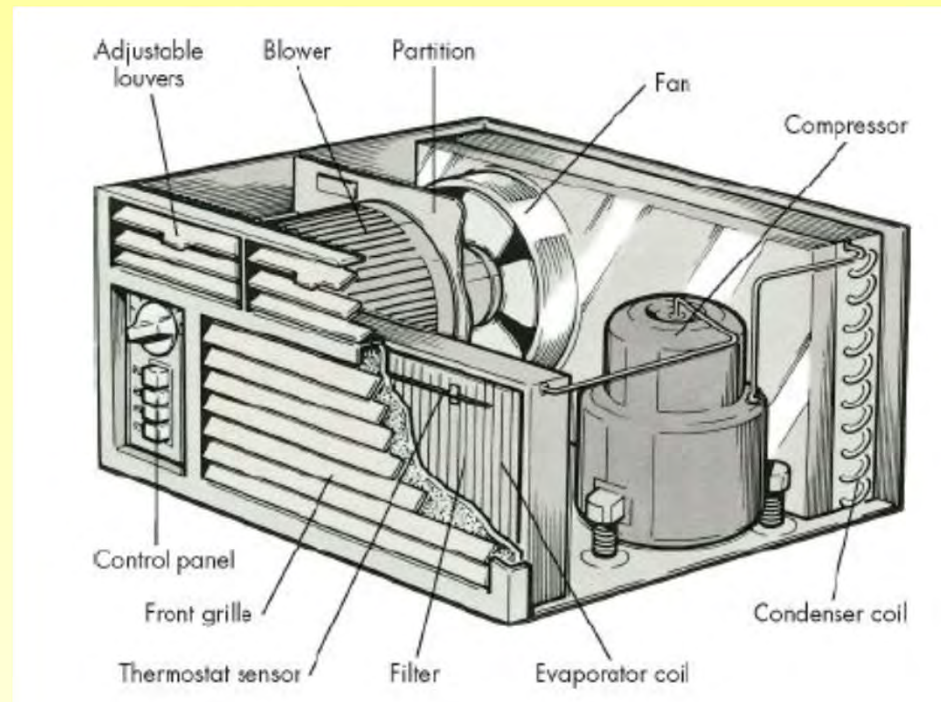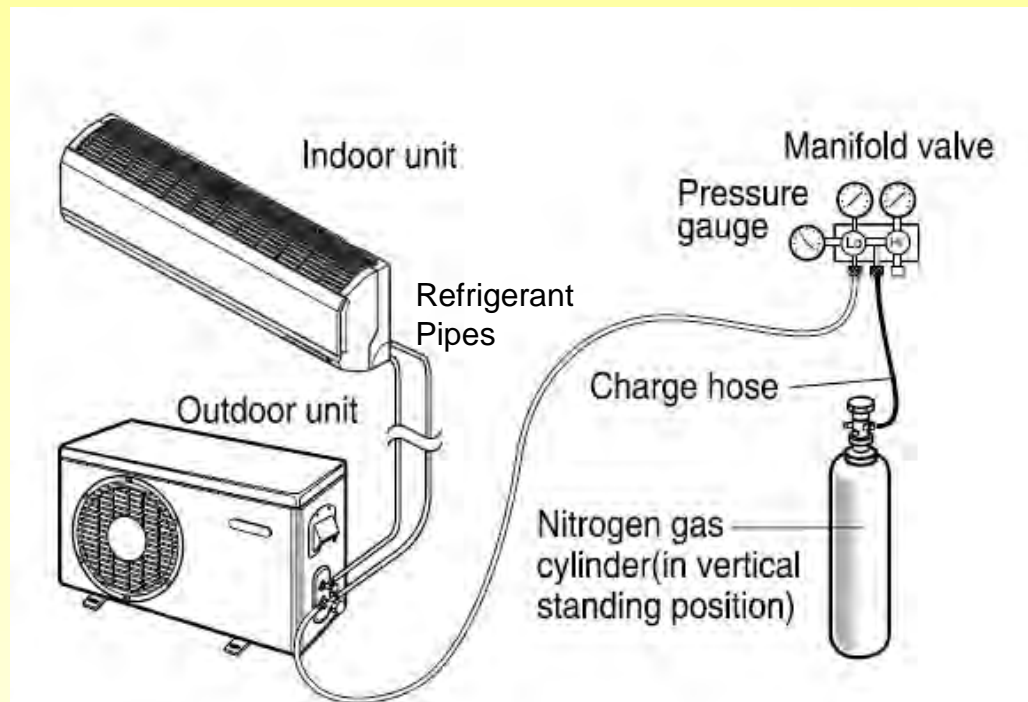
4. Type of HVAC Systems

4.1 Unitary System

Split Type Air Conditioner

- The principle is similar as window type air conditioner except the refrigeration equipment is separately housed into two units.

- It is used if remote heat rejection is required with indoor and outdoor unit interconnected by refrigerant pipes, power and control wiring.

4. Type of HVAC Systems

4.1 Unitary System

Split Type Air Conditioner

Outdoor Unit

- It composed of compressor and condenser for heat rejection to atmosphere.

- Some manufacturer integrates the expansion valve to the outdoor unit but housed inside indoor unit is also available.
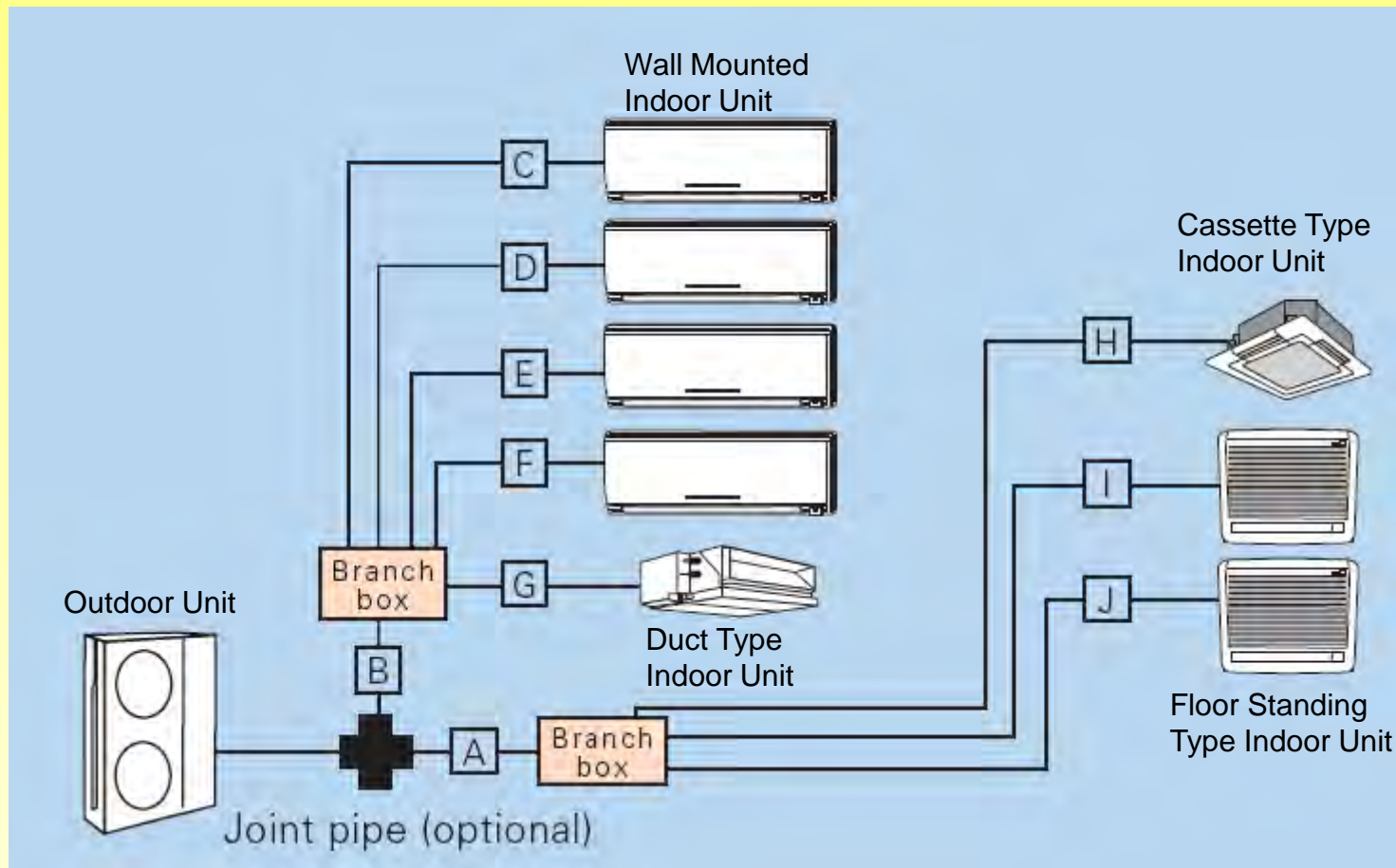
Indoor Unit

- It composed of an evaporator for extract heat from the air conditioned space.

4. Type of HVAC Systems

4.2 Mini Central System

Multi Split System – Direct Expansion

4. Type of HVAC Systems

4.2   Mini Central System

Multi Split System – Direct Expansion

- Multi split air conditioner with one or a group of outdoor unit supplying a numbers of indoor units.

- The refrigerant flow rate can be varied by adjusting the speed of compressor to suit.

   Limitation (Depends on Air Conditioner Manufacturer Specifications):

- It is suitable for mini system where individual group cooling capacity is less than 50HP.

- The distance of refrigerant pipe run between indoor and outdoor units is normally not exceeding 100m.

- The elevation between the indoor and outdoor unit should not exceed 50m to prevent the refrigerant oil cannot return back to the outdoor unit.

4. Type of HVAC Systems

4.3   Central System

- The refrigeration plant is centralized and chilled water and/or hot water is circulated within the building for cooling and/or heating of the air conditioning space respectively.

- The is no limitation on the system capacity provided that small system is economically justified

- Since the refrigeration equipment is centralized, it can easy of system maintenance

- The heat rejection can be either air cooled or water cooled but the later is preferred because of low condensing temperature thus result in higher Coefficient of Performance (COP)

- Typical COP for air cooled and water cooled chiller is 3 and 5 respectively.

5. Centralized HVAC System

5.1   All Air System

- Only air is circulating and or distributed within the air conditioned space.

  Design Consideration

- Only air ducts is installed within the air conditioned space thus eliminate the risk of water damage by water pipes.

- Ceiling space shall be sufficient to cater for air duct installation.

- Major power supply is confined within the plant room only.

- Routine maintenance of the major air handling equipment is confined inside plant room that reduce nuisance to occupant.

- Headroom constraint on condensate drain pipe is eliminated.

- Using ceiling void for air return can eliminate the provision of return air duct but special attention should be drawn on:

  - Fire compartment and smoke control of conditioned space and the adjacent compartments.

  - Surface spread of fire requirements of materials installed inside ceiling void.

5. Centralized HVAC System

5.1   All Air System

Constant Air Volume

- Only single temperature and/or humidity are used as the system control parameter.

- It is suitable for open plan application and eliminates using single system to serve the conditioned space with external wall facing different orientation.
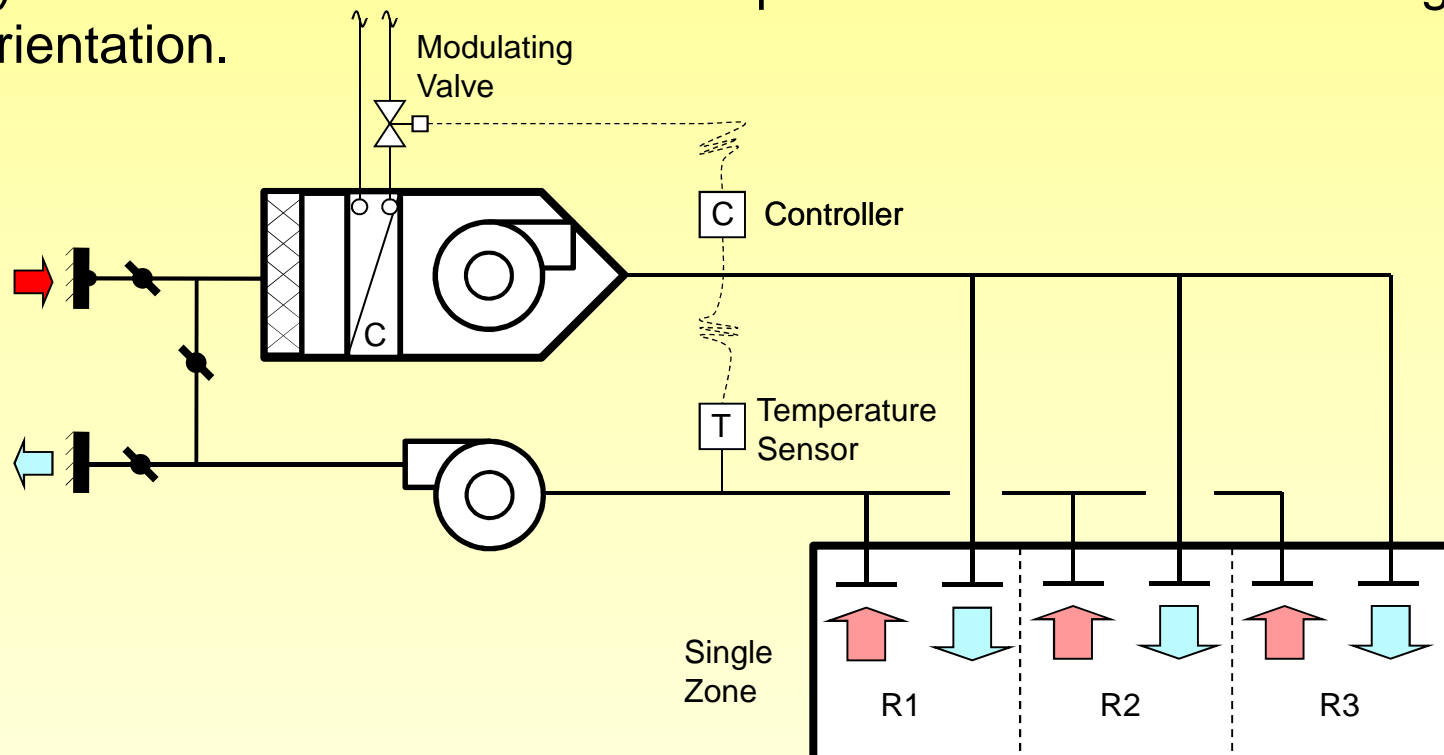
5. Centralized HVAC System

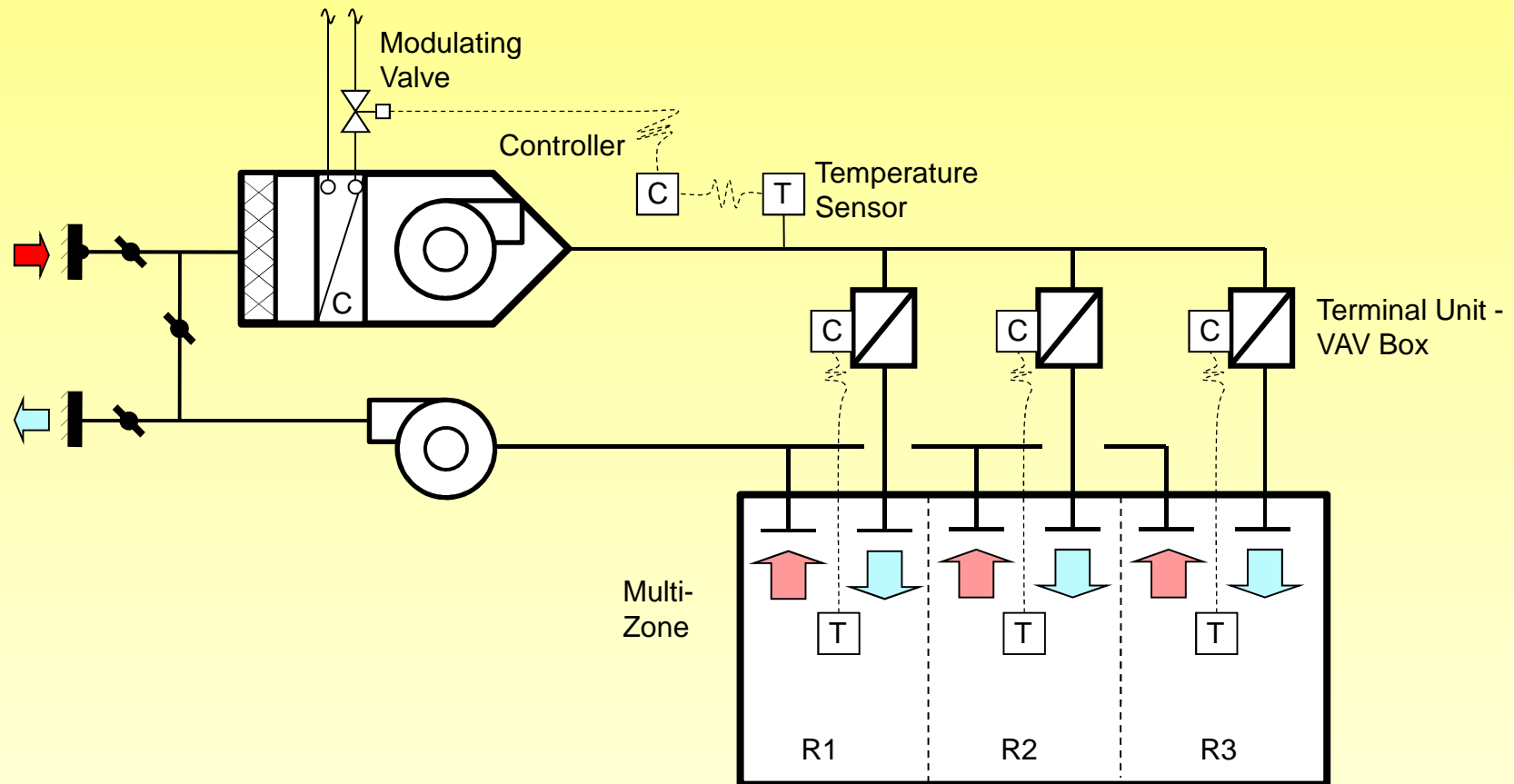5.1   All Air System

   Variable Air Volume (VAV)

- It is suitable for multi zone application with different individual temperature and/or humidity set points.

- Terminal unit (VAV Box) is installed inside conditioned space to regulate the supply air flow rate to meet the room control set point.

- VAV box composed of a damper for modulate the supply air flow rate compete with a flow sensor at downstream of the damper as a feedback signal to control the damper position such that the flow set point can be assured be maintained. The control relies on the space temperature as the set point for temperature control.

- Humidity control can be made by mixing the hot air supply by a second VAV box. Alternatively, if heating only require in perimeter zone and only a short period is require in a year, terminal reheat by duct heater at downstream can be considered as an economic solution.

5. Centralized HVAC System

5.1 All Air System

Variable Air Volume (VAV) - Single Duct

- Either heating or cooling for the air conditioned space can be provided.
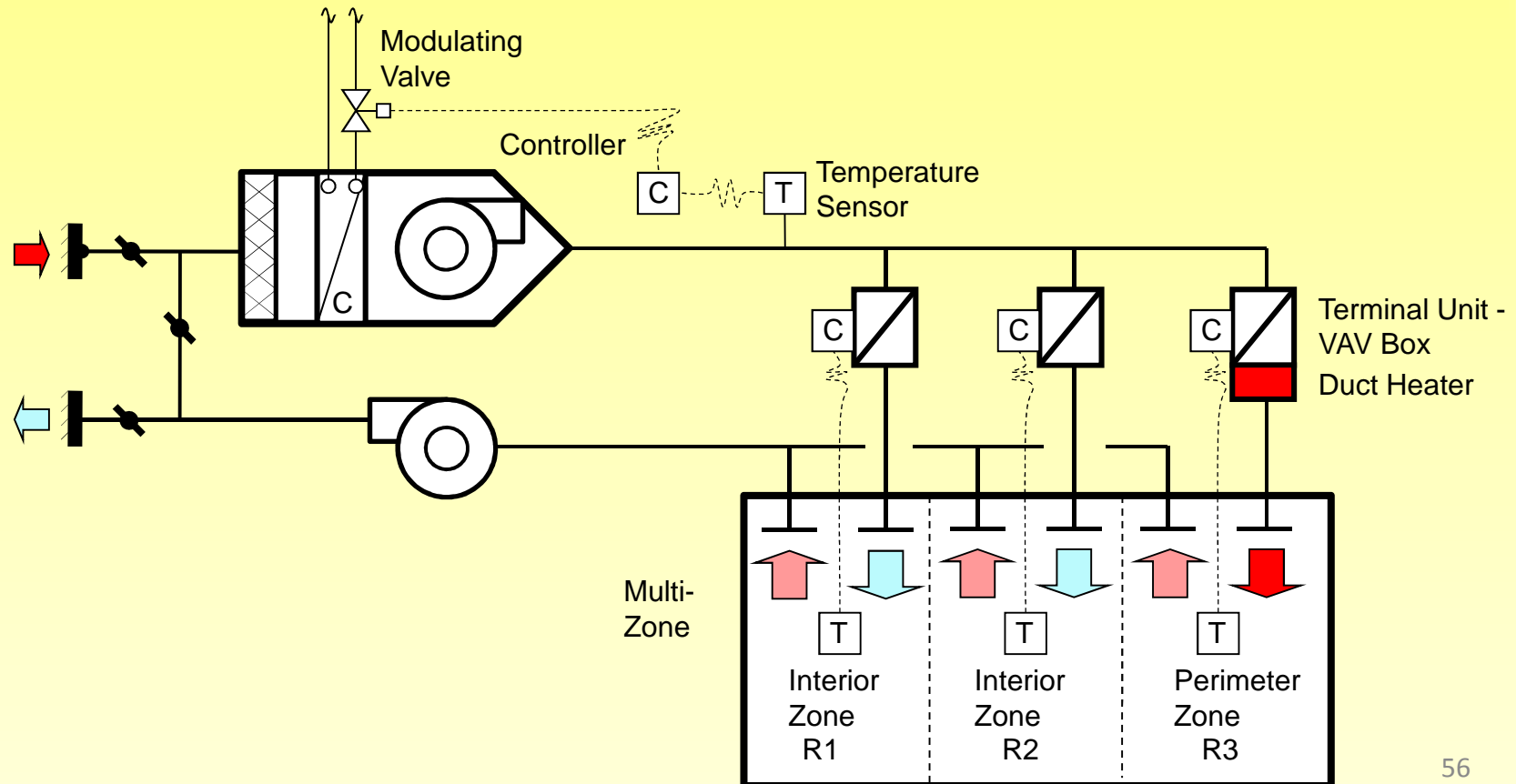
5. Centralized HVAC System

5.1   All Air System

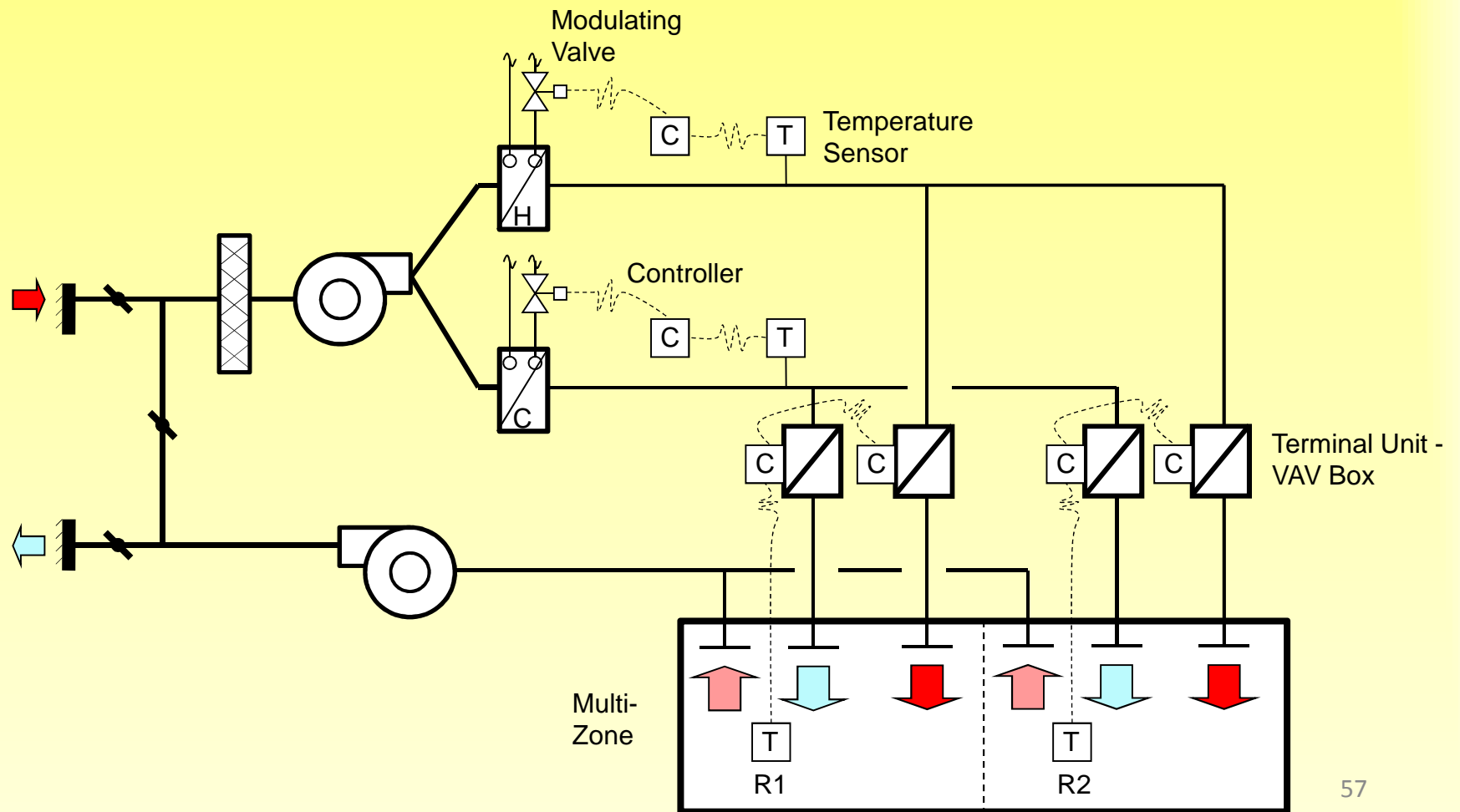*Variable Air Volume (VAV) - Single Duct with Terminal Reheat*

- Suitable for system with minor heating load in winter on perimeter zone and the duration within the season is short.

5. Centralized HVAC System

5.1 All Air System

Variable Air Volume (VAV) - Dual Duct

5. Centralized HVAC System

5.2 Air-Water System

- AIR - Pretreated fresh air supplied to conditioned space to suit ventilation requirements and dehumidification of outdoor air.

- WATER - Chilled water distributed within the conditioned space to take up the space cooling load whereas hot water for heating load.
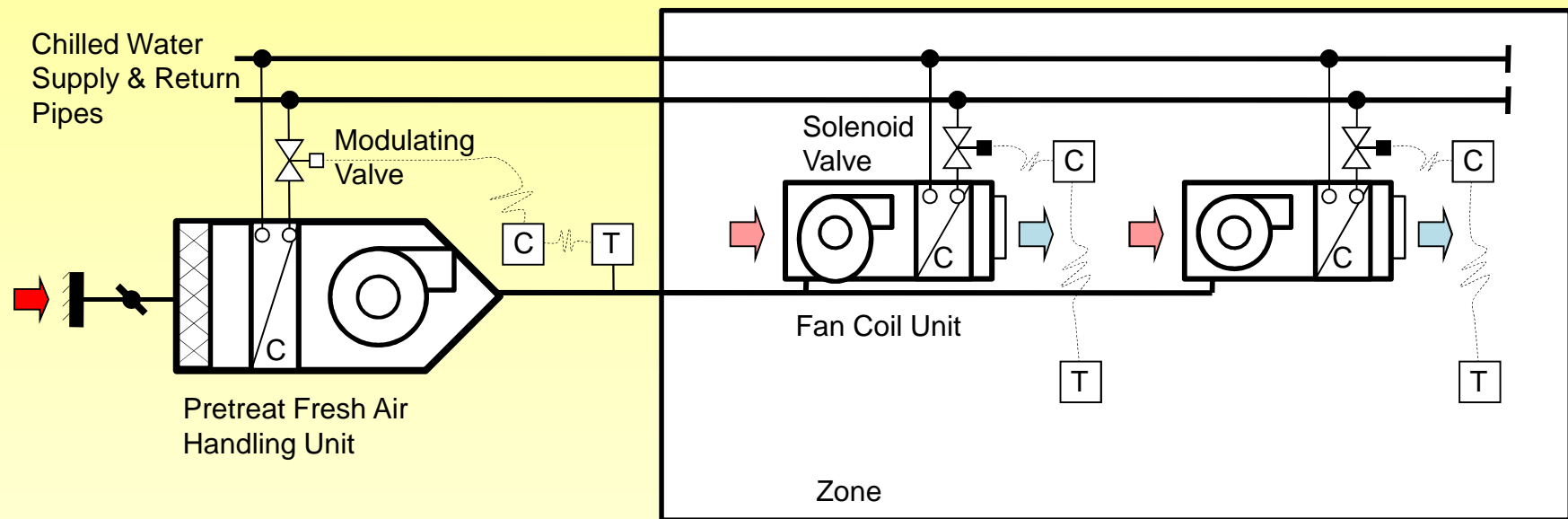
   Design Consideration

- Terminal unit can be small capacity fan coil unit and / or air handling unit to suit the spatial constraint of the conditioned space

- Space requirement for ducting installation is reduced when compare with All-Air system but another consideration on headroom for maintain the 1:100 fall of condensate drain is required.

- Normally adopt temperature control only.

5. Centralized HVAC System

5.2   Air-Water System

2-pipes system

- For either cooling or heating only.

- If system requires seasonal changes between cooling and heating, system changeover takes time for gradual changes to avoid thermal stress on system equipment.
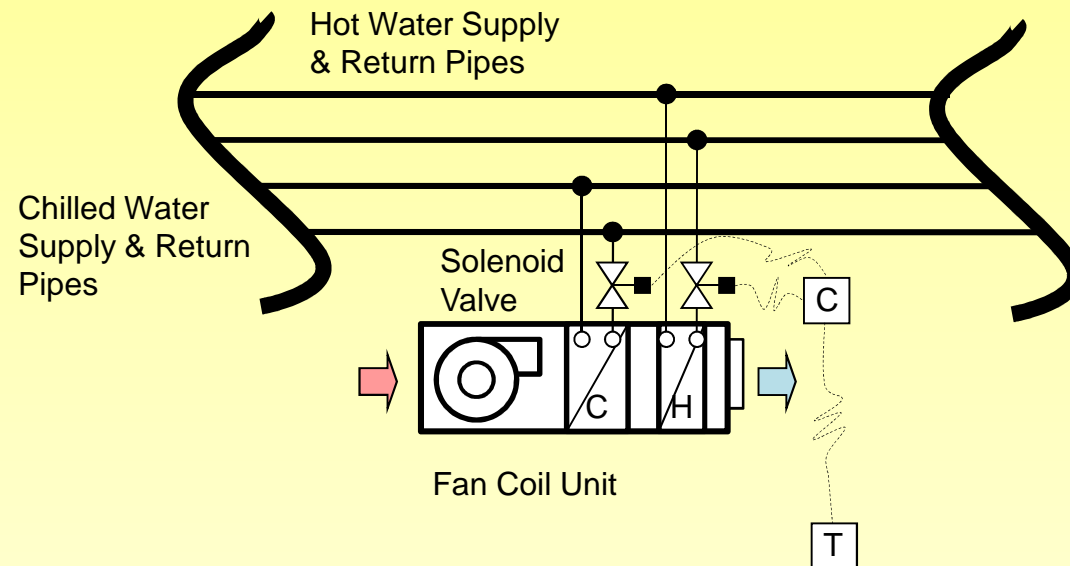

Chilled Water Supply & Return Pipes

Modulating Valve

Solenoid Valve

C

C

C

C

T

C

C

Fan Coil Unit

T

T

Pretreat Fresh Air Handling Unit

Zone

5. Centralized HVAC System

5.2 Air-Water System

4-pipes system

- Cooling and heating can be provided within the conditioned space simultaneously.
- Humidity control can be applied as well.

Hot Water Supply & Return Pipes

Chilled Water Supply & Return Pipes

Solenoid Valve

C

H

C

T

Fan Coil Unit

5. Centralized HVAC System

5.3 All-Water System

- Only chilled water distributed into the conditioned space and can be either 2-pipes or 4-pipes system.
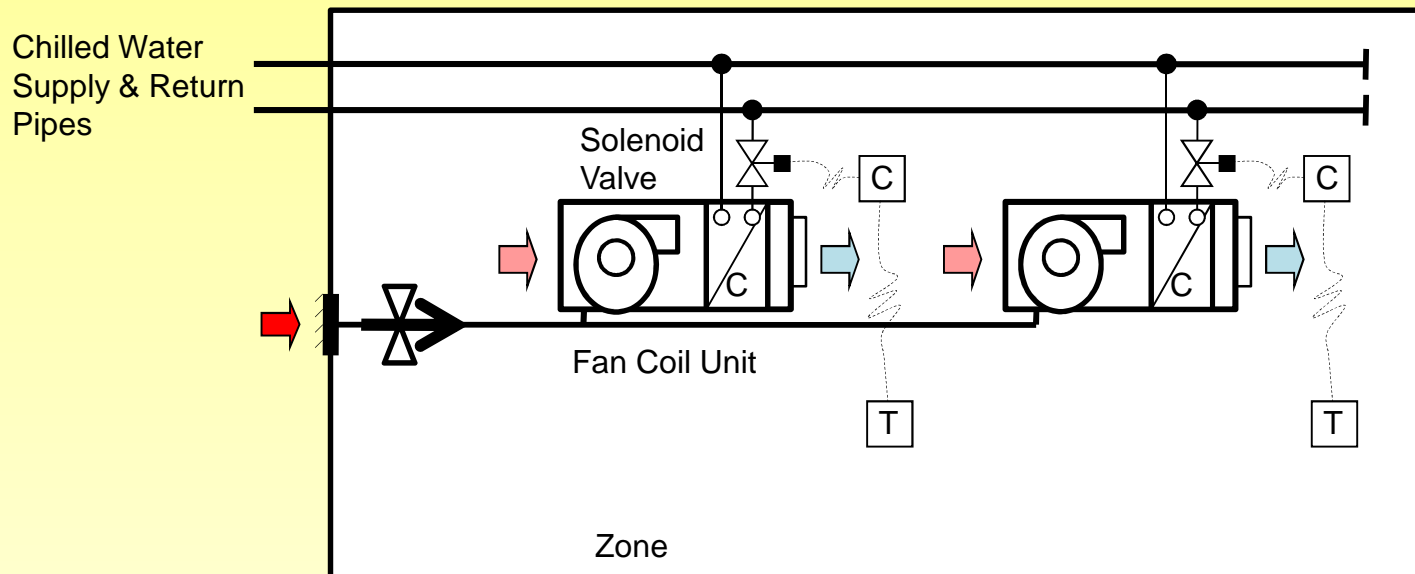
  Design Consideration

- Wall opening on external wall shall be provided for fresh air intake.

- Terminal unit can be small capacity fan coil unit and / or air handling unit to suit the spatial constrain of the conditioned space.

- For fan coil unit being used, special attention should be drawn on the humidity level could be higher because the dehumidification performance of fan coil unit is weak when compare with the cooling coil in air handling unit.

5. Centralized HVAC System

5.3 All-Water System

2-pipes system

- For either cooling or heating only.

- If system requires seasonal changes between cooling and heating, system changeover takes time for gradual changes to avoid thermal stress on system equipment.

Chilled Water Supply & Return Pipes

Solenoid Valve

Fan Coil Unit

Zone

4-pipes system

- System configuration similar as Air-Water System.

5. Centralized HVAC System

5.4   Chilled Water System

- Consideration should be made on system balancing for maintain sufficient chilled water supply to terminal unit.

- Chilled water flowing in a circuit will favour to the path with less resistance and same analogy as electric circuit theory.

- Balancing valve will be installed in chilled water distribution branch to increase the water side pressure drop such that desired water flow rate could be achieved.

- The system pressure drop, ΔP, can be represented by:
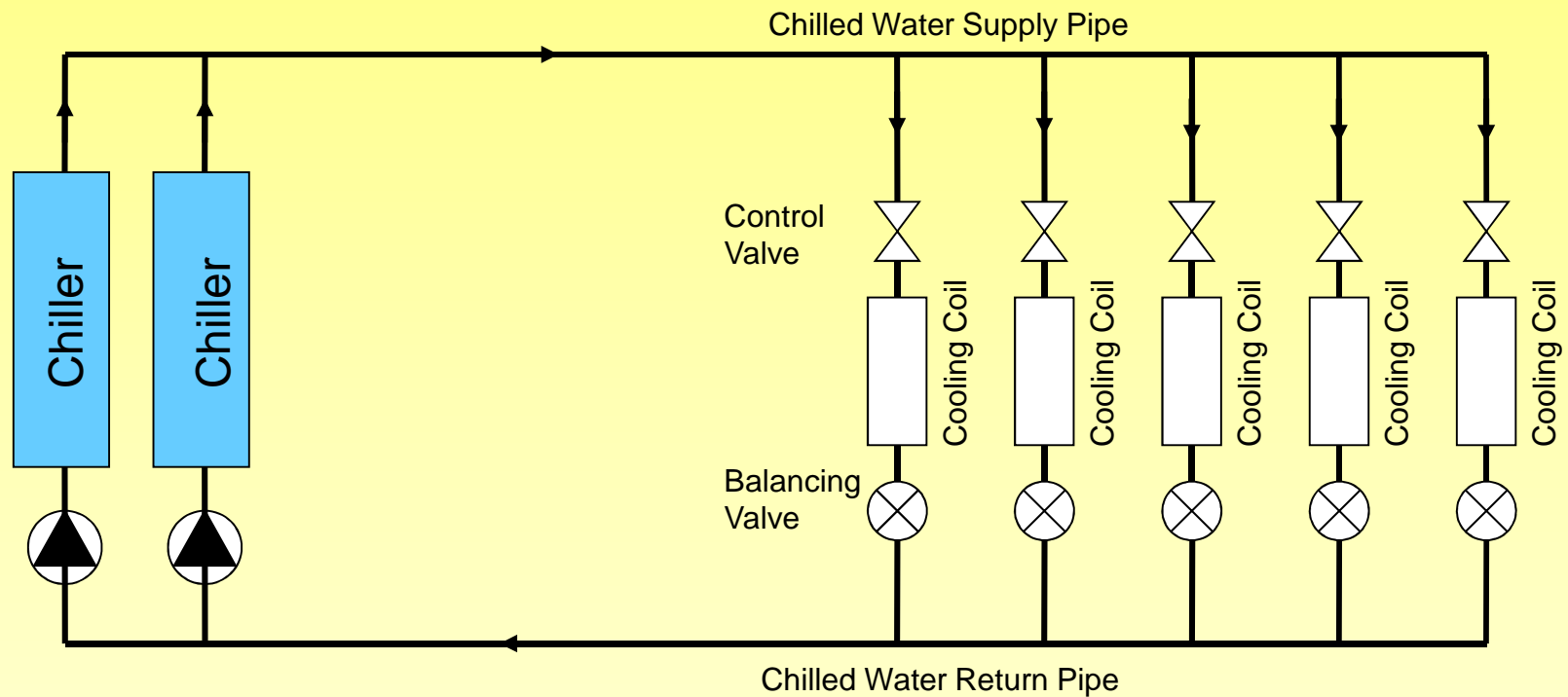
$$\Delta P = R\dot{V}^2$$

    where R is flow resistance and $\dot{V}$ is chilled water flow rate.

- For control valve which regulate the chilled water flowing through the terminal unit and the system water flow rate will vary with the simultaneous demand.

- Hot water system is using the same principle as chilled water supply.

5. Centralized HVAC System

5.4   Chilled Water System

Direct Return

Chilled Water Supply Pipe

Chiller

Chiller

Control
Valve

Cooling Coil

Cooling Coil

Cooling Coil

Cooling Coil

Cooling Coil

Balancing
Valve

Chilled Water Return Pipe

5. Centralized HVAC System
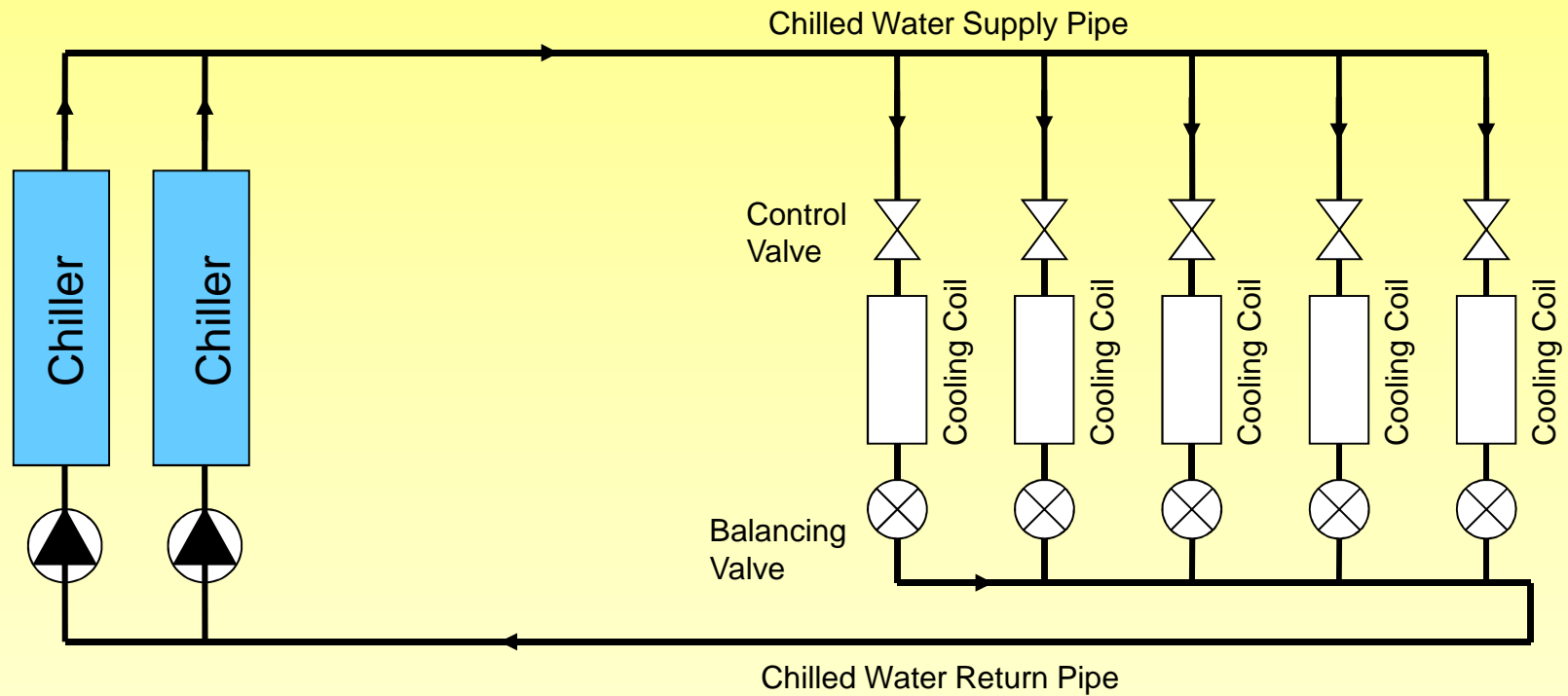
5.4   Chilled Water System

Direct Return

- The former the terminal unit connect to chilled water supply pipe that the return pipe run will be shorter.

- Difficult in chilled water flow balancing because the system pressure drop difference significantly in the first and last terminal units.

5. Centralized HVAC System

5.4 Chilled Water System

Reverse Return

Chilled Water Supply Pipe

Chiller

Chiller

Control Valve

Cooling Coil

Cooling Coil

Cooling Coil

Cooling Coil

Cooling Coil

Balancing Valve

Chilled Water Return Pipe

5. Centralized HVAC System

5.4   Chilled Water System

Reverse Return

- The former the terminal unit connect to the chilled water supply pipe that the chilled water return pipe run will be longer.

- Easier in chilled water flow balancing because the system pressure drop of each terminal unit is nearly the same and only minor adjustment by balancing valve is required.

- Higher piping cost may result because of additional reverse return pipe but can be minimized by properly allocate the chilled water risers.

6. System Components

6.1 Chiller

Factors to be Considered on Equipment Selection:

- Cooling Capacity

- Outdoor / Condenser Water Supply Temperature.

- Chilled Water Leaving Temperature.

- Fouling Factor

- Size and Configuration of Equipment

- Running and Starting Current

- Supply Voltage

  Low voltage chiller can have cooling capacity up to 1,000Ton with air cooled chiller up to the maximum limit of 400Ton

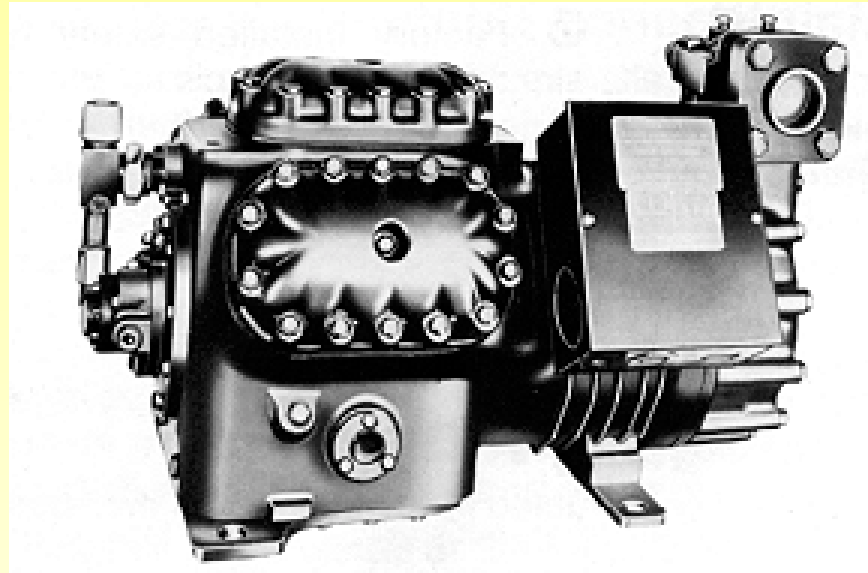 **High voltage** chiller can be considered from 1,000 Ton and onward.

6. System Components

6.1 Chiller

Factors to be Considered on Equipment Selection:

- Type of Compressor

  Reciprocating compressor suitable for small capacity with each compressor cater for around 100 Ton cooling capacity. It will generate more operating noise as it involves positive displacement component such as piston and cylinder.
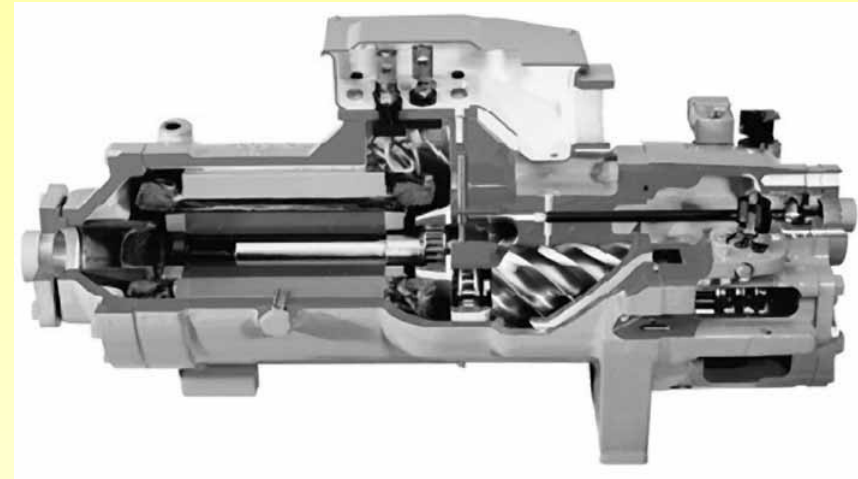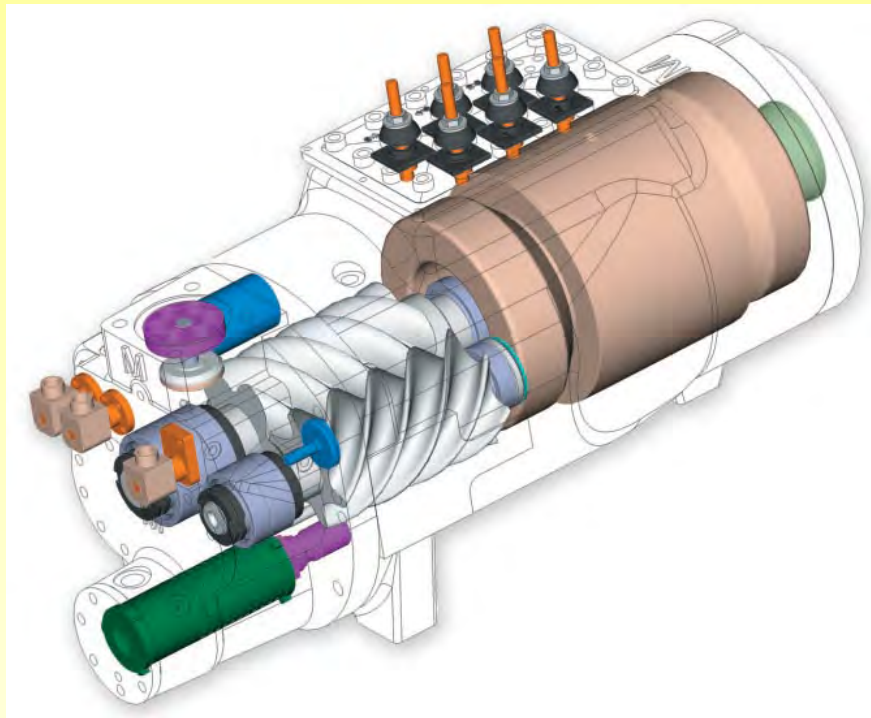
6. System Components

6.1   Chiller

Factors to be Considered on Equipment Selection:

- Type of Compressor

  Screw compressor is rotary which suitable for cooling capacity similar as reciprocating type. It generates less operating noise when compare with reciprocating type.
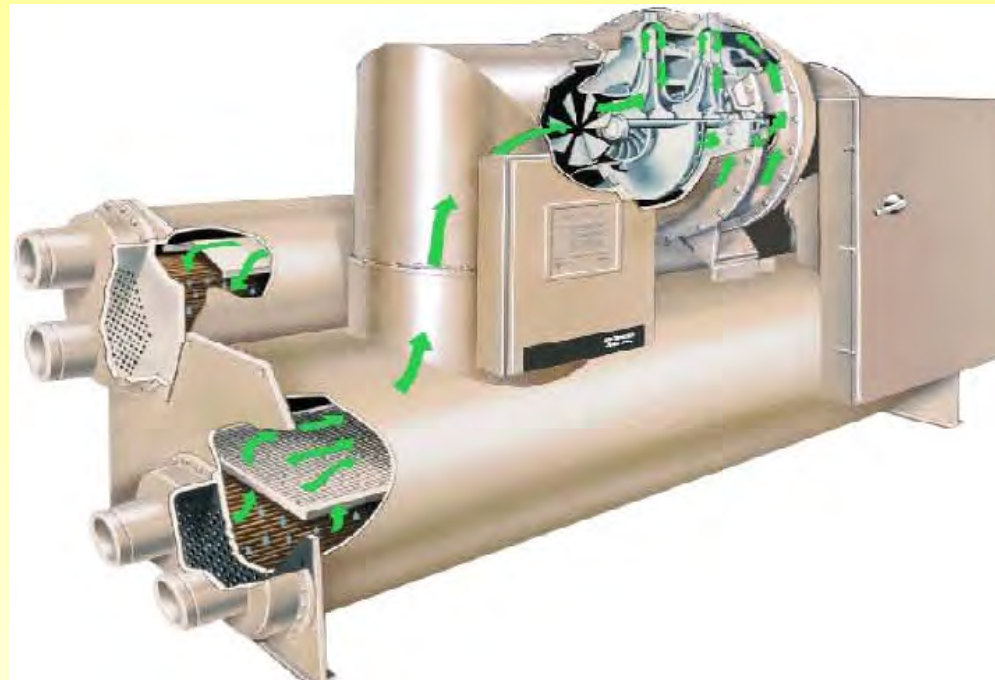
6. System Components

6.1   Chiller

Factors to be Considered on Equipment Selection:

- Type of Compressor
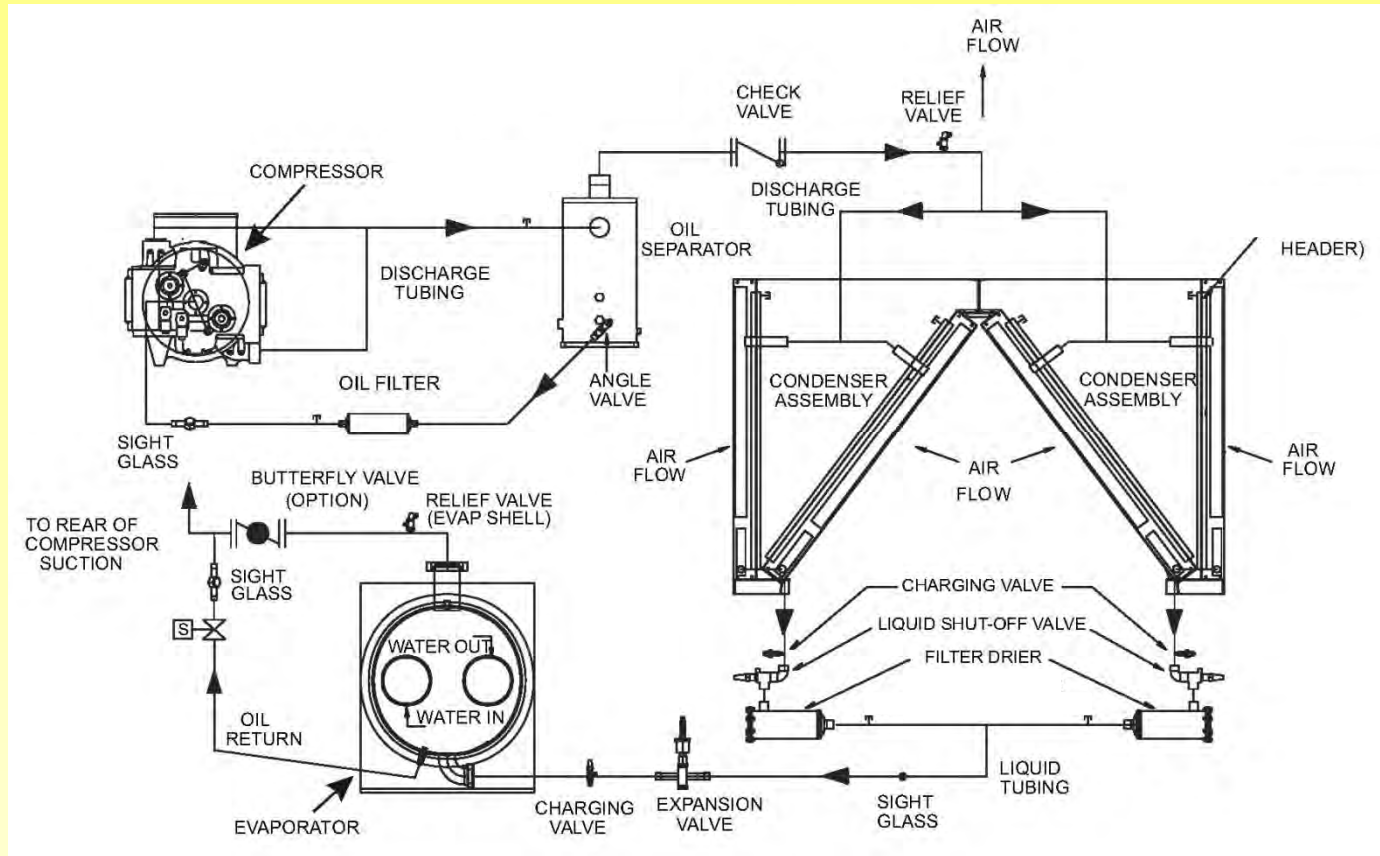
   Centrifugal compressor which is no limit in capacity and can be designed using single compressor for and cooling capacity.

6. System Components

6.1 Chiller

Air-cooled Chiller

Schematic Diagram of Air-cooled Chiller
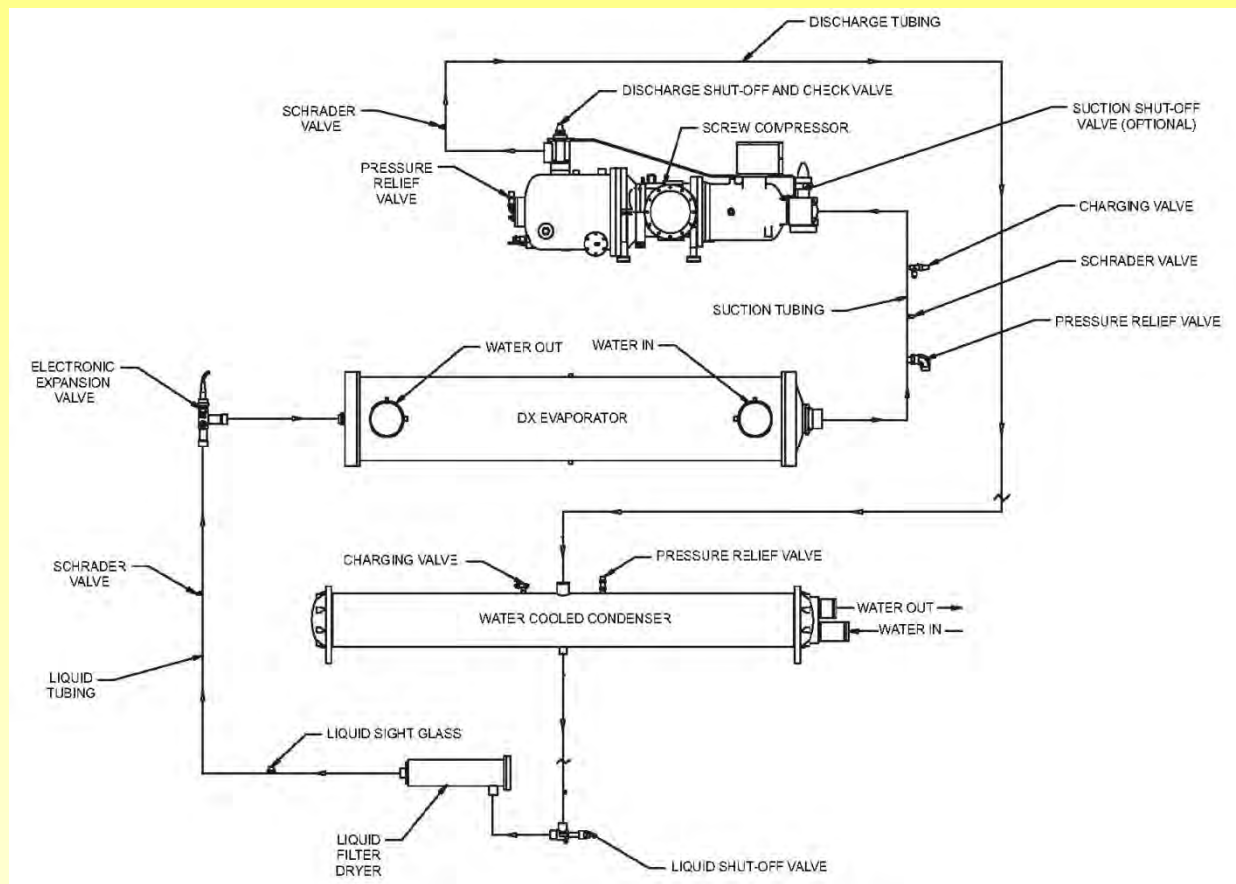
6. System Components

6.1 Chiller

Air-cooled Chiller

- Heat rejection to atmosphere directly by circulating air across the condenser.

- The condenser is constructed by copper pipe mechanically expanded to fit the aluminum fins that refrigerant run inside the pipe and air is circulating outside.

- For high corrosive environment, the condenser coil should have epoxy coating to protect the aluminum fins against corrosion or using brass fins but result in higher equipment cost.

- The condensing temperature of refrigerant must be higher than outdoor air to facilitate effective heat exchange that can take place.

- Normal condensing temperature for air cooled chiller is 45°C to suit Hong Kong climatic conditions.

- Typical chilled water supply temperature is set at 7°C.

- The condensing and chilled water temperature governs the **COP of air cooled chiller at around 3**.

6. System Components

6.1   Chiller

Water-cooled Chiller

Schematic Diagram of Water-cooled Chiller

6. System Components

6.1 Chiller

Water-cooled Chiller

- Heat rejection to atmosphere is indirectly via condenser water circulating across the shell and tube or plate type heat exchanger to absorb heat from refrigerant.

- The hot condenser water reject heat to atmosphere by evaporative cooling takes place in cooling tower.

- Since the condenser water can be cooled down to 30°C by evaporative cooling and the normal condensing temperature for water cooled chiller can be set at 35°C such that the COP can be achieved to 5.

6. System Components

6.2 Cooling Tower

The fan motor is weather-proofed and totally enclosed allowing for less noise and more efficient long-term performance.

The sprinkler pipes are sturdy PVC material pierced with closely-spaced holes allowing thorough distribution of water in a rotating spray covering the entire surface of the filler.

The round design permits maximum air intake regardless of wind direction.

Efficiency is enhanced by a low internal pressure drop.

Housing panels and water basin are built of fiberglass reinforced plastic ensuring rust-free long term performance even under the most severe environmental conditions.

The efficiently designed PVC filler creates a surface area that allows for maximum dispersion of water which creates a superior cooling effect.

A large-capacity, durable water basin constructed from rust-proof fiberglass rein-forced platic gurantees low maintenance and long-term operation.

A large diameter outlet pipe draws a constant supply of cooled water from the basin to serve the facility.

6. System Components

6.2 Cooling Tower

- Cooling tower is designed for evaporative cooling of water takes place by reject heat to atmosphere via latent heat exchange from water to air.

- The filler inside the cooling tower is increasing the wetted contact surface area to increase the heat transfer efficiency.

- Natural draft and forced draft cooling tower is available and the former commonly used in power plant whereas the later widely used in air conditioning.

- The latent heat of evaporation of 1kg of water liberate 2,400kJ of heat energy.

- The condenser water entering (T_{wi}) and leaving (T_{wo}) temperature in cooling tower is about 35°C and 30°C respectively. For 1kg of water circulating in cooling tower (m_w) which reduce in heat energy is:

    $= m_w C_{pw}(T_{wi} - T_{wo})$ where C_{pw} is Specific Heat of Water = 4.2kJ/kg

    = 21kJ (less than 1% of latent heat loss of 1kg water)

- For simplicity, loss of water in evaporation = 1% of water circulation rate.

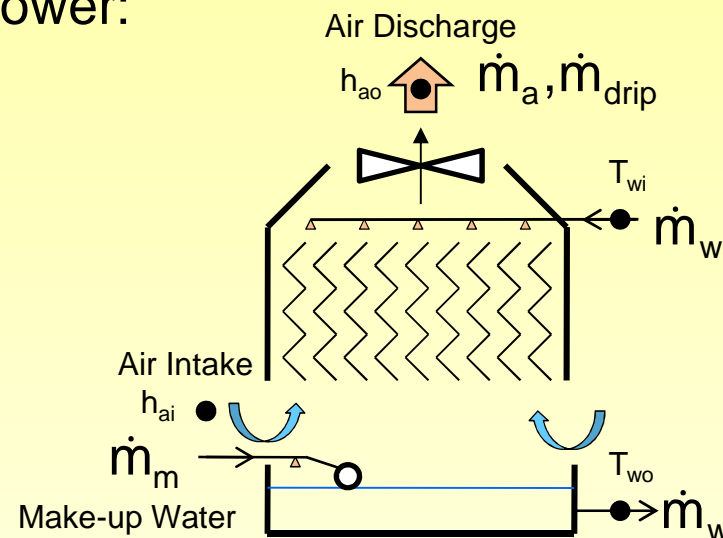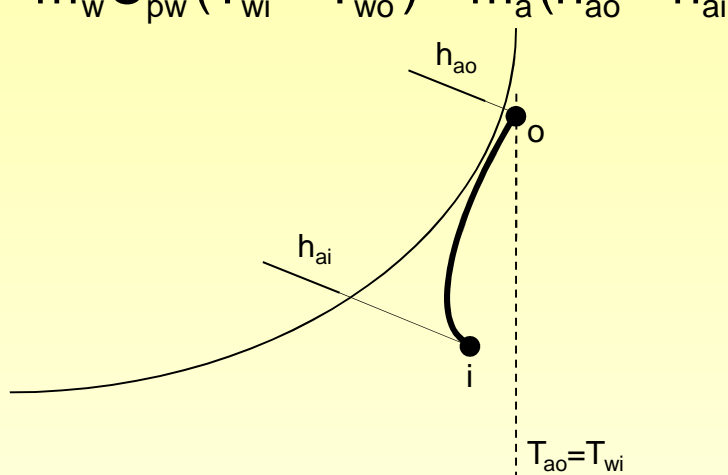# 6. System Components

6.2 Cooling Tower

Drip Loss

- Water spray on top of the cooling tower with water droplets being extracted out in the air stream which is classified as Drip Loss, $\dot{m}_{drip}$.

- It depends on cooling tower construction and air flow velocity but can be taken as 1% of the condenser water mass flow rate for system design.

Air Mass Flow Rate

- Heat balance equation of cooling tower:

$$\dot{m}_w C_{pw} (T_{wi} - T_{wo}) = \dot{m}_a (h_{ao} - h_{ai})$$

h_{ao}

o

h_{ai}

i

$T_{ao} = T_{wi}$

Air Discharge

h_{ao} $\dot{m}_a , \dot{m}_{drip}$

T_{wi}

$\dot{m}_w$

Air Intake

h_{ai}

$\dot{m}_m$

T_{wo}

Make-up Water

$\dot{m}_w$

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6. System Components

6.2 Cooling Tower

Make-up Water

- Heat balance equation of water:

$$\dot{m}_w C_{pw}(T_{wi} - T_{wo}) = \dot{m}_e h_{w-fg}$$

  where,

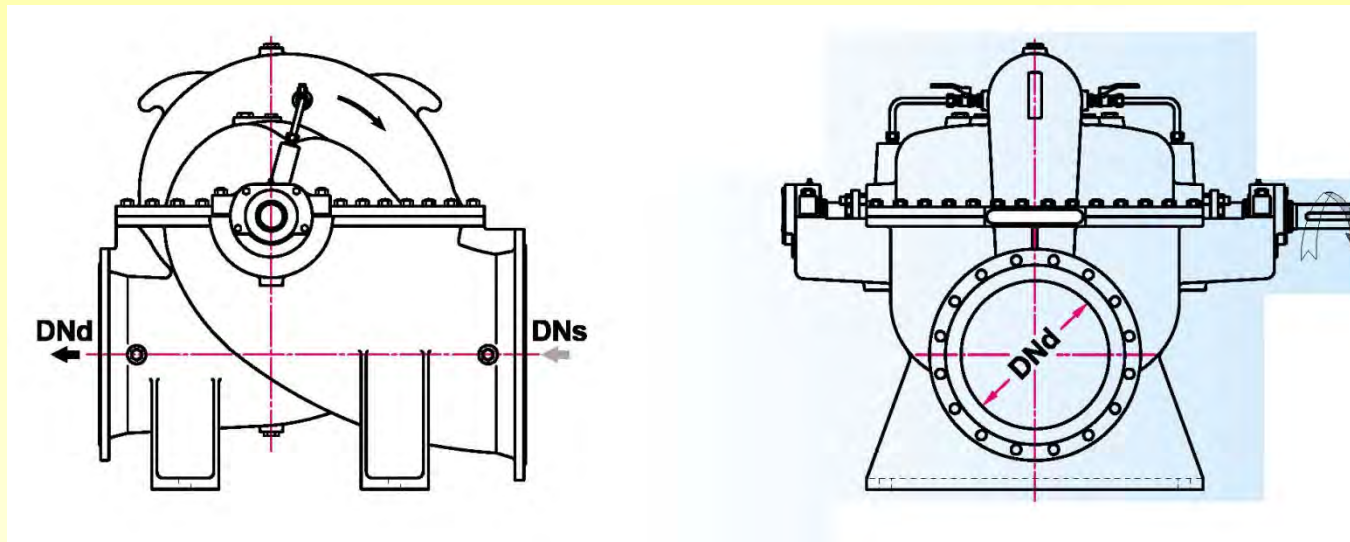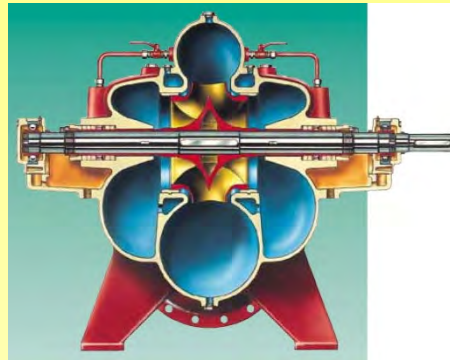 h_{w-fg} is enthalpy change of water from liquid to vapour.

- Make-up water mass flow rate:

$$\dot{m}_m = \dot{m}_e + \dot{m}_{drip}$$

$$= \dot{m}_w \left[\frac{C_{pw}(T_{wi} - T_{wo})}{h_{w-fg}} + 0.01 \right]$$

6. System Components

6.3 Pump

- It drives water within distribution piping network and increase water pressure to cater for the flow induced pressure drop within the network

6. System Components

6.4   Piping System

Pipe Friction

- Darcy Formula – Full Bore Pipe Flow

   (Chilled Water and Condenser Water Pipe)

$$\Delta P = \frac{4fl}{D} \times \frac{V^2}{2g}$$

   where,

   f is friction factor found in Moody Diagram depends on

        Reynolds Number, Re = $\rho DV/\mu$,

        Pipe roughness, ε
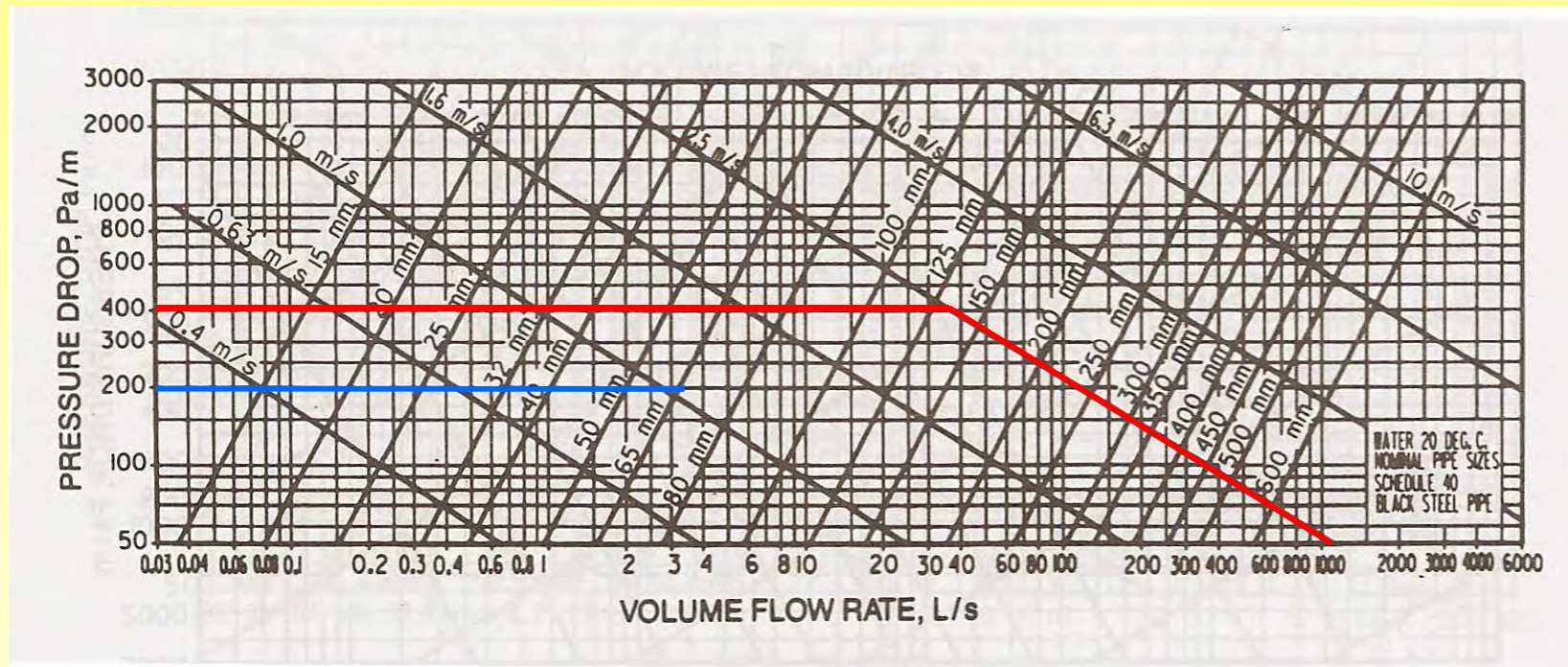
        Pipe diameter D.

   ΔP is pressure drop in (m)

6. System Components

6.4 Piping System

Chilled Water and Condenser Water Pipe

- Pressure Drop range between 200 to 400Pa/m
- Flow velocity should keep below 2.5m/s

6. System Components

6.4 Piping System

Chilled Water and Condenser Water Pipe

- Total Pressure Drop in piping and fittings,

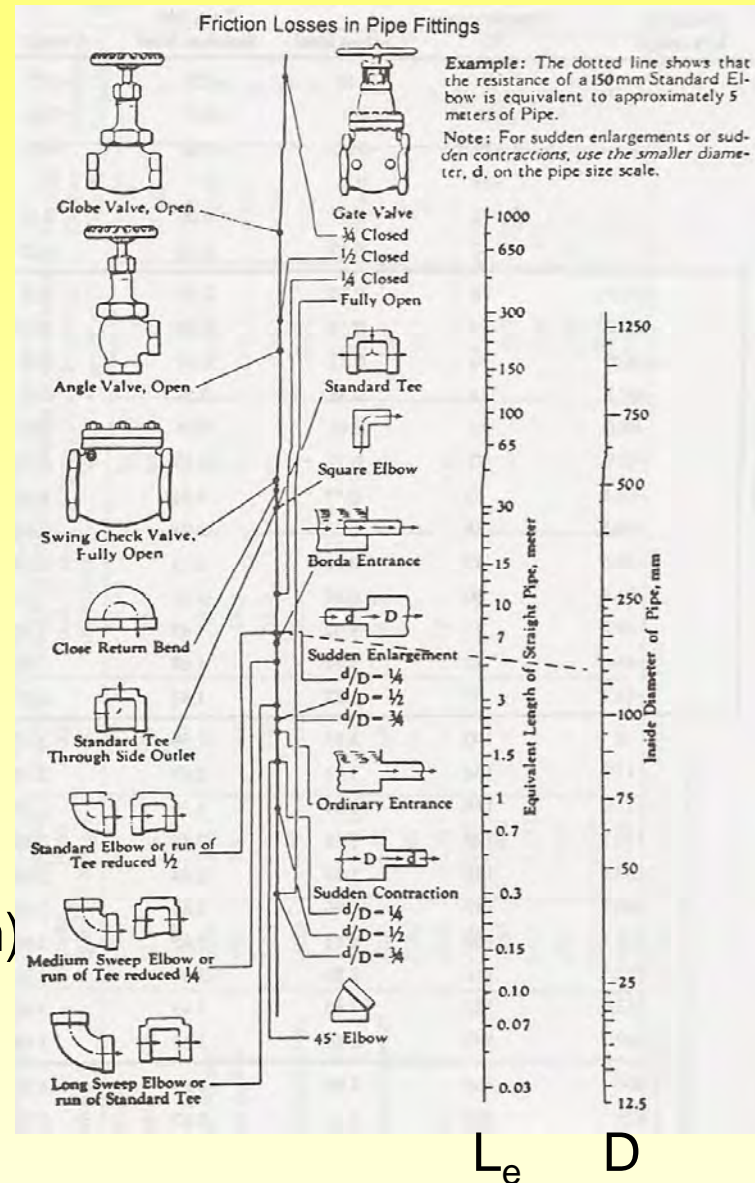$$P_{f-pipe} = (L + \sum L_e) \times \left(\frac{\Delta P}{L} \right)$$

where,

L is length of pipe (m)

$\left(\dfrac{\Delta P}{L} \right)$ pressure drop per meter

length (Pa/m)

L_e is equivalent length of fittings (m)

Friction Losses in Pipe Fittings

Example: The dotted line shows that the resistance of a 150 mm Standard Elbow is equivalent to approximately 5 meters of Pipe.

Note: For sudden enlargements or sudden contractions, use the smaller diameter, d, on the pipe size scale.

L_e D

6. System Components
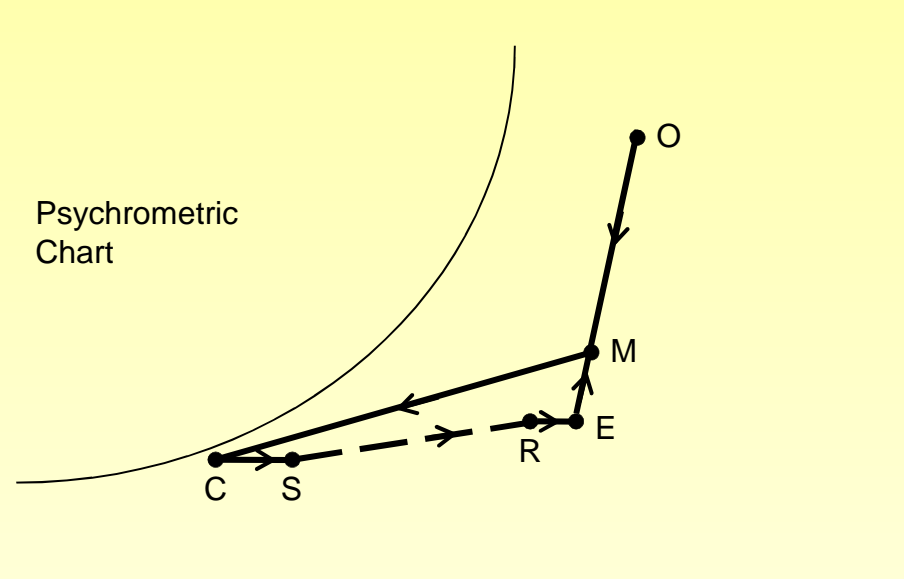
6.4 Piping System

Condensate Drain Pipe

- Mass flow rate of condensate,

$$\dot{m}_{cond} = \frac{\dot{V}_S}{v_C}(w_M - w_C)$$

- Knowing the mass flow rate and with condensate drain pipe gradient set at 1 : 100, pipe size can be determined by Colebrook-White Equation.

Psychrometric Chart

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6. System Components

6.4   Piping System

Condensate Drain Pipe

- Alternatively, condensate drain pipe can be sized by the cooling capacity of unit being served. Typical figures can be found from table below:

Pipe Size	Connected Cooling Load In Tons														
	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
¼"	Not Recommended														
⅜"	Not Recommended														
½"	Not Recommended														
¾"	Up to 2 Tons Connected Cooling Load														
1"	Up to 5 Tons Connected Cooling Load														
1¼"	Up to 30 Tons Connected Cooling Load														
1½"	Up to 50 Tons Connected Cooling Load														
2"	Up to 170 Tons Connected Cooling Load														
3"	Up to 300 Tons Connected Cooling Load														
4"	Up to 430 Tons Connected Cooling Load														
5"	Up to 700 Tons Connected Cooling Load														

Note: Where horizontal runs are employed with a pitch of less than 1" per 10 ft. — increase the above values one pipe size.

6. System Components

6.5 Fan

- It drives air in ducting system that air is transporting from one place to another or circulating within the space. There is an increase in air pressure to cater for flow induced pressure drop within the distribution system.

- Typical fan duct system:

Intake
Louver   Filter   Fan   Damper

Ducting & Fittings

Diffuser
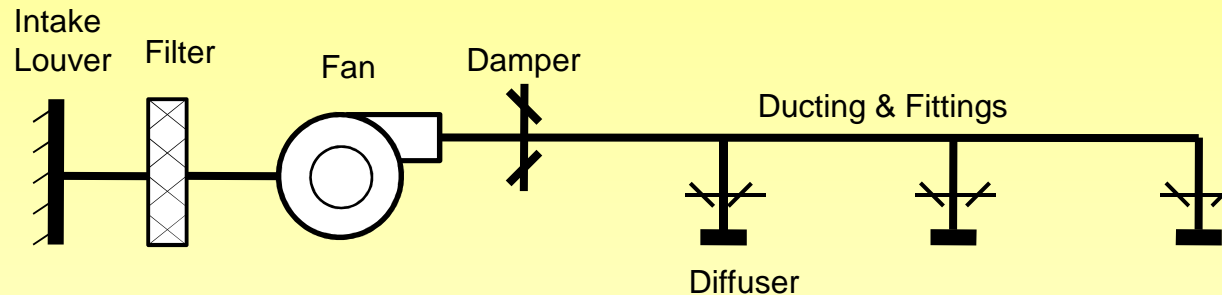
Basic Selection Criteria

- Type of Fan – Axial, Centrifugal, Propeller

- Air Flow Rate

- Pressure Differential

- Size of Equipment

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6. System Components

6.6 Air Duct

- For distribution and/or circulate air in a conditioned space in a controlled manner.

- Fire damper shall be provided for air duct passes through fire compartment wall or floor slab to maintain the integrity of fire compartment.

- In some critical area, smoke fire damper is required for smoke control as well.

- Shape of air duct can be round, oval or the commonly used rectangular.

- For rectangular duct, the aspect ratio (Width / Height) should better be maintained at not more than 4 to optimize the flow induced pressure drop.

Round Duct

Rectangular Duct

H

W

Oval Duct

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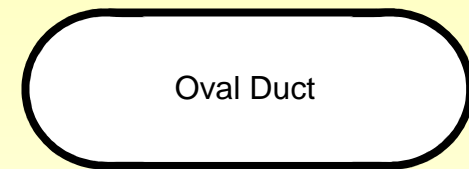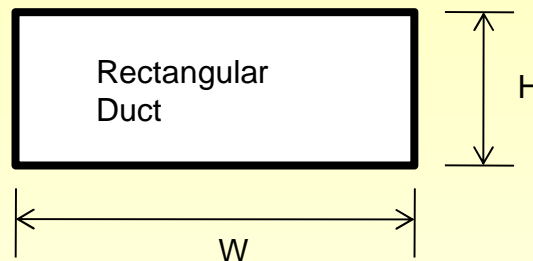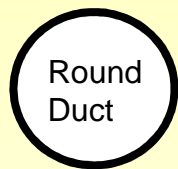
6. System Components

6.6   Air Duct

Duct Velocity (Recommended by CIBSE Guide C Table 4.34)

- Low Velocity Air Duct System – 3 to 6m/s.

- High Velocity Air Duct System – 7.5 to 15m/s

- However, due to space constrain, the main duct velocity in Low Velocity System will be up to 8m/s whereas kitchen exhaust will be up to 10m/s or above.

Application	Main Duct Velocity	Branch Duct Velocity	Final Duct Velocity
Private Office, Library	6.0	5.5	3.0
General Office, Restaurant, Bank	7.5	6.0	3.5

(Figures extracted from CIBSE Guide B3 Table 3.1)

6. System Components

6.7   Air Handling Unit

- For processing air circulating within conditioned space that house all components within a unit that can compose of the following:
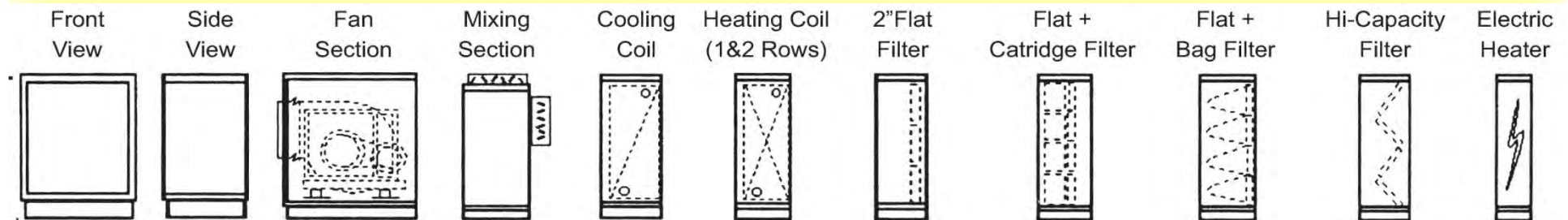
  Filters

  Cooling Coil

  Heating Coil

  Humidifier

  Fan, etc.

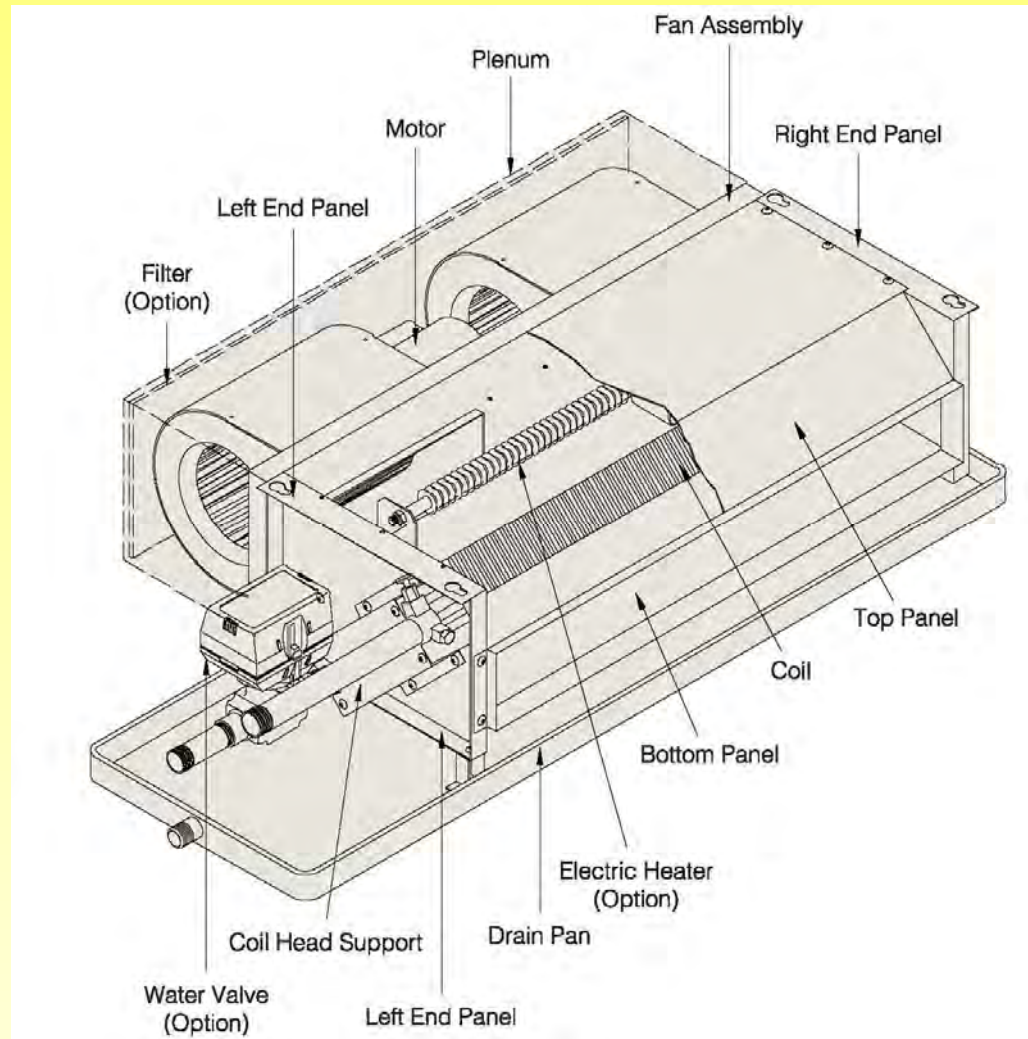| Front View | Side View | Fan Section | Mixing Section | Cooling Coil | Heating Coil (1&2 Rows) | 2"Flat Filter | Flat + Catridge Filter | Flat + Bag Filter | Hi-Capacity Filter | Electric Heater |

Modular Type Air Handling Unit

- There is no limit in capacity provided that there is no space constrain on equipment installation

6. System Components

6.8   Fan Coil Unit

Fan Assembly

Plenum

Motor

Right End Panel

Left End Panel

Filter (Option)

Top Panel

Coil

Bottom Panel

Electric Heater (Option)

Coil Head Support

Drain Pan

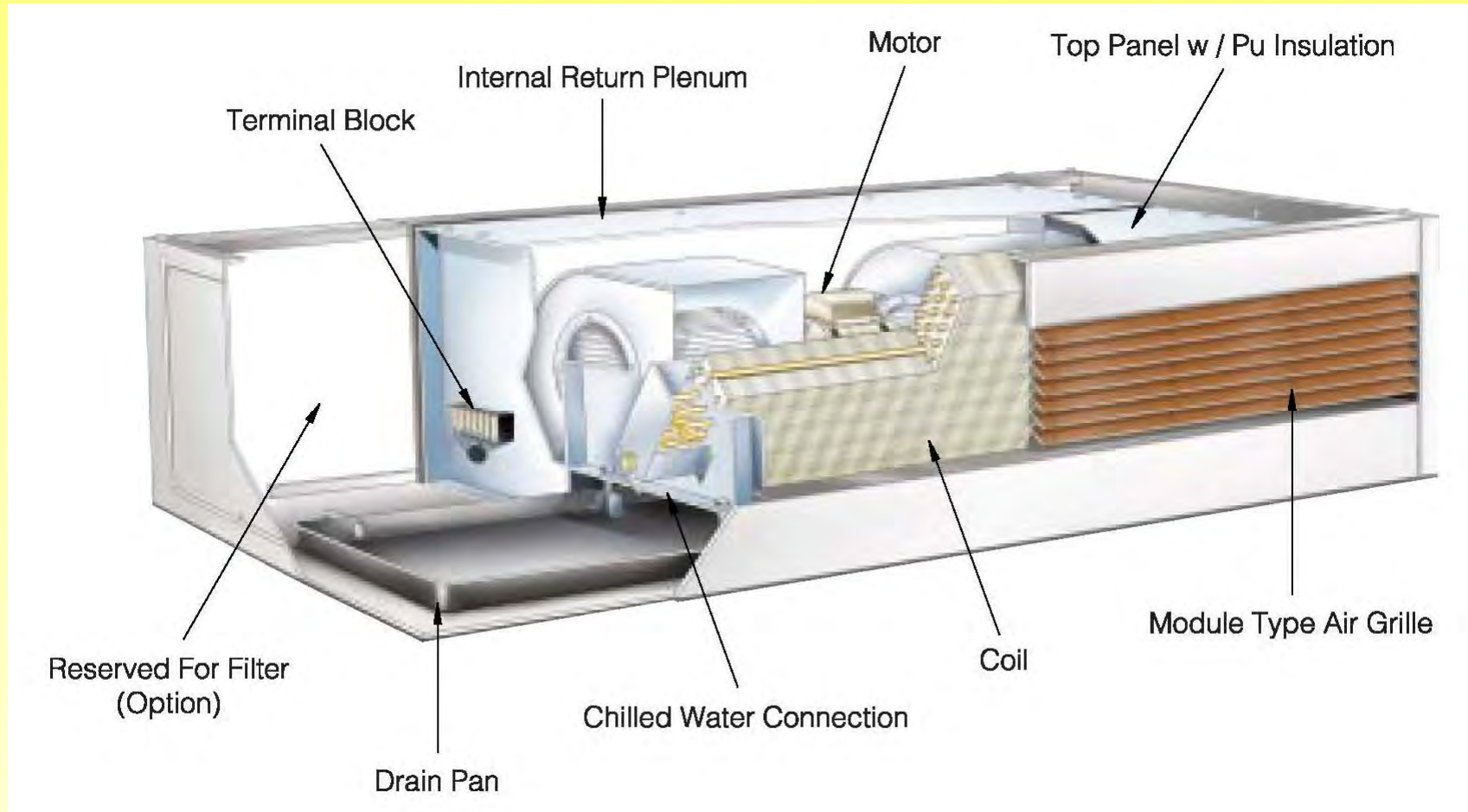Water Valve (Option)

Left End Panel

Ceiling Recessed Type

6. System Components

6.8 Fan Coil Unit

Ceiling Exposed Type

6. System Components

6.9   Terminal Unit – VAV Box

Acoustic Lining

Flow
Sensor

Damper

Upstream From
Supply Air Duct

Downstream To
Slot Diffuser

Controller

False Ceiling

Space Temperature
Sensor and Controller
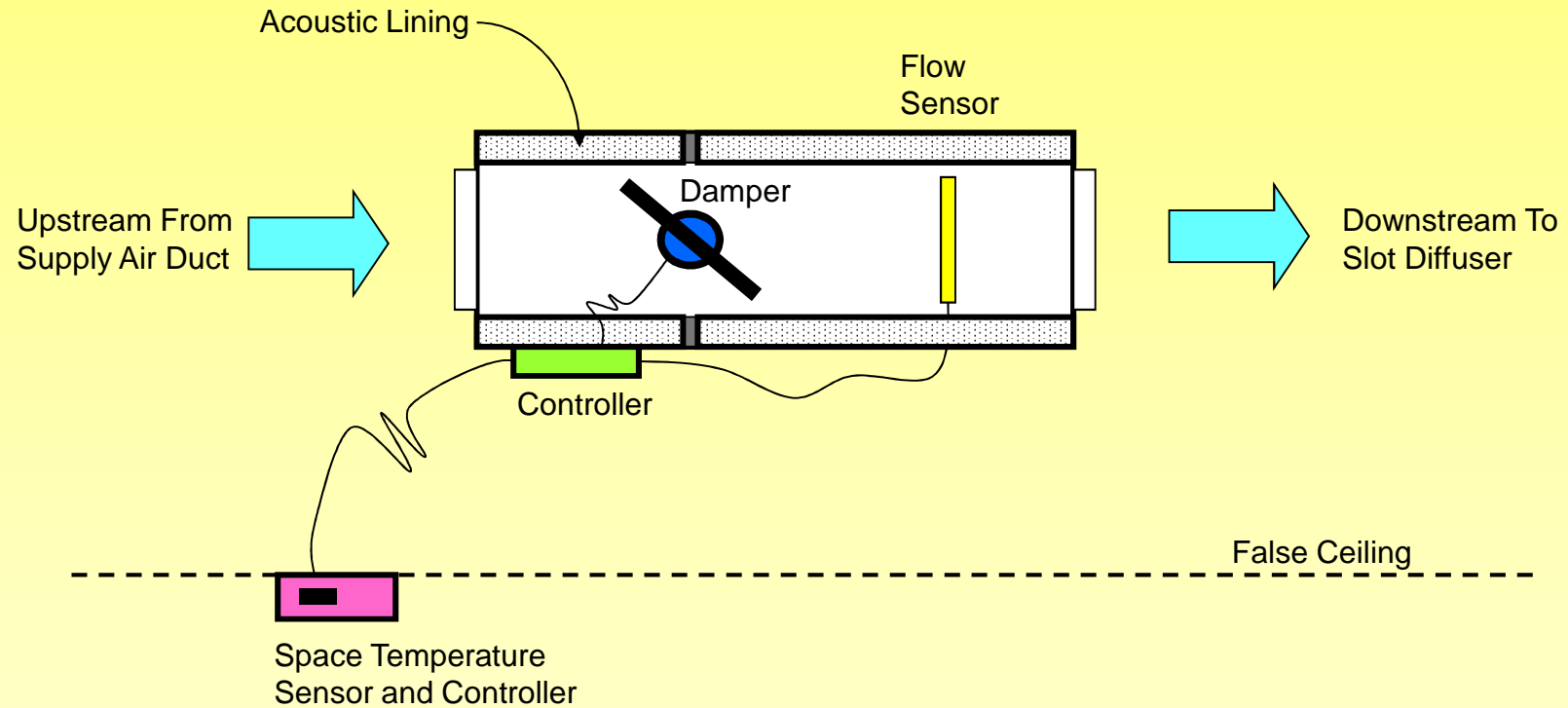
6. System Components

6.9   Terminal Unit – VAV Box

- The control set point if the room temperature for temperature control only.

- Controller regulate the supply air flow rate to achieve the control set point.

- A flow sensor at downstream of the damper provide feedback signal to the controller to reflect the actual supply flow rate.

6. System Components

6.10 Diffuser / Louver

- Diffuser is used to supply air to a conditioned space such that preferred flow pattern is achieved.

- Louver is used for air intake or discharge in which weatherproof type shall be used at building perimeter that will subject to weather conditions thus avoid water ingress into the ducting system.

- The flow velocity at diffuser / louver shall be maintained for thermal comfort and achieving acoustic requirement.

Application	Critical	Normal	Uncritical
Supply	1.5	2.5	3.0
Return	2.0	3.0	4.0

(Figures extracted from CIBSE Guide B3 Table 3.4)

6. System Components

6.10 Diffuser / Louver

Square Diffuser

- Suitable for office application installed with false ceiling such that supply air will stick along false ceiling soffit thus achieve high servicing distance.

Linear Diffuser

- Provide downward or inclined flow pattern which depends on angle of blade being selected.

- The width can be as small as 100mm and can be tailor made to suit the ceiling curvature that is it is widely used to suit the ceiling pattern designed by interior designer.

Register

- Suitable for supply air flow required minor adjustment in flow direction(s) that the blade angle can be adjusted manually.

6. System Components

6.10 Diffuser / Louver

Slot Diffuser

- It is utilized in VAV system because of satisfactory flow pattern can be achieved when the supply air flow is low.

Jet Nozzle

- Normally used in the perimeter of Atrium because the supply air can be jet at low level at a predesigned throw distance.

- For Atrium with its high ceiling height is expected, supply air vertically downward is ineffective and jet nozzle is a preferred option.

6. System Components

6.11 Air Filter

Viscous Filter

- Surface of the filtering media is coated with a layer of the viscous oil that dust particulate is stick over when air stream passing through. It is suitable for industrial application.

- Cell Type – Chips of filtering media embedded in a frame that replacement is required if duct hold down capacity reduced to unacceptable level.

Air Flowing Over

Chips coated with Viscous Oil

Dust Particulate Stick Over

Filter Cell

Air with Dust Particulate
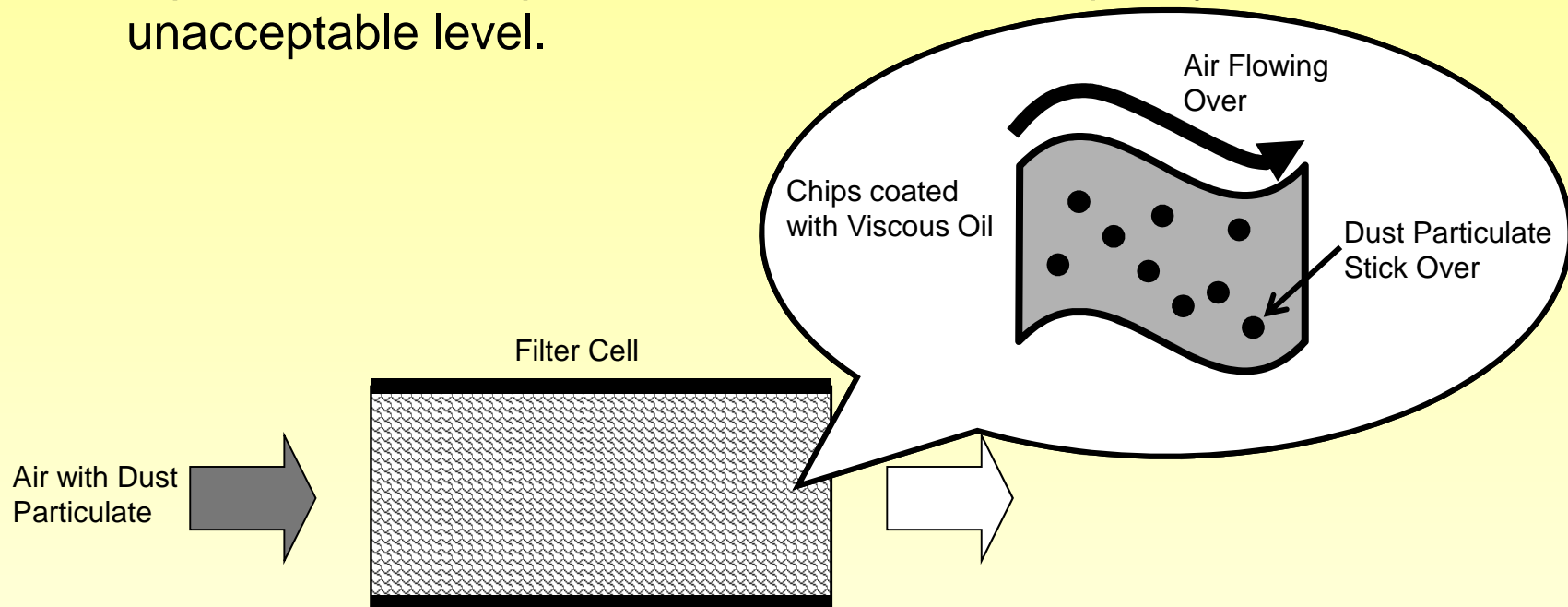
6. System Components

6.11 Air Filter

Viscous Filter

- Automatic type – Rolling belt fixed with free rotating blade that immerse in the basin of viscous oil to washout the accumulated dust and refresh the viscous oil over the blade surface for next filtering cycle.

Free Rotating Blade

Oil Basin
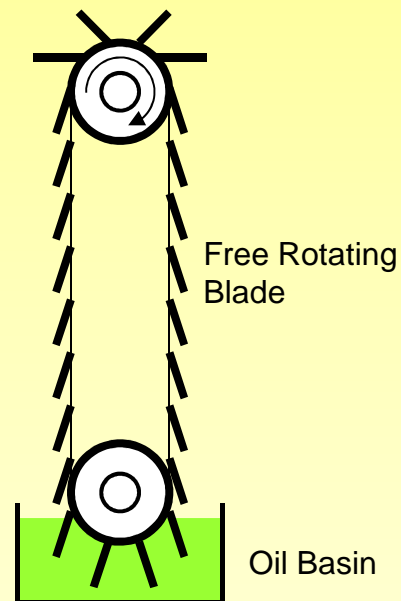
6. System Components

6.11 Air Filter

Dry Filter - Washable Filter

- The filtering media is aluminum wire that is washable for removing dust being trapped inside. Frequently used in HVAC system for air filtering in fan coil unit or pre-filter in air handling unit.

- Filtering efficiency can be 50 to 65%.

6. System Components

6.11 Air Filter

Dry Filter - Disposable Type Filter

- Modular or cell type which using cotton-wool or fiberglass as the filtering media. The dust hold down capacity is very large and filtering efficiency can be as high as 80 - 95% even higher.

- The filtering media normally installed in V shape to increase its contact surface area with some of them inserted with corrugated metal sheet to maintain air passage area thus minimize system pressure drop.
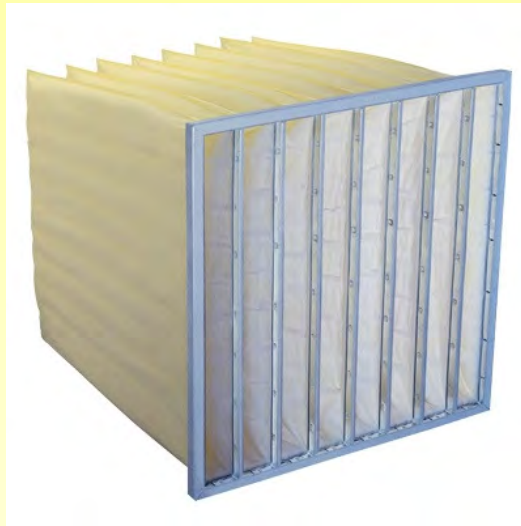

V-Shape Bag Filter

Filter with Corrugated Metal Sheet

6. System Components

6.11 Air Filter

Electric Filter – Electrostatic Precipitator

- As air enters the electrostatic precipitator, the particles pass through an electrical field that gives an electrical charge to the particles.

- The charged particles pass through a series of alternately charged collector plates.

- Particles are repelled by plates with the same polarity and attracted to plates with opposite polarity.
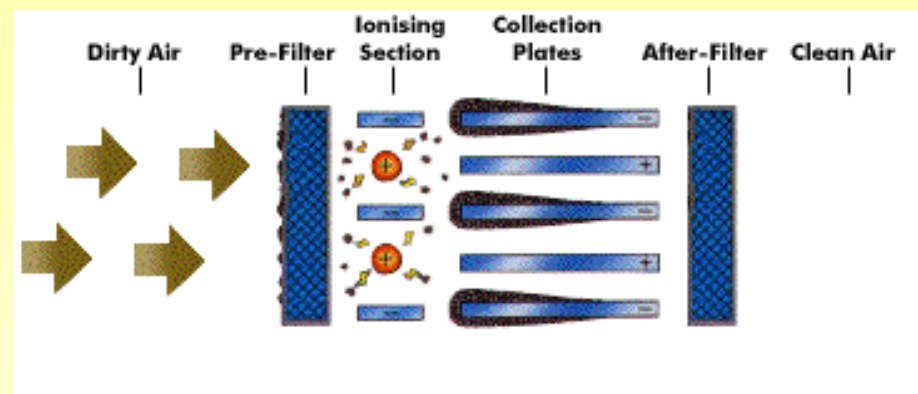
Working Principle of Electrostatic Precipitator

6. System Components

6.11 Air Filtration

Absorption Filter

- It uses water to absorb the water soluble gas in the air stream which is classified as pollutant.

- In parallel, dust particles and suspended particulate will be washing out as well that's widely used in kitchen exhaust for reduction of pollutant concentration.

- Chemical reaction will take place in the absorption process.

- It can be as simple as having a chamber with water spray and air passing through for pollutant removal.

6. System Components

6.11 Air Filtration

Adsorption Filter

- No chemical reaction will take place and is purely a physical process.

- Activated carbon that adsorb the gaseous pollutant contribute to odour.

- It is frequently used in Refuse Room for odour removal and is effective for cigarette smoke as well.

6. System Components

6.12 Thermal Insulation

- To minimize the heat transfer of water pipes and air duct to the surrounding by wrapping a layer of material with low thermal conductivity, k (W/mK).

- To maintain the temperature at the outer surface of thermal insulation to a level higher than the dew point temperature of the surrounding air thus avoid condensate appeared over the surface

- Vapour barrier shall be provided to main the air tightness of the outer surface of thermal insulation especially at the junction of insulating materials. The ingress of air in contact with cold surface will result in damping of thermal insulation thus increase in thermal conductivity that break the function of thermal insulation.

6. System Components

6.12 Thermal Insulation

- The following is table showing the commonly used thermal insulation and its surface characteristics.. Special attention shall be drawn on thermal insulation in exposed weather condition and inside plant room will be finished by cement sand plaster to protect against mechanical damage as well as deteriorated by sunlight radiation.

Type	Surface Finish	Characteristic	Remark
Fiberglass	Aluminum Foil	Highly Absorb Water	
Phenoic Foam	Aluminum Foil	Absorb Water	
Polystyrene	Bare	Flammable	Cement plaster shall be applied over external surface
Elastomer	Bare	Slightly Absorb Water	Avoid direct sunlight exposure otherwise anti-UV paint should be applied

6. System Components

6.12 Thermal Insulation

- In pipe or duct support location, high density type thermal insulation shall be used and using metal strip to spread the loading may required to avoid squeezing of the thermal insulation.

- Thermal insulation should not pass through the fire compartment wall or floor slab unless a fire collar is installed to hinder the fire propagation through the gap for thermal insulation.

6. System Components

6.13 Chemical Treatment

- By adding chemicals into chilled water, hot water and condenser water at the desired concentration to inhibit Corrosion, Scale and Biological growth.

- For hot water and condenser water system, chemically shall be added to prevent legionnaire disease control.

- Periodic water sample check is required to ensure the desired chemical concentration is being maintained.

6. System Components

6.14 Feed and Expansion System

- Water changes its temperature will changes its volume according to its change in density.

- Feed and expansion tank is required as a buffer to retain or replenish the volumetric change of water in distribution network against temperature change.

- Tank can be closed type (Pneumatic tank) or open type (Water Tank located above the topmost terminal unit)

- The change in water volume, ΔV (m³), can be determined by:

$$\Delta V = M_W \times (v_1 - v_2)$$

    where,

    M_W is total weight of system water (kg)

    v_1 is specific volume of water at initial water temperature (m³/kg)

    v_2 is specific volume of water at final water temperature (m³/kg)

- Tank effective volume shall sufficient to take up ΔV.

6. System Components

6.15 Automatic Control

- Automatic control covers from the chiller plant to as small as a single fan coil unit should be provided to maintain the system in desired operating conditions as well as energy management.

  Example 1

- Chiller plant should be automatically controlled to suit the cooling load demand.

- Sequencing can be adopted to optimize the operating life of the equipment.

- Energy management can be included to optimize the chiller operating efficiency but one should know the cooling load history for system design.

6. System Components

6.15 Automatic Control

Example 2

- Chiller Start Sequence

    1) Start the chilled water pump.

    2) Open the motorized valve at downstream of chiller for chilled water pass through.

    3) If **sufficient** chilled water flow is detected by the flow meter, chiller can be started.

    4) The chiller capacity and operating characteristic will be adjusted by its built-in chiller control to maintain the preset chilled water supply temperature.

6. System Components

6.15 Automatic Control

Example 2

- Chiller Stop Sequence:
    1) Stop the chiller.
    2) **Continue** operate the chilled water pump for a short period (say 5 minutes) for the residual liquid refrigerant at evaporator to absorb heat from chilled water.
    3) Close the motorized valve at downstream of chiller.
    4) Stop the chilled water pump.

- For water cooled chiller, similar approach for condenser water pump, cooling tower shall be applied

7. References

7.1   Building Service and Equipment - F Hall (Pearson Publishing)

7.2   ASHARE – Fundamentals

7.3   CIBSE Guide A, B & C

7.3   Air Conditioning Engineering – W.P. Jones (ELBS)