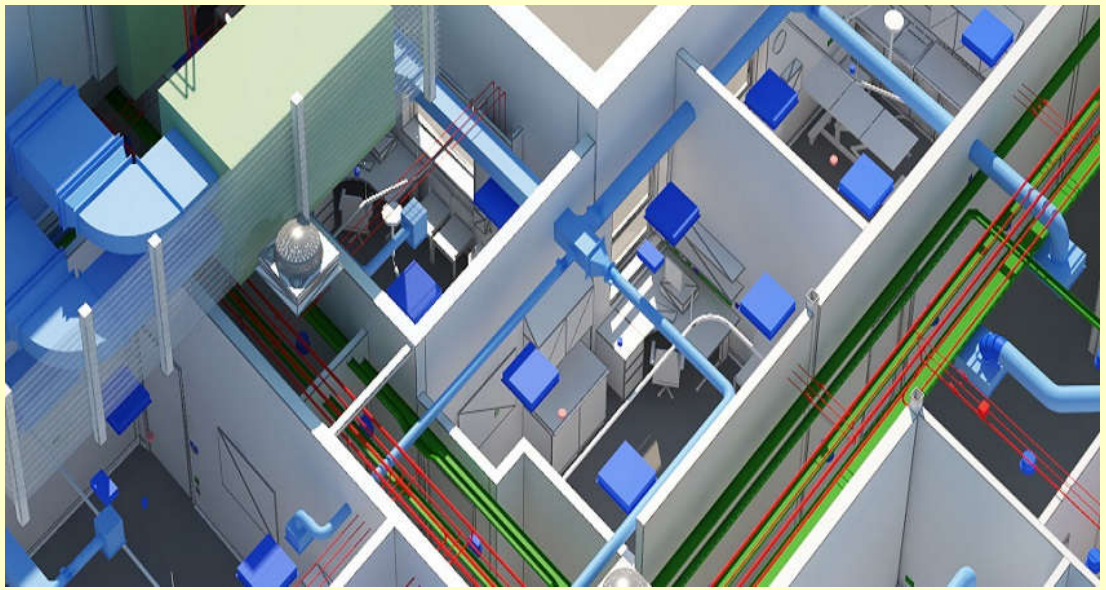


5. HVAC Part 1

5.1 Basic principles and practice

Ir Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

May 2021

Contents 內容

- HVAC fundamentals 暖通空調基礎知識
- Psychrometry 測濕學
- Thermal comfort 熱舒適度
- Load estimation 負荷估算
- Examples of HVAC systems 暖通空調系統示例

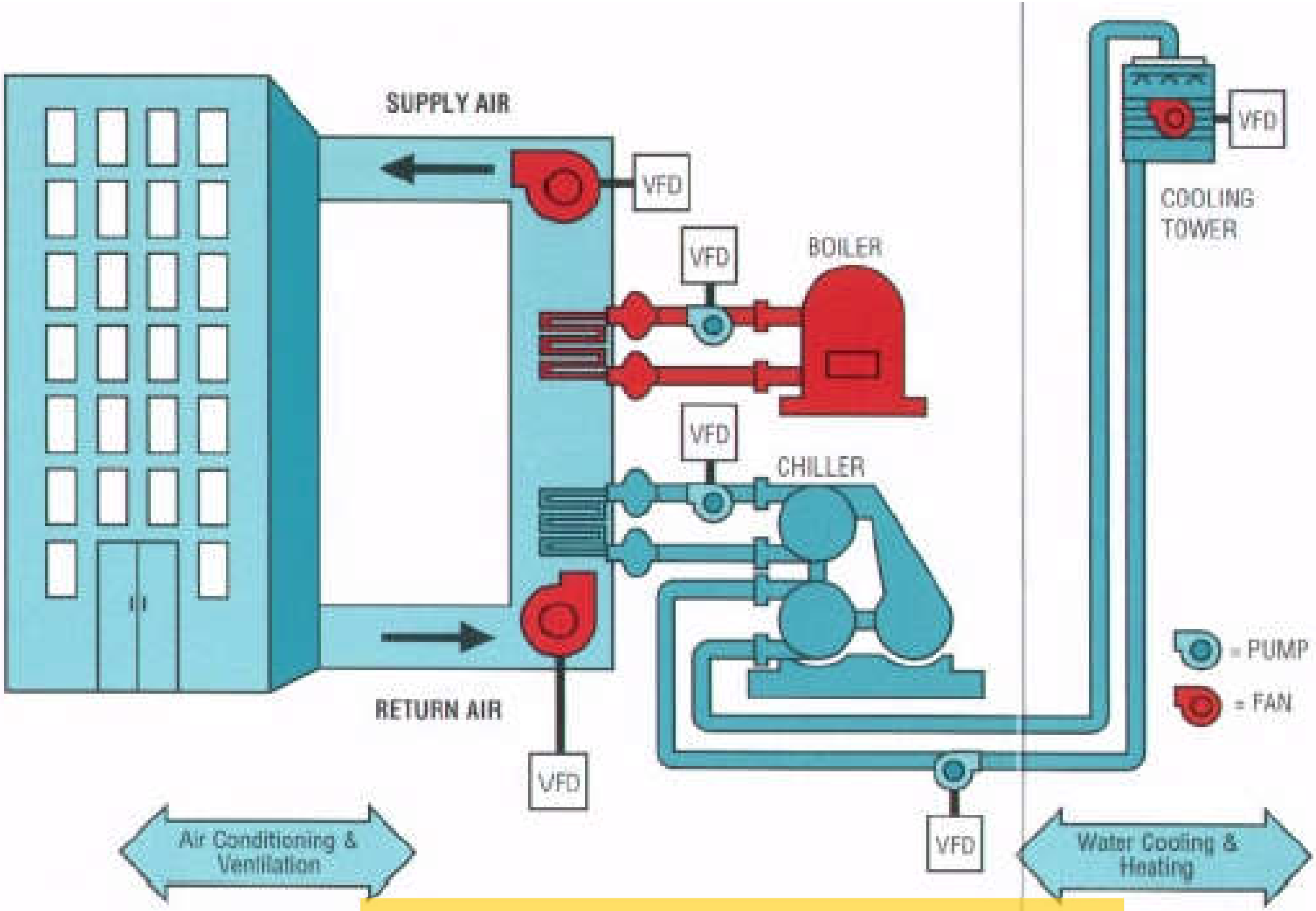
HVAC fundamentals

- What is HVAC&R?
  - HVACR is an acronym or abbreviation for the products and services related to the functions of:
  - **H**eating 採暖
  - **V**entilation 通風
  - **A**ir-**C**onditioning 空調
  - **R**efrigeration 製冷

HVAC fundamentals

- They are the engineering systems that help to control and maintain the conditions of indoor built environment
- Also known as:
  - Environmental control systems (ECS)
  - Heating, ventilating, air-conditioning and refrigerating (HVAC&R) systems
  - Heating, ventilating and air-conditioning (HVAC)
  - Mechanical ventilating and air-conditioning (MVAC)
  - Air conditioning and refrigeration (AC&R)

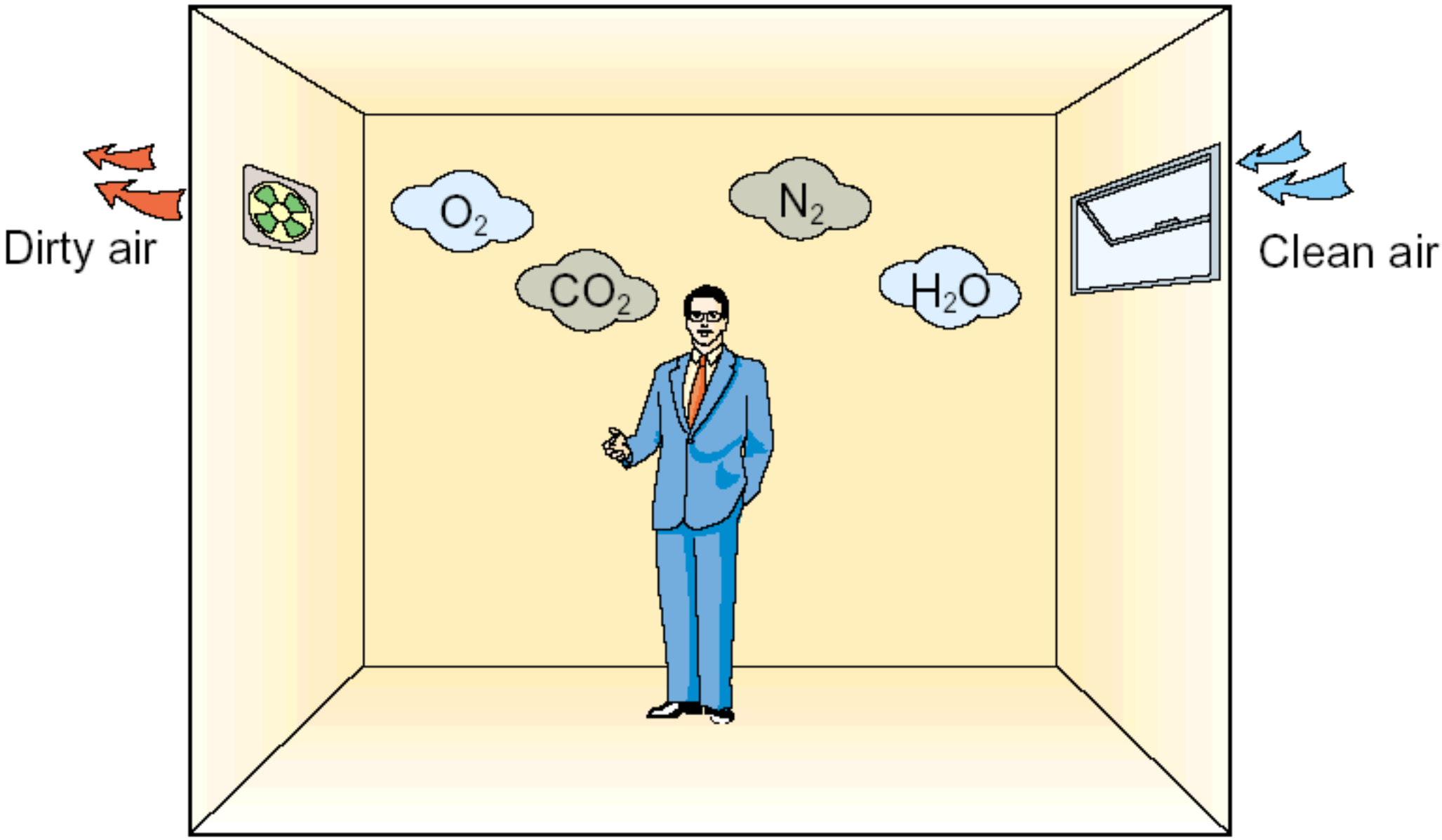
Example of a centralised HVAC system



Do you know the HVAC components?

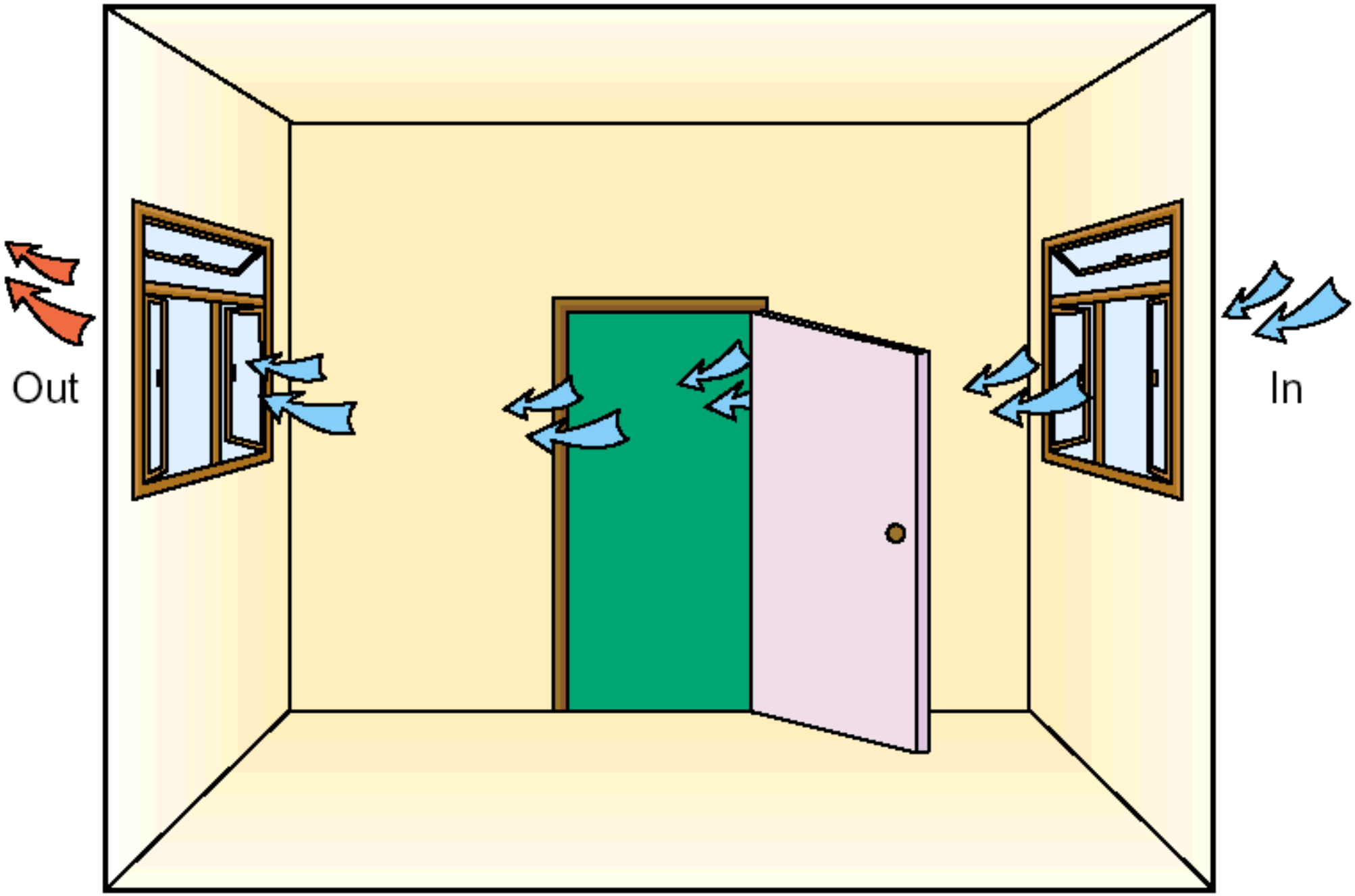
(Source: http://www.allhvacinfo.com/)

Simple ventilation design



(Source: www.iaq.hk)

Cross ventilation (natural)



(Source: www.iaq.hk)

Cross ventilation (mechanical assisted)

(Source: www.iaq.hk)

HVAC fundamentals

- The term “air conditioning” has gradually changed, from meaning just cooling to the total control of:
  - Temperature
  - Moisture in the air (humidity)
  - Supply of outside air for ventilation
  - Filtration of airborne particles
  - Air movement in the occupied space

“冷氣”

▼

“空氣調節”

“空調”

(See also: Air conditioning http://en.wikipedia.org/wiki/Air_conditioning)

HVAC fundamentals

- Definition (from ASHRAE*)
  - Air conditioning is the process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.
    - Basic processes: Cooling and Heating
- Comfort cooling (air conditioning)
  - To meet comfort requirements of occupants

(*ASHRAE = American Society of Heating, Refrigerating & Air-conditioning Engineers, Inc.)

HVAC fundamentals

- Seven main air-conditioning processes:
  - 1. Heating (adding thermal energy)
  - 2. Cooling (removing thermal energy)
  - 3. Humidifying (adding moisture)
  - 4. Dehumidifying (removing moisture)
  - 5. Cleaning (removing particulates/contaminants)
  - 6. Ventilating (exchanging air between the outdoors and the conditioned space)
  - 7. Air Movement (circulating and mixing air)

HVAC fundamentals

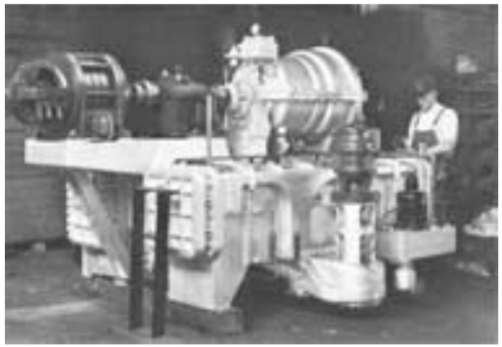
- The History of Air Conditioning
  - http://www.air-conditioners-and-heaters.com/air_conditioning_history.html
    - 1830: Dr. John Gorrie (ice for cooling hospital rooms)
    - 1881: James Garfield (device w/ melted ice water)
    - Late 19th century: “manufactured air” (controlling humidity in textile mills)
    - Early 1900s’: Willis Carrier (designed modern A/C systems for offices, apartments, hotels, hospitals)
    - 1917-1930: movie theatres were kept cool by A/C

(Video: Air Conditioning History (1:09) https://youtu.be/6NFmsU3Am7c)

HVAC fundamentals

- The Father of Modern Air Conditioning
  - Dr. Willis Haviland Carrier (1875-1950)

  - Formed Carrier Air Conditioning Company (1907)
  - Published a paper on rational psychrometric formulae in 1911
  - Invented and patented many HVAC equipment
  - Wrote a well-known air conditioning textbook



(Video: Air Conditioning History (5:31) https://youtu.be/rf5okqLX-Uo)

HVAC fundamentals

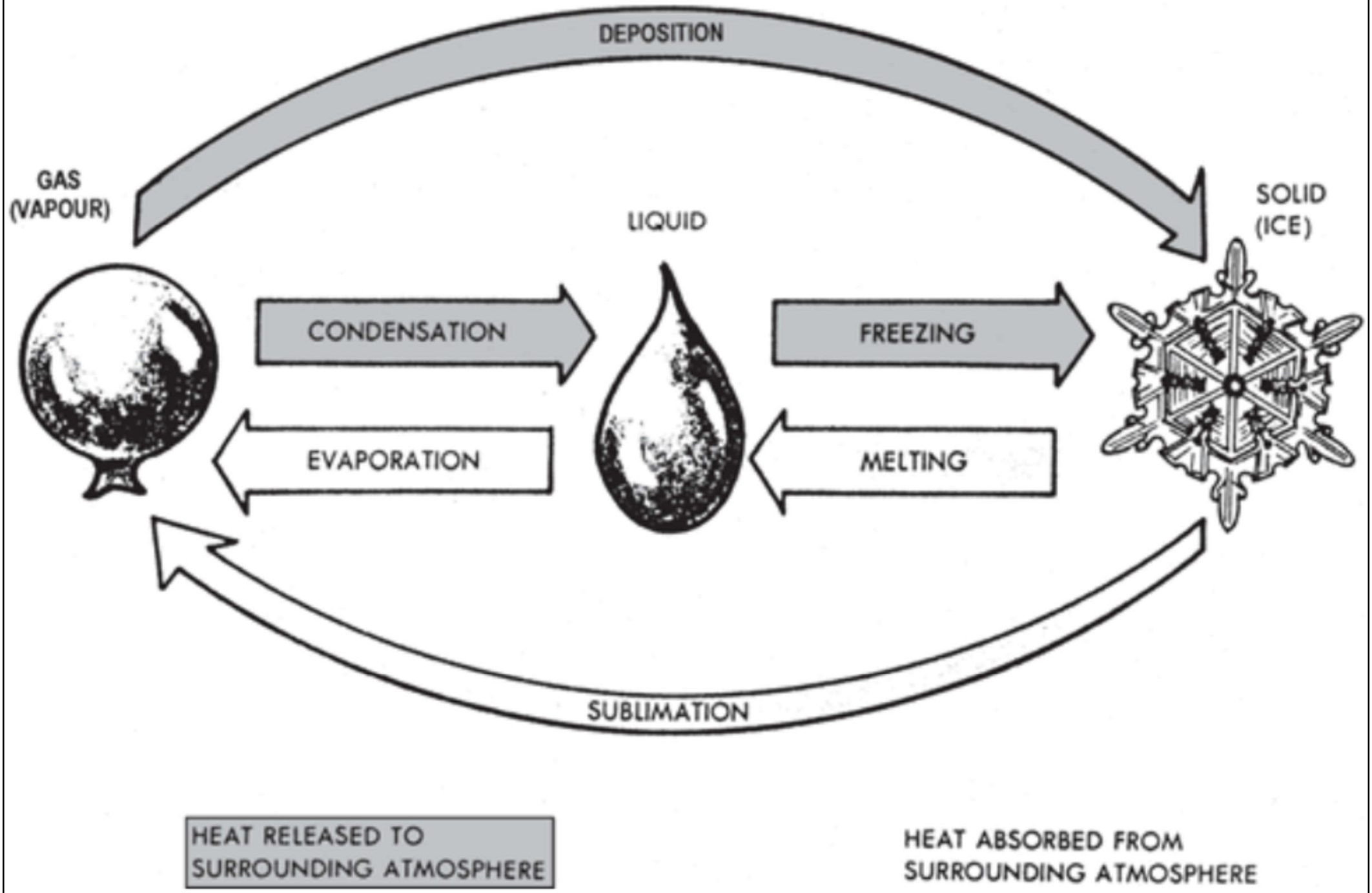
- Applications of air conditioning:
  - Industrial sector
    - e.g. textile mills, electronics, pharmaceutical
  - Commercial sector
    - e.g. offices, hotels, retails
  - Residential sector
    - e.g. apartments, houses
  - Transport sector
    - e.g. aircrafts, buses, private cars, trains

Psychrometry

- Psychrometry (測濕學)
  - The measurement or study of the thermodynamic properties of moist air (dry air + water vapour)
    - The Greek term psuchron (ψυχρόν) meaning "cold" and metron (μέτρον) meaning "means of measurement"
  - Moist air properties:
    - Ideal gas laws: Dalton's law of partial pressures
    - Standard atmospheric pressure = 101.325 kPa
    - Saturated vapour pressure: Max. pressure of water vapour that can occur at any given temperature

(See also: Psychrometrics - Wikipedia http://en.wikipedia.org/wiki/Psychrometrics)

Phase change processes for H_2O



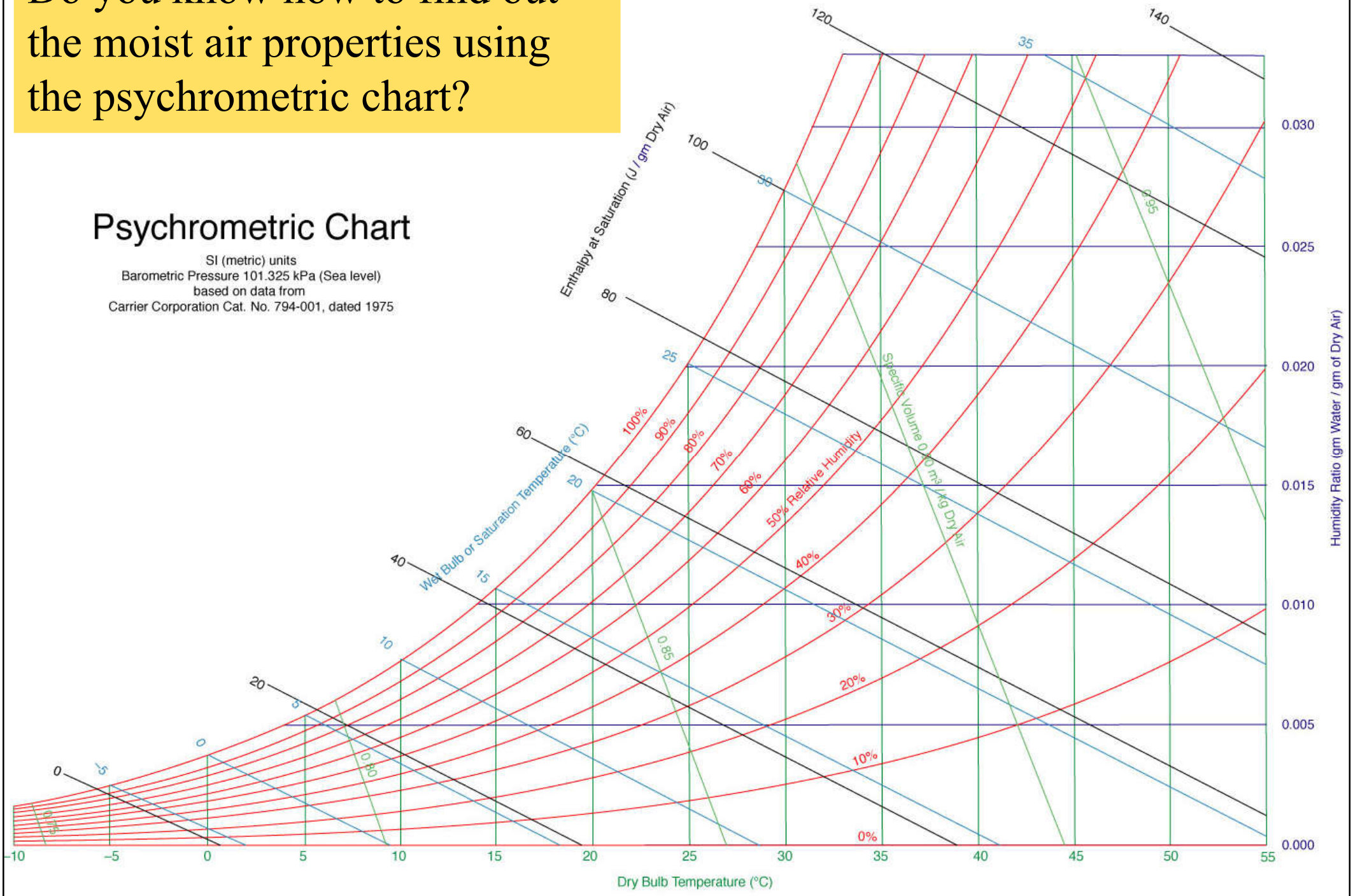
(Source: Gatley, D. P., 2013. *Understanding Psychrometrics*, 3rd ed.)

Psychrometry

- Psychrometric chart (空氣濕度線圖)
  - A tool for understanding the relationships between the various parameters of supply air and the relative humidity
    - Can be used to assess the physical and thermodynamic properties of gas-vapour mixtures at a constant pressure
  - Learning to use psychrometric chart
    - Identify parts of the chart
    - Determine moist air properties
    - Use chart to analyse processes involving moist air

(See also: https://www.designingbuildings.co.uk/wiki/Psychrometric_charts)

Do you know how to find out the moist air properties using the psychrometric chart?

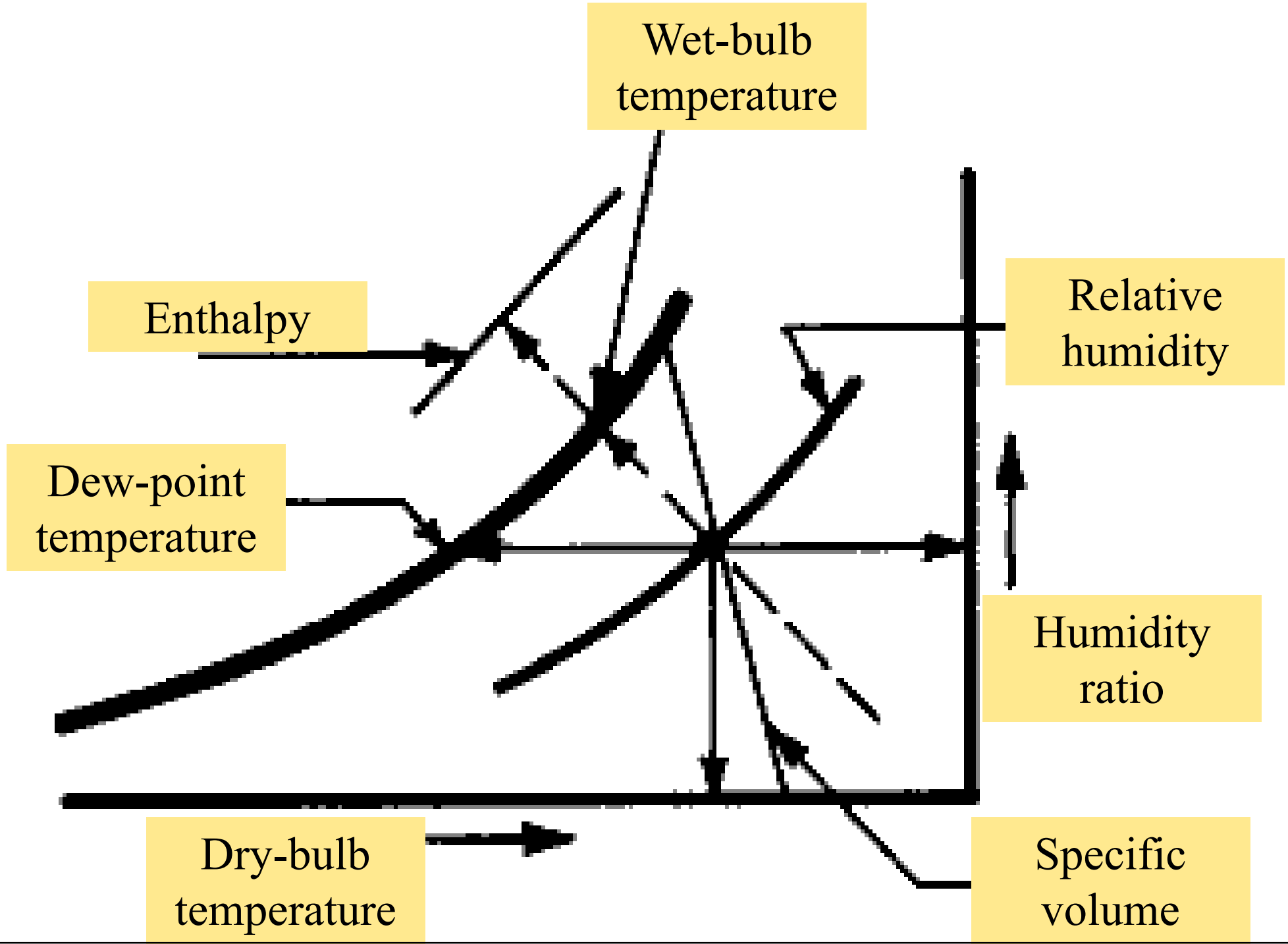


(Source: https://www.designingbuildings.co.uk/wiki/Psychrometric_charts)

Psychrometry

- Major parameters:
  - Moisture content (g), or absolute humidity (w)
  - Relative humidity (rh or RH)
  - Percentage saturation (μ)
  - Wet-bulb temperature (t_{wb})
  - Dew-point temperature (t_{dp})
  - Specific enthalpy (h)
  - Specific volume (v)
  - Density (ρ)

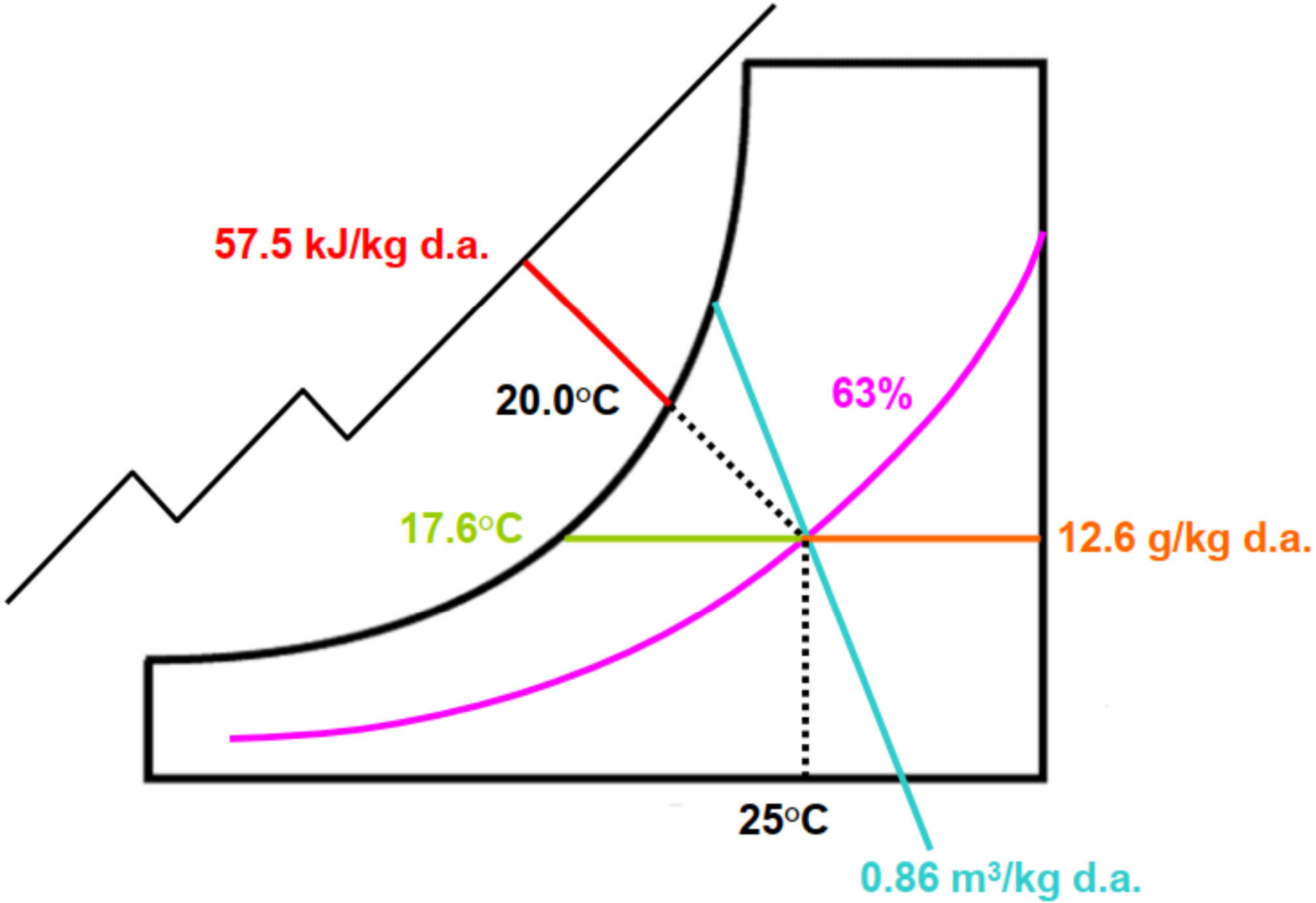
Major parameters on a psychrometric chart



Psychrometric chart: Example 1

Given: DBT = 25°C, WBT = 20°C

Find: (a) RH, (b) dew point temp., (c) humidity ratio, (d) specific volume, (e) enthalpy



(Source: Perry Peralta, NC State University)

Measurement of moist air by sling psychrometer

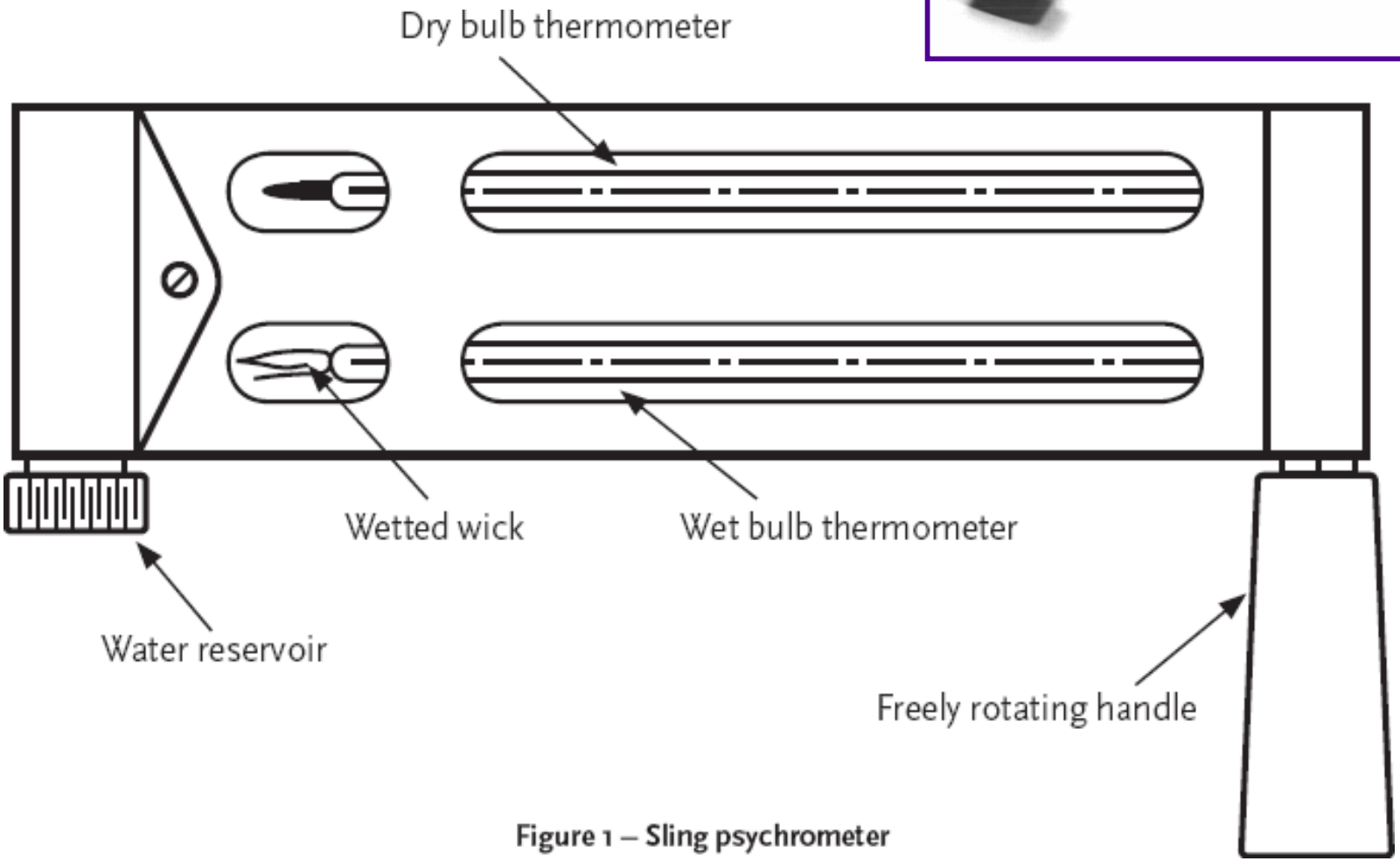
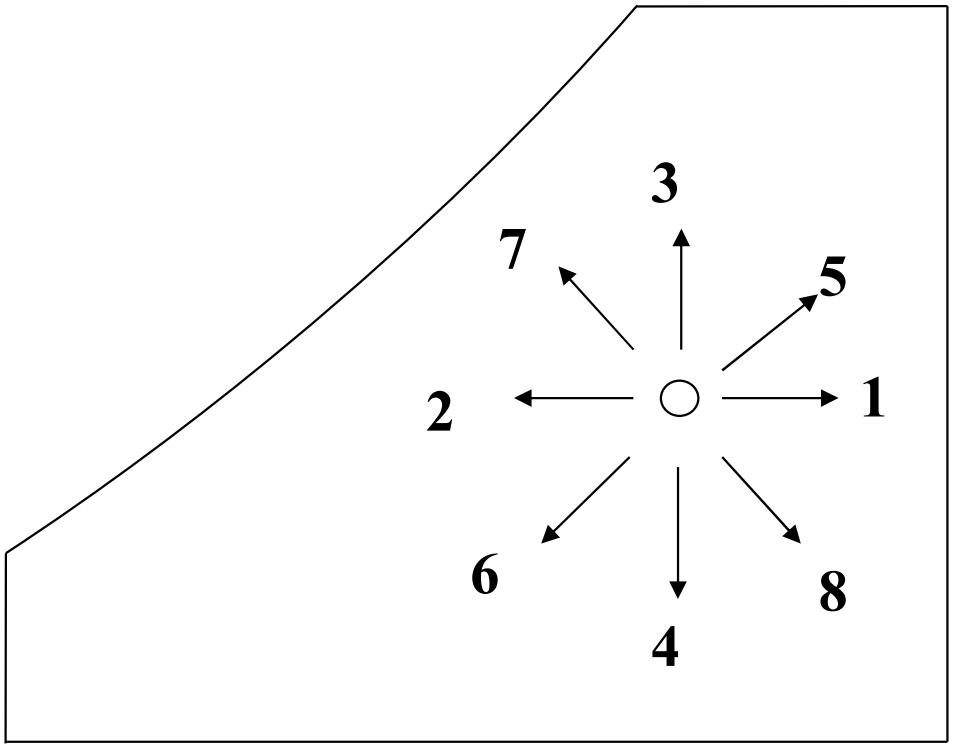


Figure 1 – Sling psychrometer

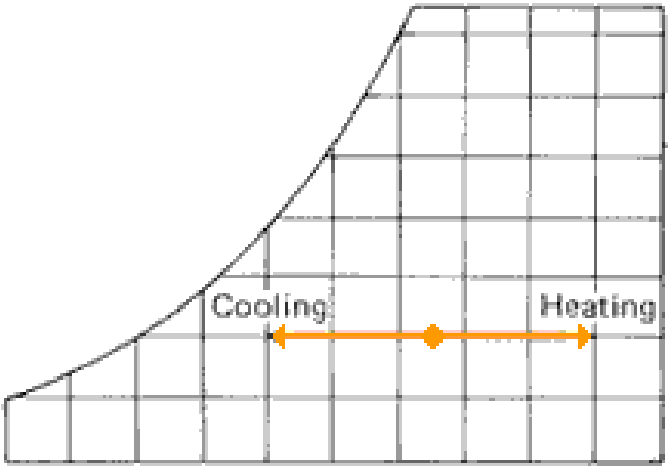
Basic psychrometric processes



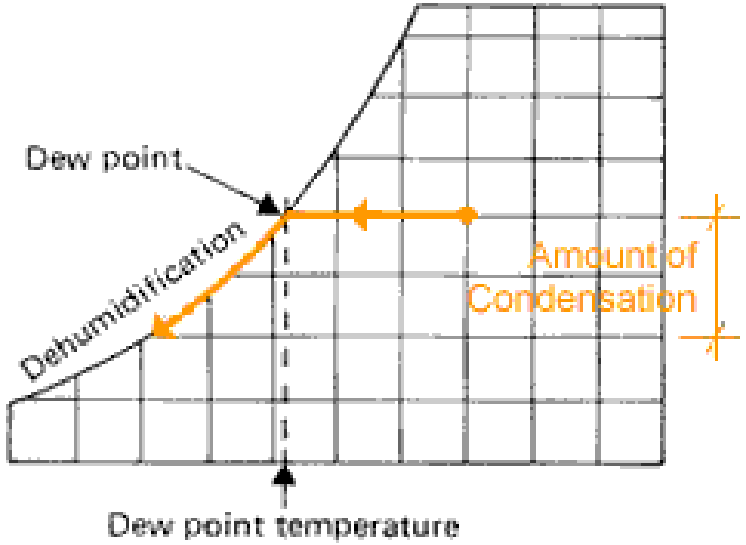
Process 0-1: Sensible heating
Process 0-2: Sensible cooling
Process 0-3: Humidifying
Process 0-4: Dehumidifying
Process 0-5: Heating and humidifying
Process 0-6: Cooling and dehumidifying
Process 0-7: Cooling and humidifying
Process 0-8: Heating and dehumidifying

(Video: Psychrometric Chart - air conditioning processes (3:00) https://youtu.be/C93mWf3rr30)

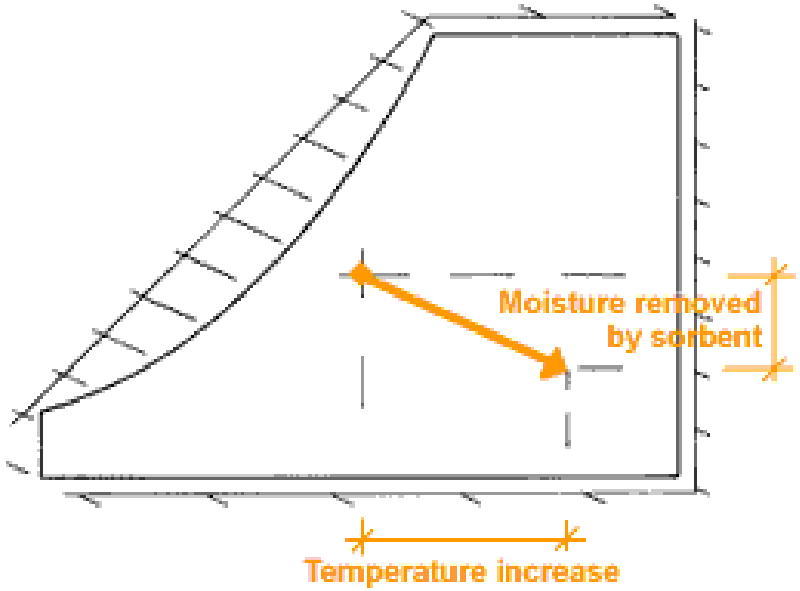
Psychrometric processes



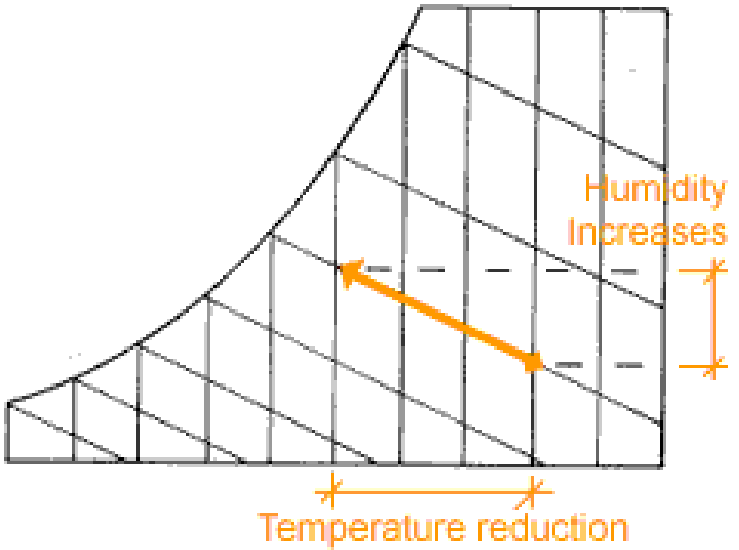
Sensible cooling/heating



Cooling and dehumidification

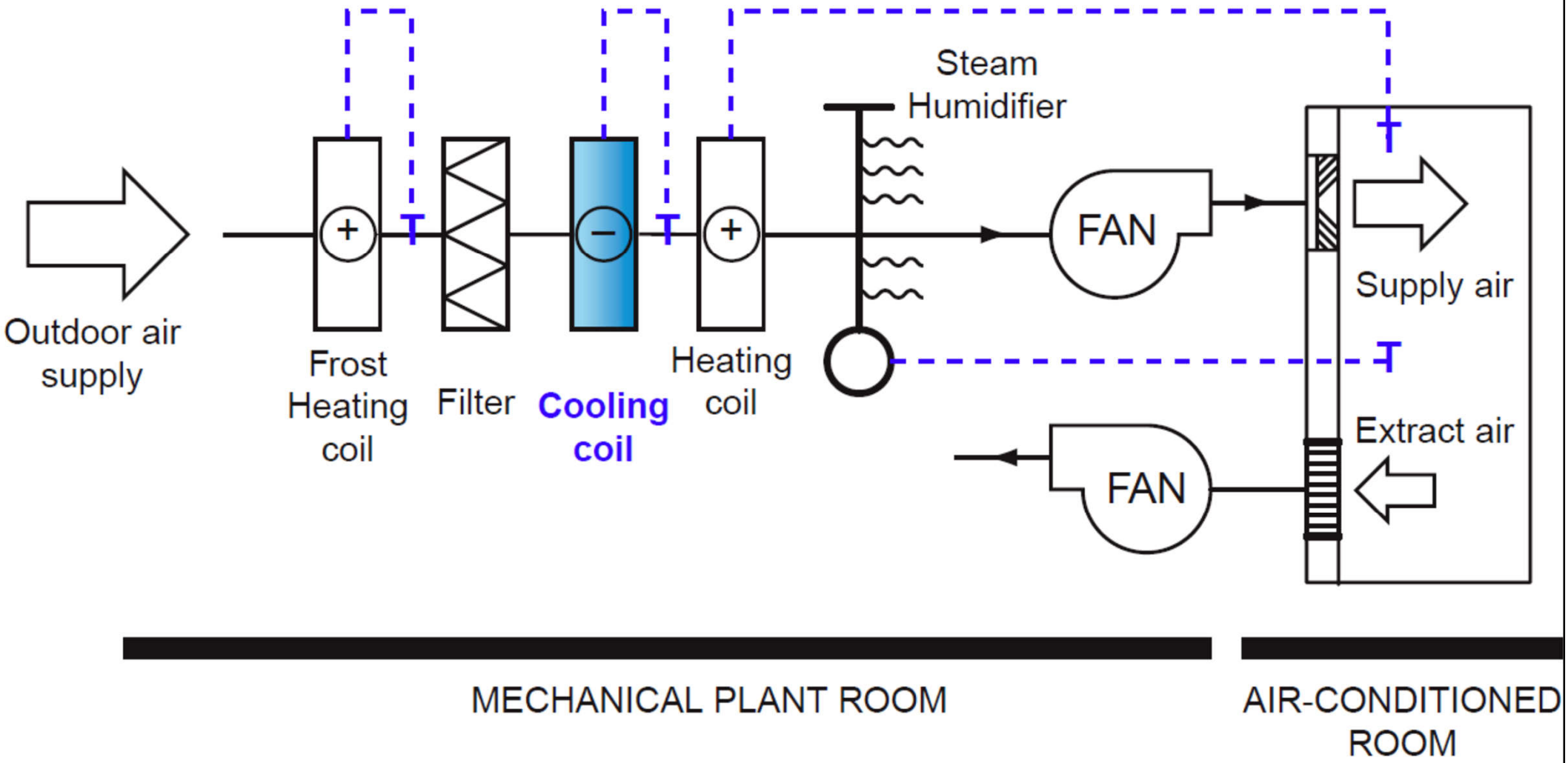


Adiabatic dehumidification



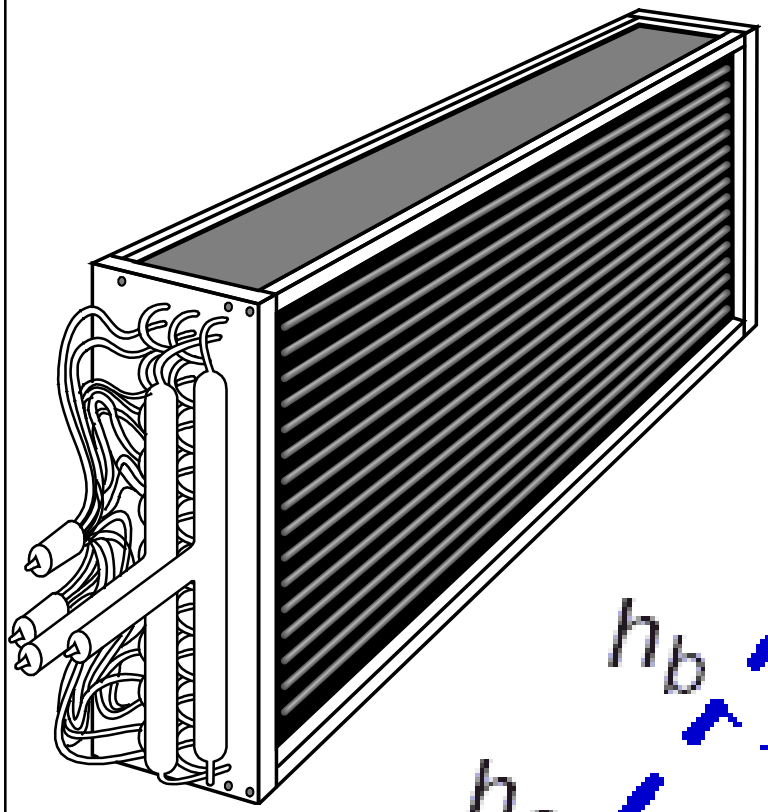
Evaporative cooling

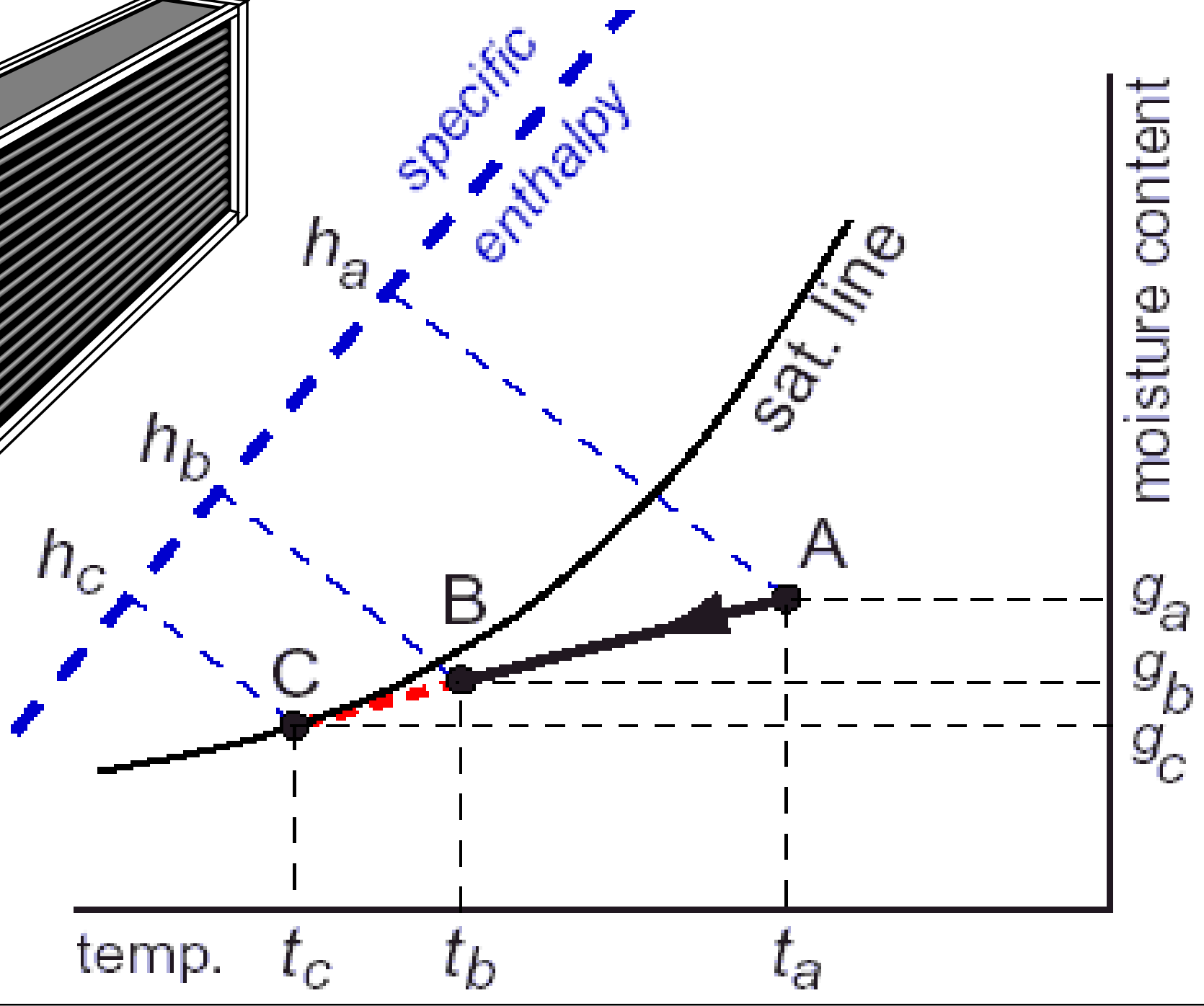
Schematic representation of all fresh-air, constant volume air conditioning system



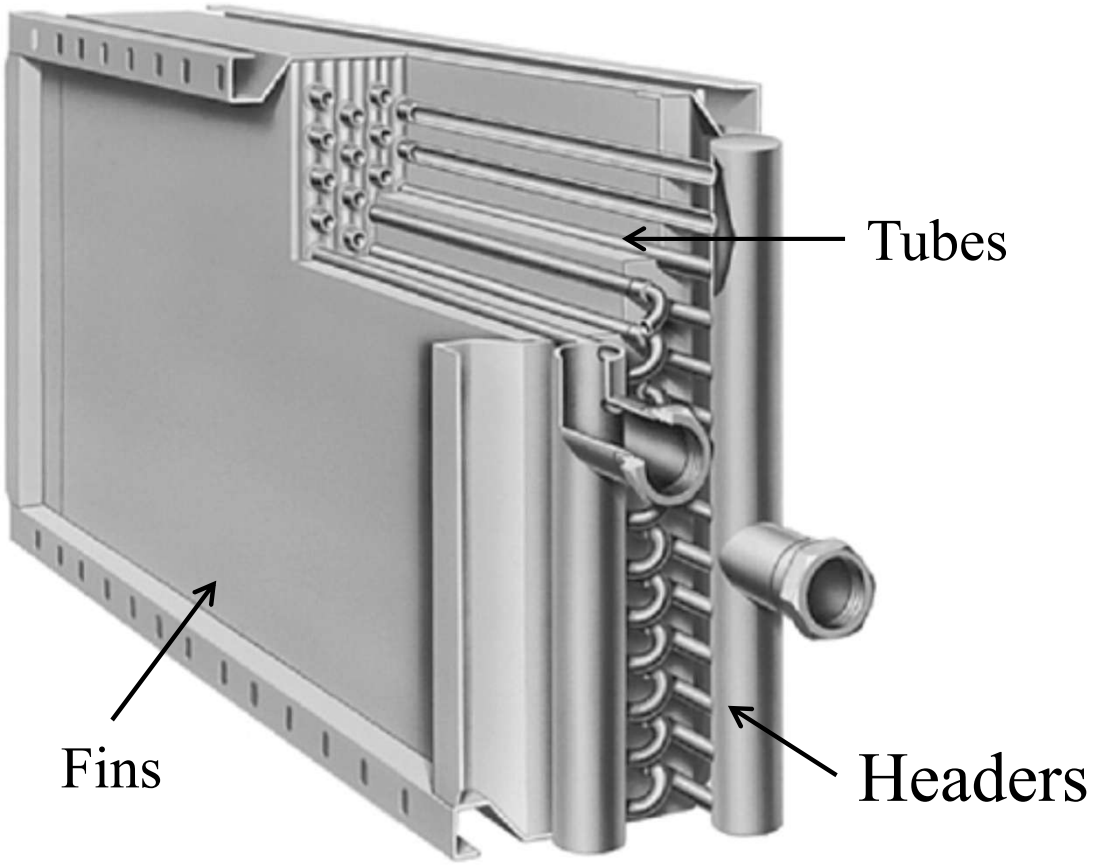
Can you explain the functions of each components?

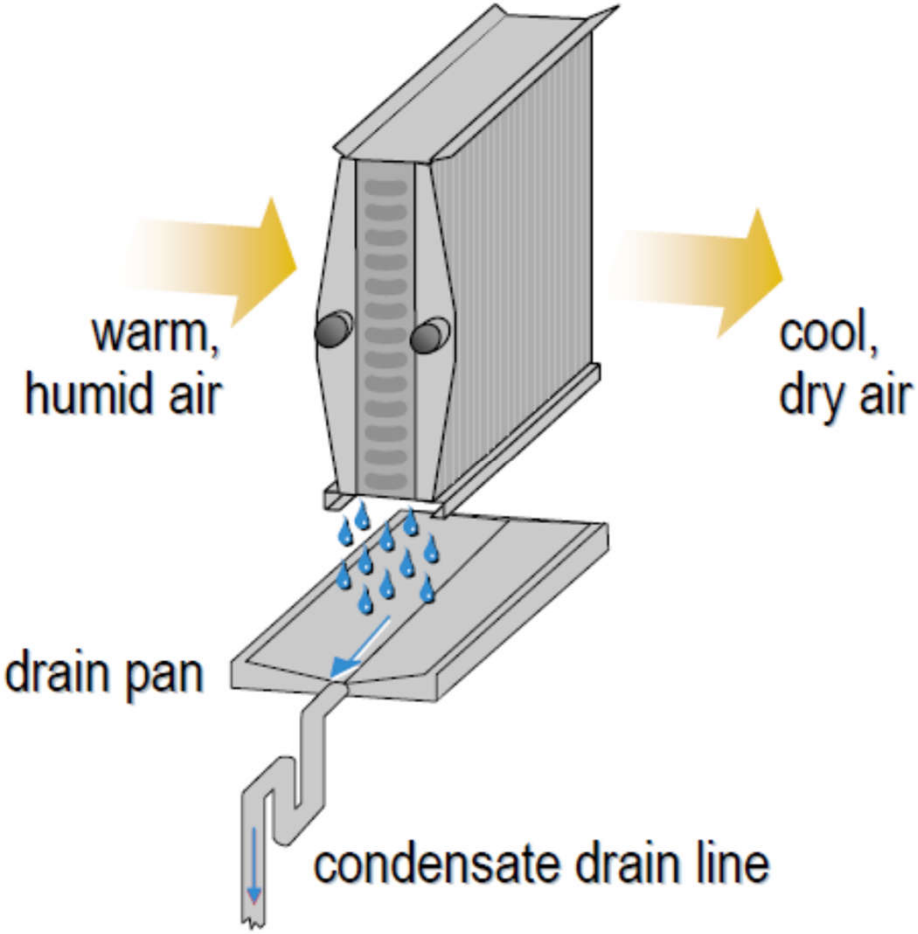
Cooling and dehumidification process at the cooling coil





Chilled water cooling coil (a heat exchanger)





Sensible heat exchange: $q_S = m_a \text{ x } c_p \text{ x } (t_b - t_a)$

Latent heat exchange: $q_L = m_a \text{ x } h_{fg}$

(Source: Trane)

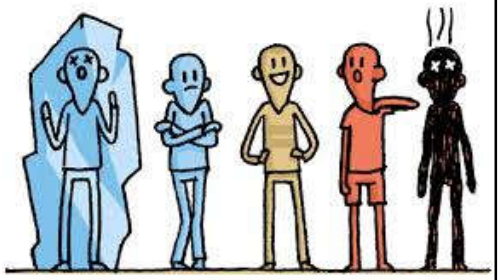
What is Thermal Comfort?

Definition

- That condition of mind which expresses satisfaction with the thermal environment.
ISO 7730

熱舒適性

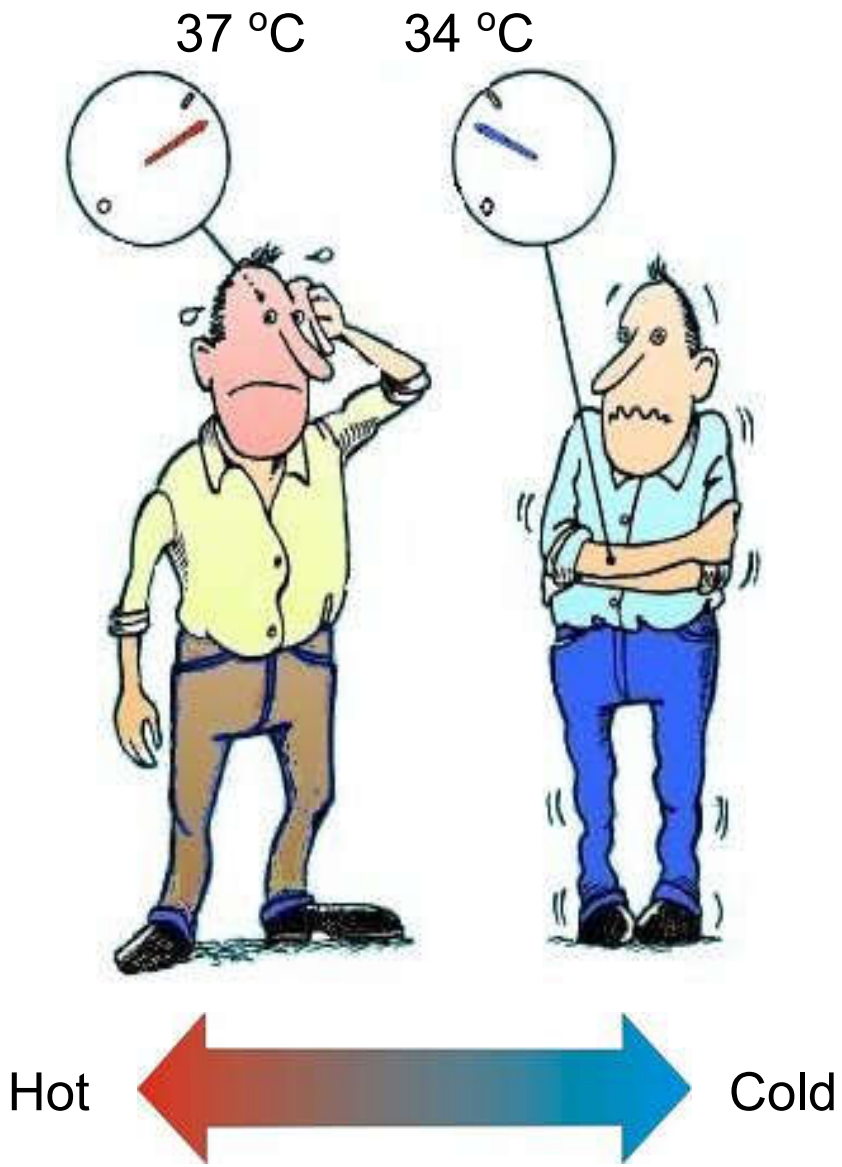
Thermal comfort



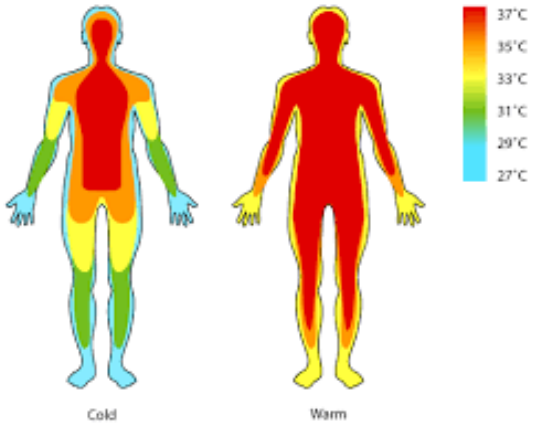
- Thermal comfort is experienced via a number of conscious interactions between three personal and environment factors
  - Physiological: the way our bodies work and interact with our environment
  - Physical: the main parameters of the environment around us (air temperature, air humidity, air movement, room surface temperature)
  - Socio Psychological: the way we feel as a whole (for example, if we are tired, stressed, happy…) and the kind of social environment we live in

(See also: Thermal Comfort (Saint-Gobain) https://multicomfort.saint-gobain.com/comforts-and-solutions/thermal-comfort)

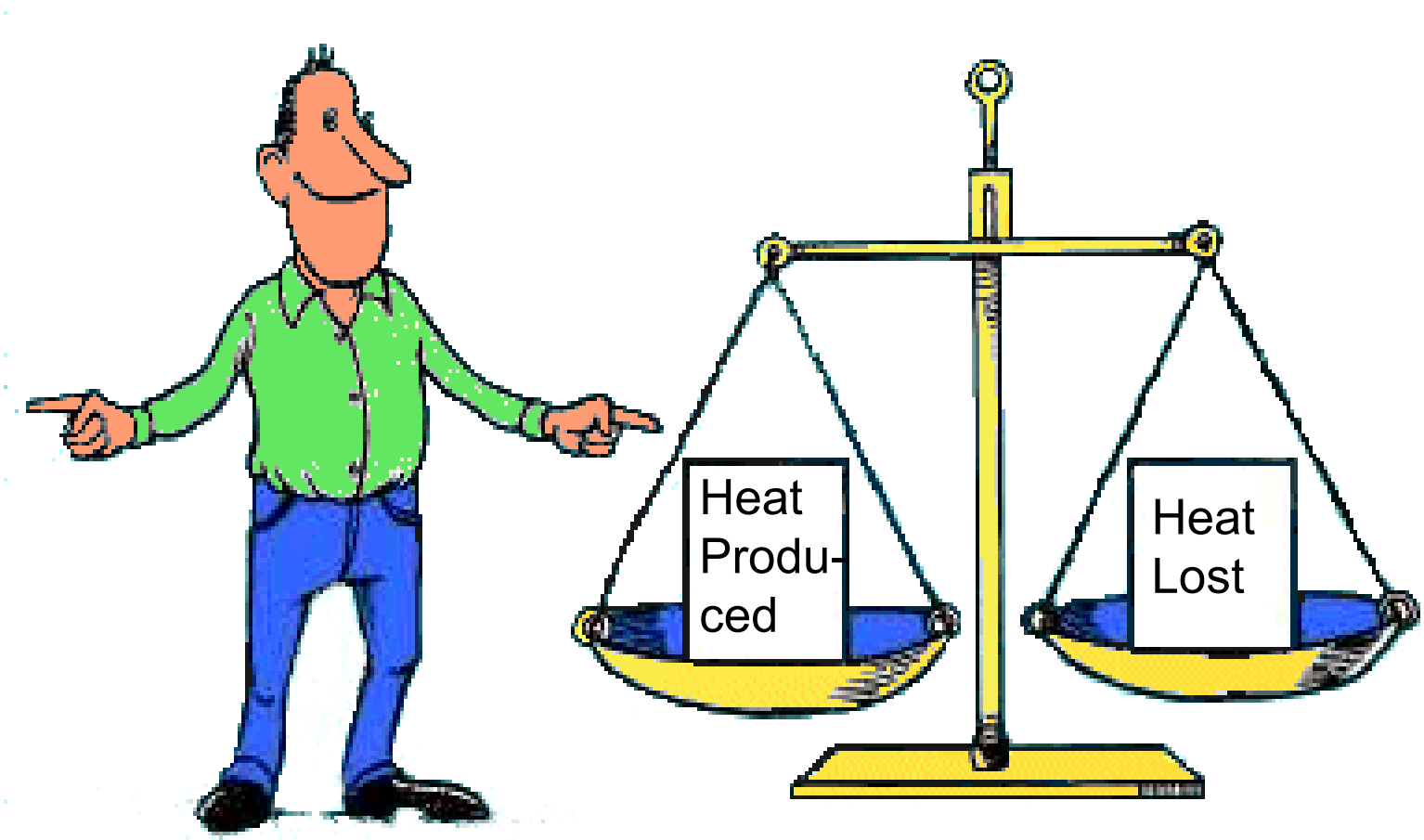
Body Temperature



- Normal body core temperature: 37 °C.
- We have separate Heat- and Cold-sensors.
  - Heat sensor is located in hypothalamus. Signals when temperature is higher than 37 °C.
  - Cold sensors are located in the skin. Send signals when skin temperature is below 34 °C.
- Heating mechanism:
  - Reduced blood flow.
  - Shivering.
- Cooling mechanism:
  - Increased blood flow.
  - Sweating (Evaporation).

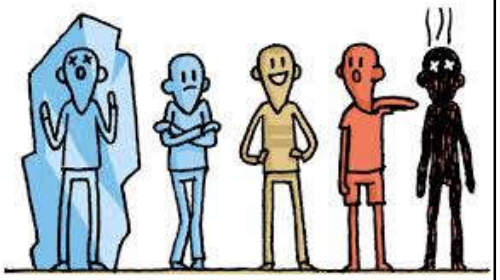


The Energy Balance



- Thermal Comfort can only be maintained when heat produced by metabolism equals the heat lost from body.

Thermal comfort



- General heat balance

$$S = M - W - E - (R + C)$$

where

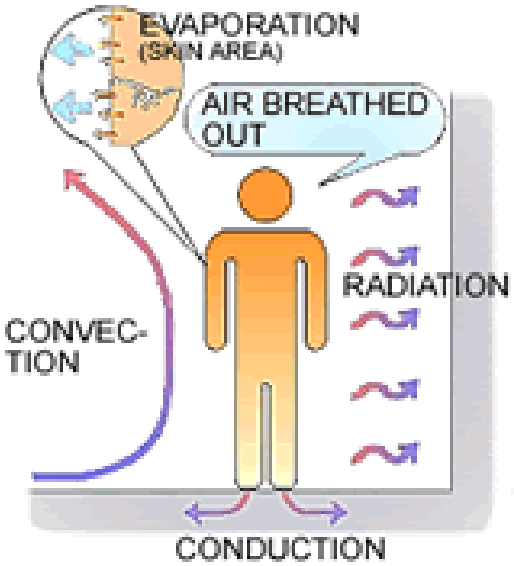
S = rate of heat storage of human body

M = metabolic rate

W = mechanical work done by human body

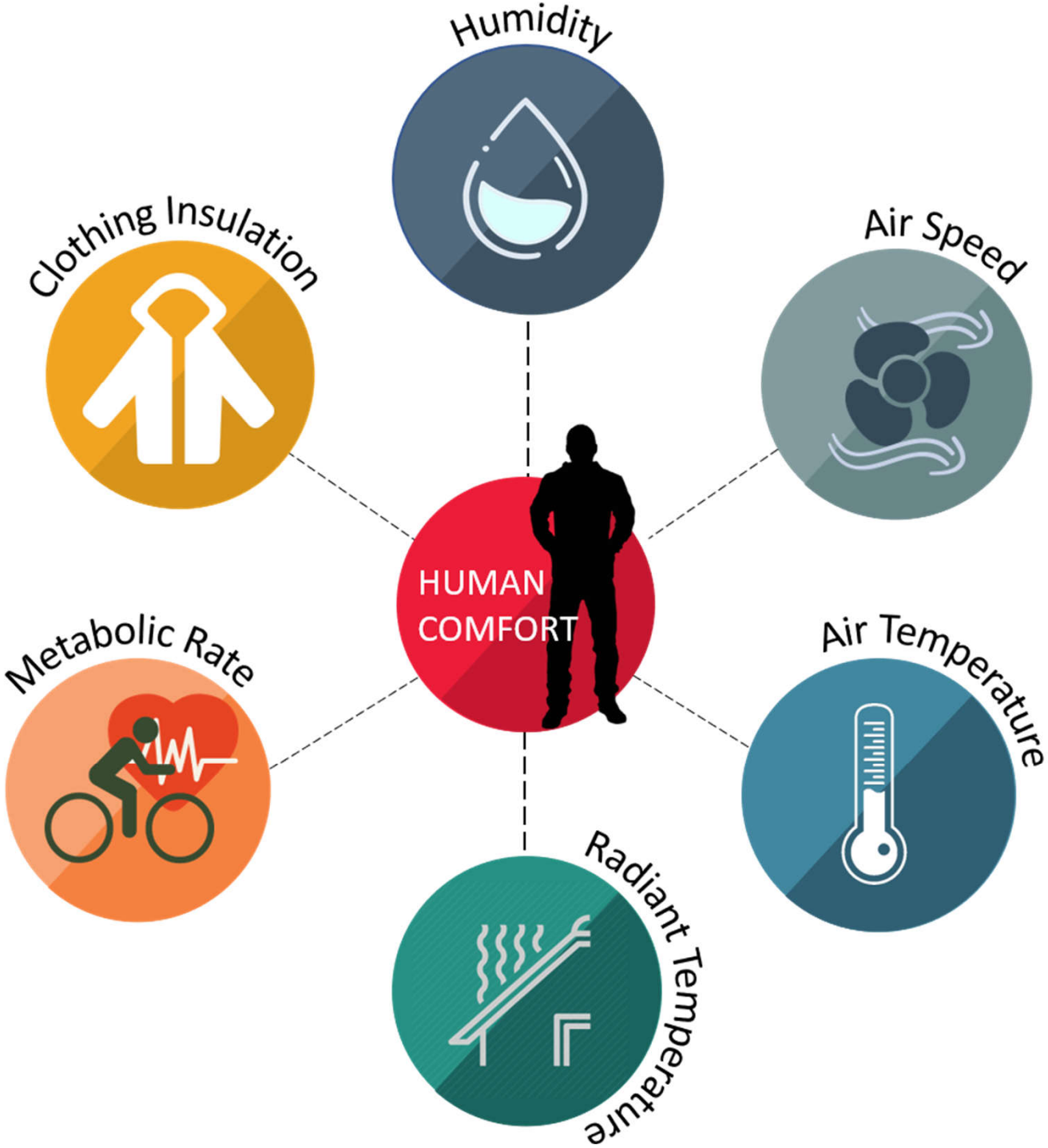
E = rate of total evaporation loss

R + C = dry heat exchange through radiation & convection



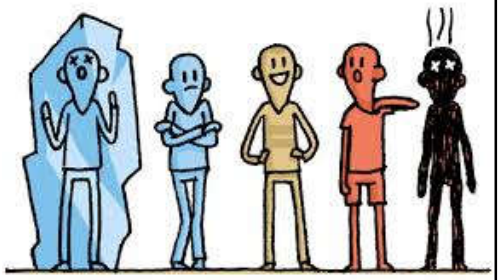
Storage = Production – Loss

Environmental and personal factors that influence thermal comfort



(Source: https://www.linkedin.com/pulse/role-cfd-evaluating-occupant-thermal-comfort-sandip-jadhav/)

Thermal comfort



- Fanger's comfort criteria
  - developed by Prof. P. O. Fanger (Denmark)
  - **Fanger's comfort equation**:

$$f(M, I_{cl}, V, t_r, t_{db}, P_s) = 0$$

where M = metabolic rate (met)

I_{cl} = cloth index (clo)

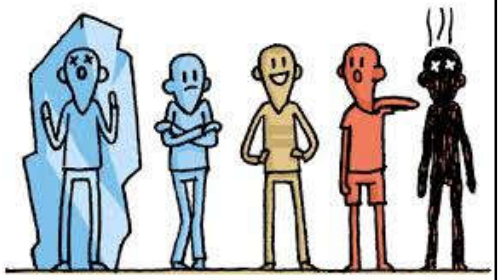
V = air velocity (m/s)

t_r = mean radiant temp. (°C)

t_{db} = dry-bulb temp. (°C)

P_s = water vapour pressure (kPa)

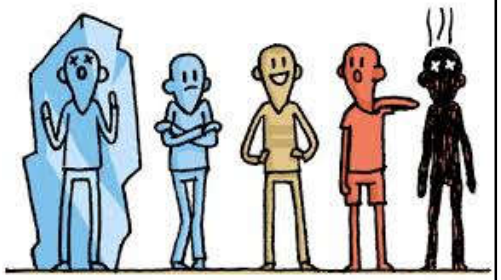
Thermal comfort



- Fanger's equation is complex
  - but it may be transformed to comfort diagrams
  - it can also be used to yield three indices:
    - predicted mean vote (PMV)
    - predicted percentage of dissatisfied (PPD)
    - lowest possible percentage dissatisfied (LPPD)

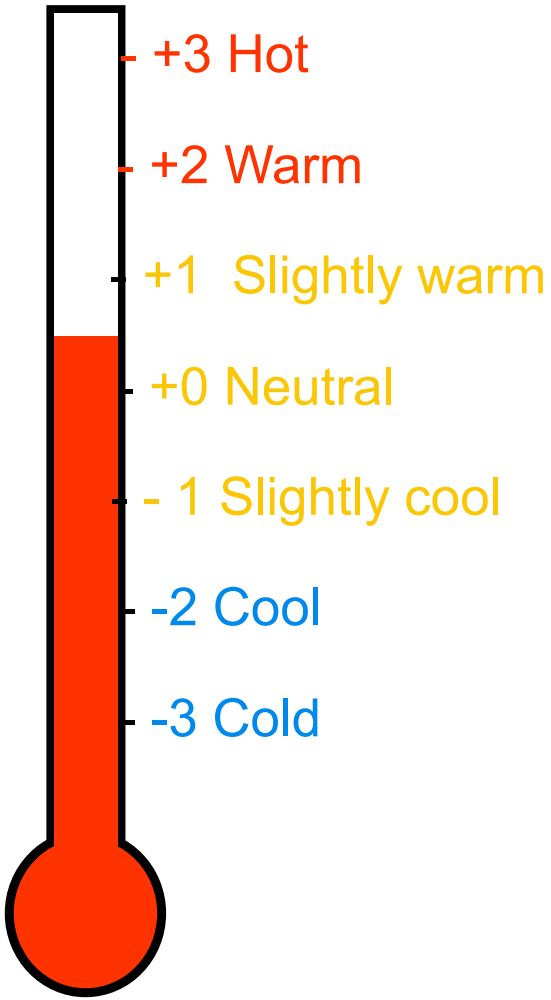
(See also: Thermal comfort - Wikipedia http://en.wikipedia.org/wiki/Thermal_comfort)

Thermal comfort



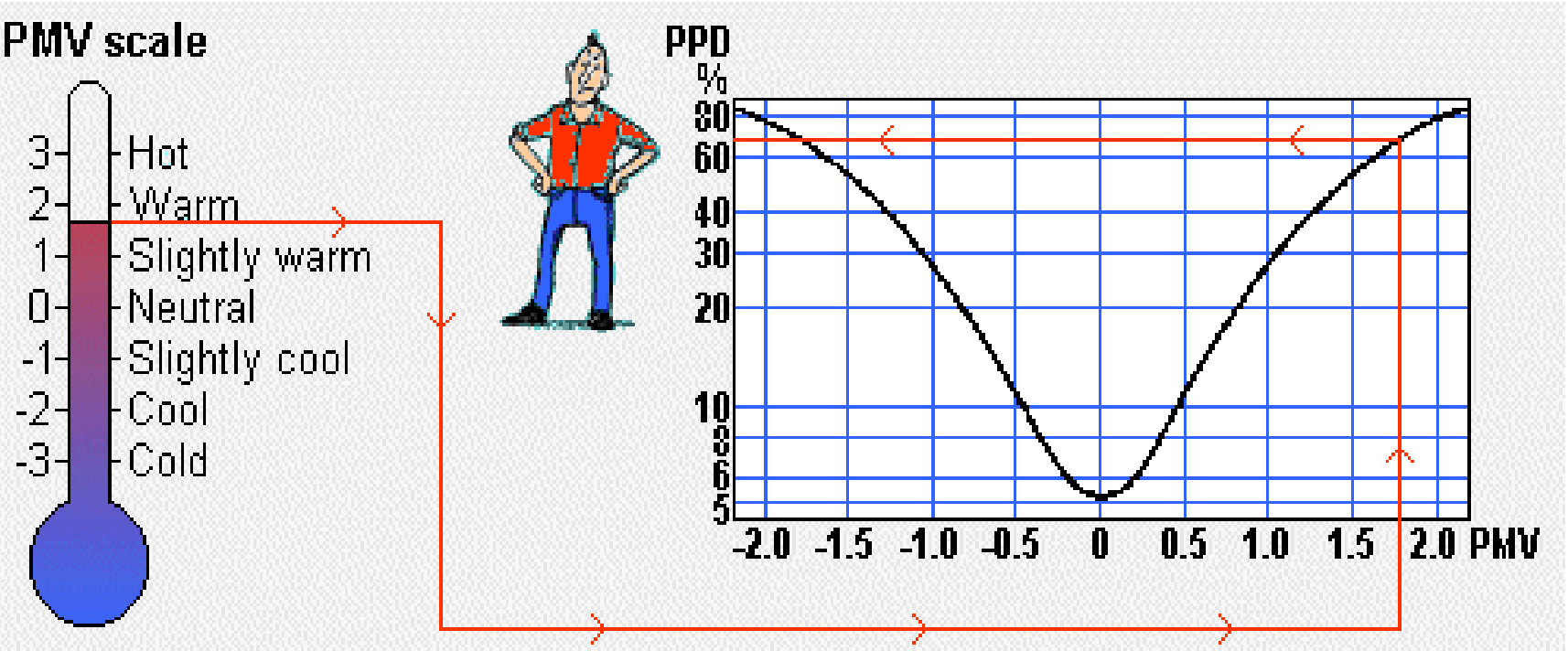
- **Predicted mean vote (PMV)**
  - a complex function of six major comfort parameters;
  - predict mean value of the subjective ratings of a group of people in a given environment
- **Predicted percentage of dissatisfied (PPD)**
  - determined from PMV as a quantitative measure of thermal comfort
  - 'dissatisfied' means not voting -1, +1 or 0 in PMV
  - normally, PPD < 7.5% at any location and LPPD < 6%

Predicted Mean Vote scale



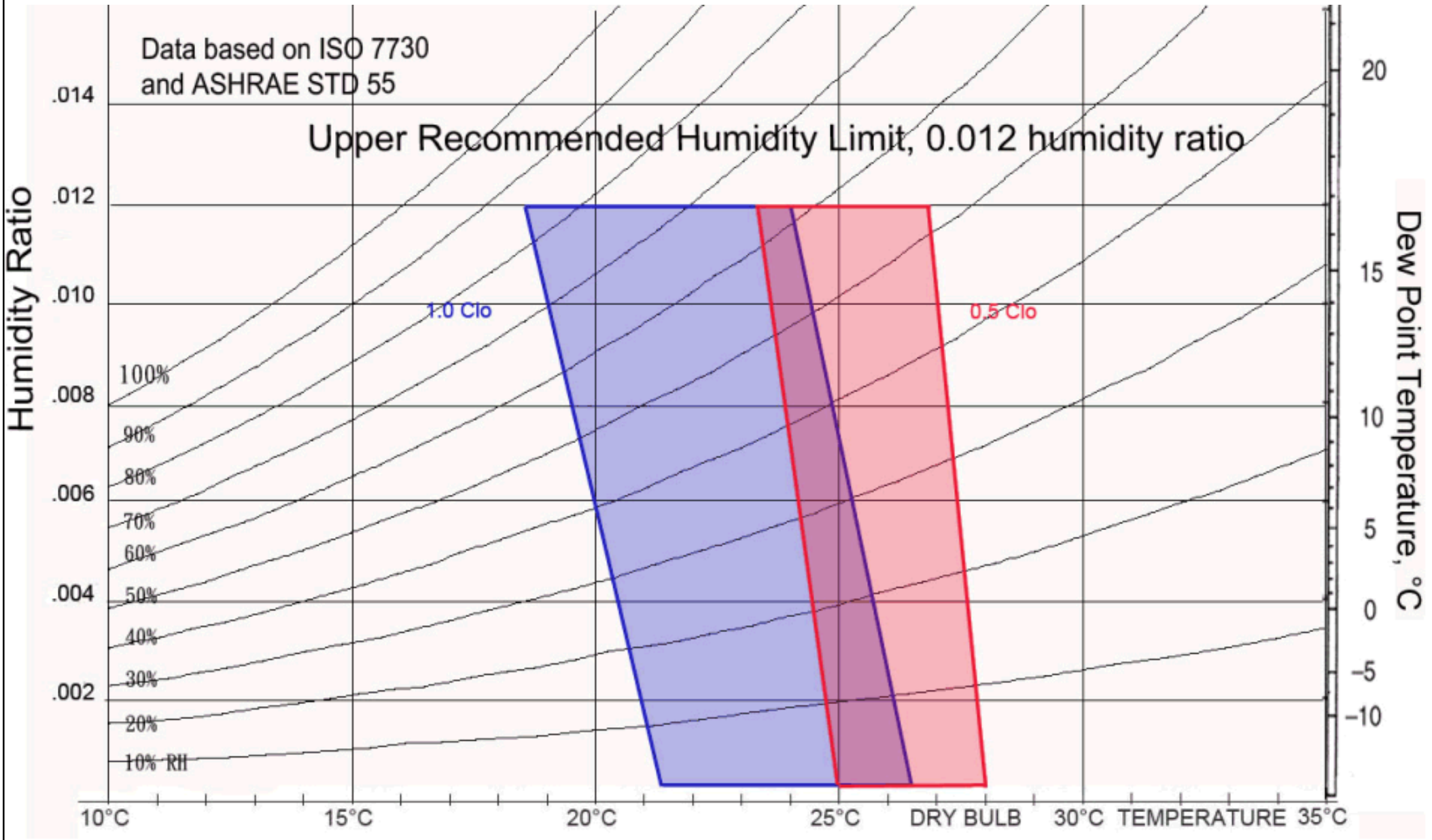
The PMV index is used to quantify the degree of discomfort

PMV and PPD



- PMV-index (Predicted Mean Vote) predicts the subjective ratings of the environment in a group of people.
  - 0 = neutral (still 5% people are dissatisfied)
- PPD-index predicts the number of dissatisfied people.

ASHRAE Comfort Zones
(based on 2004 version of ASHRAE Standard 55)

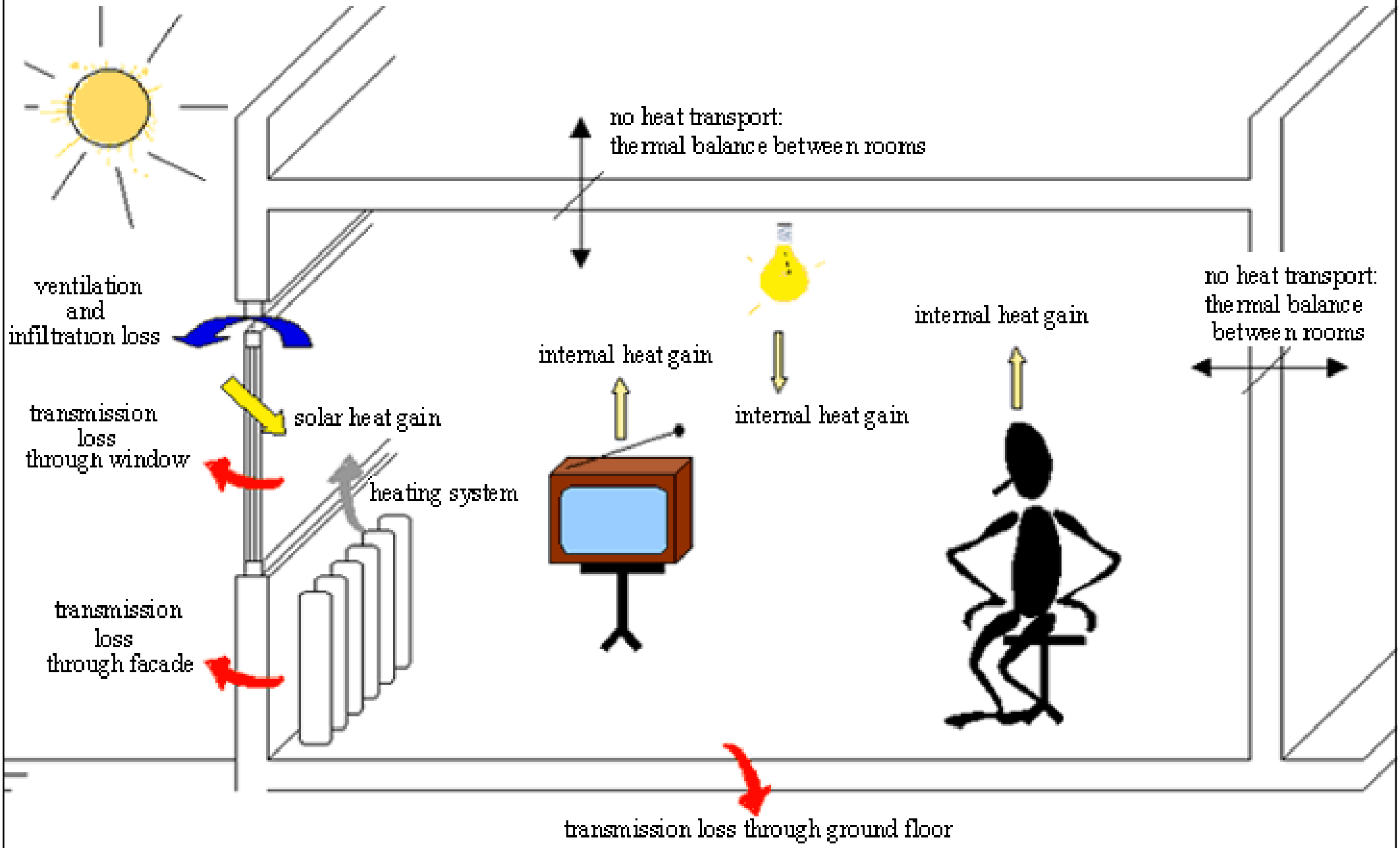


Load estimation

- Thermal load 熱負荷
  - The amount of heat that must be added or removed from the space to maintain the proper temperature in the space
- When thermal loads push conditions outside of the comfort range, HVAC systems are used to bring the thermal conditions back to comfort conditions

What will happen if the thermal load cannot be tackled by the HVAC system?

Heat transmission & heat transport in buildings



(Source: https://www.new-learn.info/packages/clear/thermal/buildings/building_fabric/index.html)

Load estimation

- Purpose of HVAC load estimation
  - Calculate peak design loads (cooling/heating)
  - Estimate likely plant/equipment capacity or size
  - Specify the required airflow to individual spaces
  - Provide info for HVAC design e.g. load profiles
  - Form the basis for building energy analysis
- Cooling load is our main target
  - Important for warm climates & summer design
  - Affect building performance & its first cost

Cooling load estimation guidelines from a manufacturer

冷氣機製冷量與房間面積參考
Reference for Cooling Capacity of Air Conditioner and Room Size

房間面積Room Size （以石屎間隔為準 Calculated according to concrete partition）	製冷量 Cooling Capacity	
70平方呎內 Within 70 Square Feet	7,000	Btu/小時 Btu/hour
90平方呎內 Within 90 Square Feet	9,000	Btu/小時 Btu/hour
120平方呎內 Within 120 Square Feet	12,000	Btu/小時 Btu/hour
170平方呎內 Within 170 Square Feet	17,000	Btu/小時 Btu/hour
230平方呎內 Within 230 Square Feet	23,000	Btu/小時 Btu/hour

1. BTU是一個以英制的能量單位。
   BTU refers to British Thermal Unit.

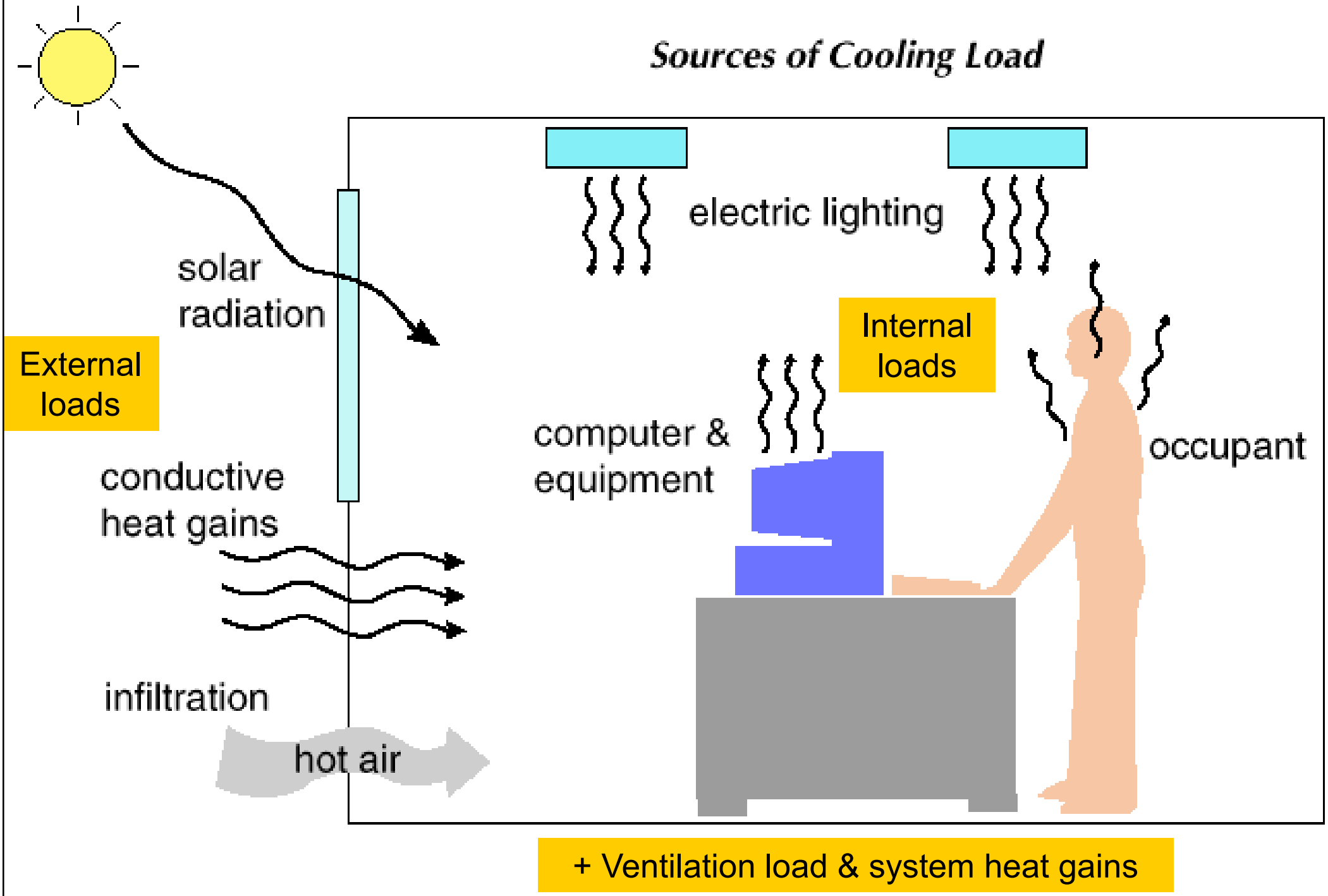
1 kW = 3412 Btu/hour

(Source: https://www.panasonic.hk/)

Load estimation

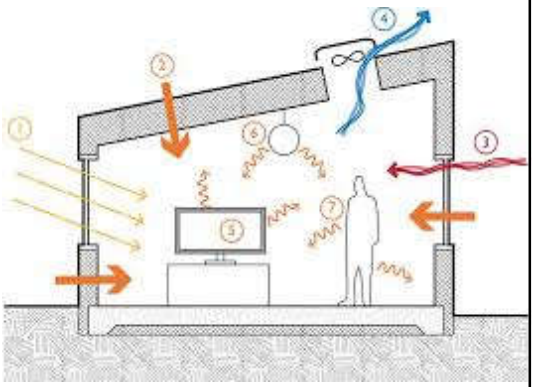
- Heating load calculations 熱負荷計算
  - Estimate heat loss from the building in winter to determine required heating capacities
  - Assume steady state conditions (no solar radiation & steady outdoor conditions) & neglect internal heat sources
- Cooling load calculations 冷負荷計算
  - Estimate heat gains & peak cooling load in summer to determine required cooling capacities
  - Unsteady state processes (more complicated)

Components of building cooling load

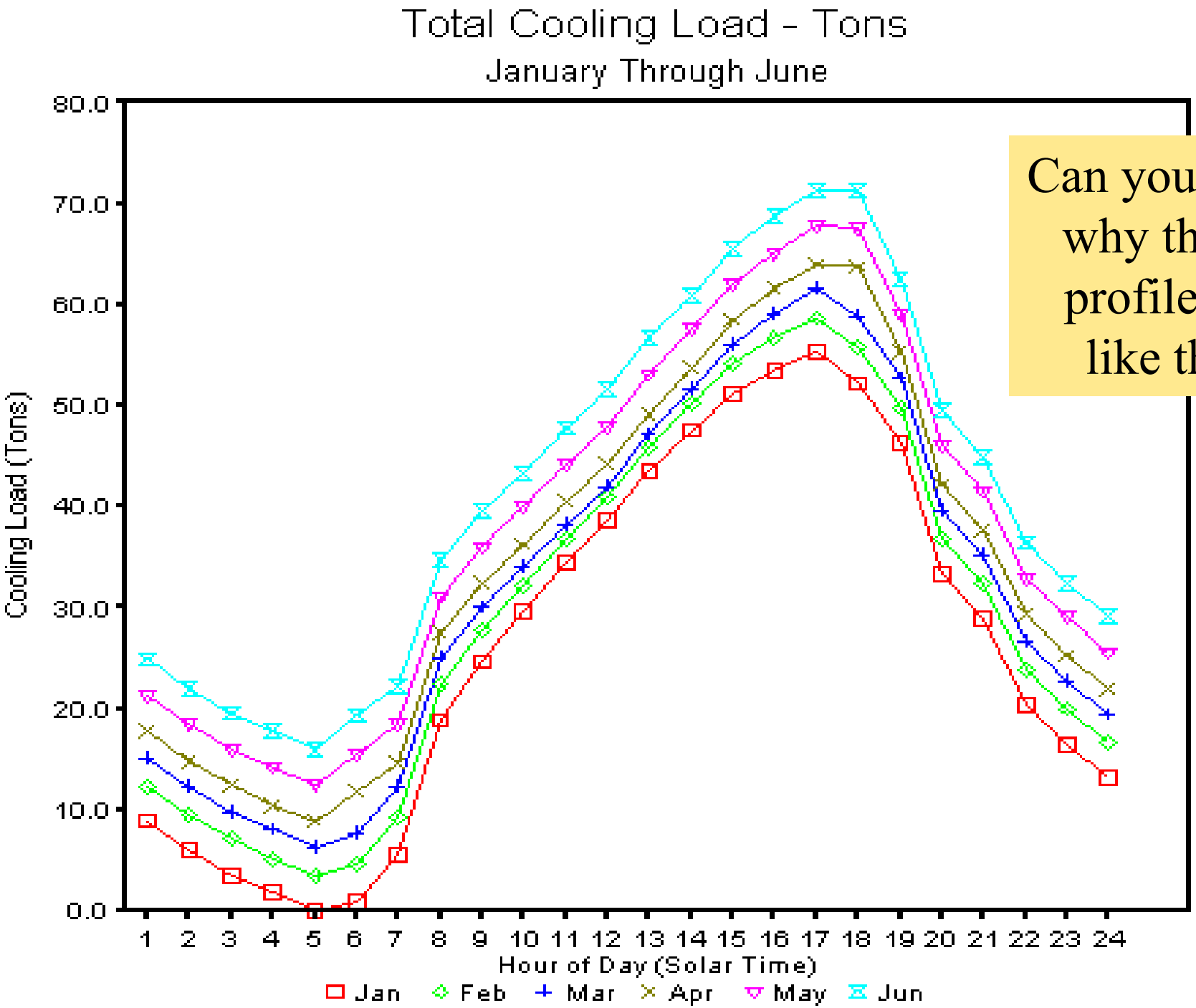


Load estimation

- Calculating heat gains
  - Heat gain through external walls
  - Heat gain through roof
  - Solar heat gain through window glass
  - Conduction heat through window glass
  - Internal heat gains
  - Ventilation and/or infiltration heat gains
  - Latent heat gains (moisture transfer/generation)

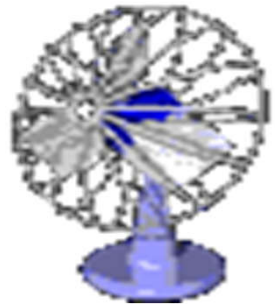


Examples of cooling load profiles



Can you explain why the load profiles look like these?

Examples of HVAC systems



- Common ventilation strategies
  - Natural ventilation
  - Mechanical ventilation
  - Comfort cooling
  - Air conditioning (full control of temp./humidity)
  - Mixed mode or hybrid systems
- If internal heat gains are sufficiently low and the external environment is suitable, natural ventilation can provide a low energy solution

Is it feasible to use
Natural Ventilation?

If situation prevents this,
is it feasible to use
Mechanical Ventilation?

If situation prevents this,
is it feasible to use
Hybrid/Mixed Mode Ventilation?

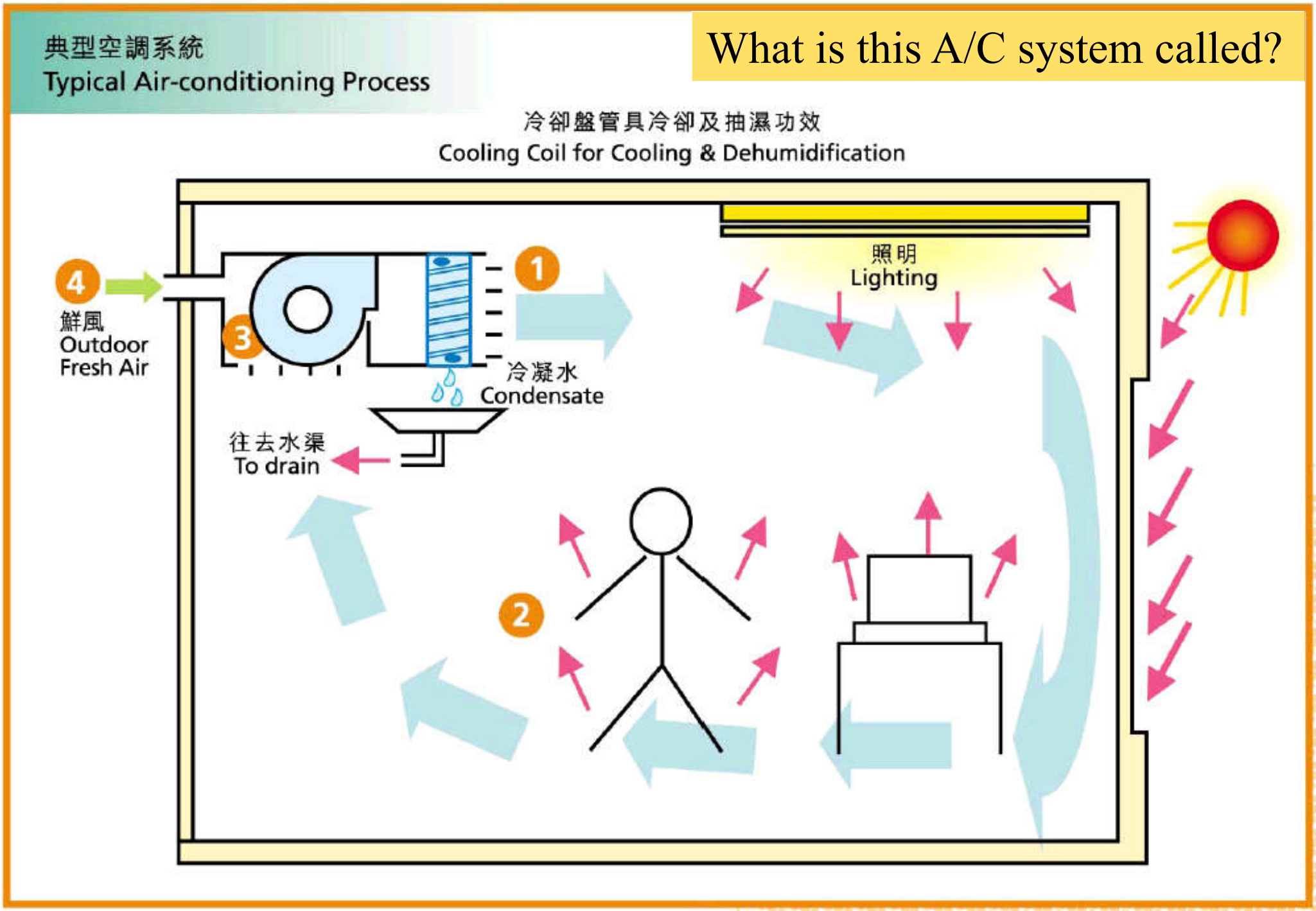
If situation prevents this,
is it feasible to use
Cooling and Heating
(without humidity control)?

If situation prevents this,
is it feasible to use
Full Air Conditioning
(with humidity control)?

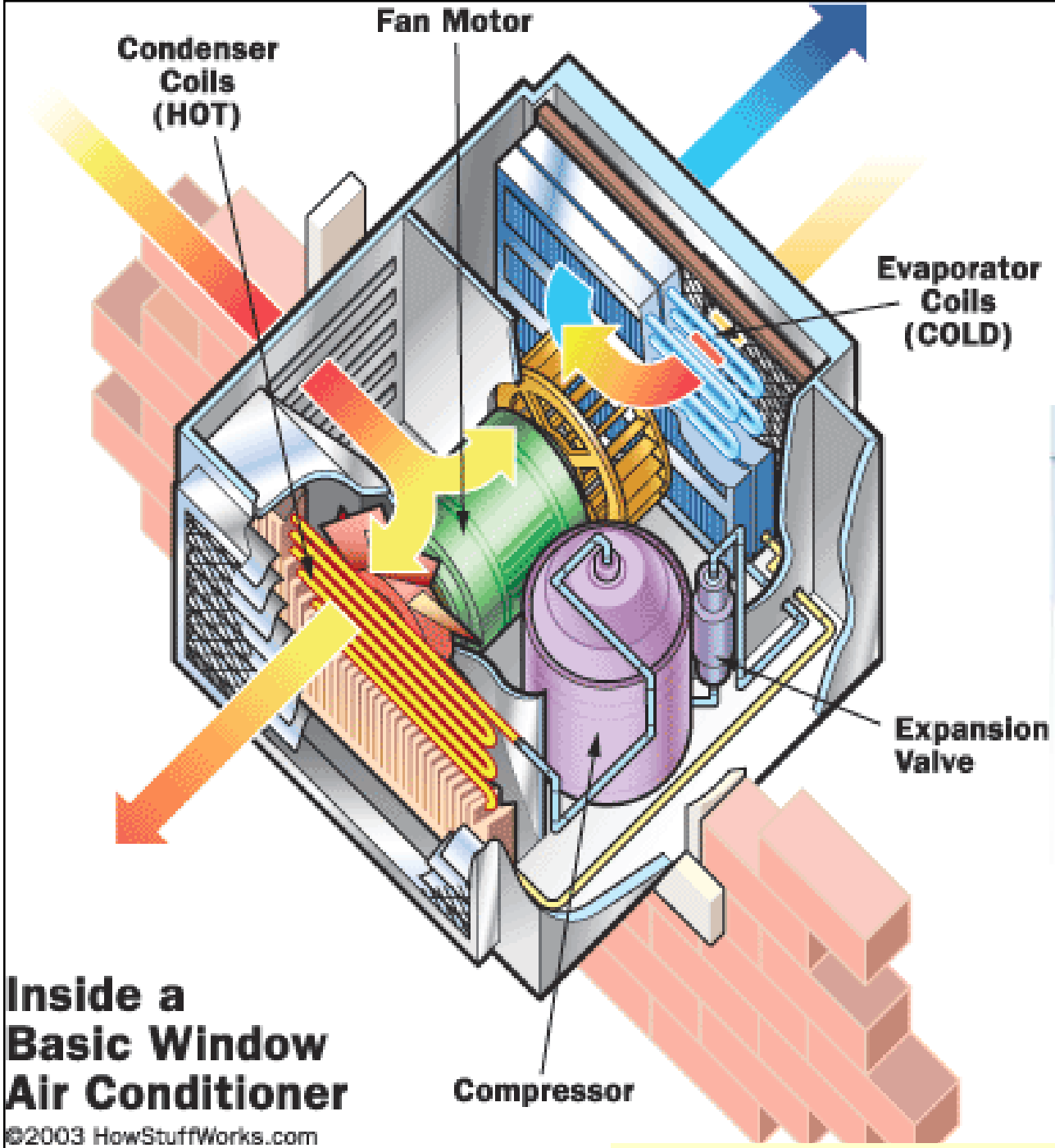
Ventilation design hierarchy

Increasing:
- energy consumption
- capital cost
- running costs
- maintenance
- complexity

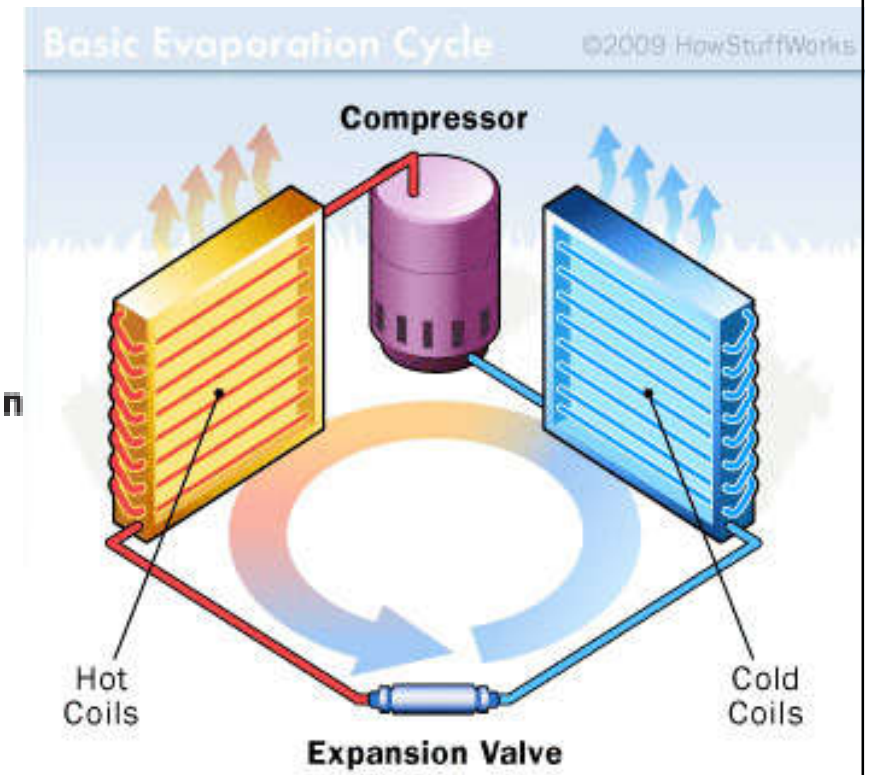
What is this A/C system called?



(Source: EnergyWitts newsletter, EMSD)



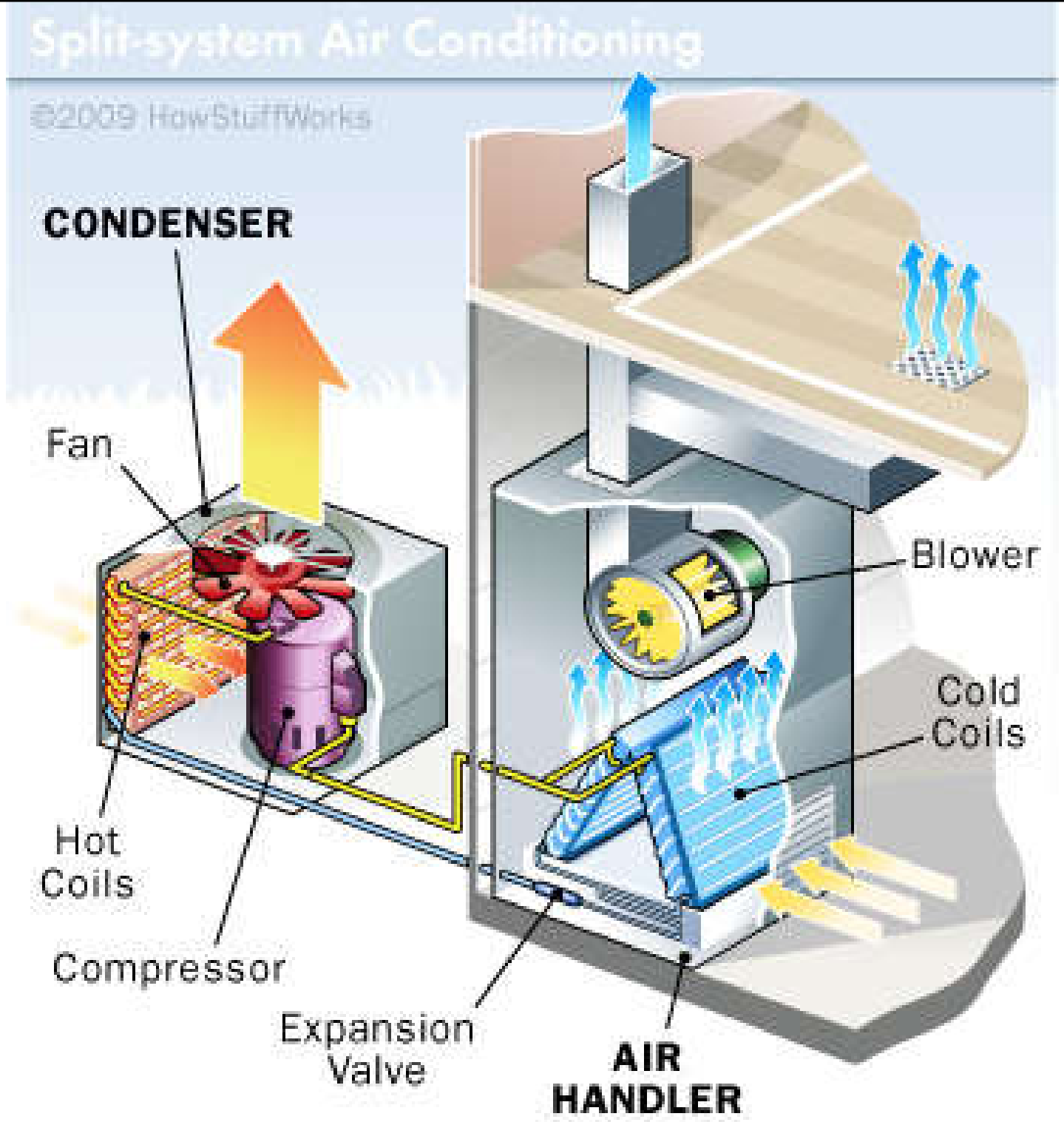
Window-type air conditioner



See also: "How Air Conditioners Work" (1:07)
http://youtu.be/nKZ2DPvvua8

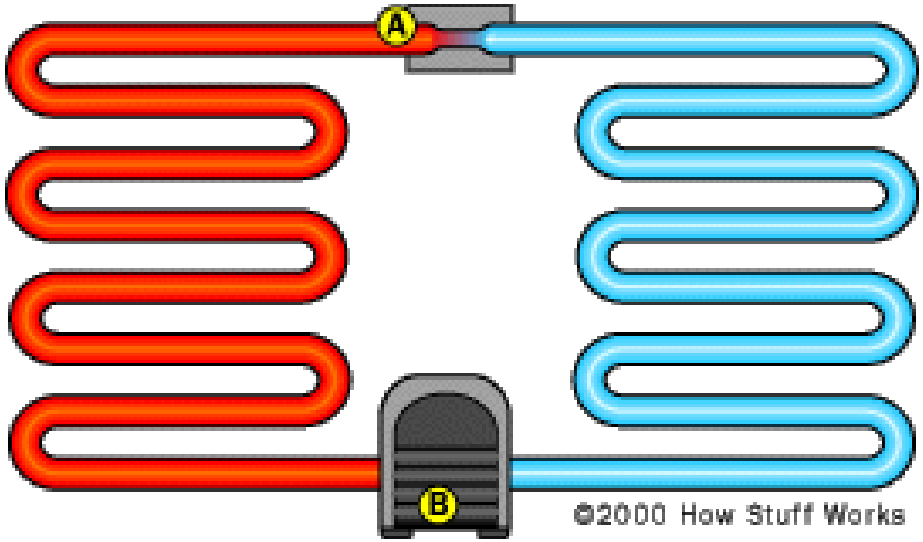
(Source: www.howstuffworks.com/ac.htm)

Split-type air conditioner



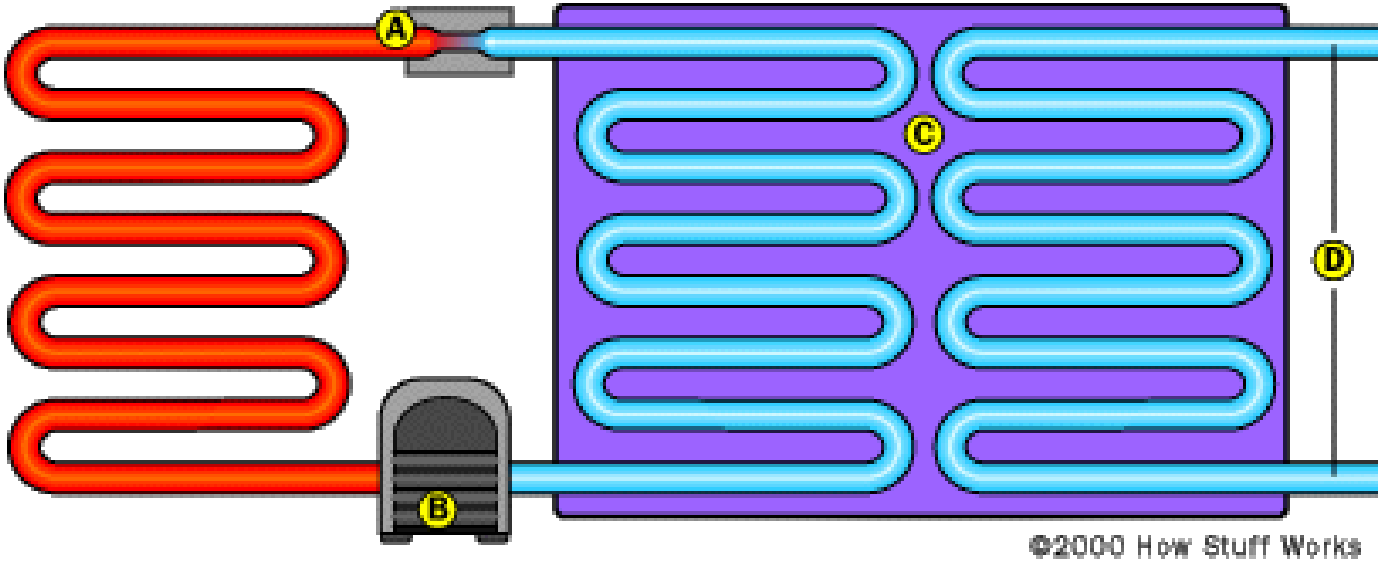
(Source: www.howstuffworks.com/ac.htm)

Refrigerant cycle



What are the major components?

A typical air conditioner

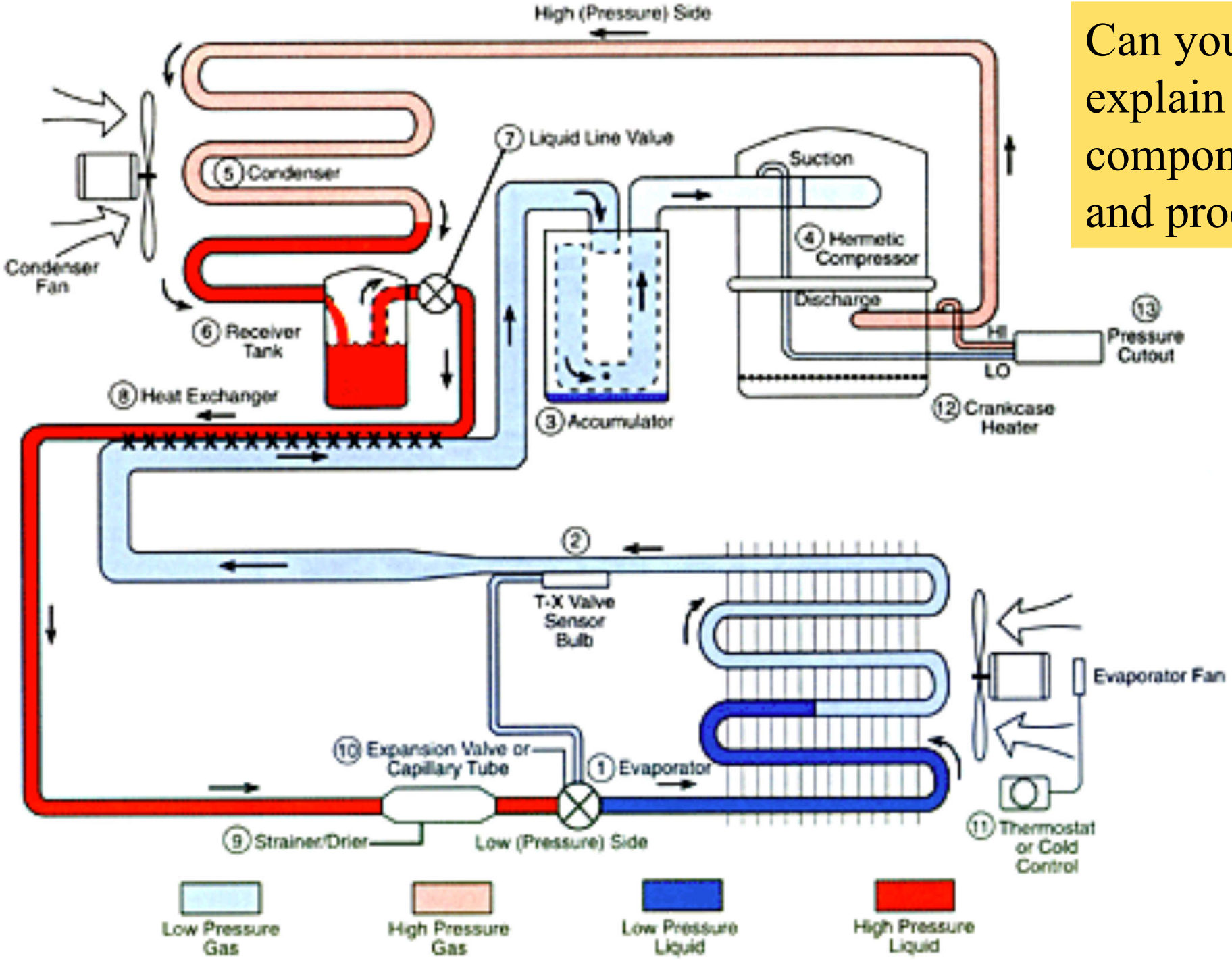


Chilled water system

Air conditioning with a chilled water system

(Source: www.howstuffworks.com/ac.htm)

Basic refrigeration cycle



Can you explain the components and process?

(See also: www.swtc.edu/ag_power/air_conditioning/lecture/basic_cycle.htm)