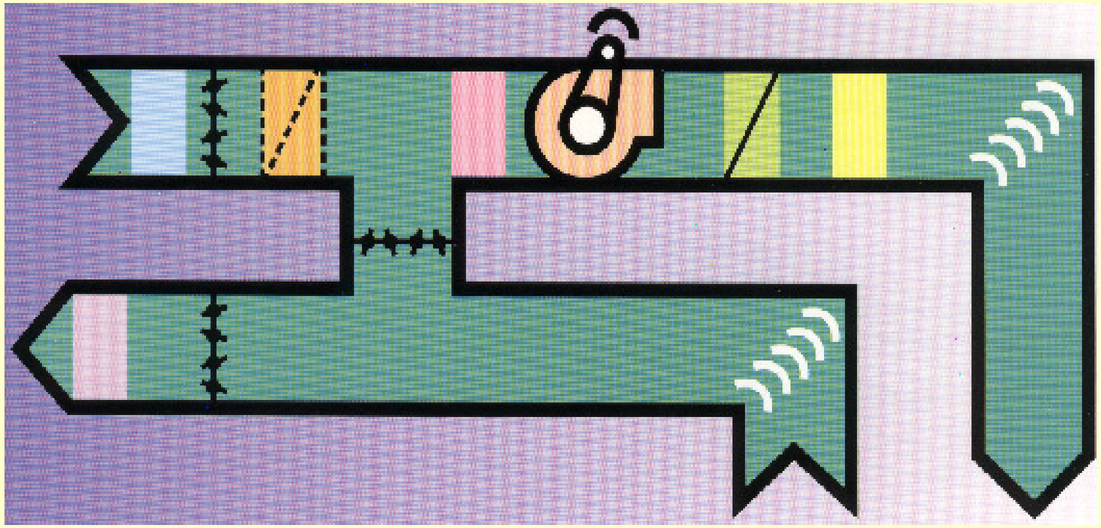


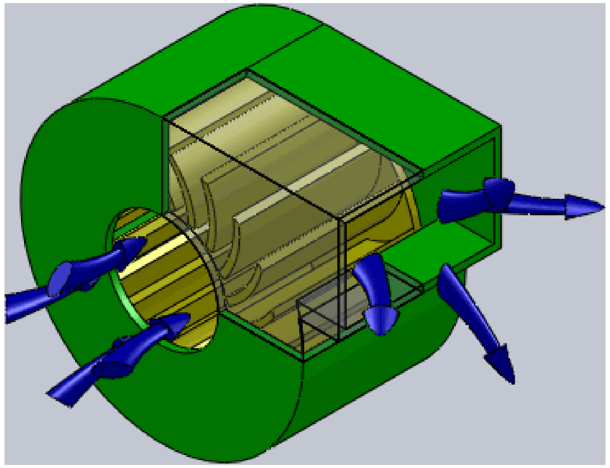
HVAC Air-side Systems: Part 1 Fans and AHUs

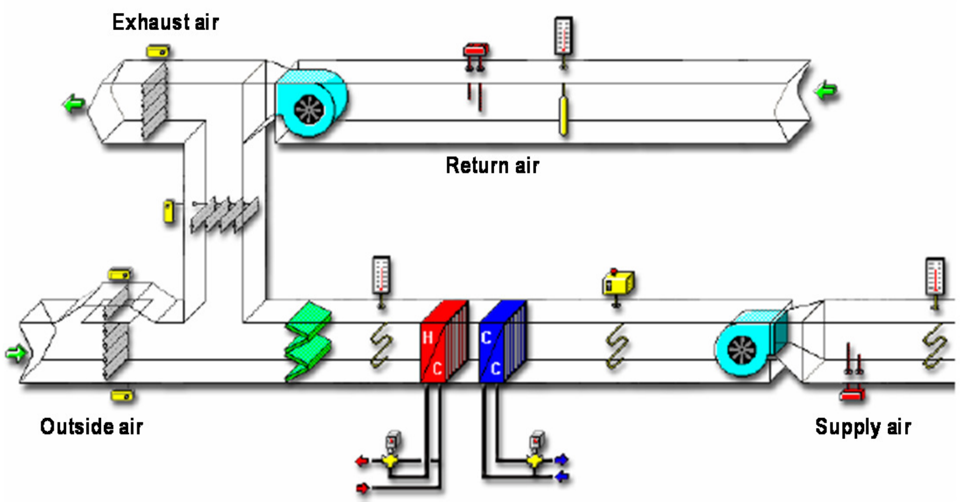
Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

Jan 2016

Contents

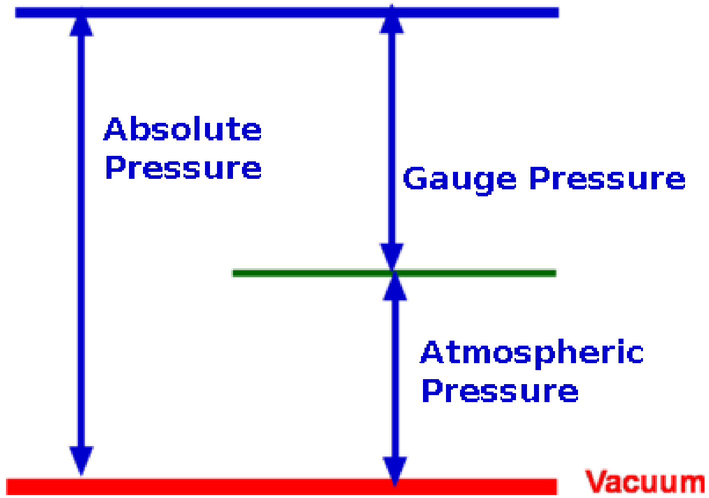
- Air Flow Dynamics
- Fan Design
- Air System Basics
- Air Handling Units
- Main AHU Components





Air Flow Dynamics

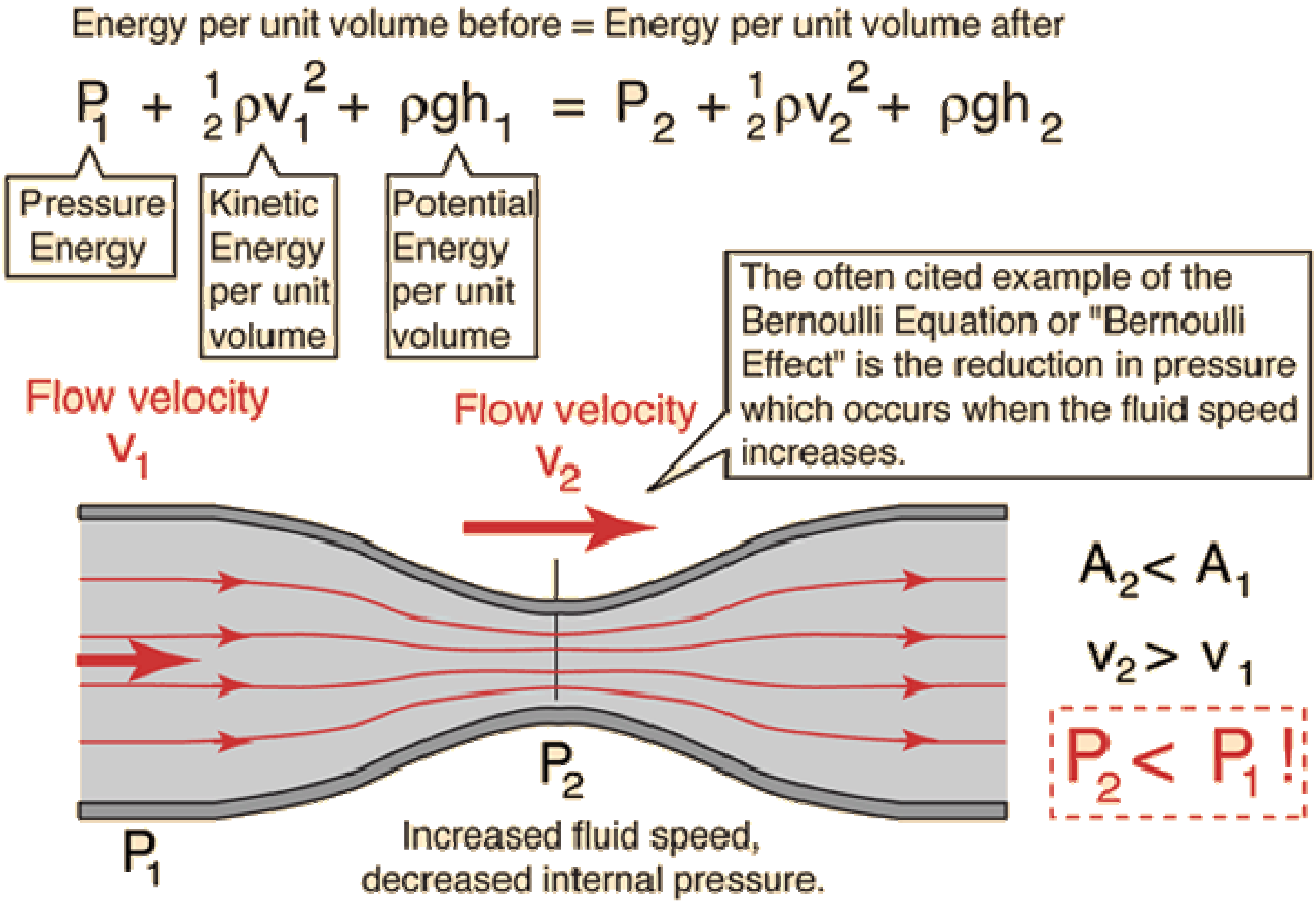
- The fluid = AIR
  - Fluid properties
    - Air density = 1.204 kg/m^3
    - Air specific volume = 0.831 m^3/kg
    - Specific heat (C_p) = 1.0 kJ/kg.K
  - Fluid pressure
    - Static pressure/head
    - 1 standard atmospheric pressure = 101.325 kPa (≈1 bar)
    - Absolute pressure & gauge pressure

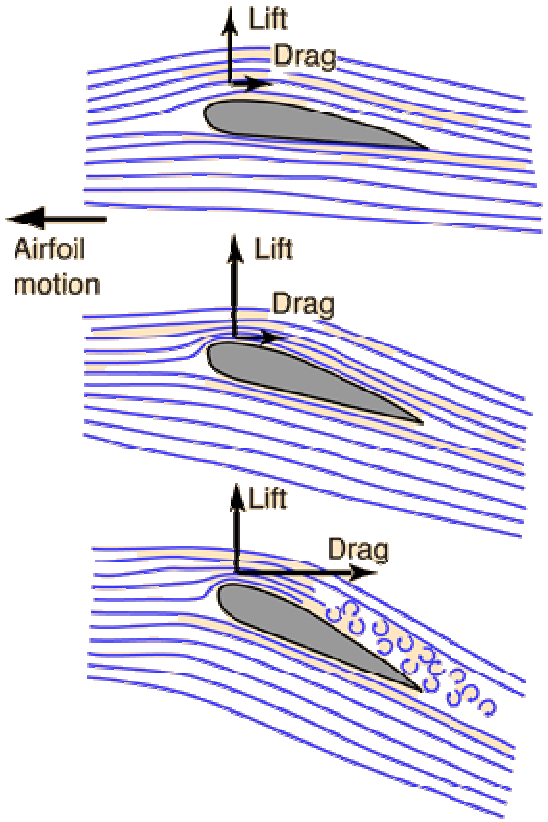


It is useful to remember some typical data of air.

Bernoulli Equation:

You have learnt them at the fluid mechanics lessons.



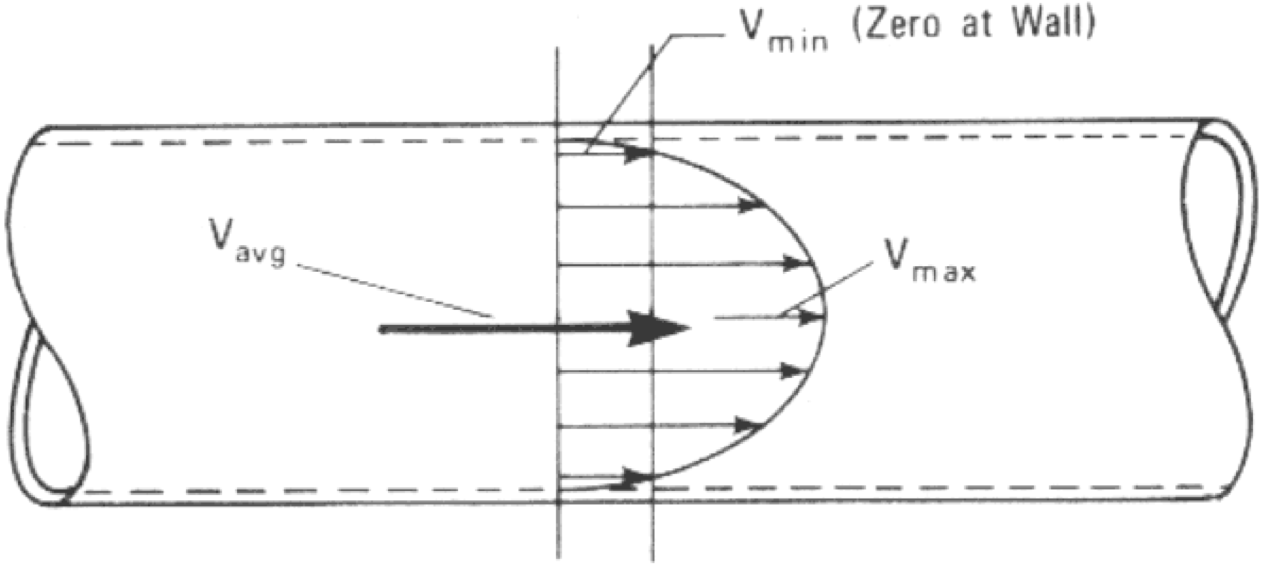


(See also: Bernoulli Equation [HyperPhysics] http://hyperphysics.phy-astr.gsu.edu/hbase/pber.html
Lesson 6 Review of fundamentals: Fluid flow http://nptel.ac.in/courses/112105129/6)

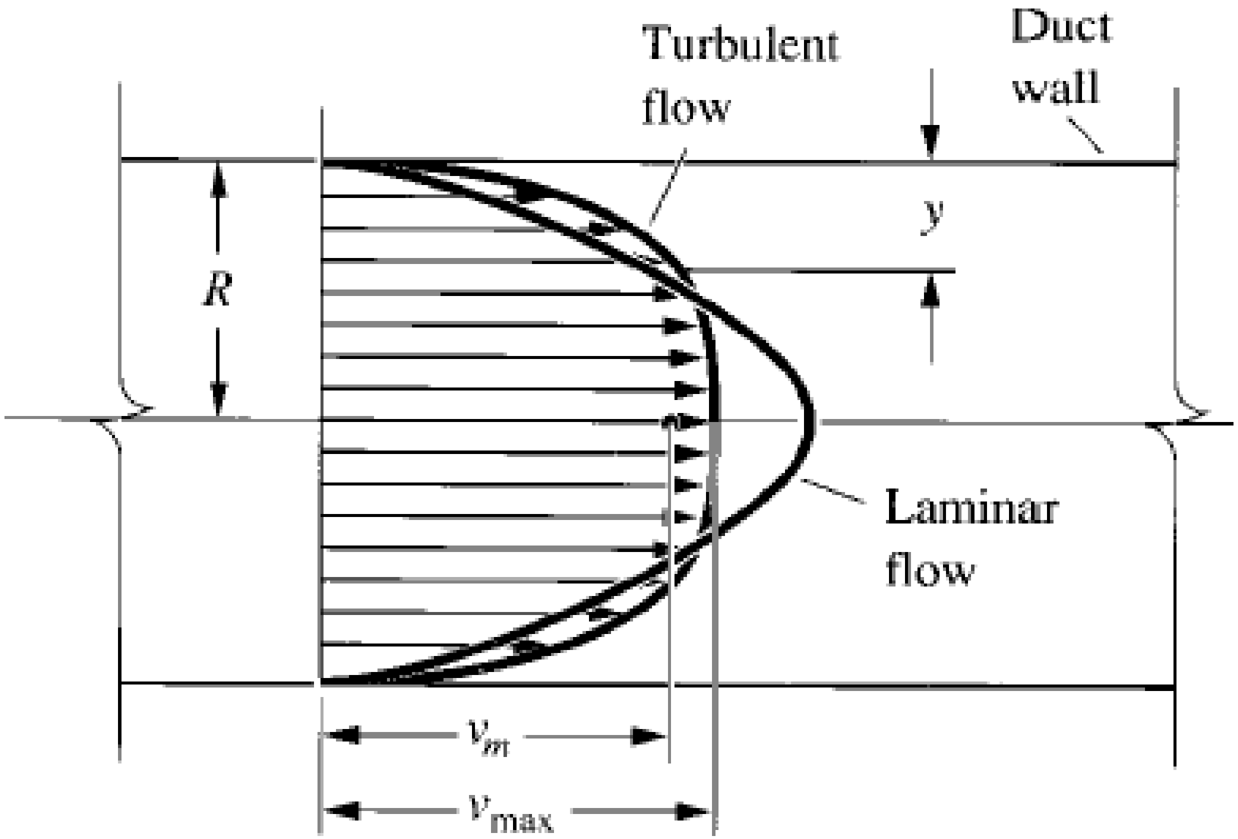
Air Flow Dynamics

- Air flow velocity and flow rate
  - Based on cross-sectional area of the duct
  - Flow rate Q = Area x Velocity
- Velocity profile (in duct or pipe)
  - Friction between duct walls and the fluid
  - Turbulent flow and laminar flow
  - System resistance (frictional losses)
  - Dynamic losses (e.g. change of flow direction)

Velocity profile (in duct or pipe)



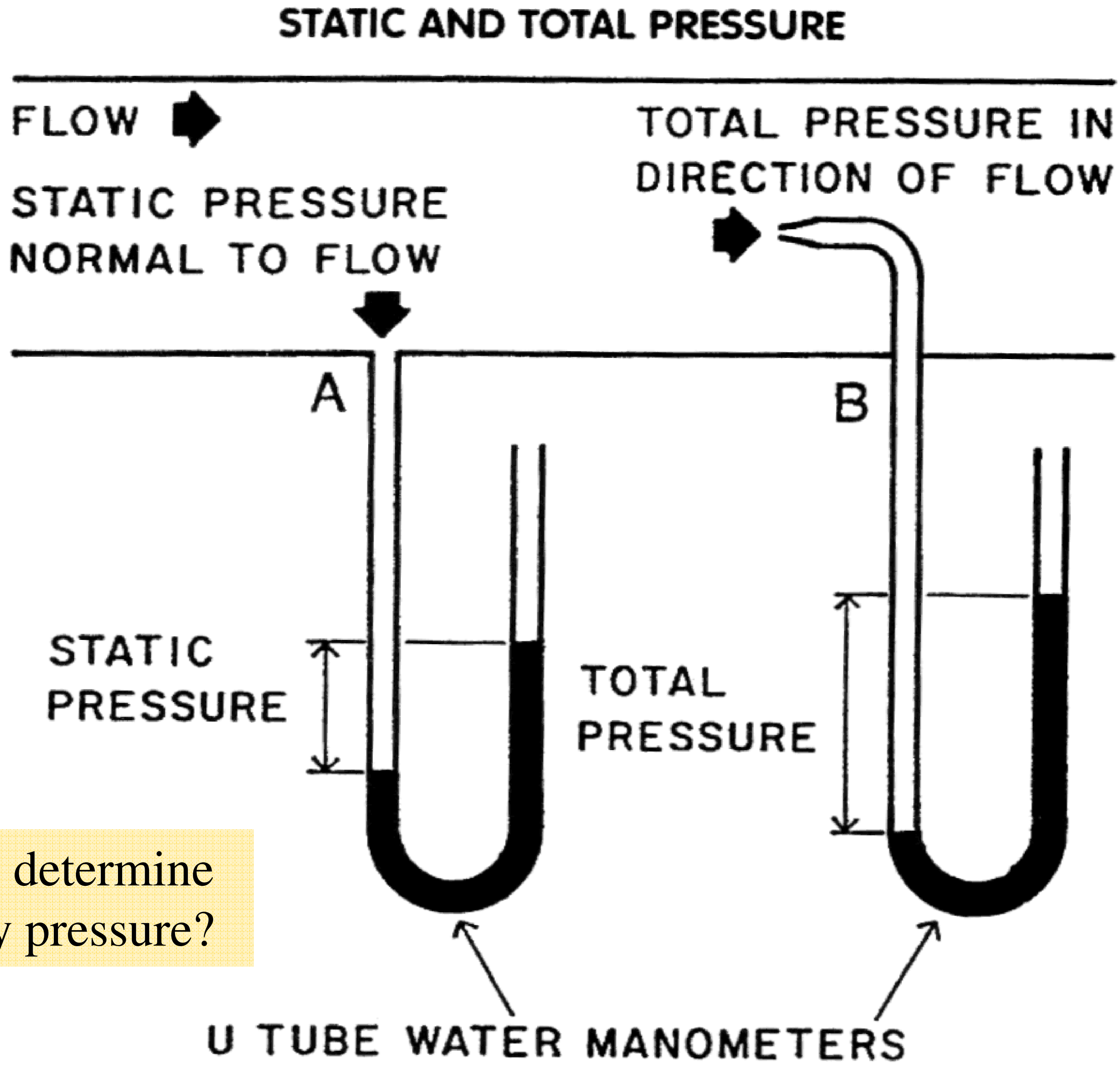
Why the velocity profile looks like this?



What is the difference between laminar and turbulent flow?

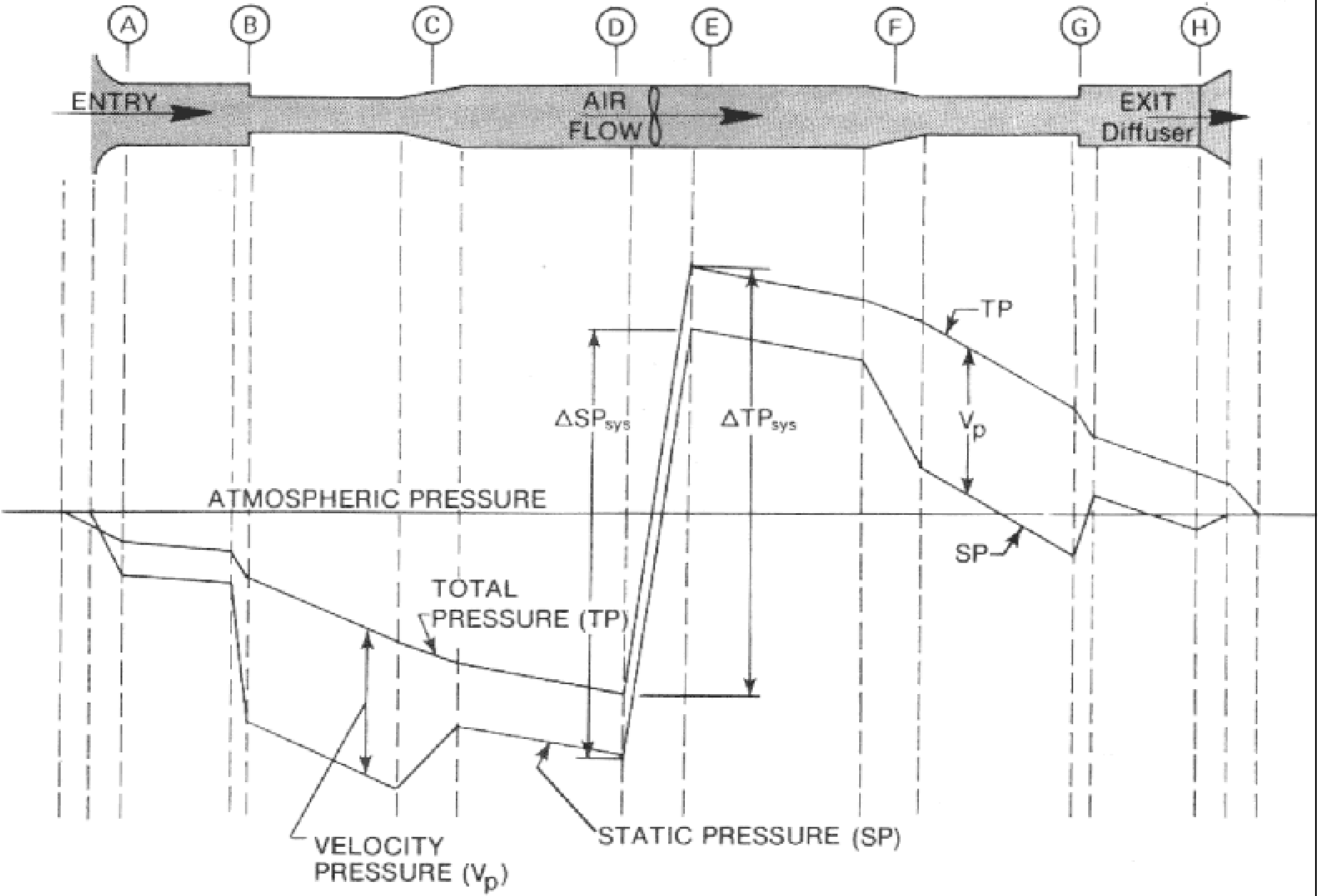
Air Flow Dynamics

- Duct pressure changes (c.f. atm pressure)
  - Static pressure (SP), Pa
  - Velocity pressure (VP), Pa: $VP = \rho V^2 / 2$
  - Total pressure (TP), Pa: $TP = SP + VP$
- Fan: a pumping device
  - Fan (total) pressure = pressure difference between fan inlet and fan discharge
  - At fan suction/inlet, SP = negative (c.f. atmospheric); at discharge, SP = positive



How to determine velocity pressure?

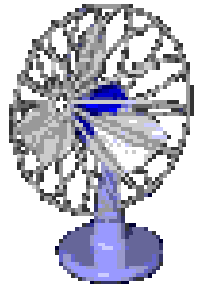
Pressure characteristics of a fan-duct system



Air Flow Dynamics

- Pressure characteristics of a fan-duct system
  - SP and VP are mutually convertible (↑or↓)
  - TP always decreases in the direction of airflow
  - For constant-area straight duct sections
    - Velocity and VP are constant
    - TP change = SP change
  - When duct cross-sectional areas are reduced
    - Velocity and VP increase
    - Absolute value of both TP and SP decrease
    - Dynamic losses may also from elbow, dampers, etc.

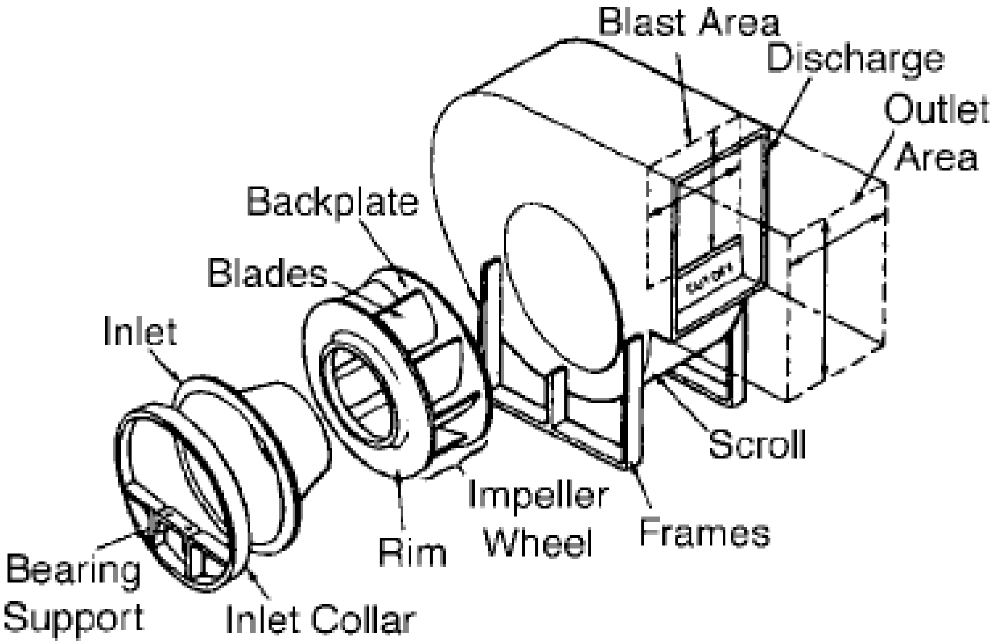
Fan Design

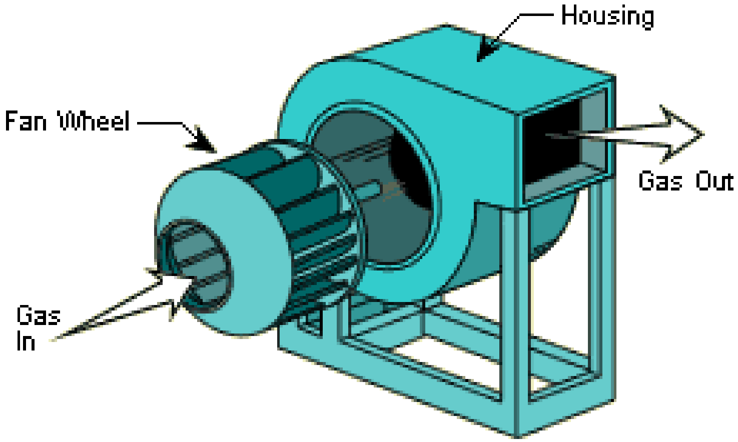


- Common types of fans
  - **[Centrifugal fans (離心風機)]**: radial, forward curved, air foil (backward curved), backward inclined, tubular, roof ventilator
  - **[Axial fans (軸流風機)]**: propeller, tube-axial, vane-axial
- Fan arrangements
  - Motor location, air discharge orientation, drive train type (direct drive or pulley drive)
  - Centrifugal: single width single inlet (SWSI), double width double inlet (DWDI)

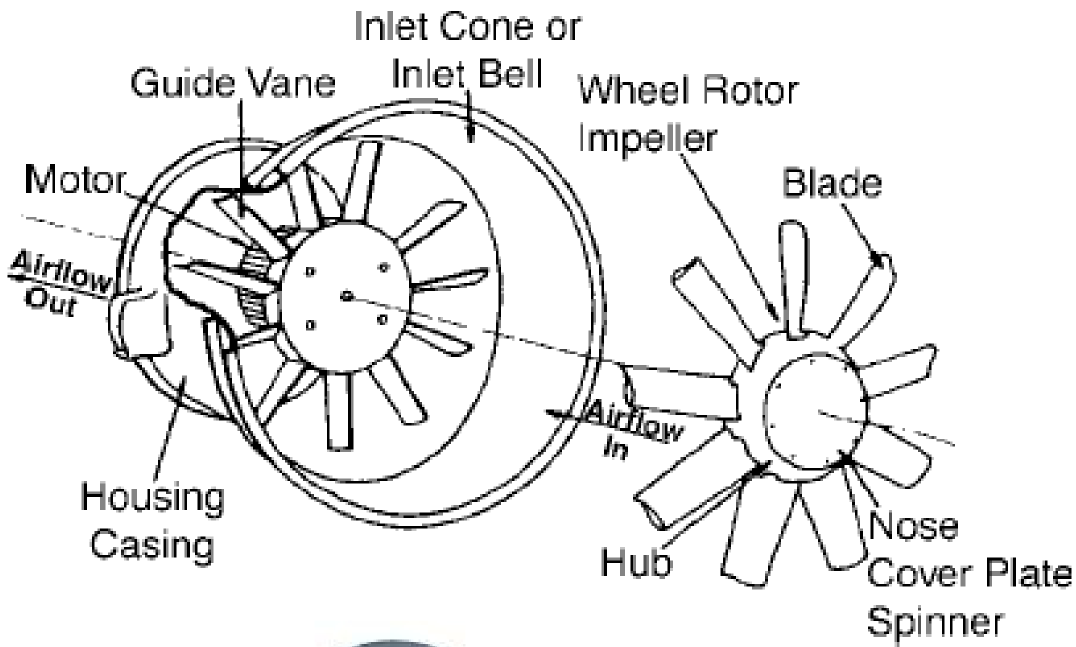
Centrifugal and axial fan components

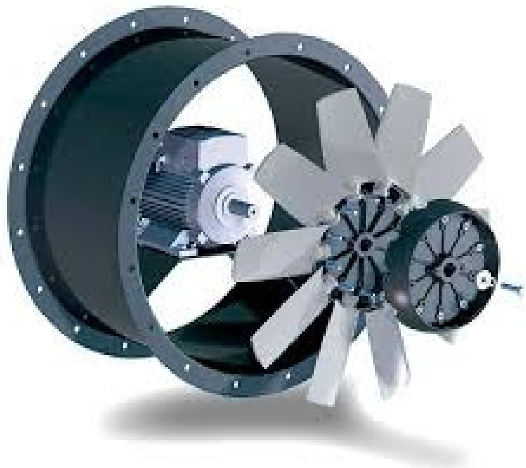
CENTRIFUGAL FANS





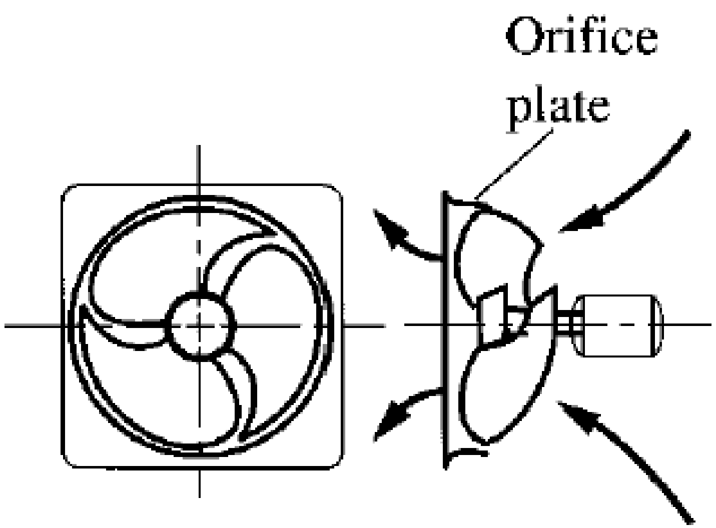
AXIAL FANS



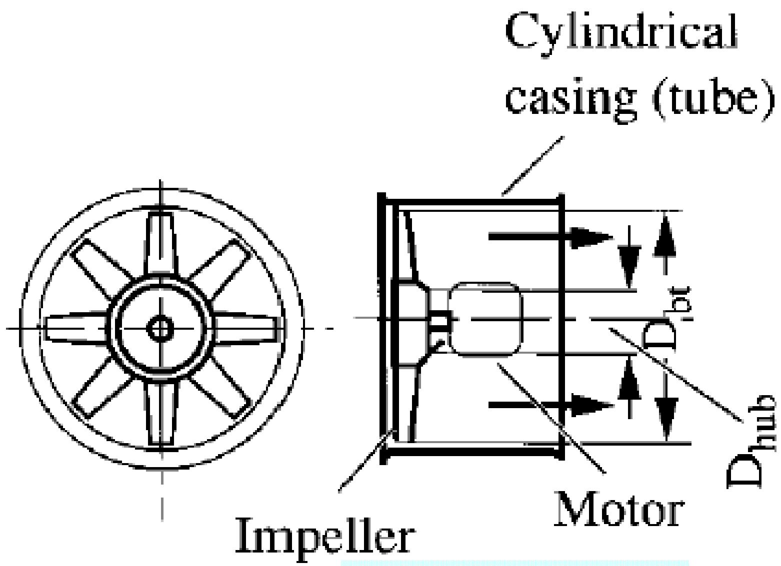


[Source: Kreider, K. F. (ed.), 2001. *Handbook of Heating, Ventilation, and Air Conditioning*, CRC Press, Boca Raton, FL.]

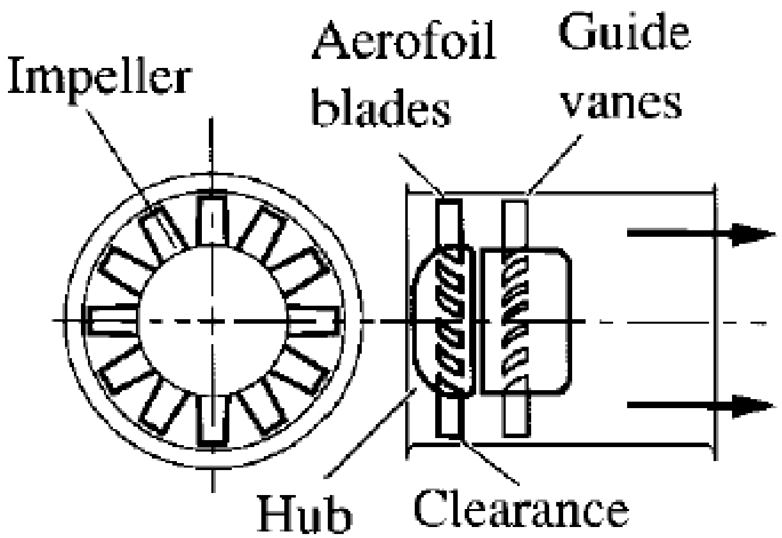
AXIAL FANS



Propeller



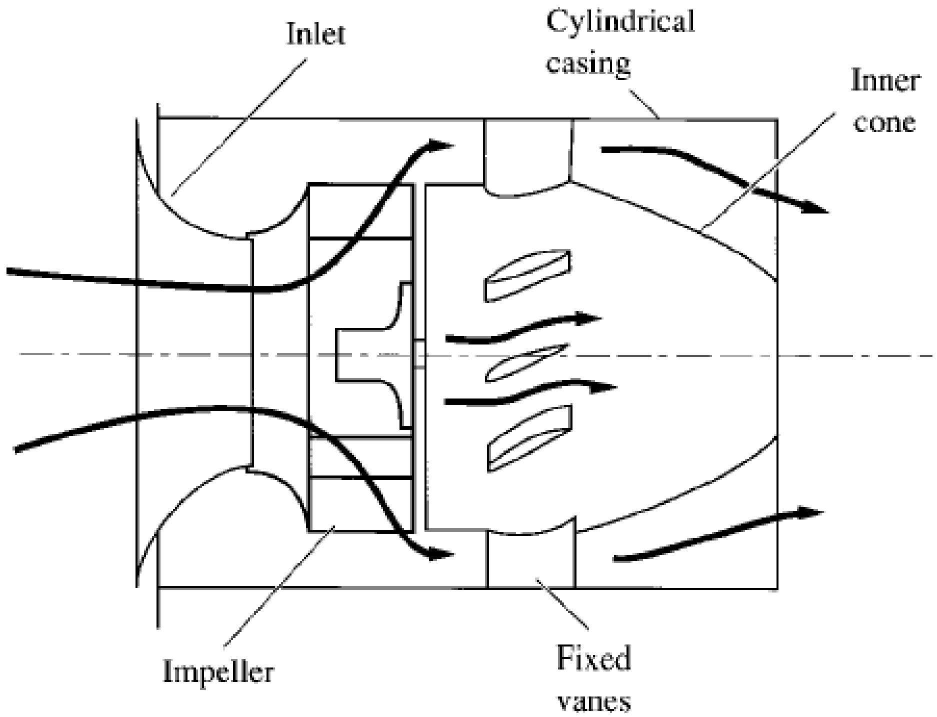
Tube-axial



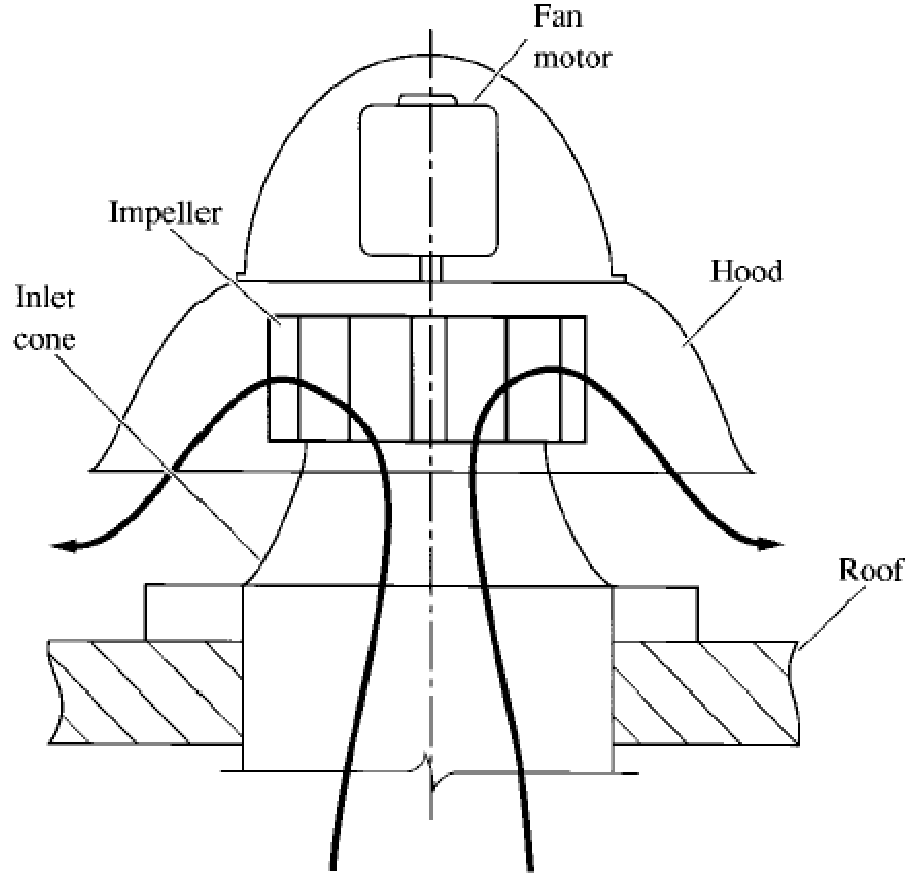
Tube-vane

Can you suggest where are they being used?

CENTRIFUGAL FANS



Tubular centrifugal fan

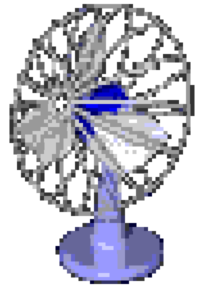


Centrifugal roof ventilator

(* Note the airflow paths and impeller design.)

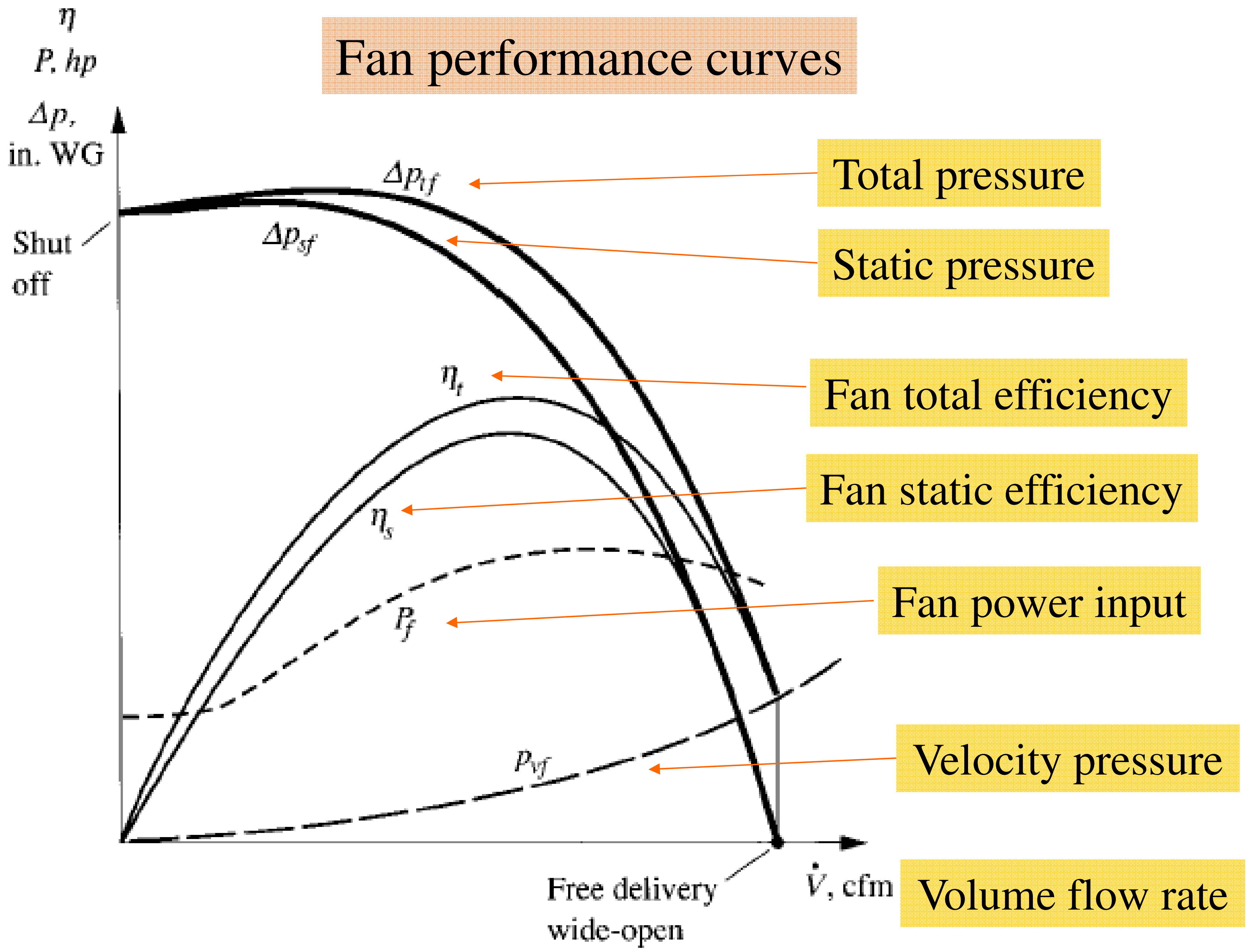
(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Fan Design



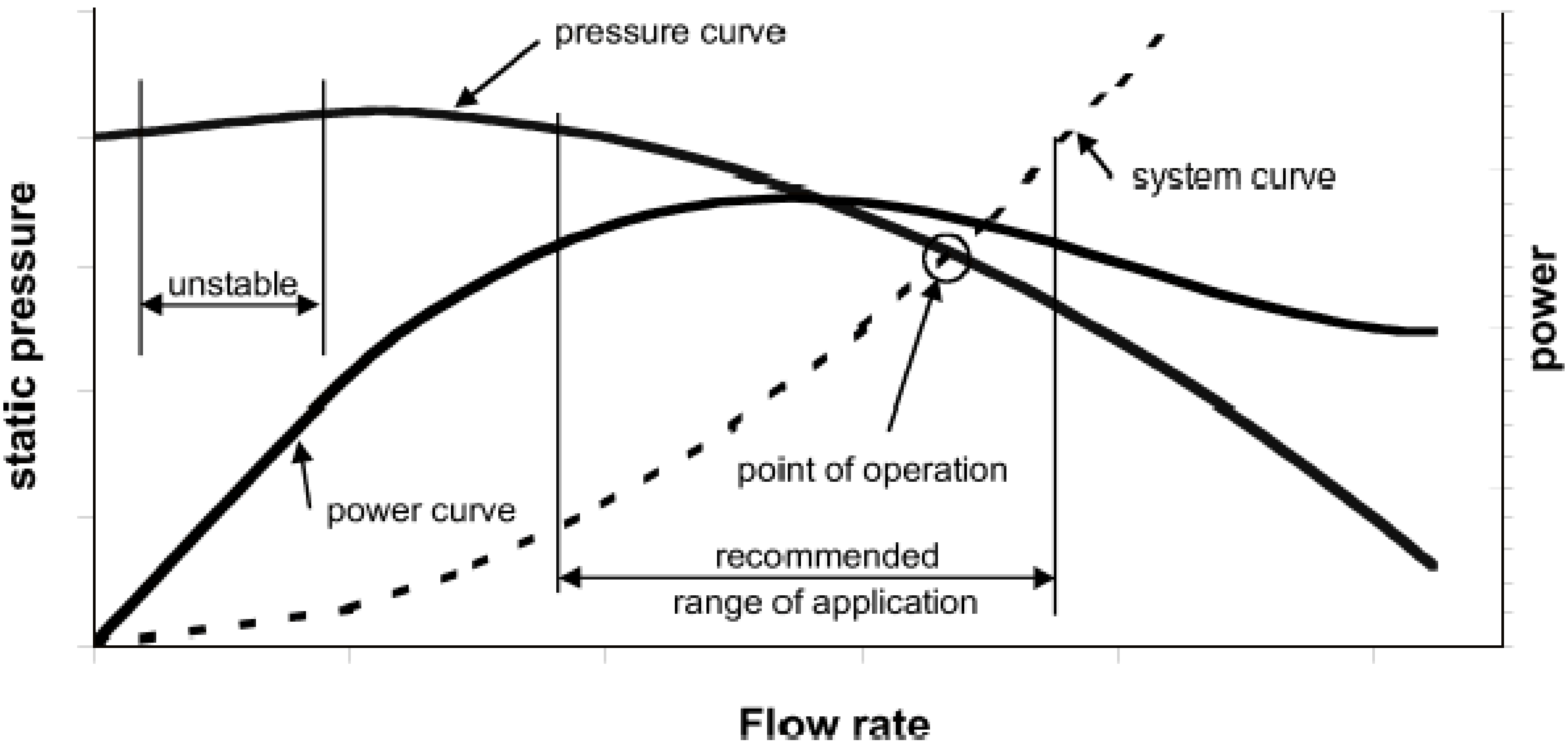
- Major parameters
  - Fan volume flow rate (m^3/s or l/s), V_f
  - Fan total pressure Δp_{tf}, fan velocity pressure p_{vf} & fan static pressure Δp_{sf} (Pa)
  - Fan power & efficiency
    - Fan power or air power (W) = $\Delta p_{tf} \times V_f$
    - Fan power input on the fan shaft (brake horsepower), P_f
    - Fan total efficiency: $\eta_t = \Delta p_{tf} \times V_f / P_f$
      - Combined aerodynamic, volumetric & mechanical efficiencies
    - Fan static efficiency: $\eta_s = \Delta p_{sf} \times V_f / P_f$
    - Air temp. increase through fan, $\Delta T_f = \Delta p_{tf} / (\rho c_{pa} \eta_t)$

Fan performance curves



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

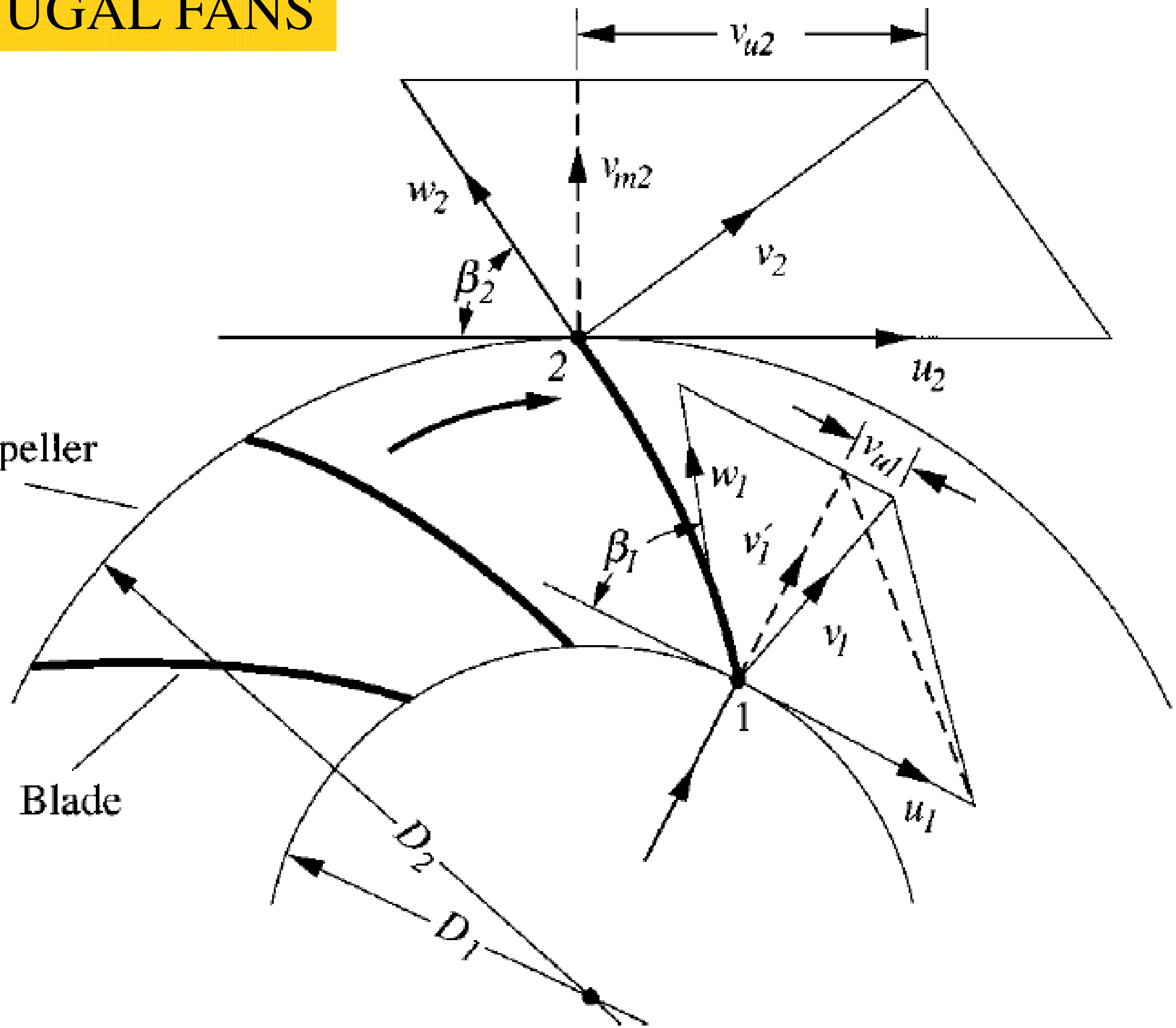
Typical fan performance curve



Why there is an unstable region and a recommended range of application?

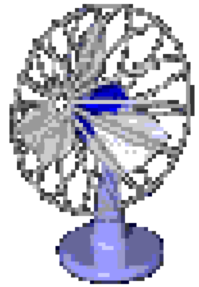
Velocity triangle at the blade inlet and outlet of a centrifugal fan

CENTRIFUGAL FANS



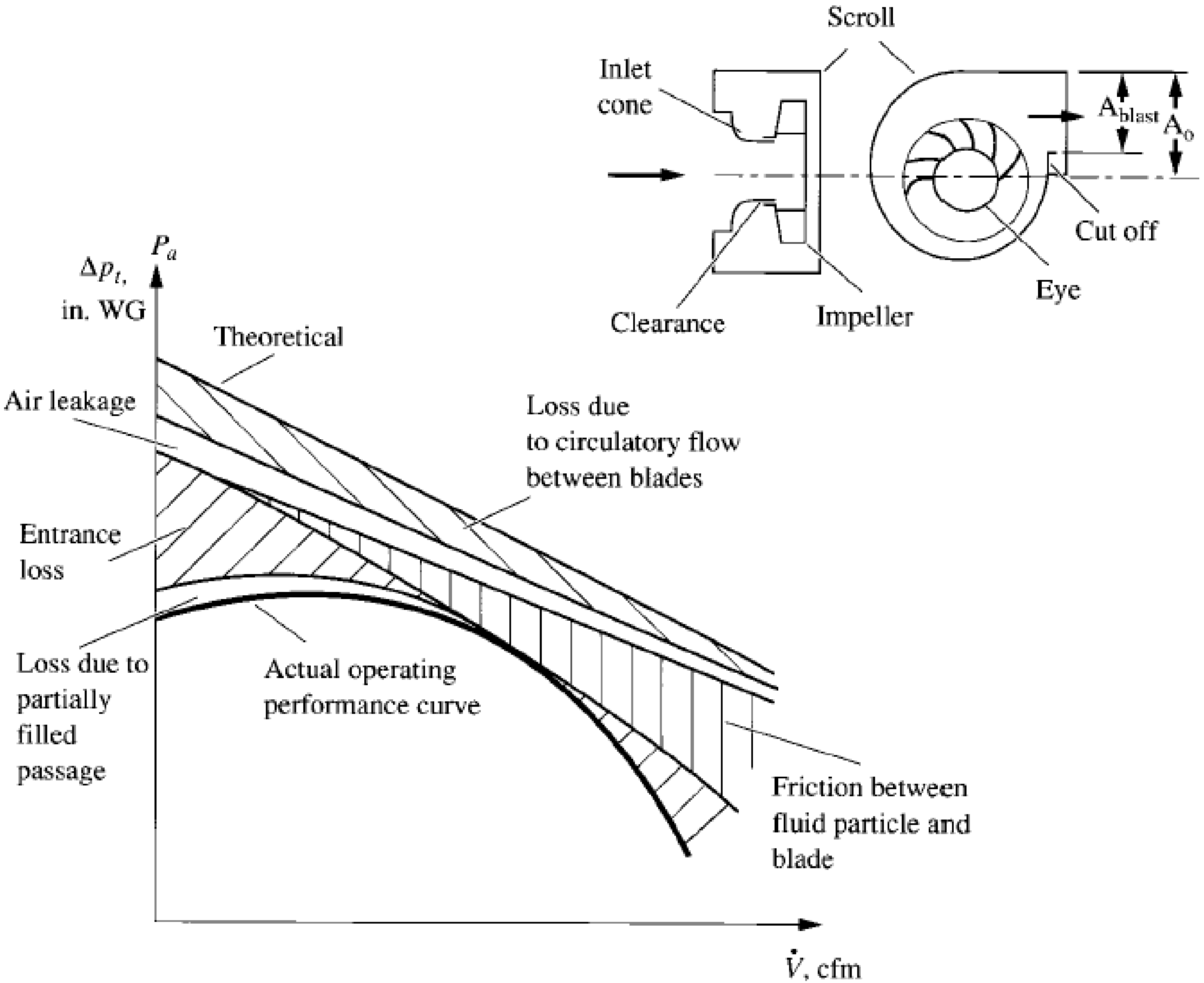
(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Fan Design

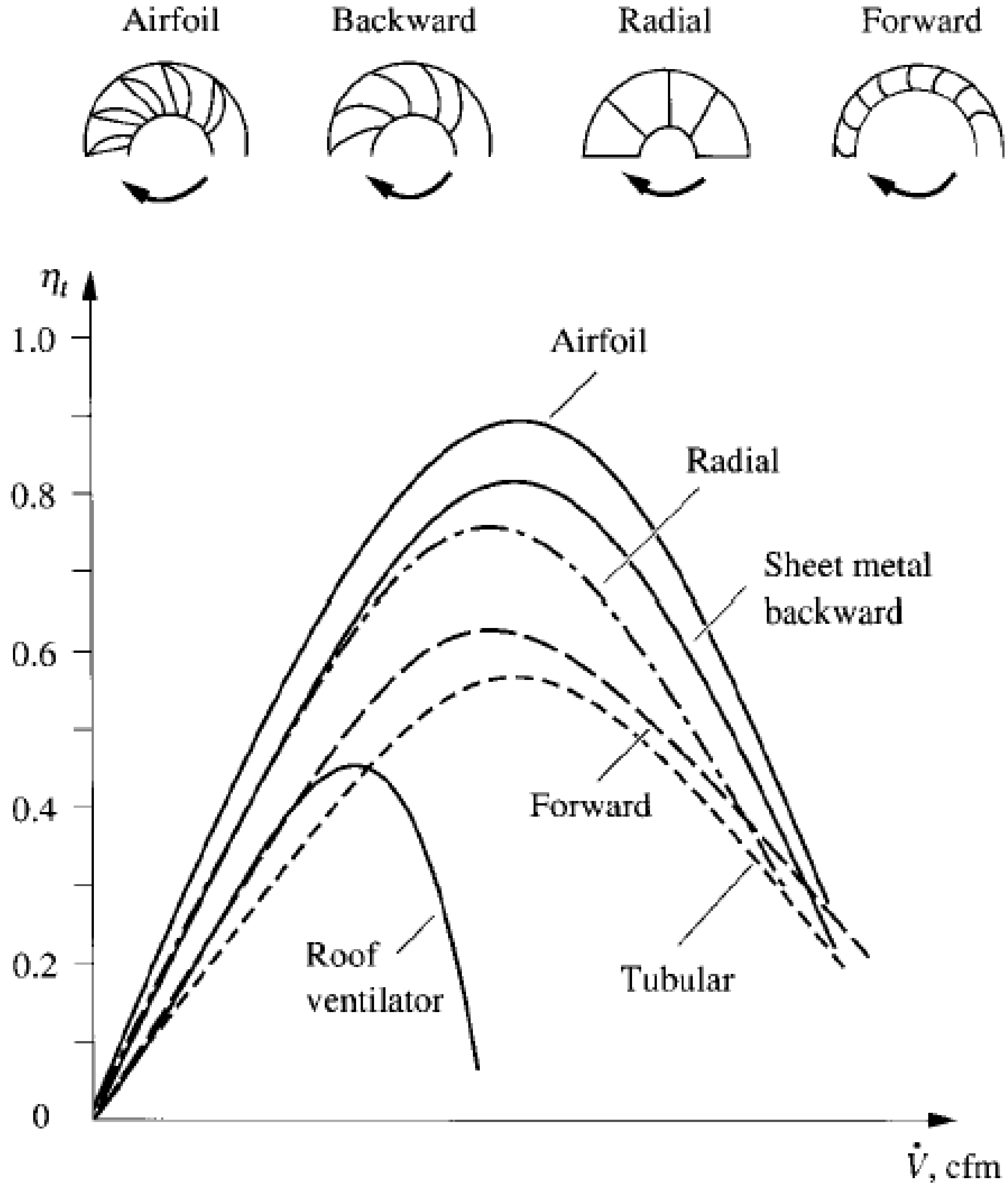


- Energy losses of a centrifugal fan
  - Circulatory flow between the blades
  - Air leakage at the inlet
  - Friction between fluid particles and the blade
  - Energy loss at the entrance
  - Partially filled passage

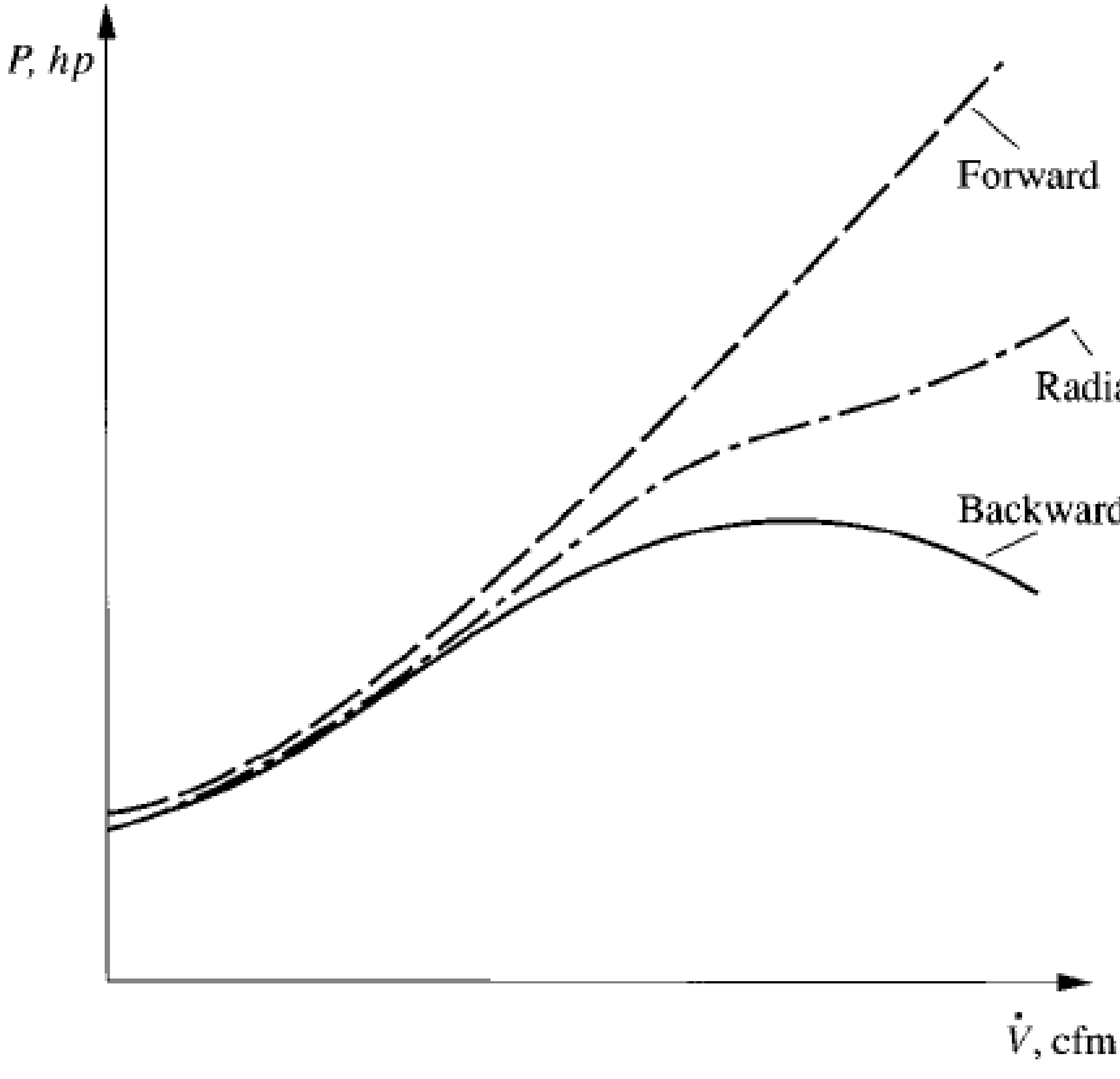
Operating characteristics for a backward-curved centrifugal fan



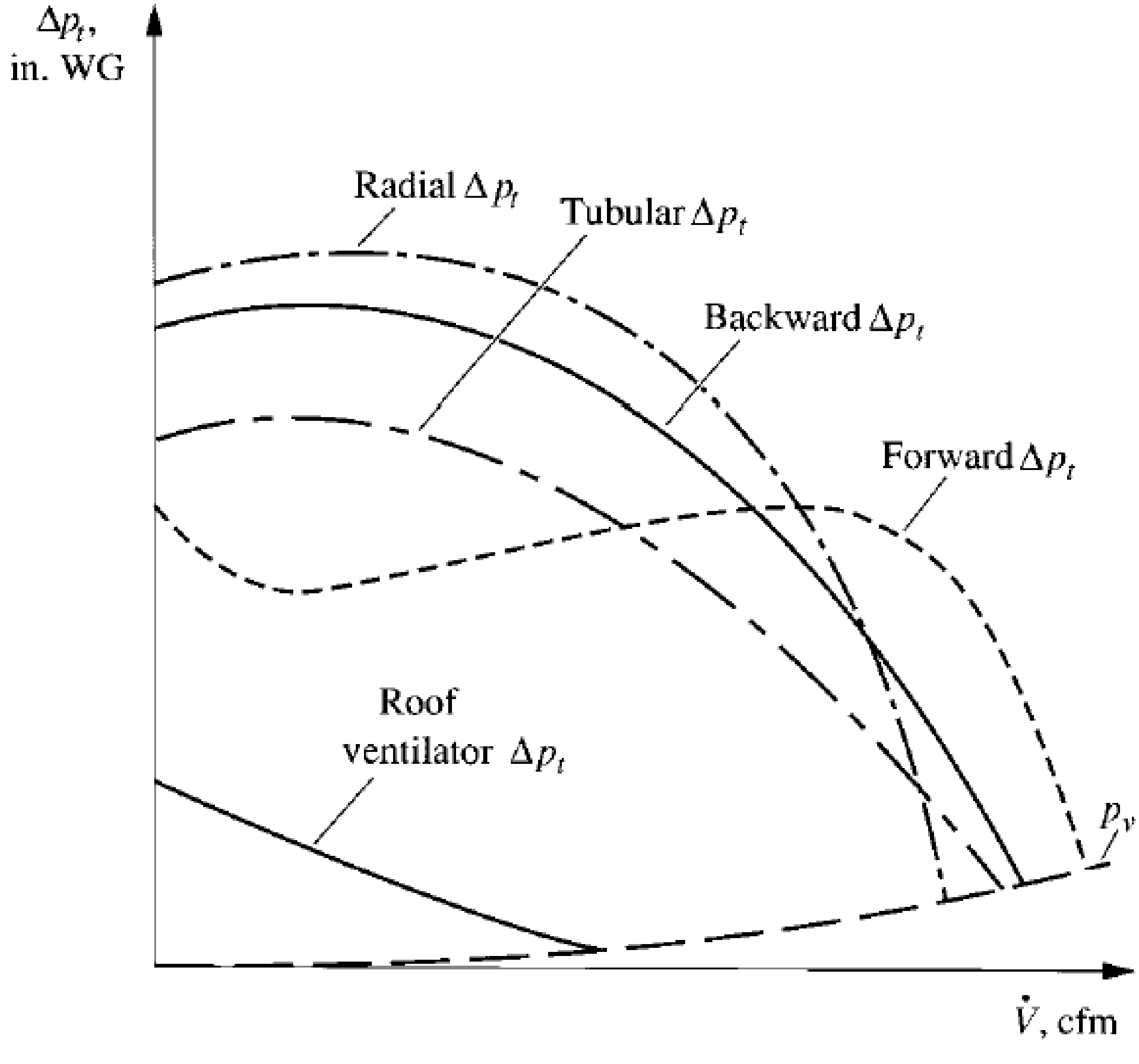
Total efficiency curves for centrifugal fans



Fan power curves for centrifugal fans with same impeller diameter

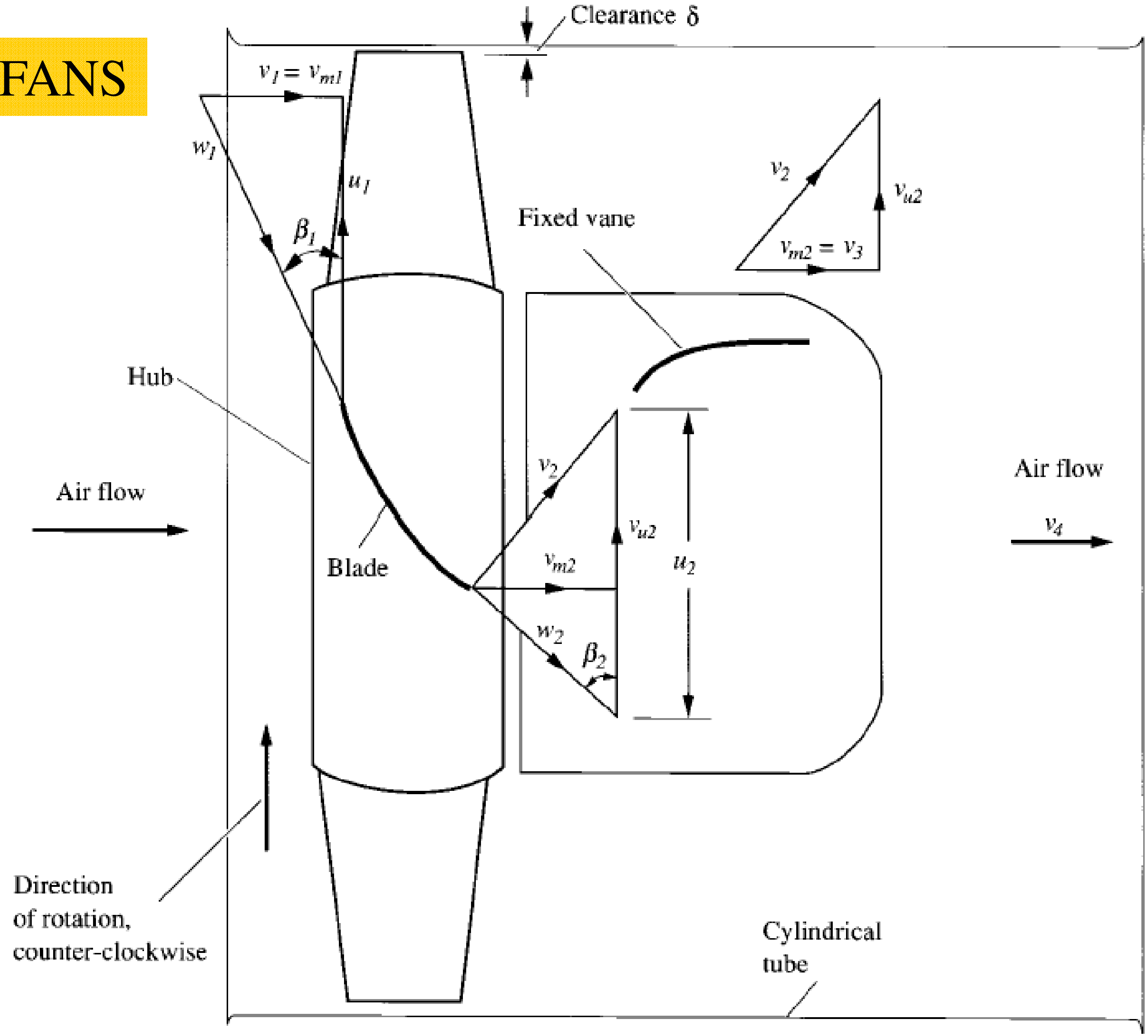


Fan pressure curves for centrifugal fans with same impeller diameter



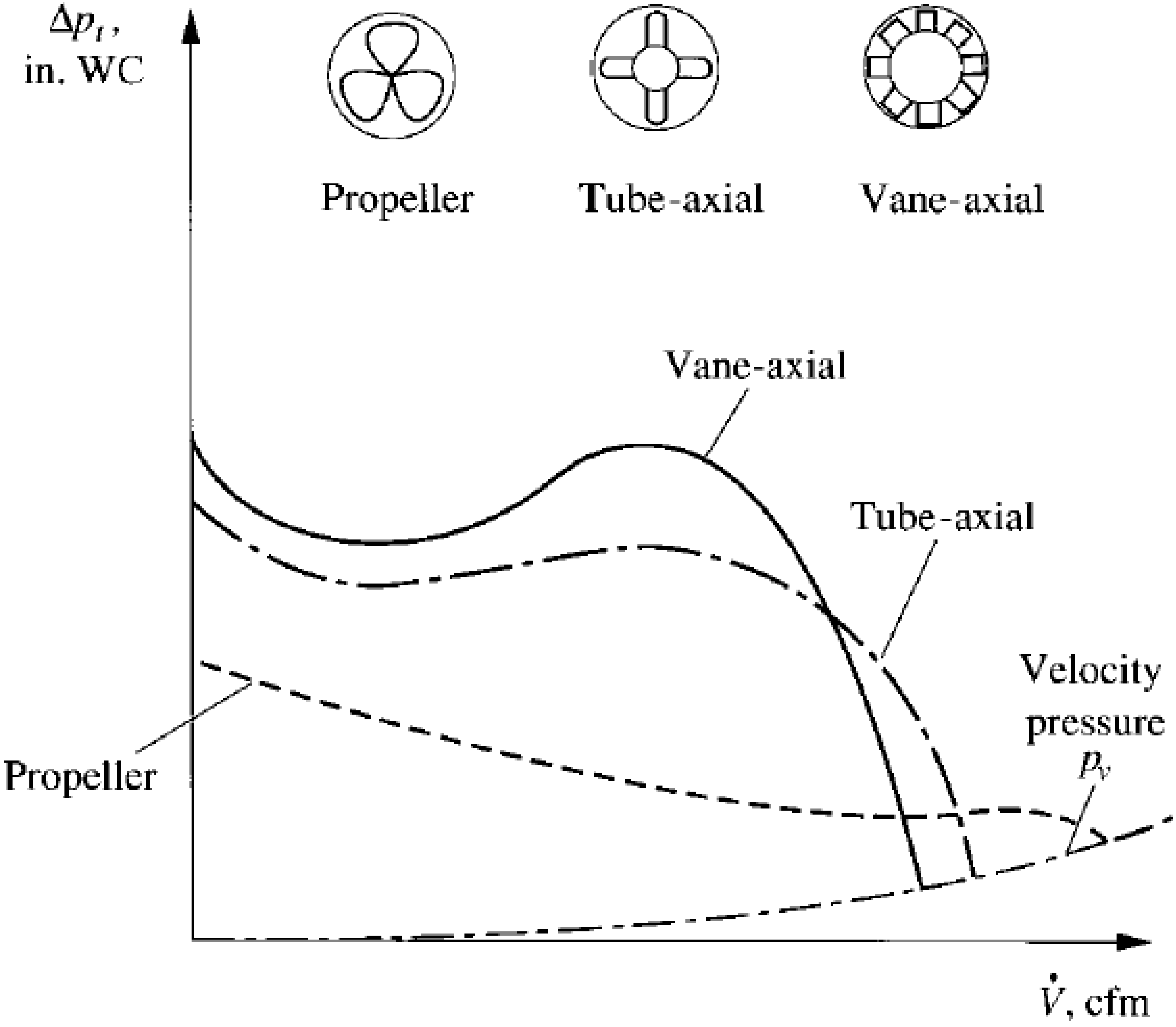
Velocity triangles for a vane-axial fan

AXIAL FANS

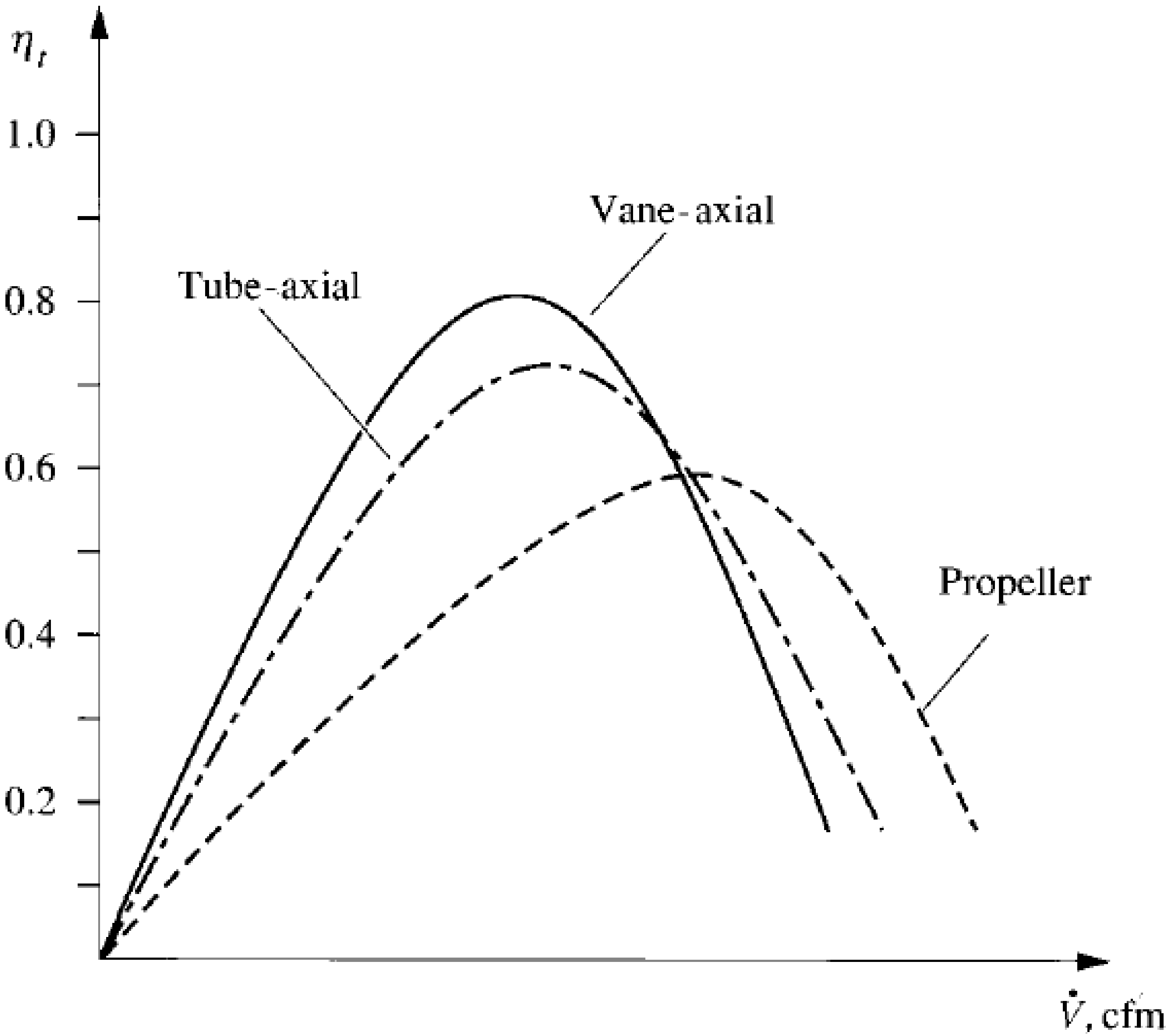


(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

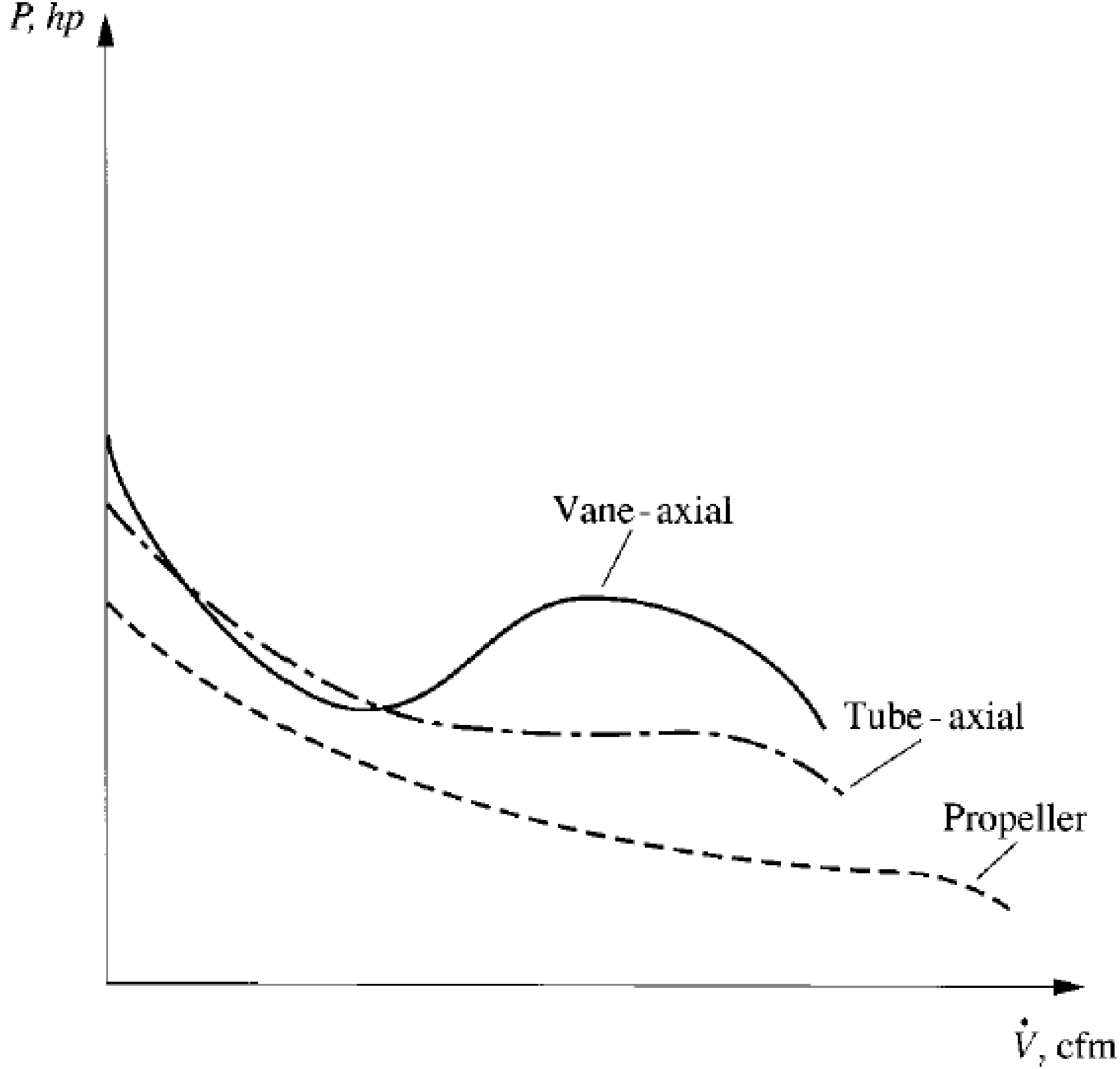
Fan pressure curves for axial fans with same impeller diameter



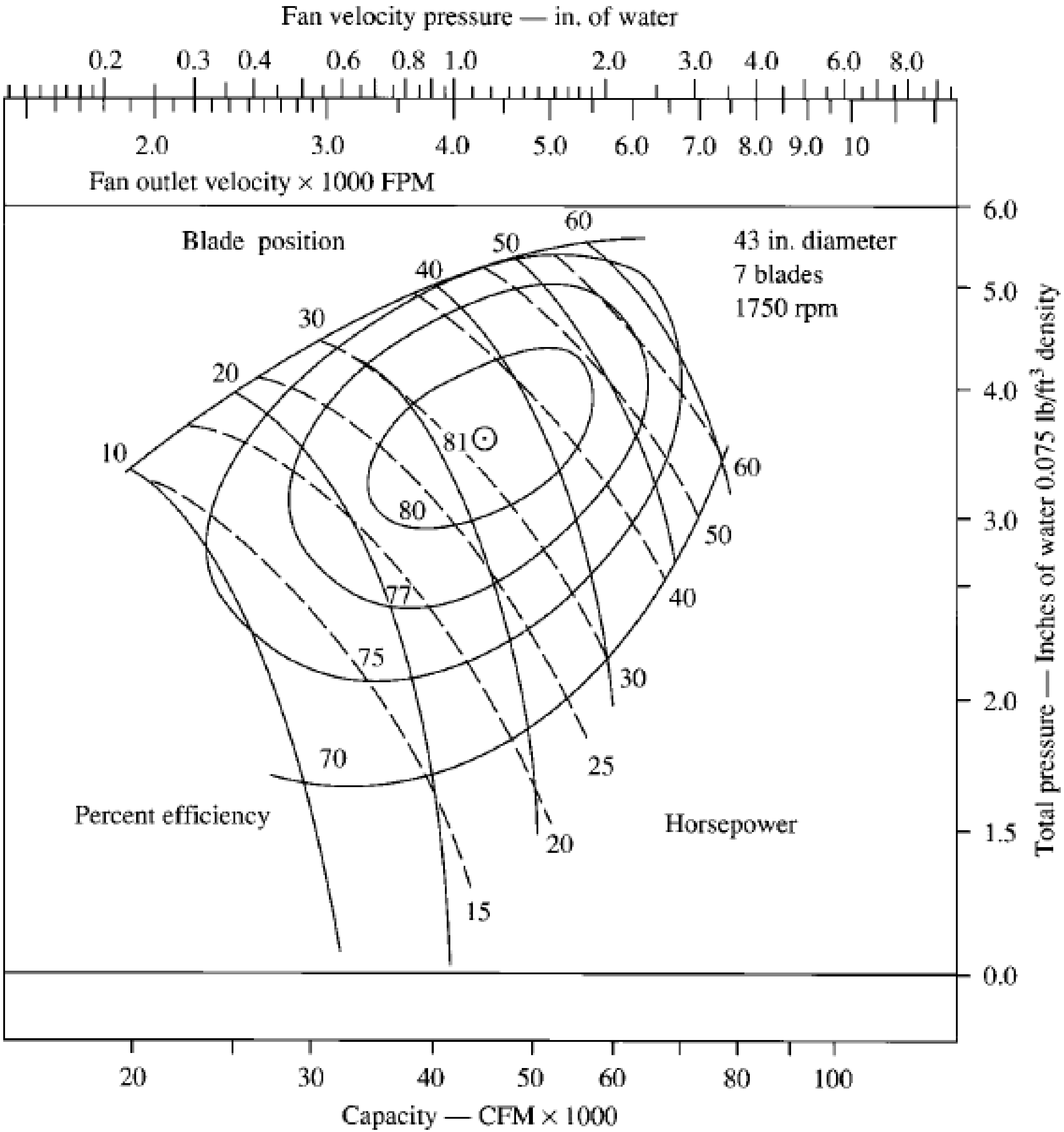
Fan efficiency curves for axial fans with same impeller diameter



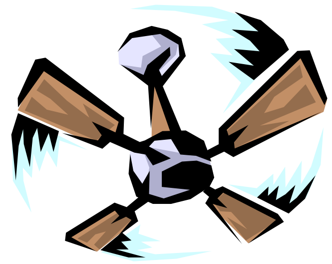
Fan power curves for axial fans with same impeller diameter



Performance curves for controllable-pitch vane-axial fans



Air System Basics



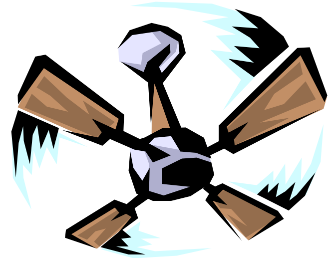
- Fan-duct systems
  - Flow resistance R, pressure drop Δp and volume flow rate $\dot{V}$

$$\Delta p = R \cdot \dot{V}^2$$

  - Duct sections in series: $R_s = R_1 + R_2 + \ldots + R_n$
  - Duct sections in parallel:

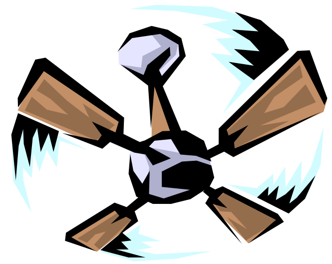
$$\frac{1}{\sqrt{R_p}} = \frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \ldots + \frac{1}{\sqrt{R_n}}$$

Air System Basics



- Fan-duct systems
  - Terminology
    - Primary air (conditioned air or makeup air)
    - Secondary air (induced space air, plenum air, or recirculating air)
    - Transfer air (indoor air that moves from an adjacent area)
  - System curve: volume flow vs pressure loss
  - System operating point

Air System Basics



- **Fan Laws**
  - Speed (n)
  - Volume flow (V)
  - Total pressure loss (Δp)
  - Air density (ρ)
  - For air systems that are geometrically & dynamically similar: (D = impeller diameter)
- c.f.: pump laws

$$\mathring{V}_2 / \mathring{V}_1 = n_2 / n_1$$

$$\Delta p_{t2} / \Delta p_{t1} = (n_2 / n_1)^2 (\rho_2 / \rho_1)$$

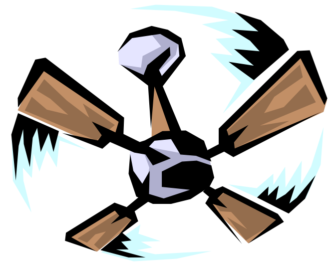
$$P_2 / P_1 = (n_2 / n_1)^3 (\rho_2 / \rho_1)$$

$$\mathring{V}_2 / \mathring{V}_1 = (D_2 / D_1)^3 (n_2 / n_1)$$

$$\Delta p_{t2} / \Delta p_{t1} = (D_2 / D_1)^2 (n_2 / n_1)^2 (\rho_2 / \rho_1)$$

$$P_2 / P_1 = (D_2 / D_1)^5 (n_2 / n_1)^3 (\rho_2 / \rho_1)$$

Air System Basics



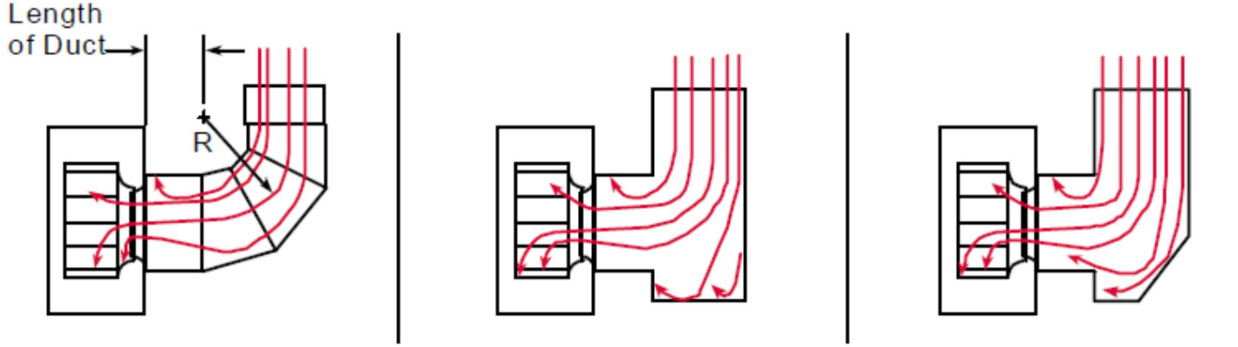
- System effect Δp_{ts}
  - Its additional total pressure loss caused by uneven or non-uniform velocity profile at the fan inlet, or at duct fittings after fan outlet
  - Due to the actual inlet and outlet connections as compared with the total pressure loss of the fan test unit during laboratory ratings

$$\Delta p_{ts} = \Delta p_{sy} + \Delta p_{se} = \Delta p_{sy} + \Delta p_{s.i} + \Delta p_{s.o}$$

$$= \Delta p_{sy} + C_{s.i}\left(v_{fi}/4005\right)^2 + C_{s.o}\left(v_{fo}/4005\right)^2$$

Inlet Outlet

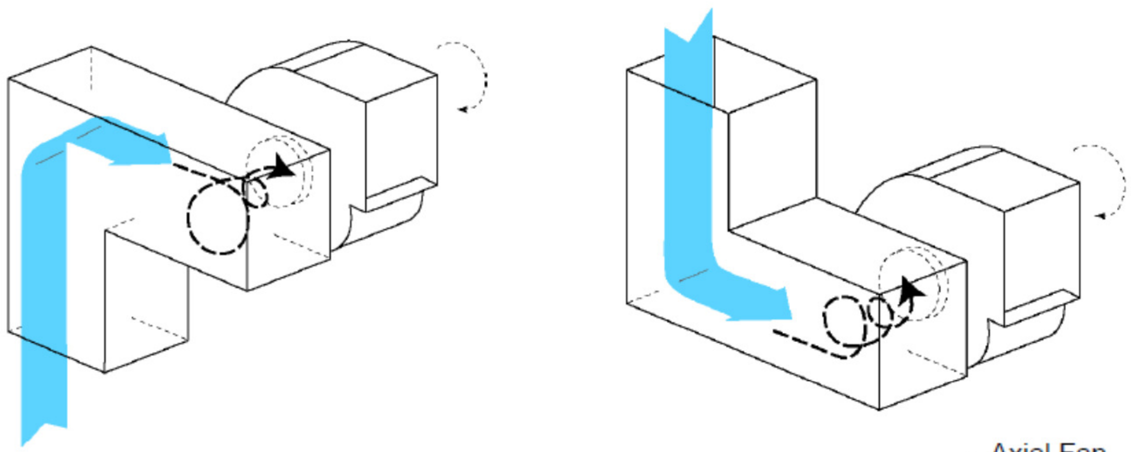
Inlet conditions



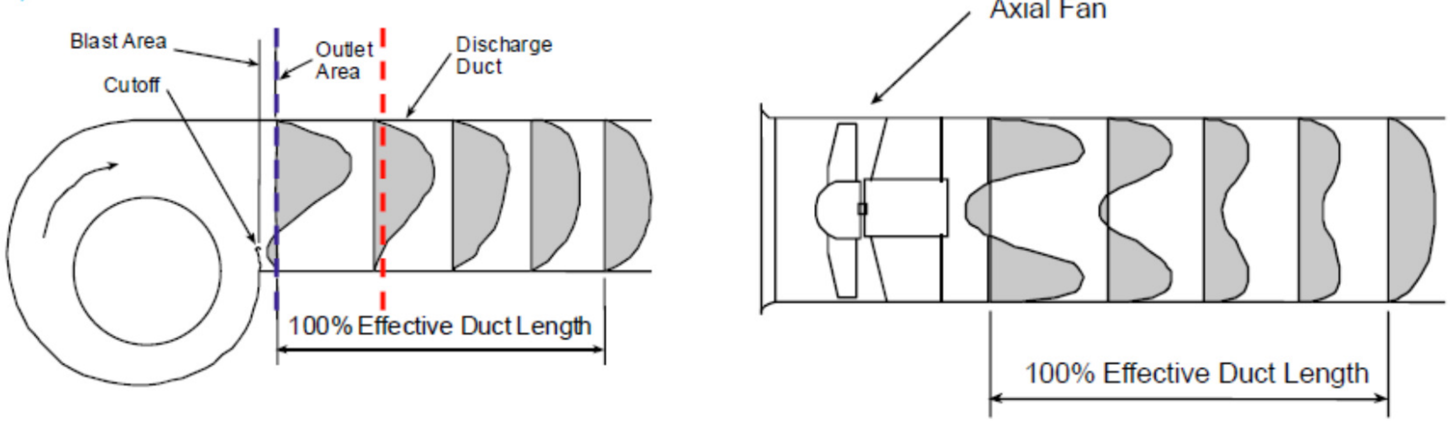
Inlet with 3-piece elbow | Inlet with rectangular inlet Duct | Inlet with special designed inlet box

Inlet swirl

Pre-Rotation | Counter-Rotation

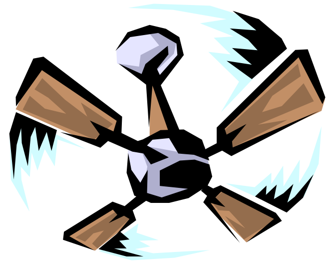


Outlet duct



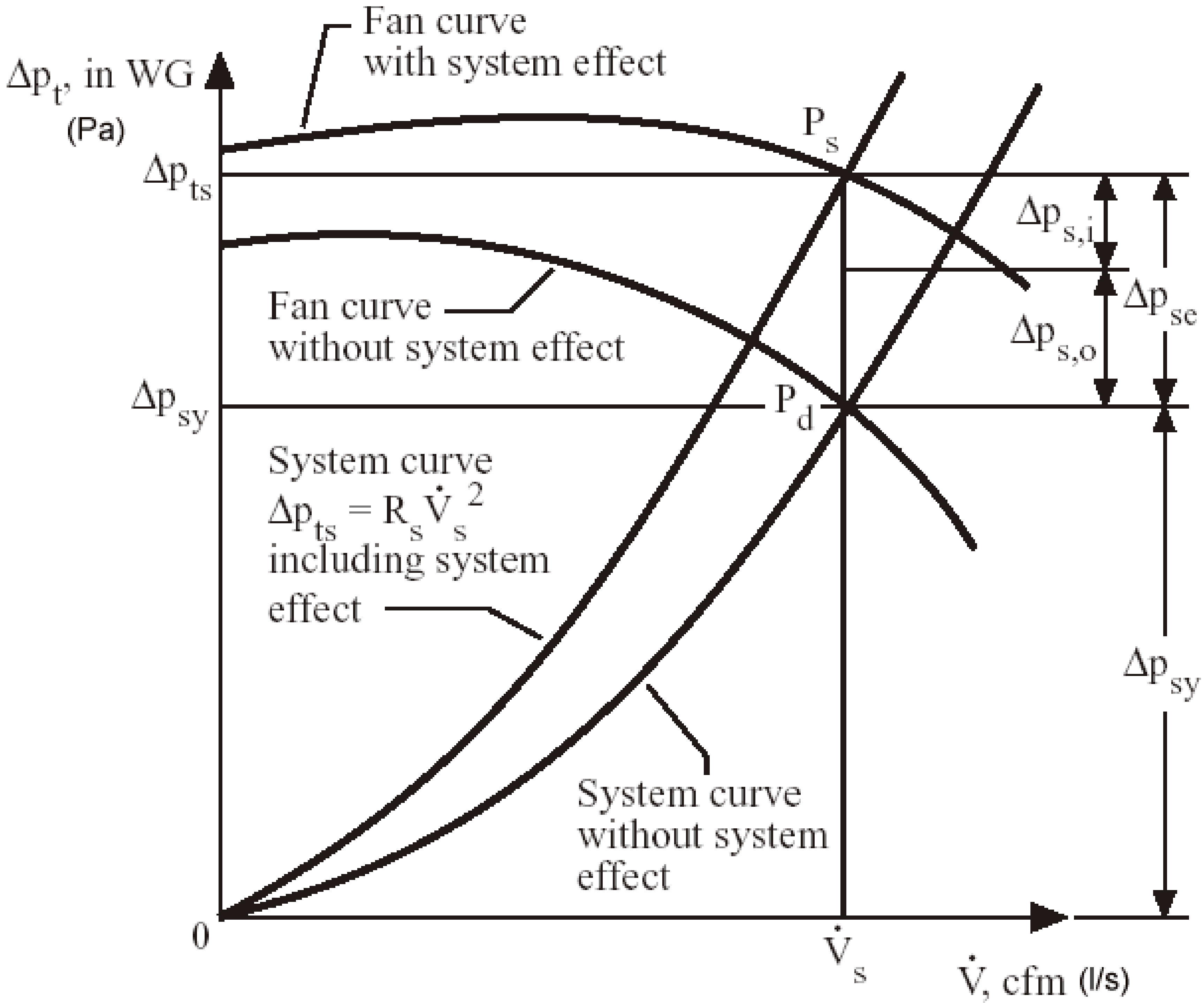
(Source: Air Movement and Control Association (AMCA))

Air System Basics

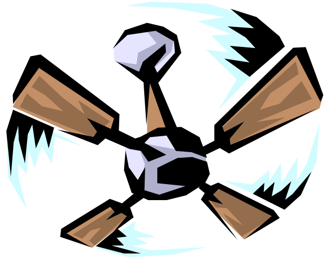


- Why system effect is important?
  - Can decrease performance
  - Can cause excess vibration
  - Can cause excess noise
  - Can require more energy to achieve rated performance
  - Takes time to determine and understand

Fan system operating point & system effect

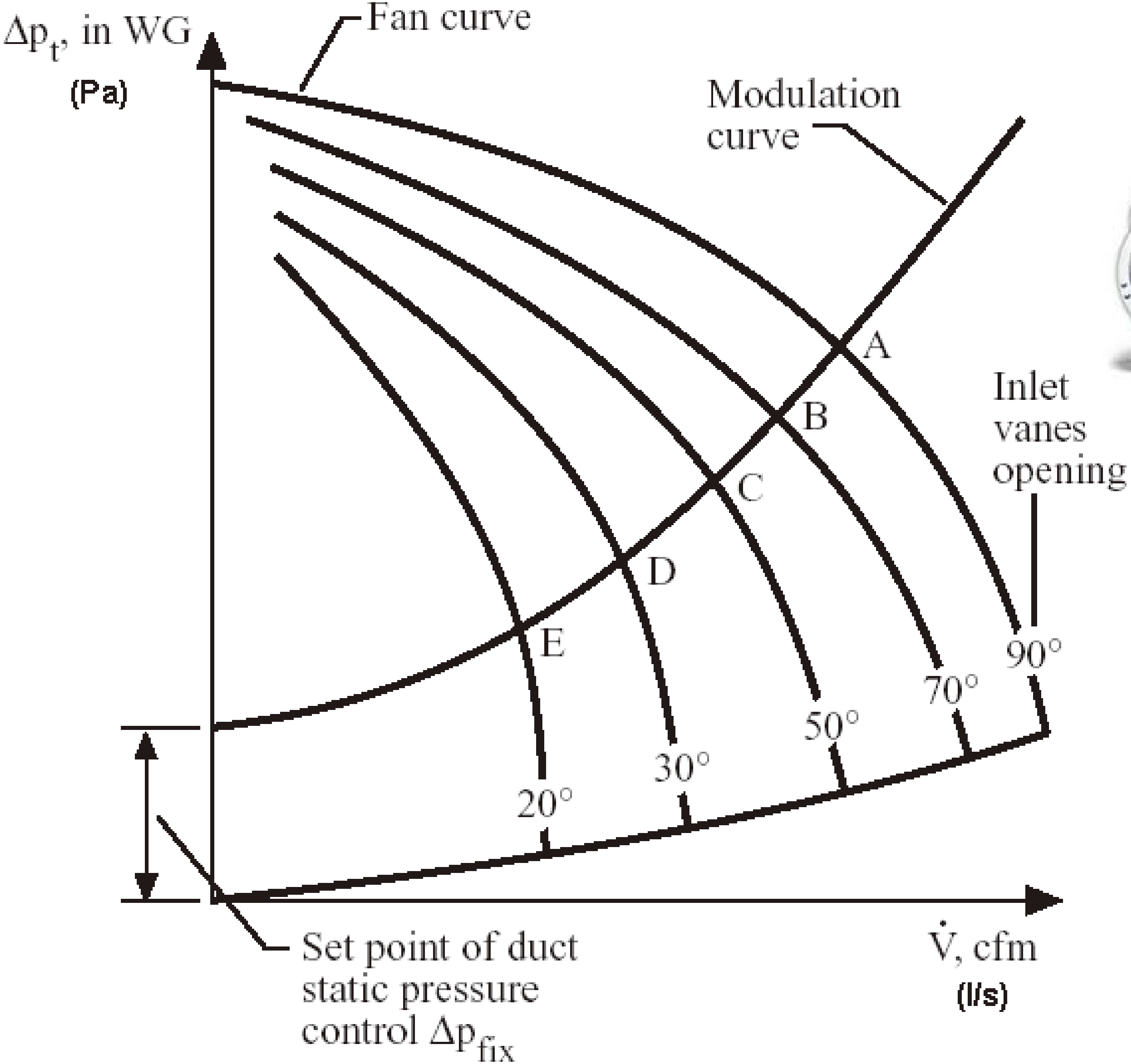


Air System Basics

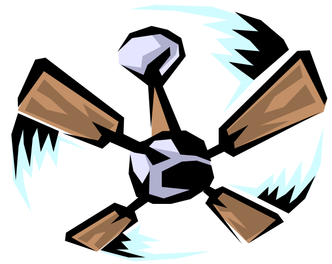


- Modulation of air systems
  - Constant volume (CAV) system
    - Volume flow rate remains constant; supply temperature is raised during part load
  - Variable-air-volume (VAV) system
    - Volume flow rate is reduced to match part load operation
    - Modulation curve

Fan modulation curve (inlet guide vanes)

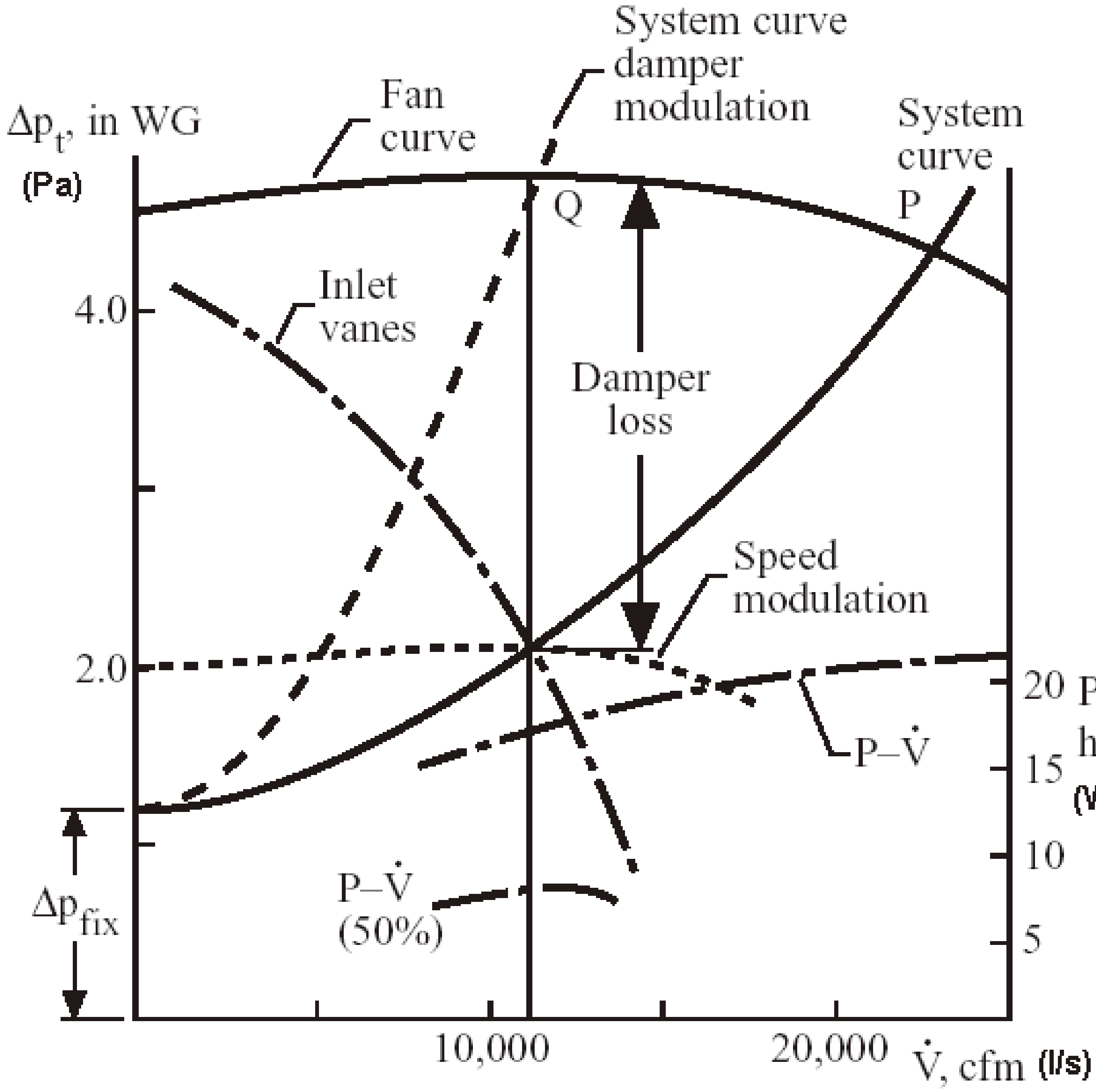


Air System Basics

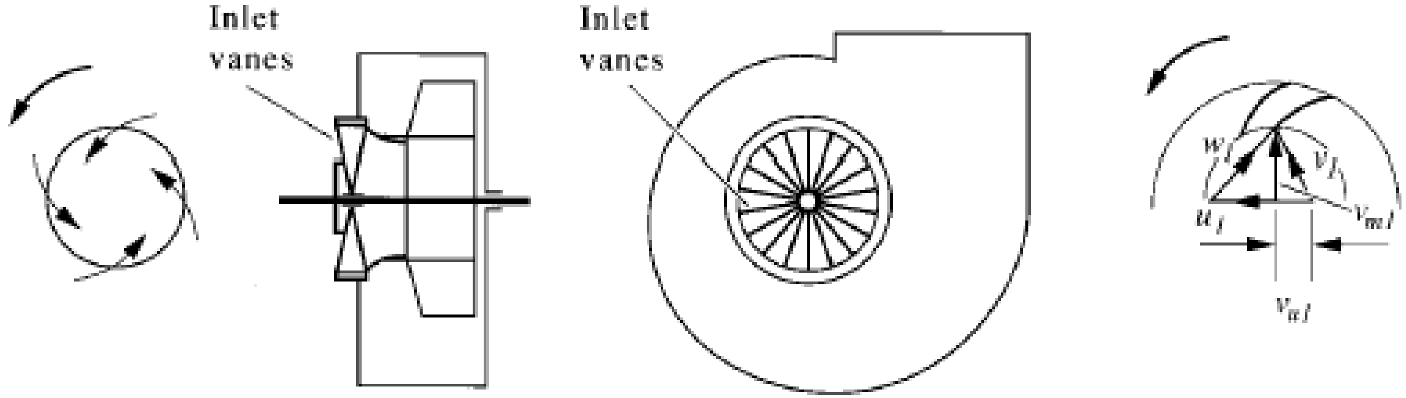


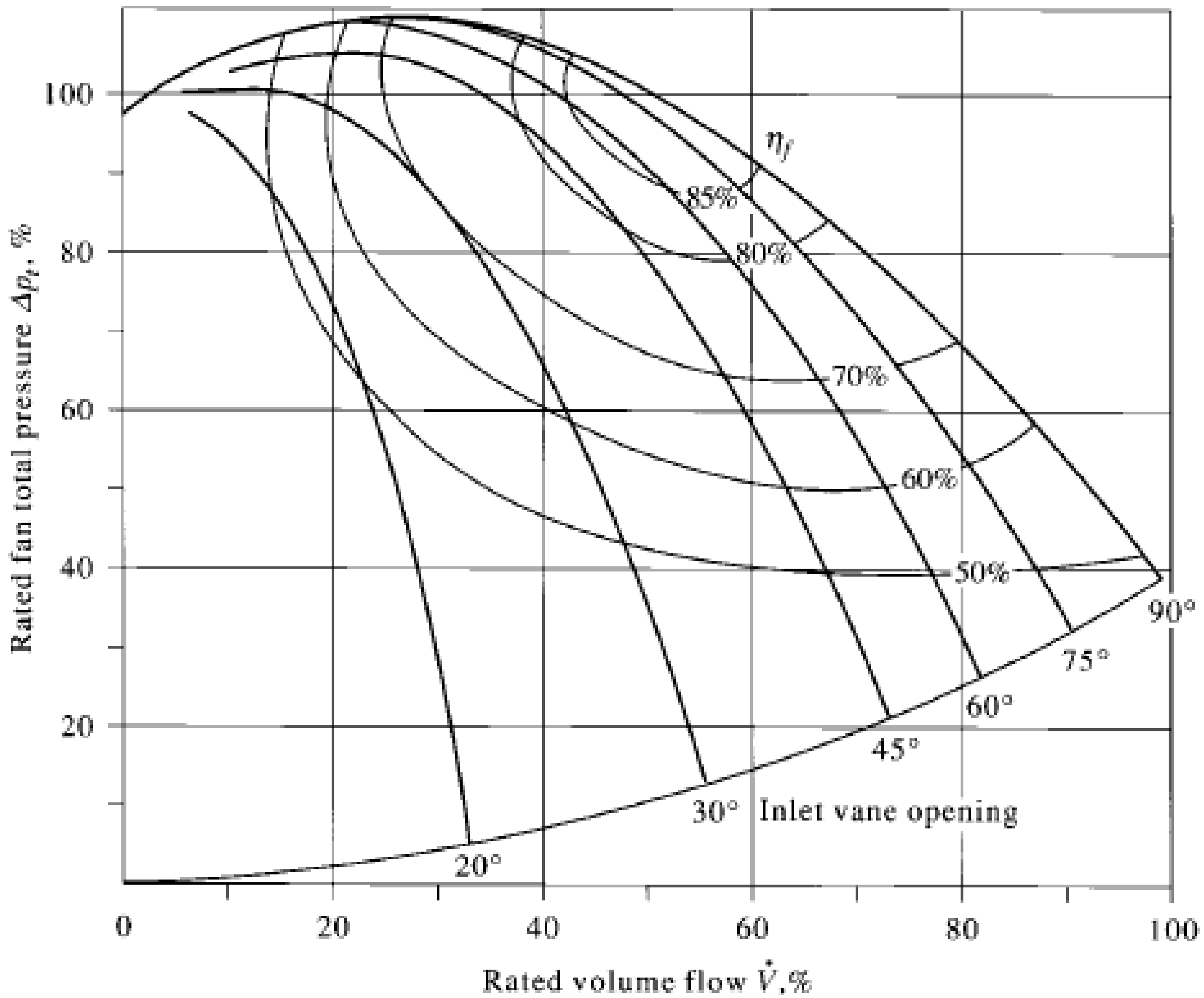
- Fan modulation methods
  - Damper (vary the opening of the air flow passage)
    - Waste energy
  - Inlet vanes (opening & angle of inlet vanes)
    - Low cost; less efficient than following types
  - Inlet cone (peripheral area of fan impeller)
    - Inexpensive; for backward curved centrifugal fan
  - Blade pitch (blade angle of axial fan)
  - Fan speed (using adjustable frequency drives)
    - Most energy-efficient; but more expensive

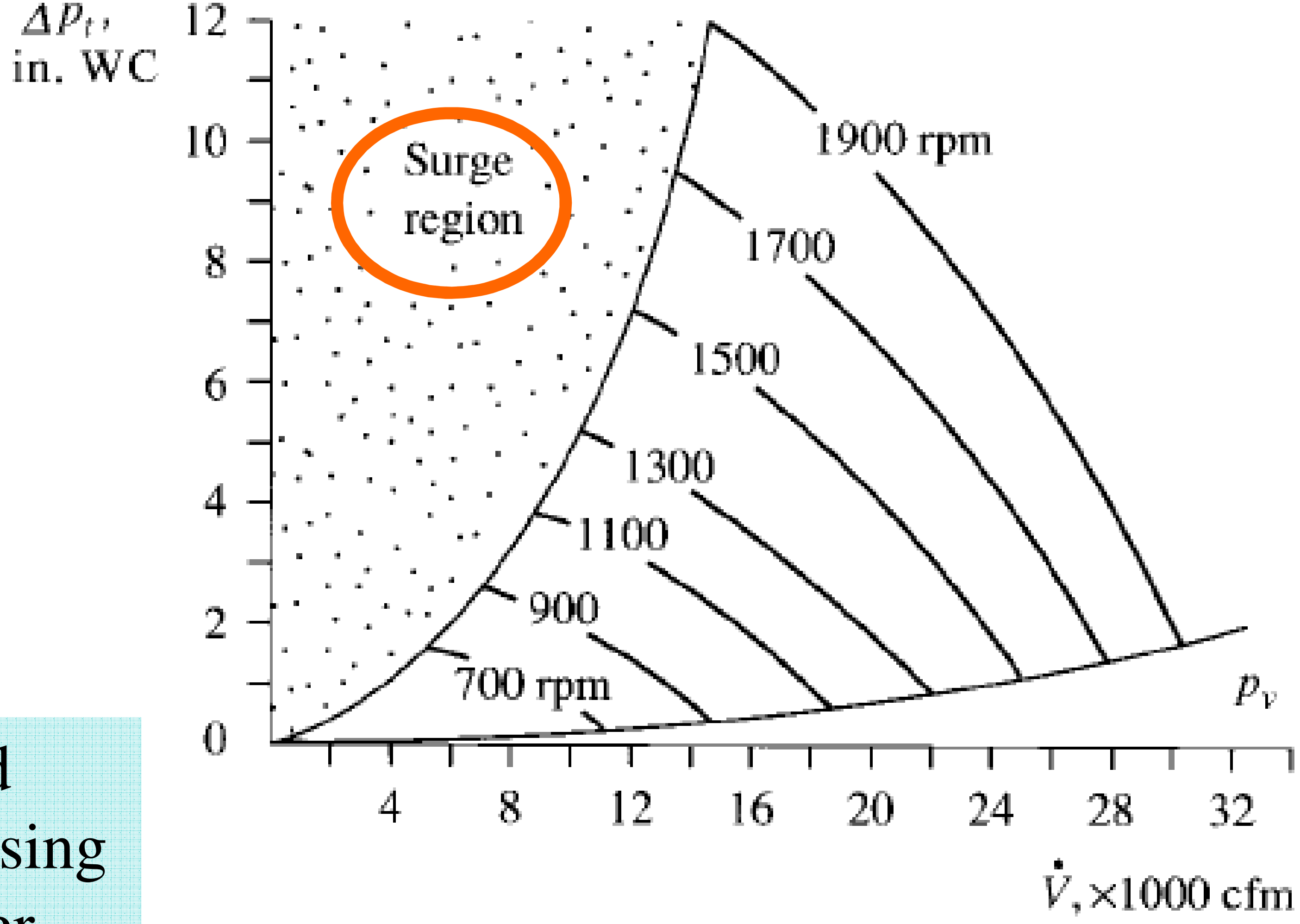
Damper, inlet vanes & fan speed modulation



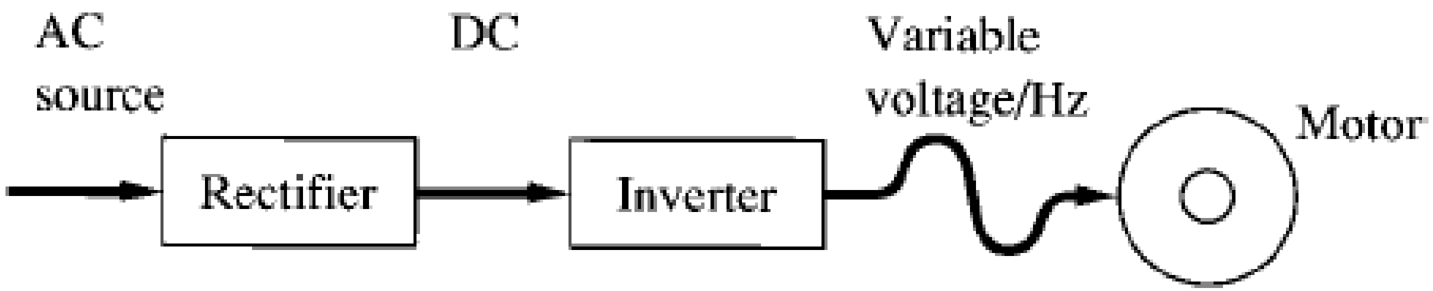
Inlet vane modulation





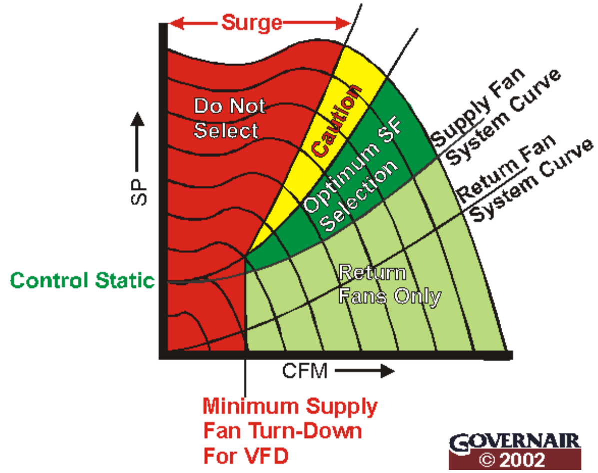


Fan speed modulation using AC inverter



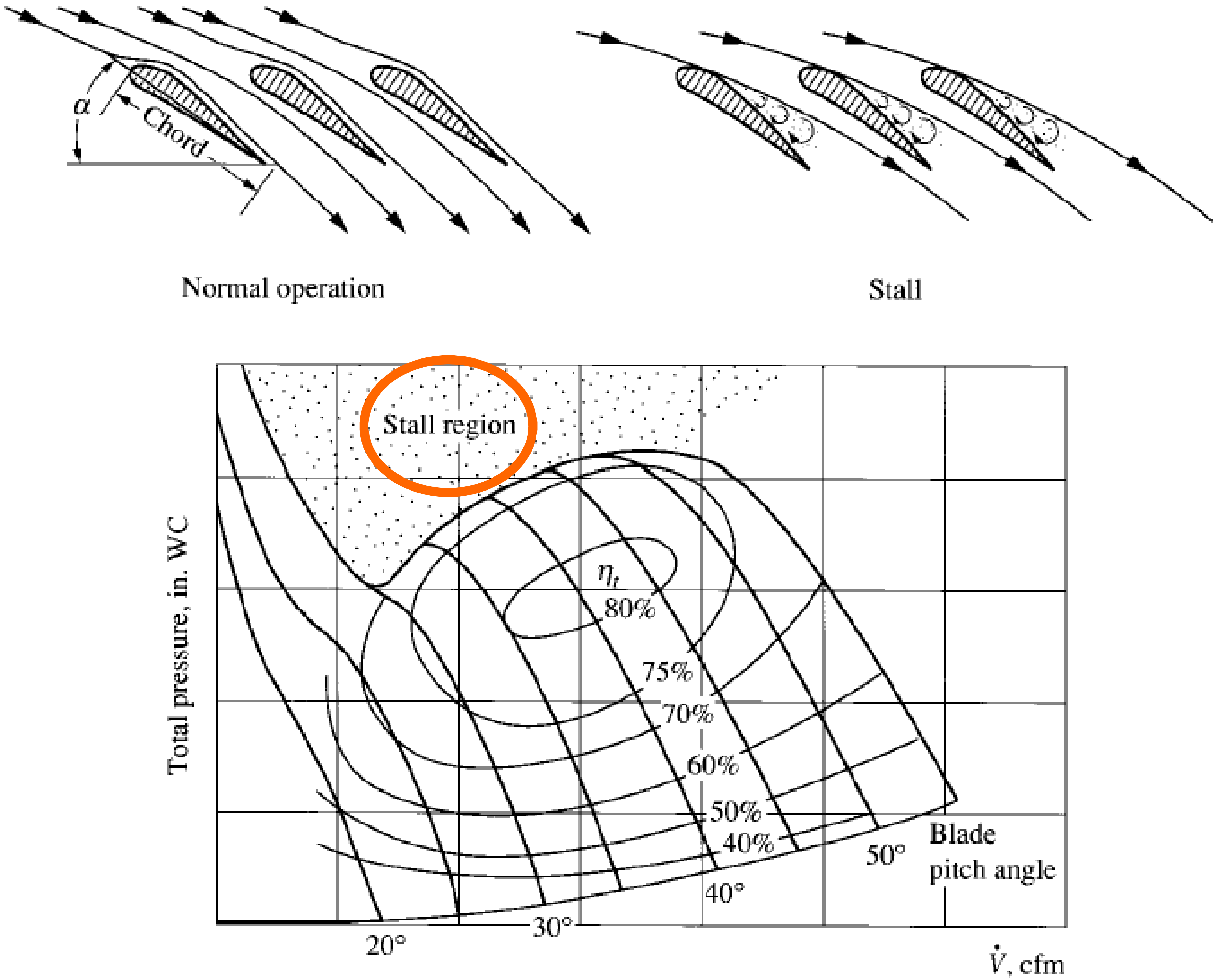
Air System Basics

- **Fan surge (喘振)** (in centrifugal fan)
  - Occurs when air volume flow is not sufficient to sustain the static pressure difference between discharge & suction
    - Discharge pressure is reduced momentarily
    - Volume flow & pressure fluctuations
    - Create noise & vibration
  - Surge region: shall avoid operation in it



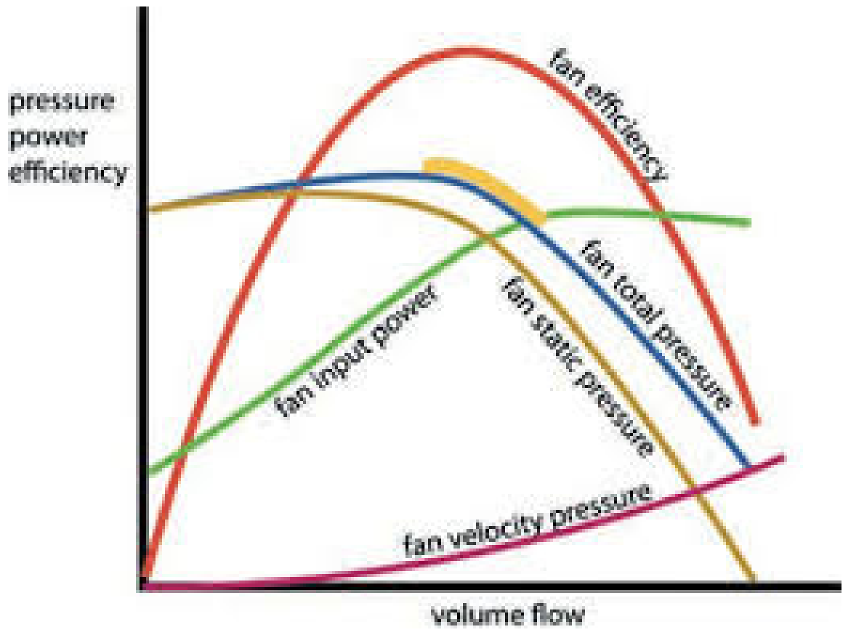
- **Fan stall (失速)** (in axial fans)
  - When smooth air flow suddenly breaks & pressure difference across the blades decreases
  - The fan loses pressure capability drastically
- Instabilities in fans e.g. "hunting" (time varying flow)

Stall and stall region of an axial fan



Air System Basics

- Fan selection
  - Select fan type + determine fan size
  - Important factors:
    - Pressure-volume flow operating characteristics
    - Fan capacity modulation
    - Fan efficiency
    - Sound power level
    - Airflow direction
    - Initial cost

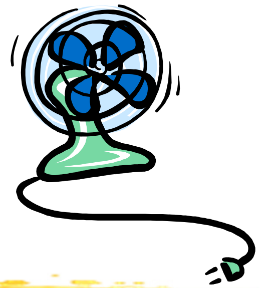


Comparison of common types of fans for HVAC systems

TABLE 15.2 Comparison between Various Types of Fans

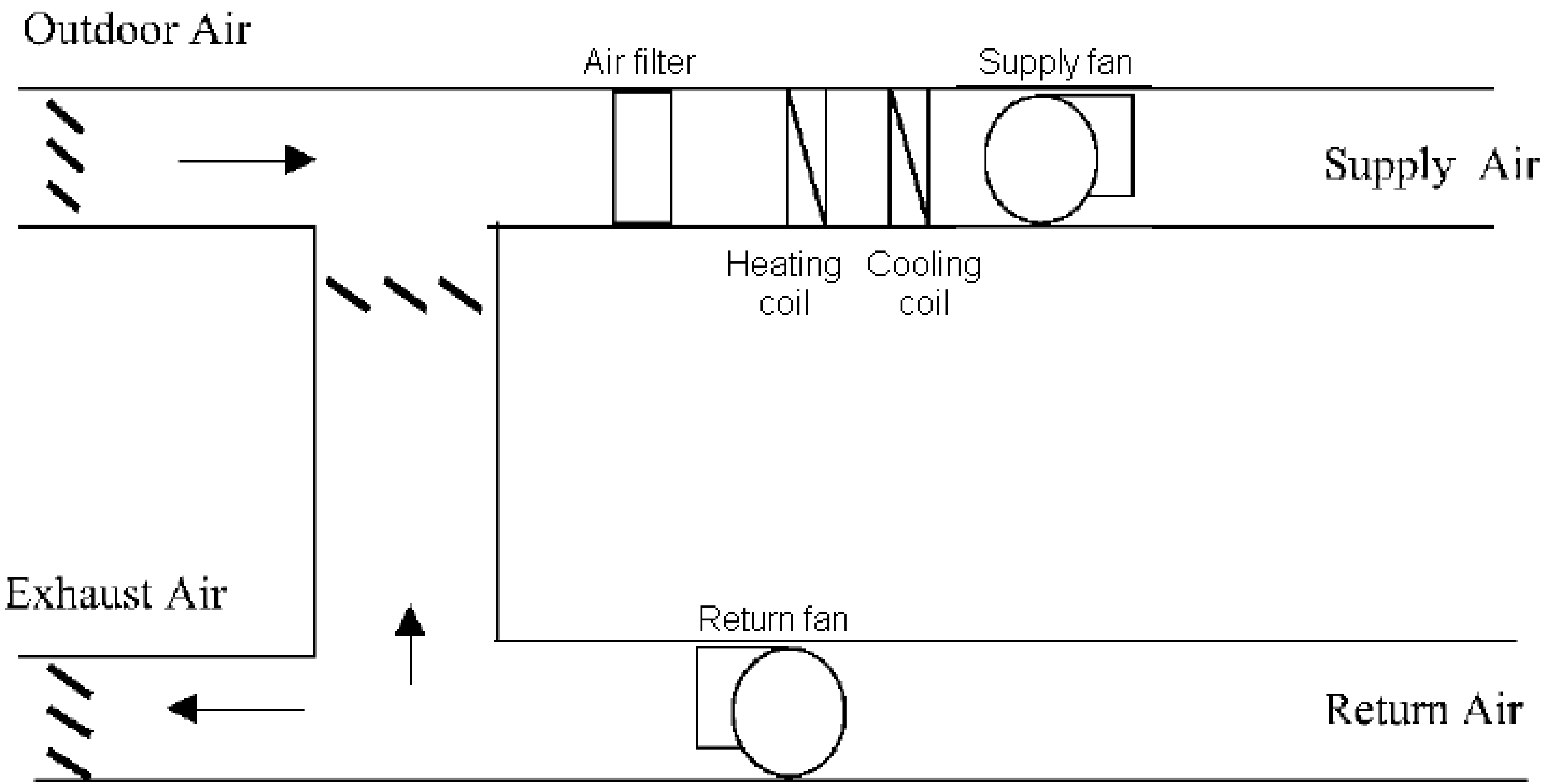
	Backward, airfoil centrifugal fan	Forward-curved centrifugal fan	Vane-axial	Propeller fan
Fan total pressure Δp_{tf}	Higher Δp_t	Comparatively lower Δp_t	Higher Δp_t	Low Δp_t
Flow rate	All flow rates	Larger flow rate	All flow rates	Larger flow rate
Fan power input	Nonoverloading	Overloading	Nonoverloading	Nonoverloading
Fan modulation	Inlet vanes AC inverter	Inlet vanes AC inverter	Controllable pitch AC inverter	
Fan total efficiency	0.7 to 0.86	0.6 to 0.75	0.7 to 0.88	0.45 to 0.6
Sound power level	Lower, higher L_w at low frequencies	Medium, higher L_w at low frequencies	Medium, difference of L_w values is small at various Hz	Higher, higher L_w at high frequencies
Airflow direction	90° turn	90° turn	Parallel to axle	Parallel to axle
Volume and weight	Greater	Less	Greater	Medium volume and lower weight
Initial cost	Higher	Medium	Higher	Low
Applications	Large HVAC&R systems	Lower pressure, small HVAC&R systems	Large HVAC&R systems	Low-pressure, high-volume flow exhaust systems

Air Handling Units



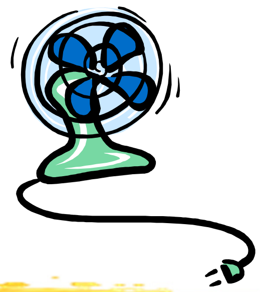
- Terminal unit or device
  - Such as fan coil units, VAV boxes
- Air handling unit (AHU)
  - Primary equipment of the air system
  - Handle & condition the air, control it to a required state, and transport it
  - Basic components:
    - Supply fan, water cooling coil, filters, mixing box, dampers, controls & outer casing
    - A return or relief fan is optional, so as a humidifier

Simple air-handling unit



Example of an air-handling unit (modular type)

Air Handling Units



- Types of AHUs:
  - Horizontal or vertical
  - Draw-through or blow through
  - Factory-fabricated and field built-up
  - Rooftop and indoor
  - Make-up (primary) air
  - Recirculating
- Many AHUs are "<u>modular</u>" by design. Why?

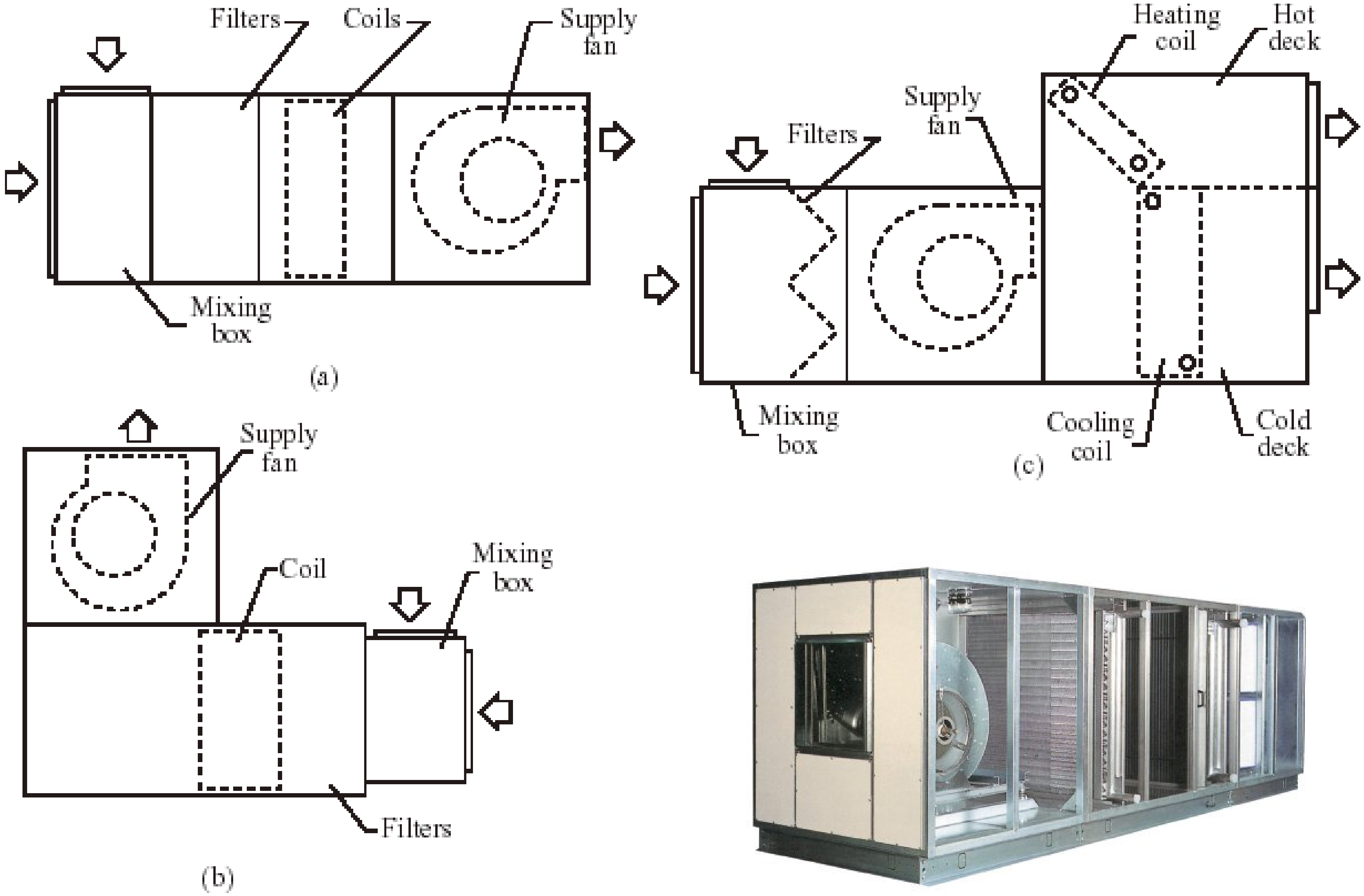
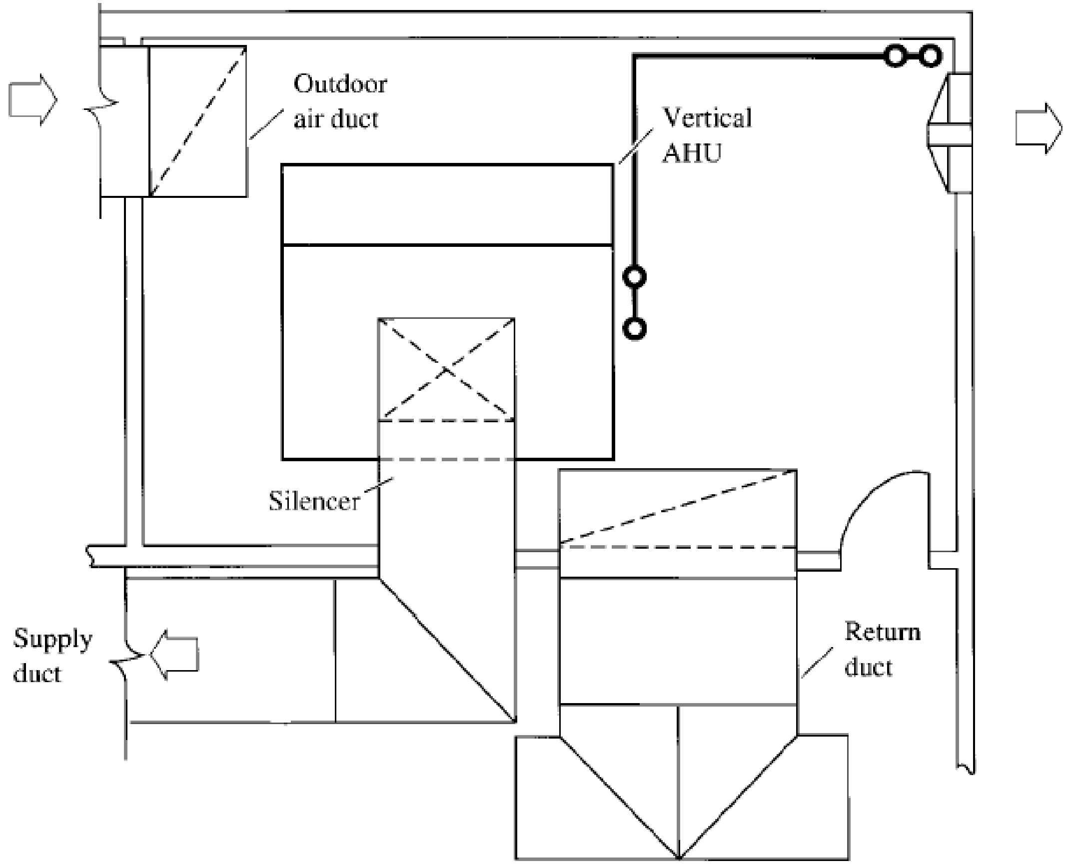
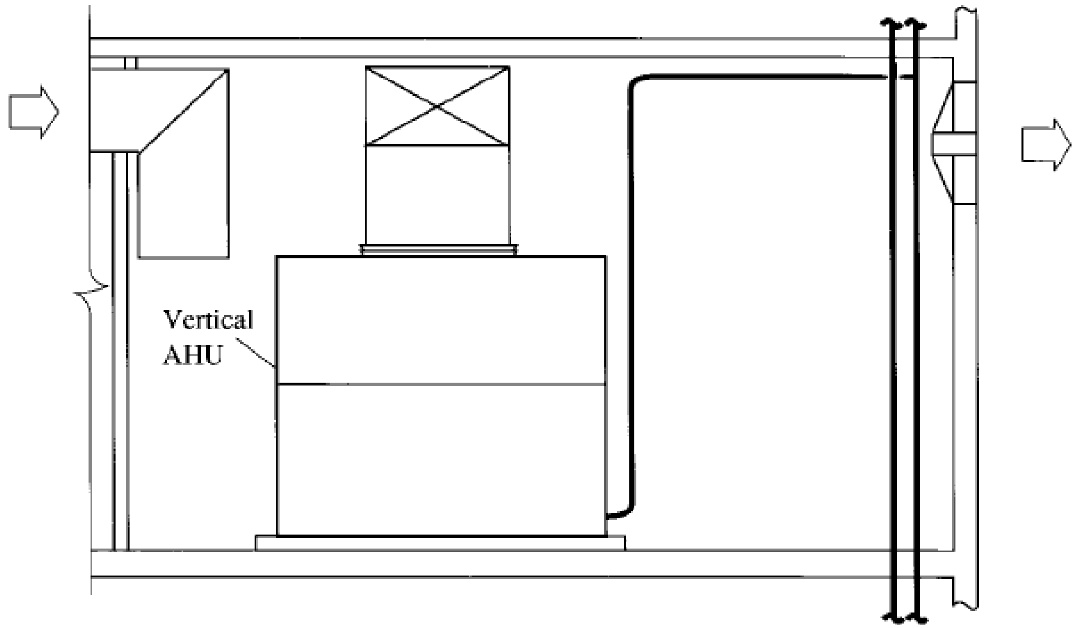


FIGURE 9.7.1 Type of air handling units: (a) horizontal draw-through unit, (b) vertical draw-through unit, and (c) multizone blow-through unit.

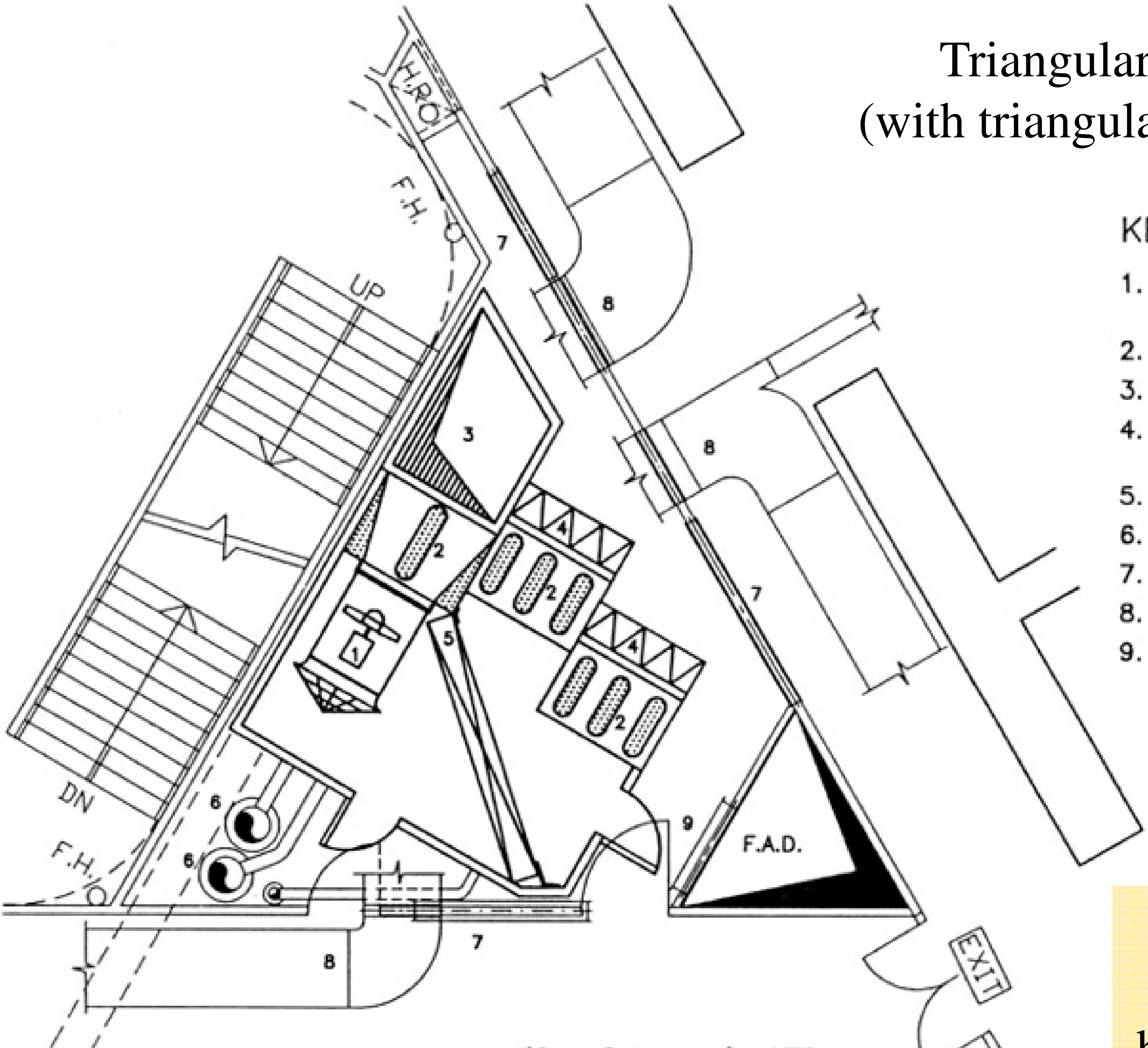
Open Fan Room

(fan room become the mixing box)





Triangular AHU room
(with triangular fresh air duct)



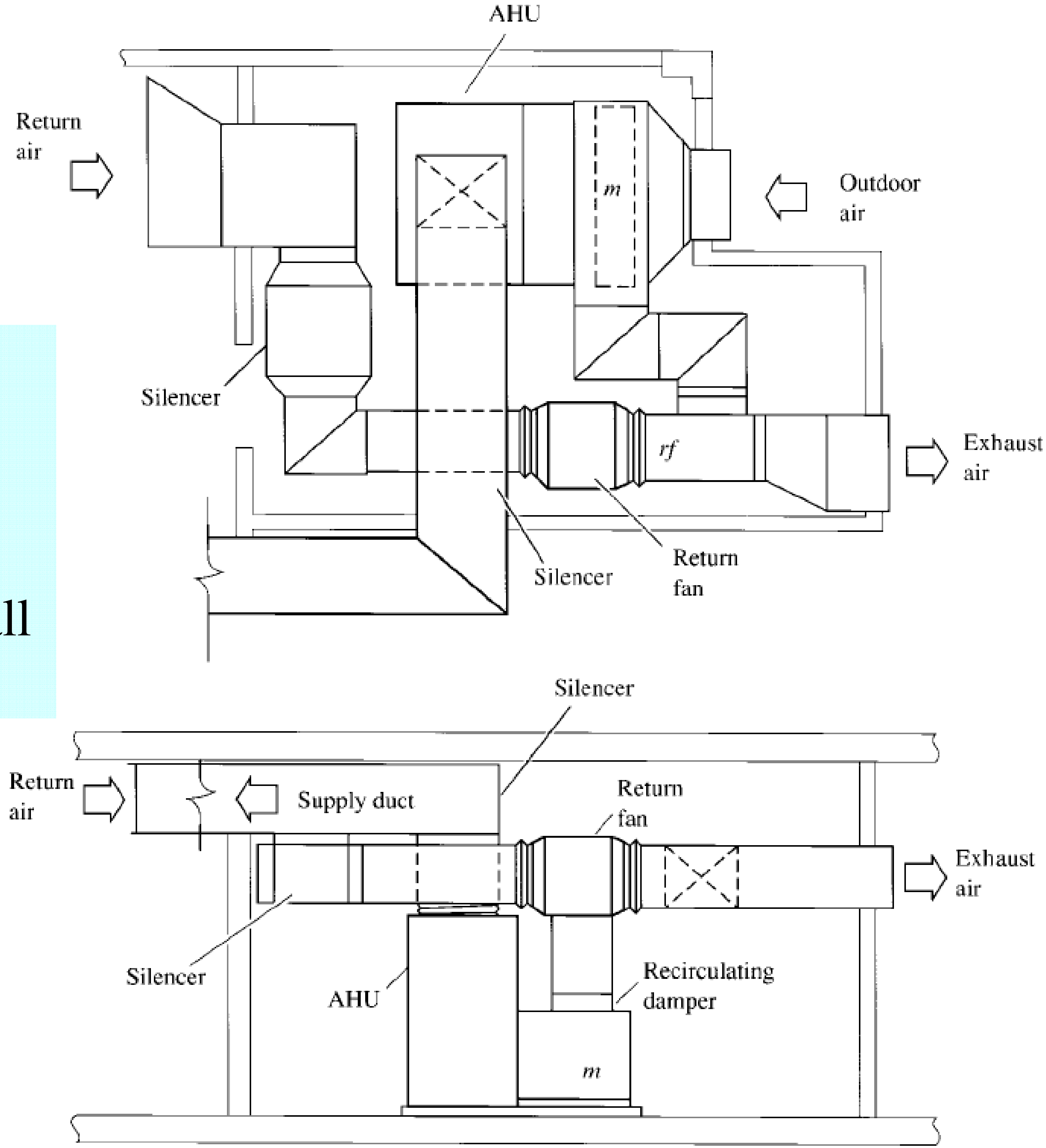
Details of Acoustic AHU

KEY:

1. VARIABLE PITCH VAN AXIAL FAN
2. SILENCER
3. DISCHARGE PLENUM
4. HIGH EFFICIENCY AIR FILTER
5. CHILLED WATER COIL
6. CHILLED WATER PIPE
7. RETURN AIR LOUVRE
8. SUPPLY AIR DUCT
9. FRESH AIR LOUVRE

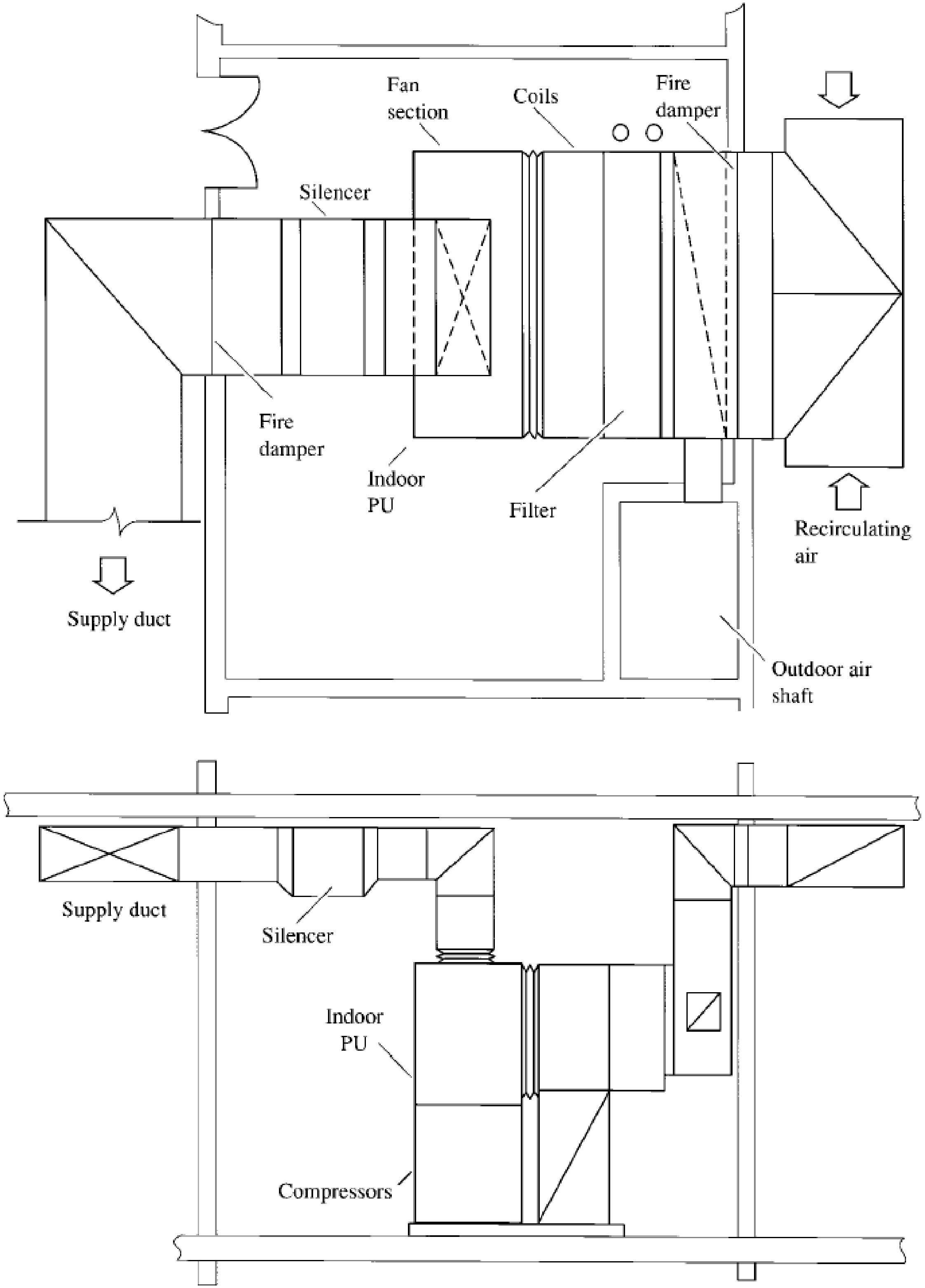
A tailor-made design for a building in HK

Isolated
Fan Room
(outdoor air, return air & exhaust air are all in ductwork)



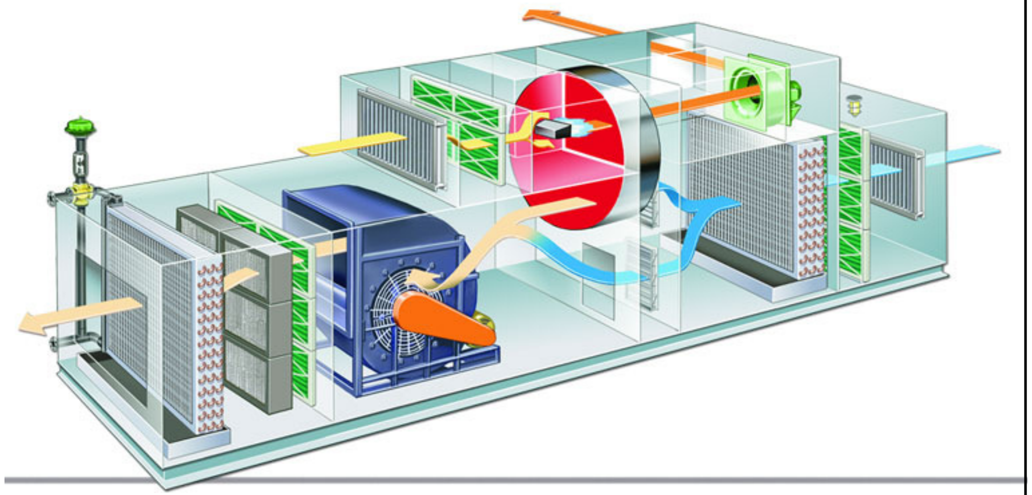
Interior Core Fan Room

(for an indoor package unit)

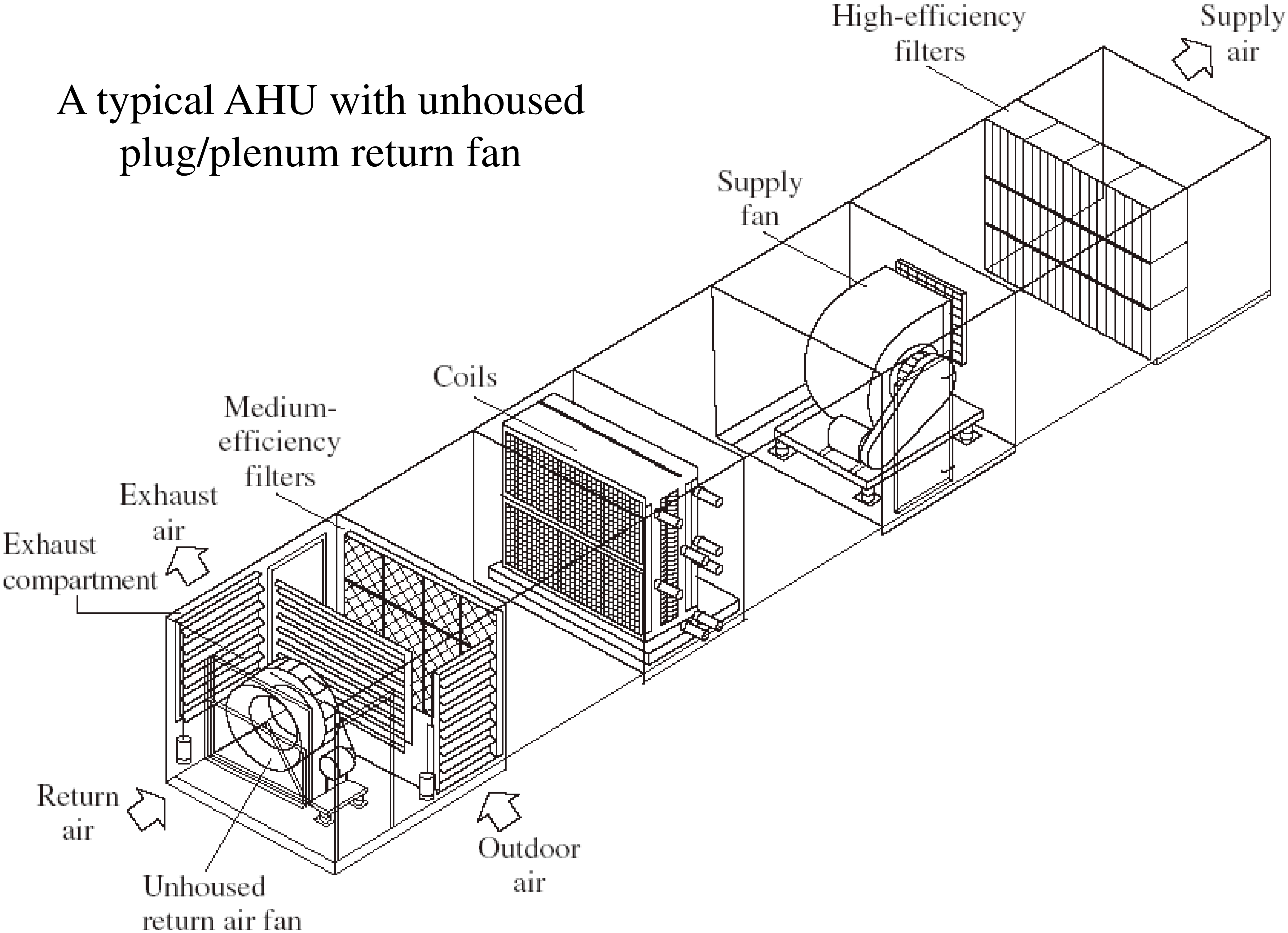


Main AHU Components

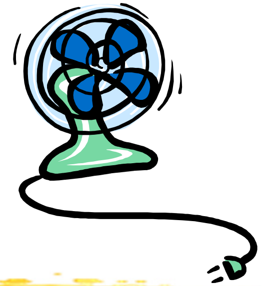
- Main components of AHU
  - Casing
  - Fans
  - Coils
  - Filters
  - Humidifiers (optional)
  - Outdoor air intake, mixing & exhaust section
  - Controls



A typical AHU with unhoused plug/plenum return fan

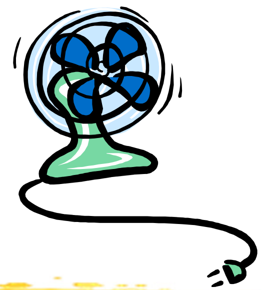


Main AHU Components

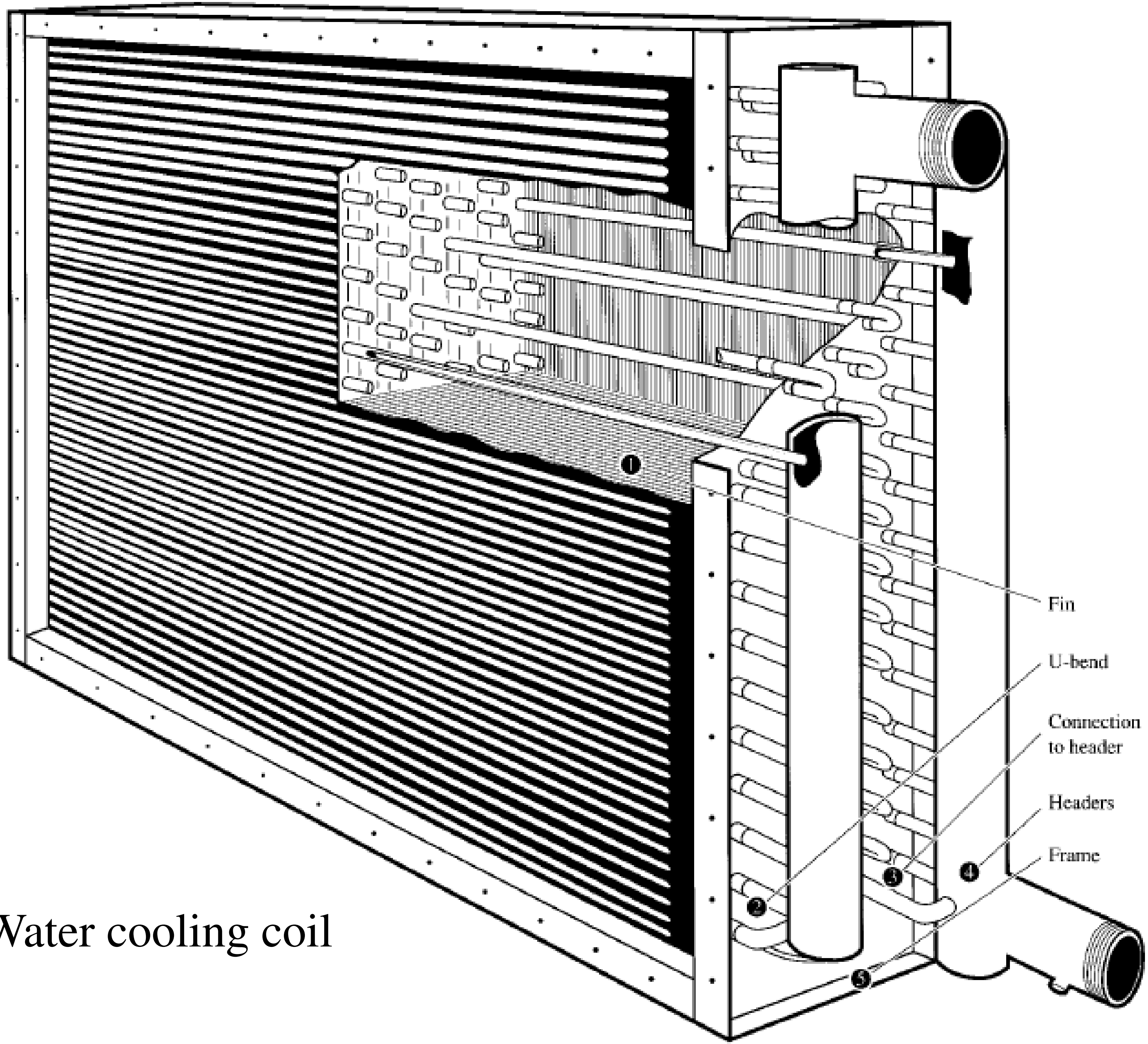


- Coils
  - Indirect contact heat exchangers
  - Heat transfer between air flowing over the coil and water, refrigerant, steam or brine insider the coil
  - Fins: extended (secondary) surfaces
    - Fin spacing and density
  - Water circuits
    - Number of water flow passages

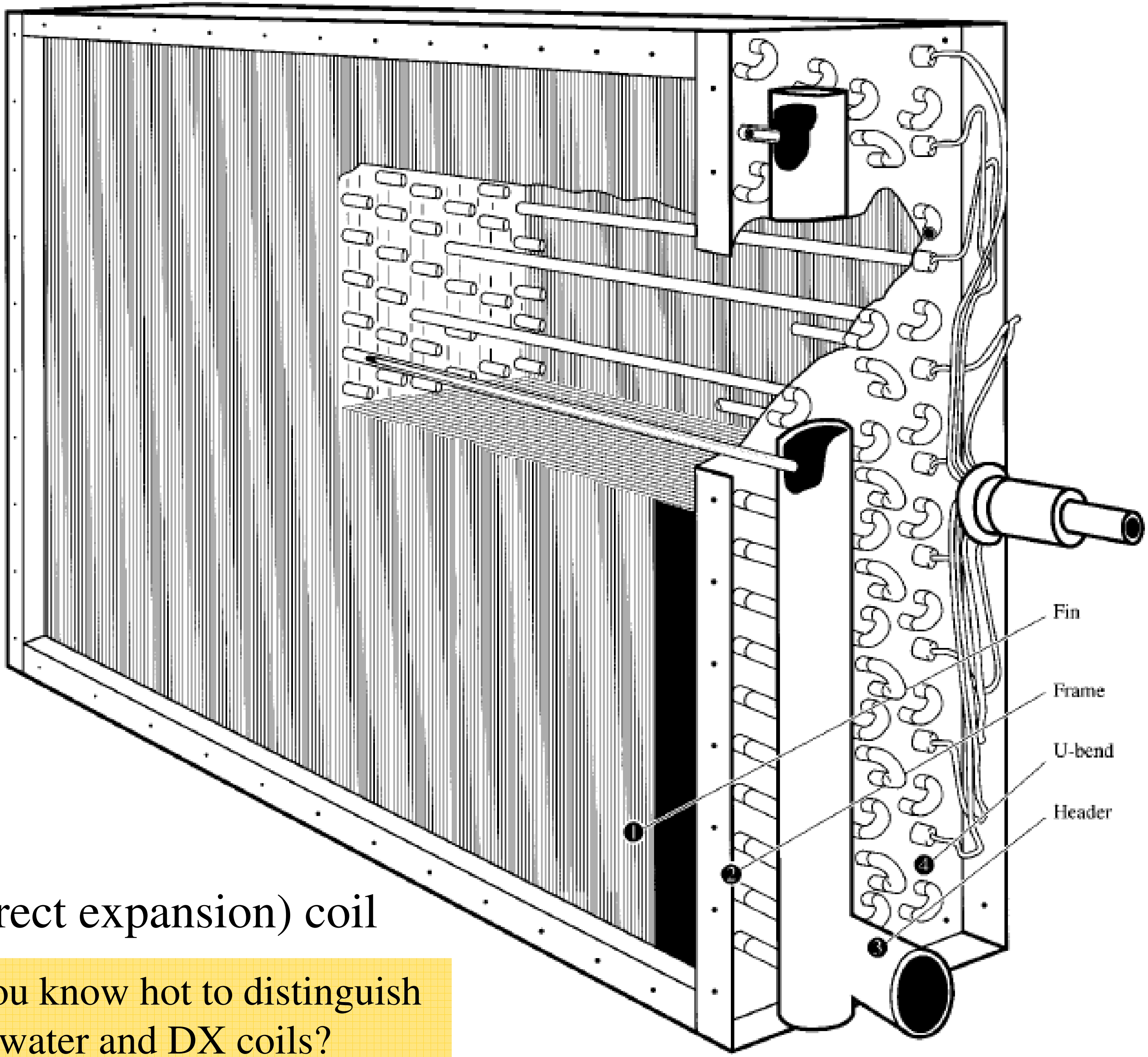
Main AHU Components



- Types of coils
  - Water cooling coil
  - Direct-expansion (DX) coil
  - Water heating coil
  - Steam heating coil
- Coil accessories
  - Air vents
  - Condensate collection & drain system
  - Coil cleaning & freeze protection



Water cooling coil



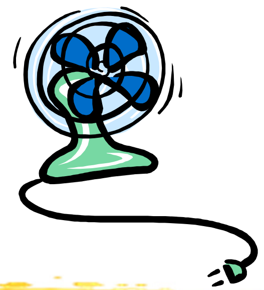
DX (direct expansion) coil

Do you know hot to distinguish water and DX coils?

Main AHU Components

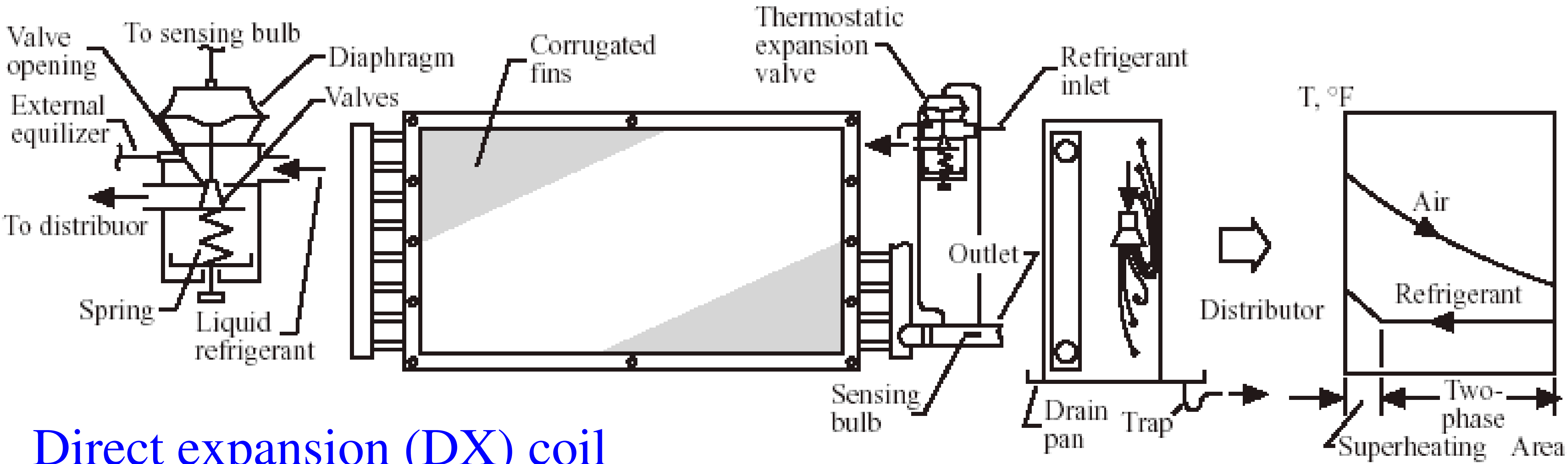
- Direct expansion (DX) coil
  - Refrigerant is fed (e.g. R-22 and R-134a)
  - Air and refrigerant flow:
    - Usually counterflow and cross flow
  - Typical evaporating temperature = 3-10 ^{o}C
  - Condensate drain pan (to collect condensation)
  - Performance factors:
    - Face velocity, heat transfer coefficients, air-side pressure drop, physical size

Main AHU Components



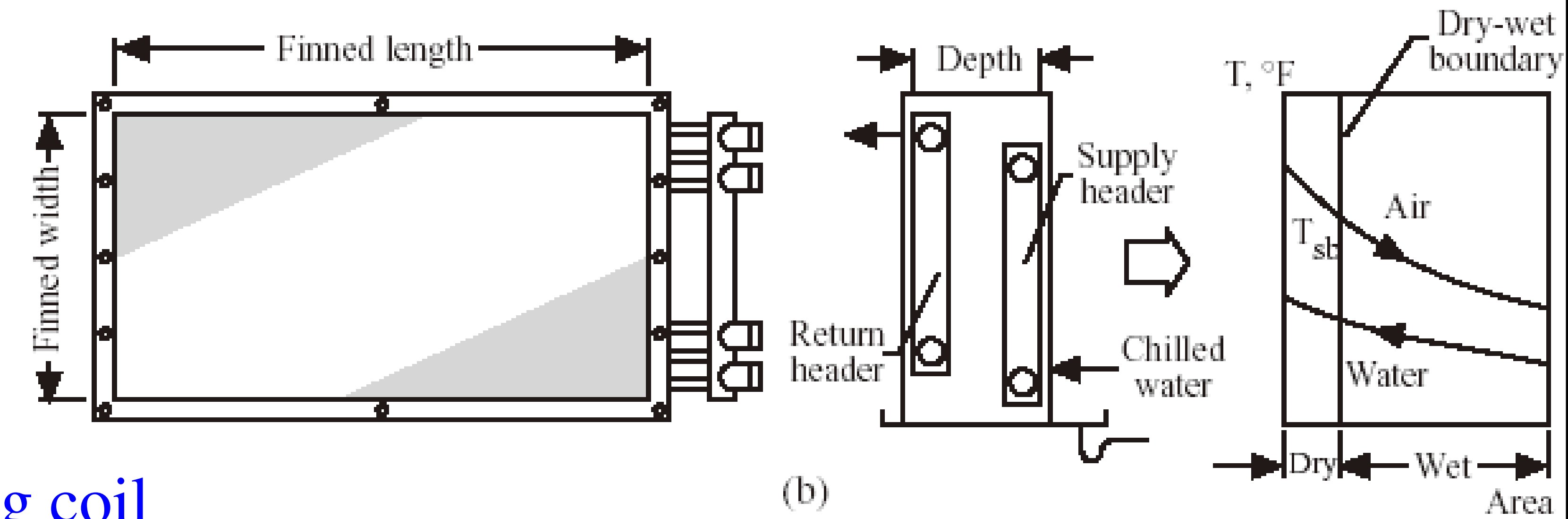
- Water cooling coils - dry-wet coil
  - Chilled water flowing at 4-10 ^{o}C
  - Brine or glycol-water at 1-4 ^{o}C
  - Temperature rise (typical) = 7-14 ^{o}C
- Water cooling coils - dry coil
  - Sensible cooling (dry); no condensation
  - Poorer heat transfer coefficient
- Steam heating coil

Direct expansion (DX) coil

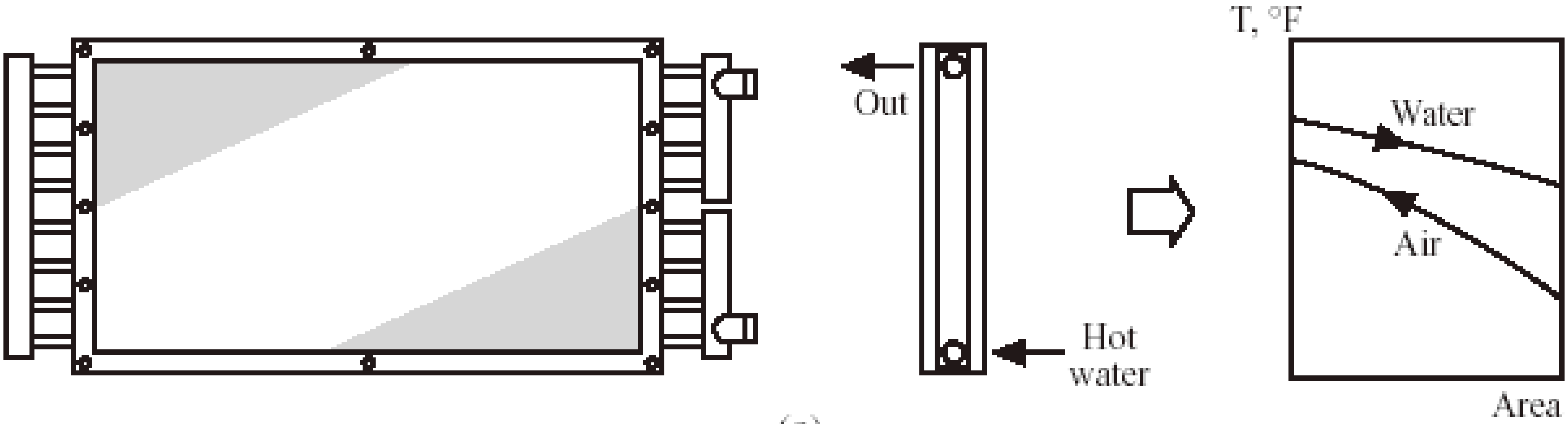


(a)

Water cooling coil

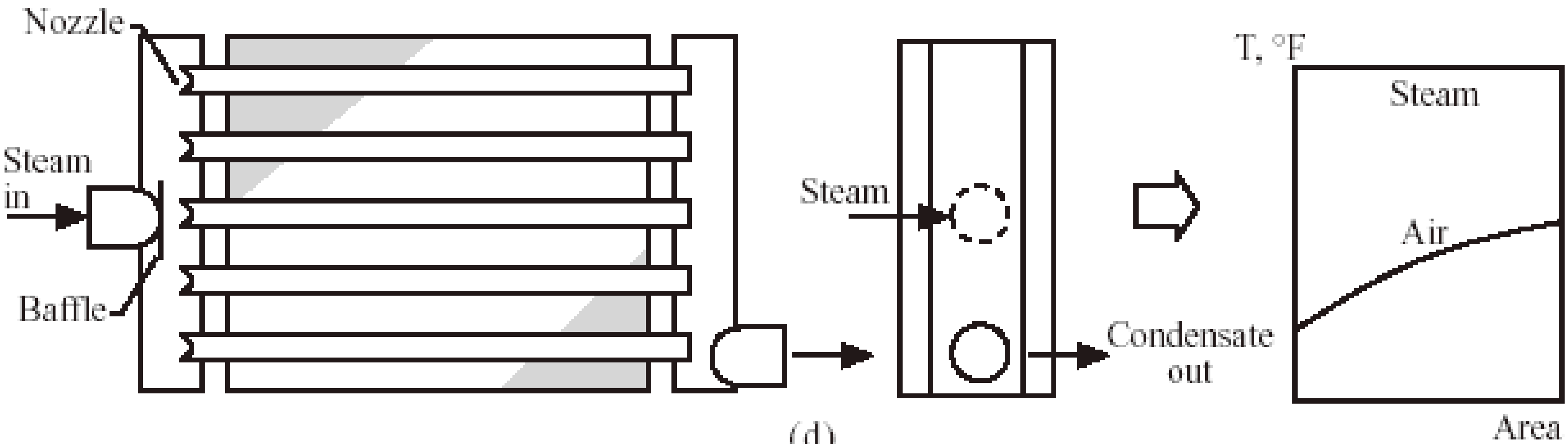


(b)



(c)

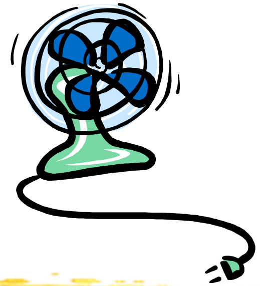
Water heating coil



(d)

Steam heating coil

Main AHU Components

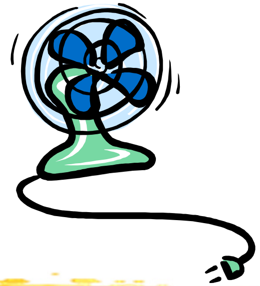


- Coil selection process
  - Specify supply air conditions & determine flow rate

$$\dot{m}_{\text{air}} = \frac{Q_{\text{sensible,zones}}}{Cp_{air} \cdot (T_{\text{return air}} - T_{\text{supply air}})}$$

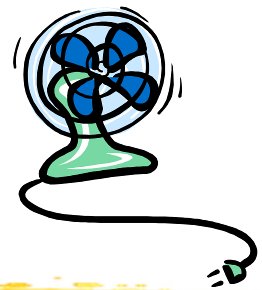
  - Calculate the coil entering conditions & loads
  - Select coil to meet the coil loads at the design conditions

Main AHU Components

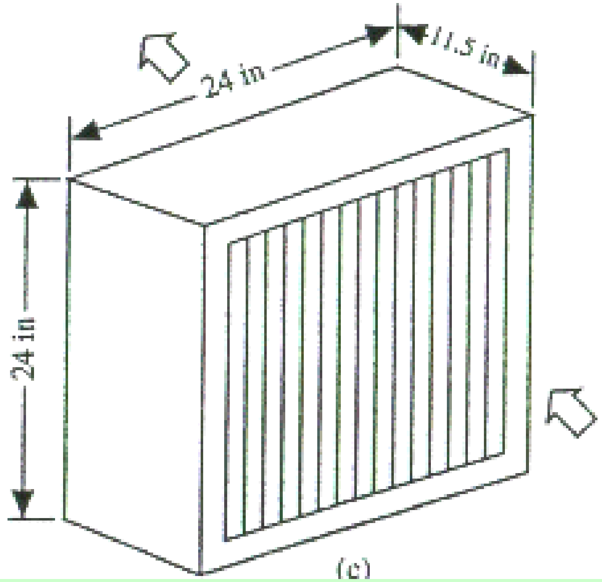


- Air filters
  - Air cleaning and filtration
  - Operating performance:
    - Efficiency or effectiveness of dust removal
    - Dust holding capacity
    - Initial & final pressure drop
    - Service life
  - Types: low-, medium-, and high-efficiency filters + carbon activated filters

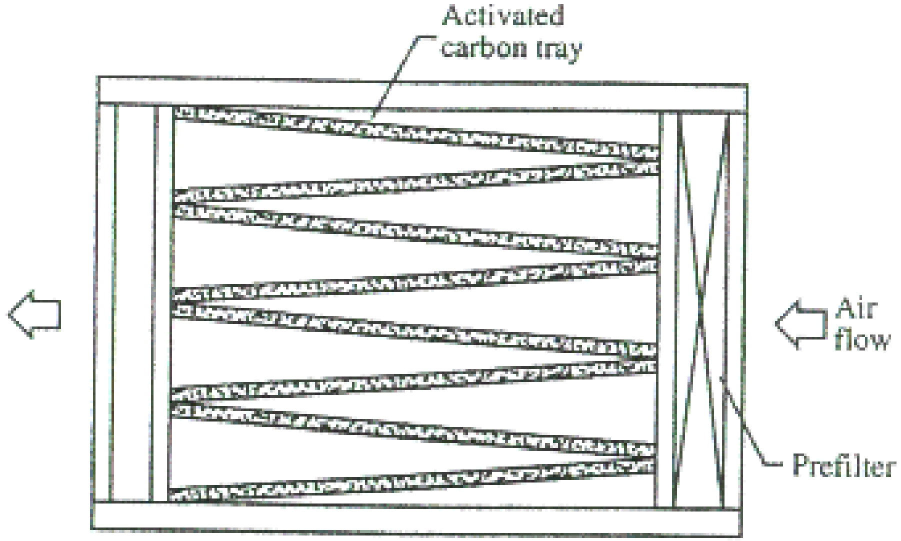
Main AHU Components



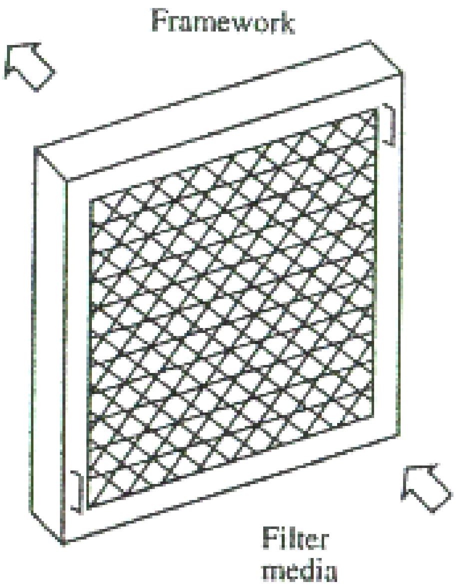
- Test methods of air filters
  - Weight arrestance test
    - For low-efficiency air filters
  - Atmospheric dust spot efficiency
    - For medium-efficiency air filters
  - DOP (dioctyl phthalate) penetration and efficiency test
    - For high-efficiency air filters
      - HEPA (high-efficiency particle air)
      - ULPA (ultra-low penetration air)



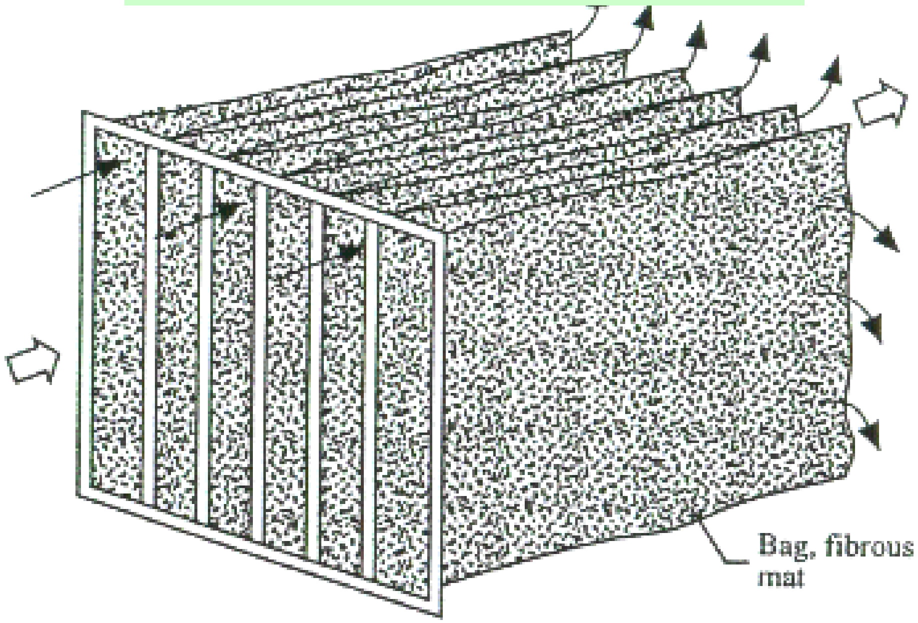
HEPA and ULPA filters



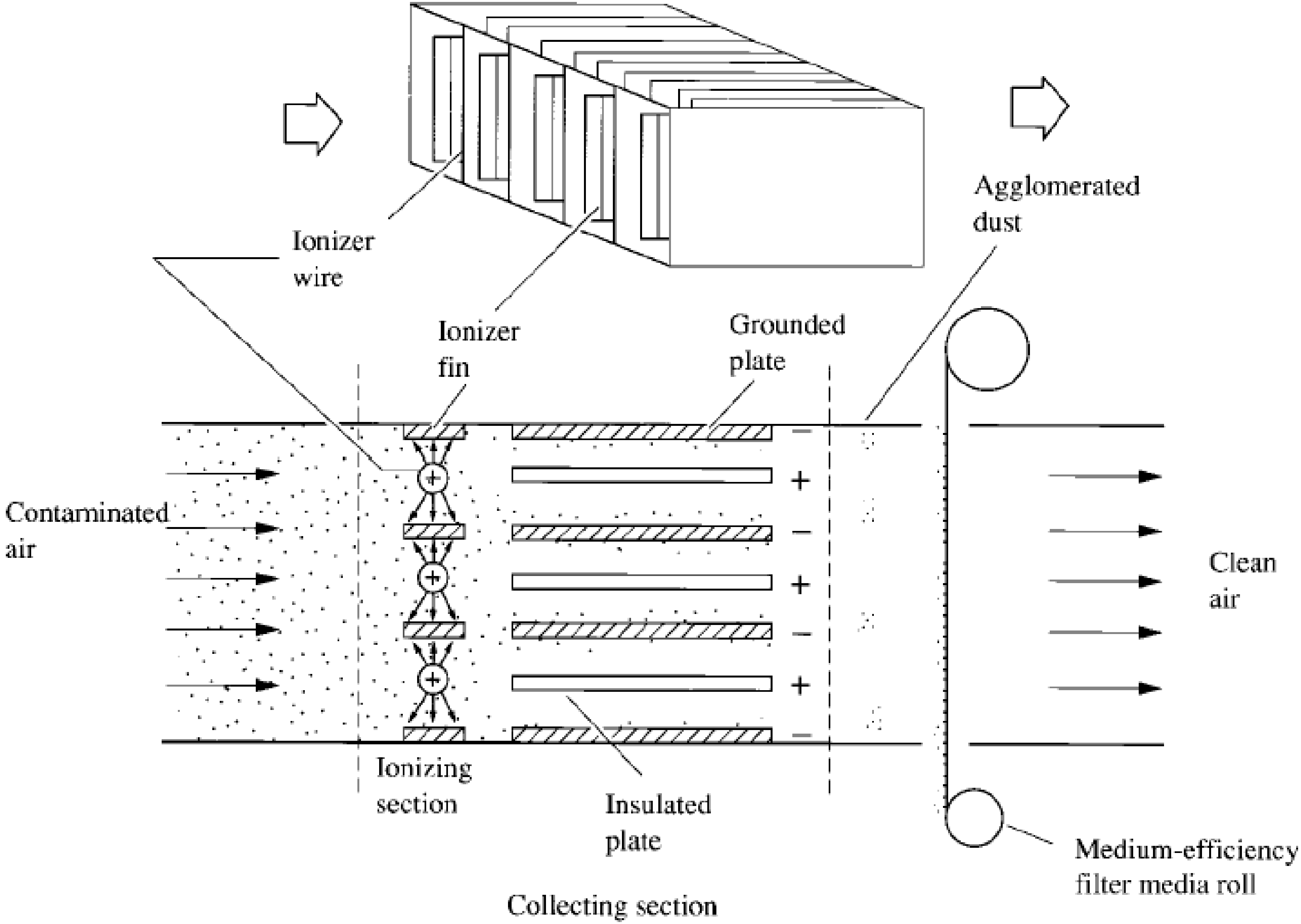
Activated carbon filter



Low efficiency (panel-type)

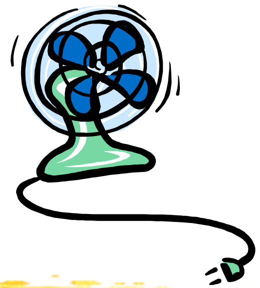


Medium efficiency (bag-type)

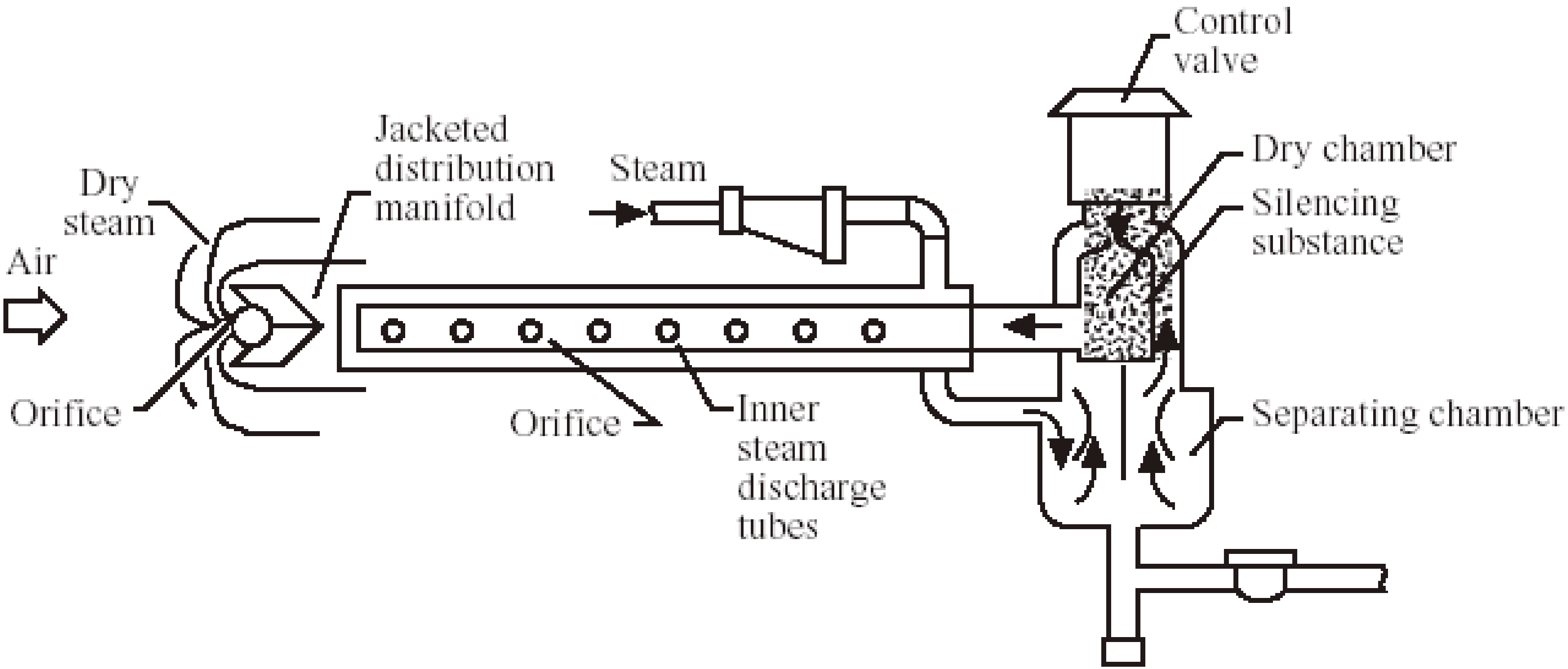


Electronic or electrostatic air cleaner

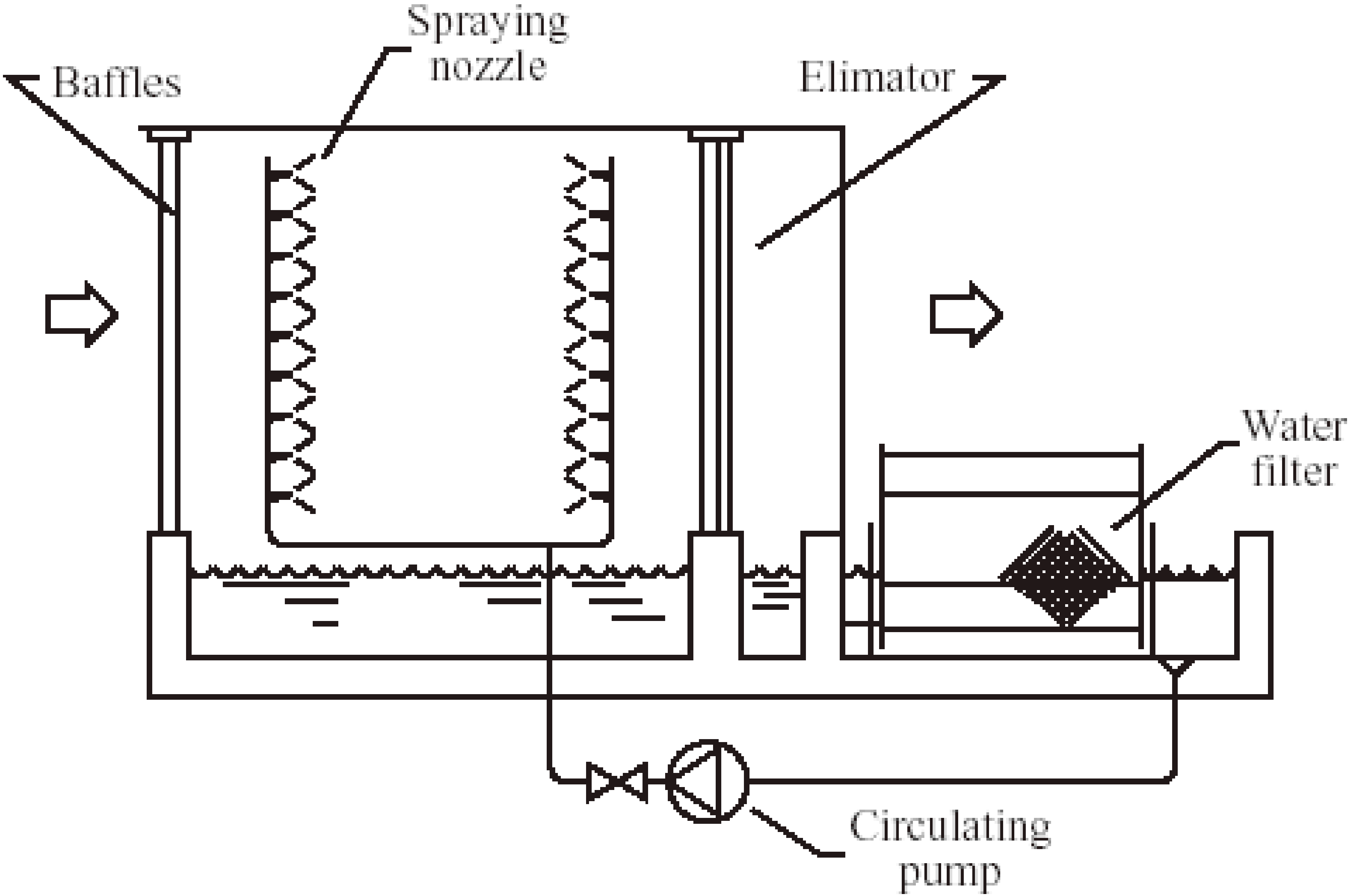
Main AHU Components



- Humidifiers
  - Steam & heating element humidifiers
  - Atomizing & wetted element humidifiers
  - Air washers
  - Design factors:
    - Energy consumption & operating cost
    - Quality of humidification, humidifying capacity
    - Capacity control, equipment noise
    - Initial cost, maintenance, space occupied



Steam grid humidifier


Spraying nozzle
Baffles
Elimator
Water filter
Circulating pump

Air washer