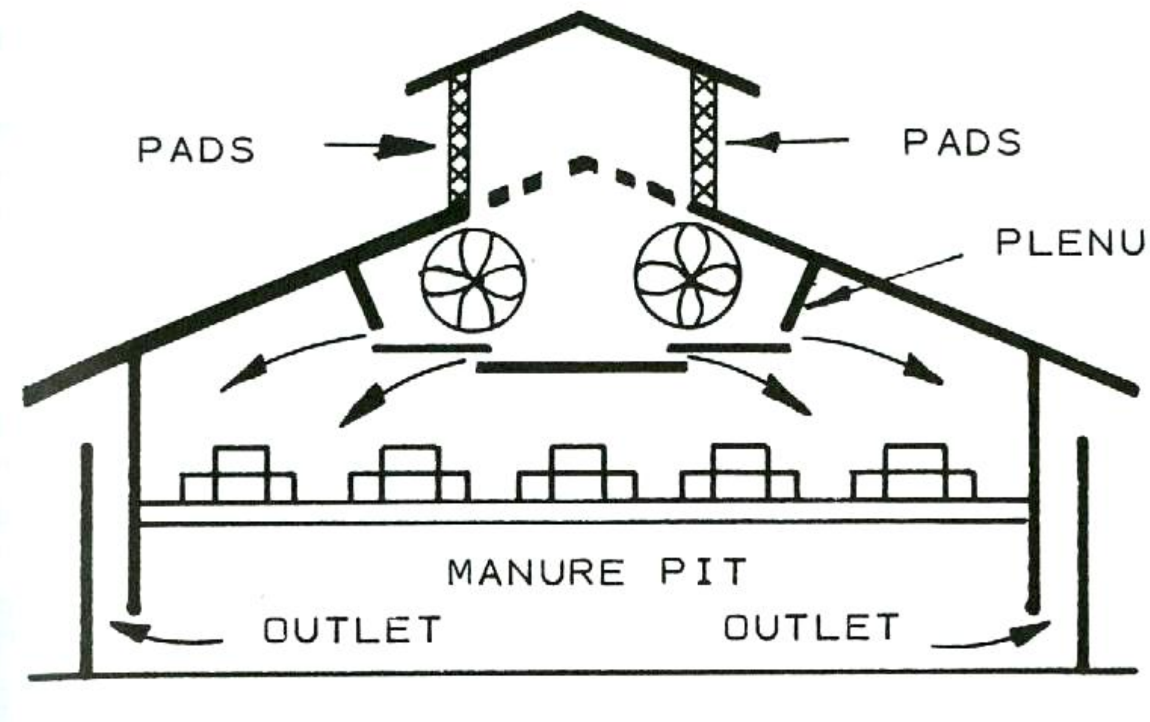
Ventilation of Agricultural Structures

Lecture 4 & 5: Ventilation Equipment and Controls



Concepts

Lindley and Whitaker (1996) cited that, a mechanical ventilation system has the following components:

(1) an envelope (building),

(2) inlets,

(3) fans or air movers,

(4) control system, and

(5) often a supplemental cooling/heating source .

Concepts

➢ The effective ventilation of any animal or plant growth structure is dependent upon the selection, installation, and use of appropriate air handling equipment and controls.

➢ Fans, inlets, outlets, controls, heaters, coolers, and filtration equipment may be used to provide the desired air exchange, to condition the air, to change its composition, or to influence its movement within the ventilation space.

➢ Fans are a central feature of any mechanically ventilated building and serve two primary functions: (a) they create a pressure difference, and (b) they cause air to flow.

➢ To ventilate **greenhouses** and **livestock housing**, the primary goal is to achieve a substantial air flow rate with only a small air pressure difference between the inlet and outlet sides of the fan.

Concepts

- In ventilating **crop storage (grain, vegetables, fruit, etc.)** the primary goal is to create a relatively large pressure difference across the fan, with a sacrifice of some air moving capacity.

- A "fan“ includes the motor, shutters, storm hood, etc. as well as the blade and its housing.

- Different types of fans have been developed to meet these very different needs: axial flow fans and centrifugal flow fans, respectively. Axial flow and centrifugal flow fans are differentiated by the direction of air flow leaving the fan's blades.

- Air leaves an axial flow fan moving parallel to the shaft on which the fan blades are mounted. With centrifugal fans, air is drawn through a center inlet and is forced by centrifugal action to move laterally away from the fan through an outlet duct.

Fan Types

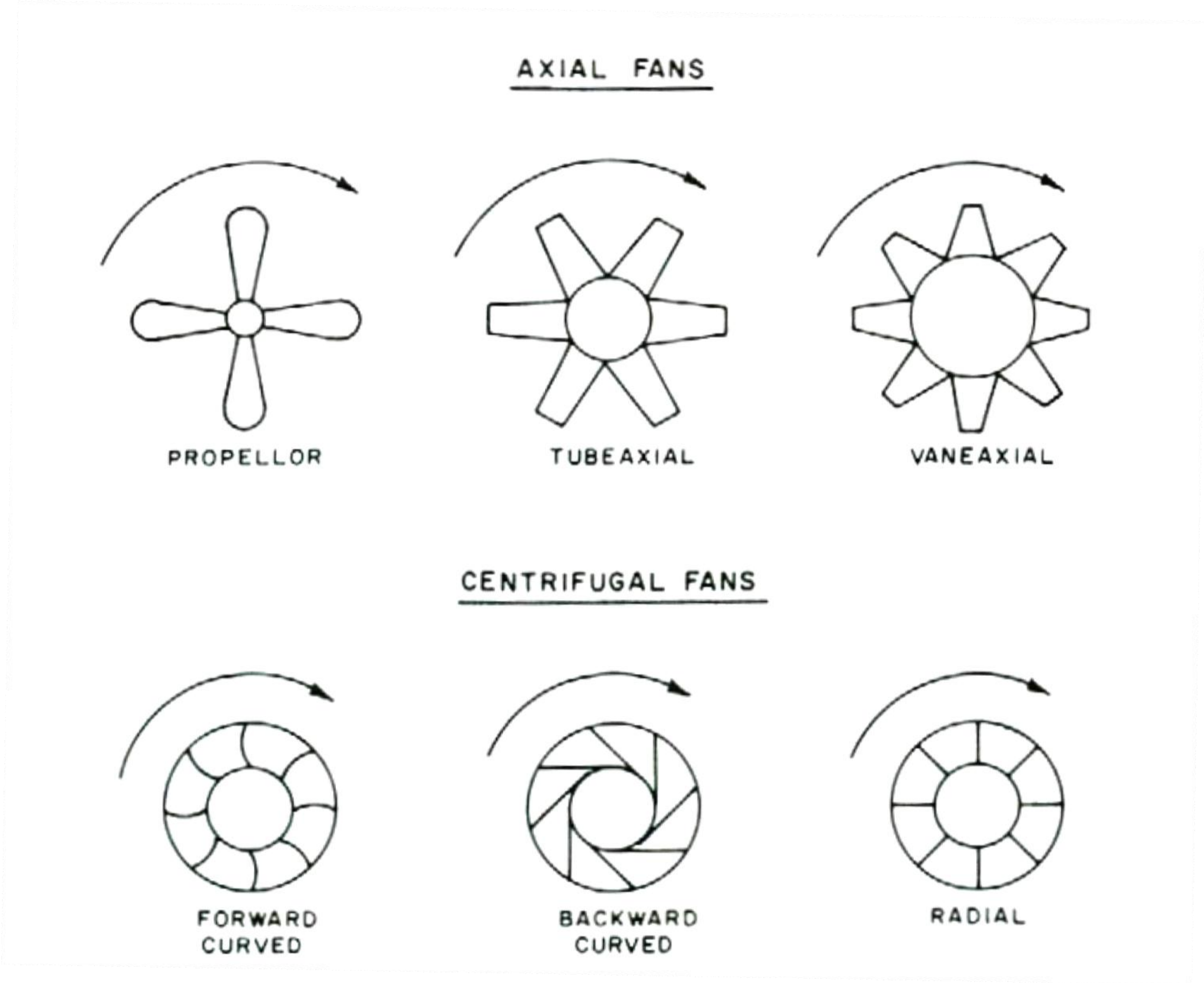
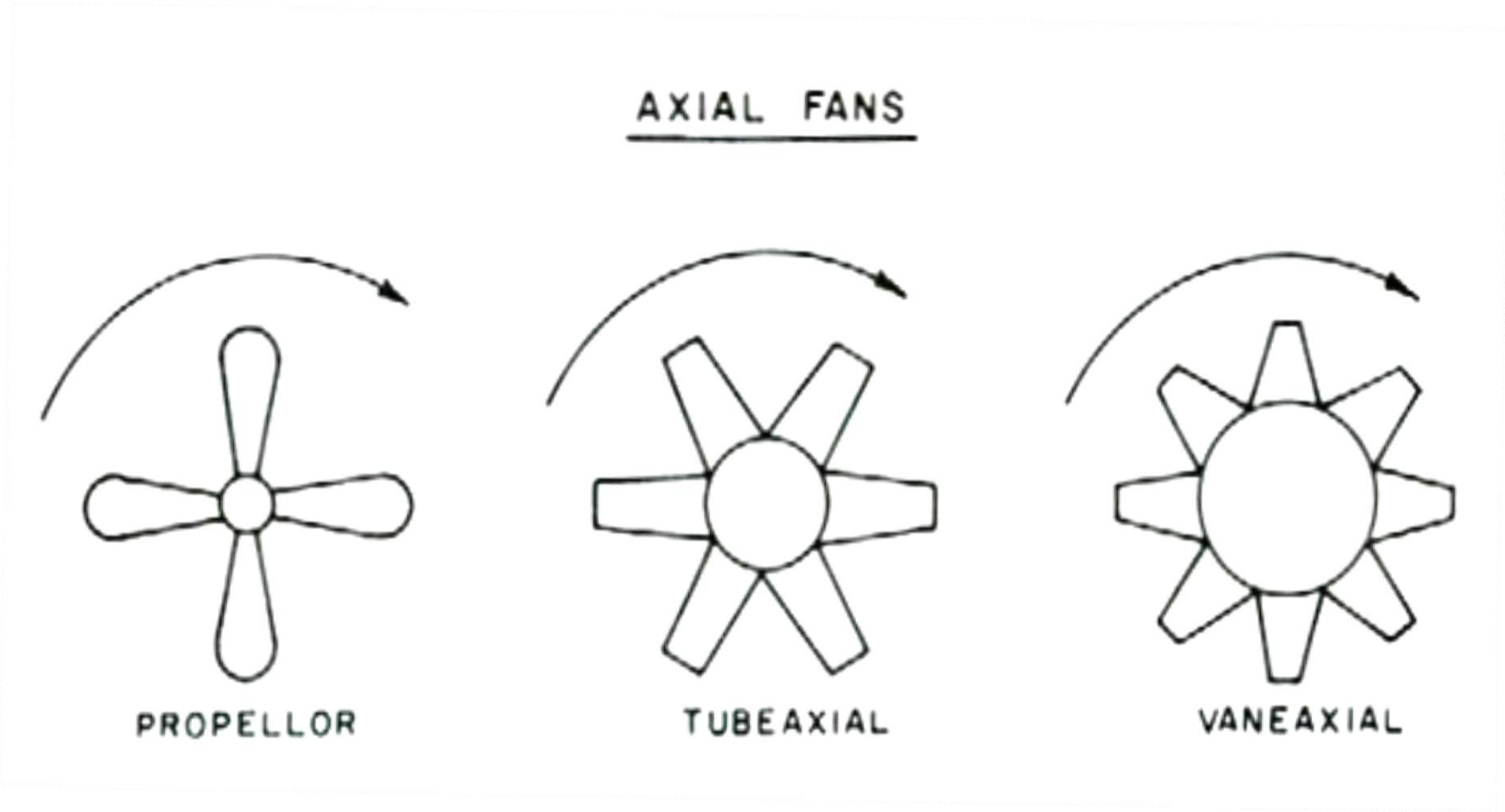


Figure 4.1: Types of fans commonly used in ventilation applications.

Axial Fans

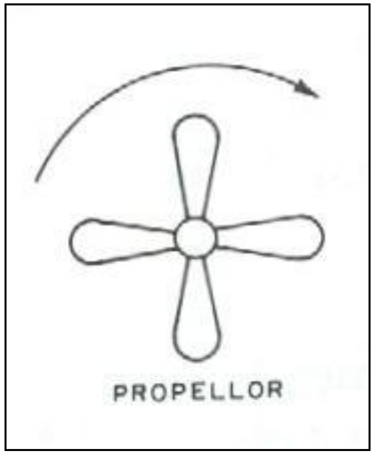


Types of Axial Fans

Propeller Fans

- Propeller fans have two or more blades attached to a central, rather small hub, which is either driven directly by the motor (1140-1750 rpm), or through a belt and pulley mechanism to lower the speed of rotation.

- Propeller fans are limited to low pressure difference applications and function to move air, not to generate significant total pressure differences.



- Therefore, such fans are used for ventilation through walls, air circulation within a space, or to provide make-up air.

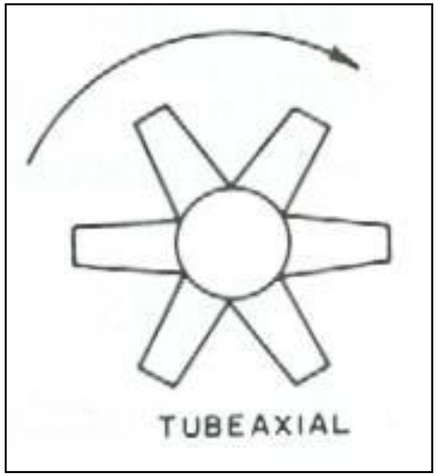
- Blade tip clearance is an important factor in the performance of such fans, with a small, uniform clearance being more desirable. Small tip clearances prevent air from flowing back around.

Tubeaxial Fans

➢ This is basically a 4 to 8 blade propeller fan with a somewhat larger hub, which has been mounted in a duct or tube. This facilitates connecting the fan to low or medium pressure duct air distribution system.

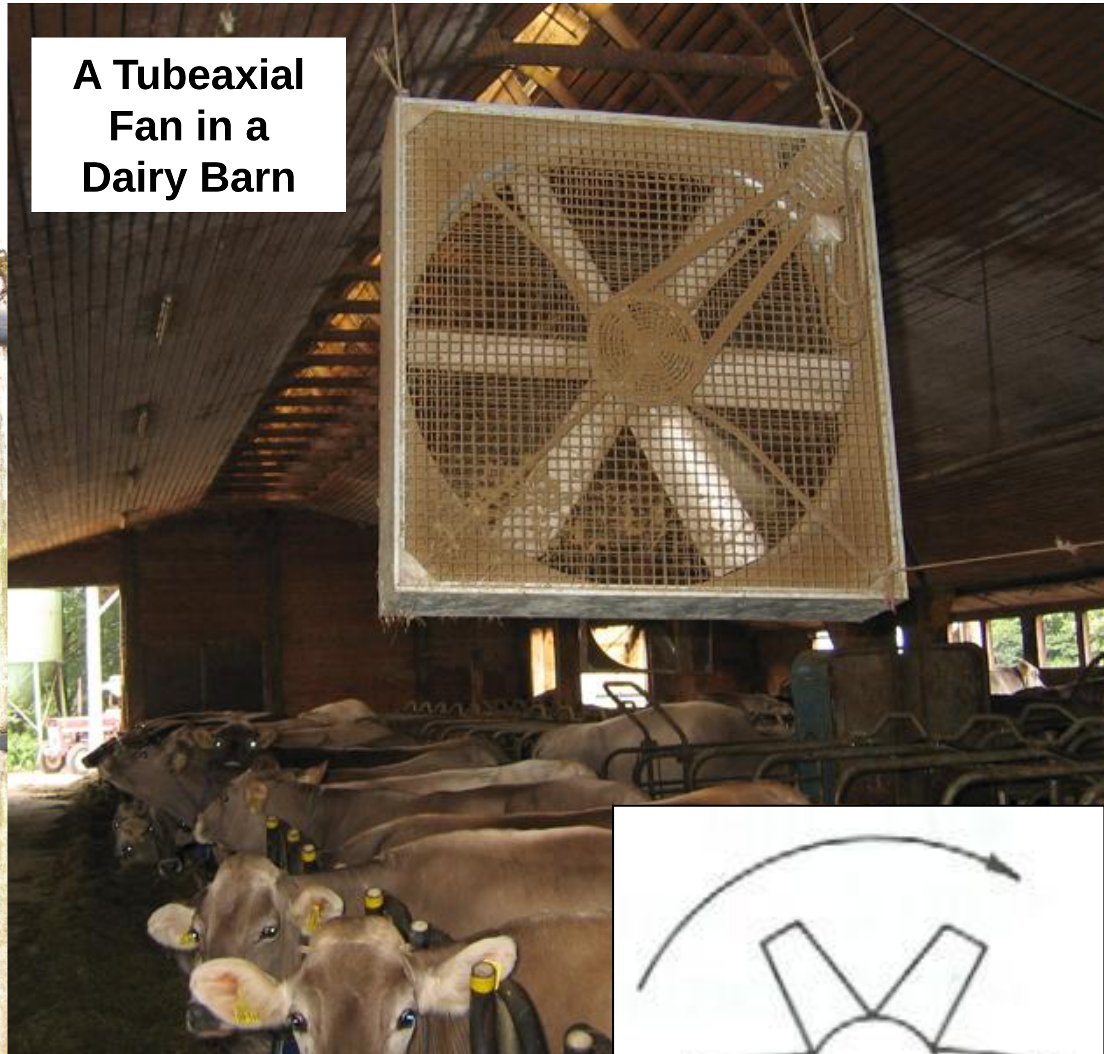
➢ The tube is cylindrical, with limited tip clearance between housing and the fan blades. The tubeaxial fan, due to its larger hub and reduced tip clearance, can generate a substantially higher pressure than can the propeller type fan.

➢ The central area around the hub imparts little energy-energy which results in a pressure difference. Thus, if a propeller fan operates at a total pressure difference somewhere near its cutoff, a significant amount of air flows back through the fan near the hub.

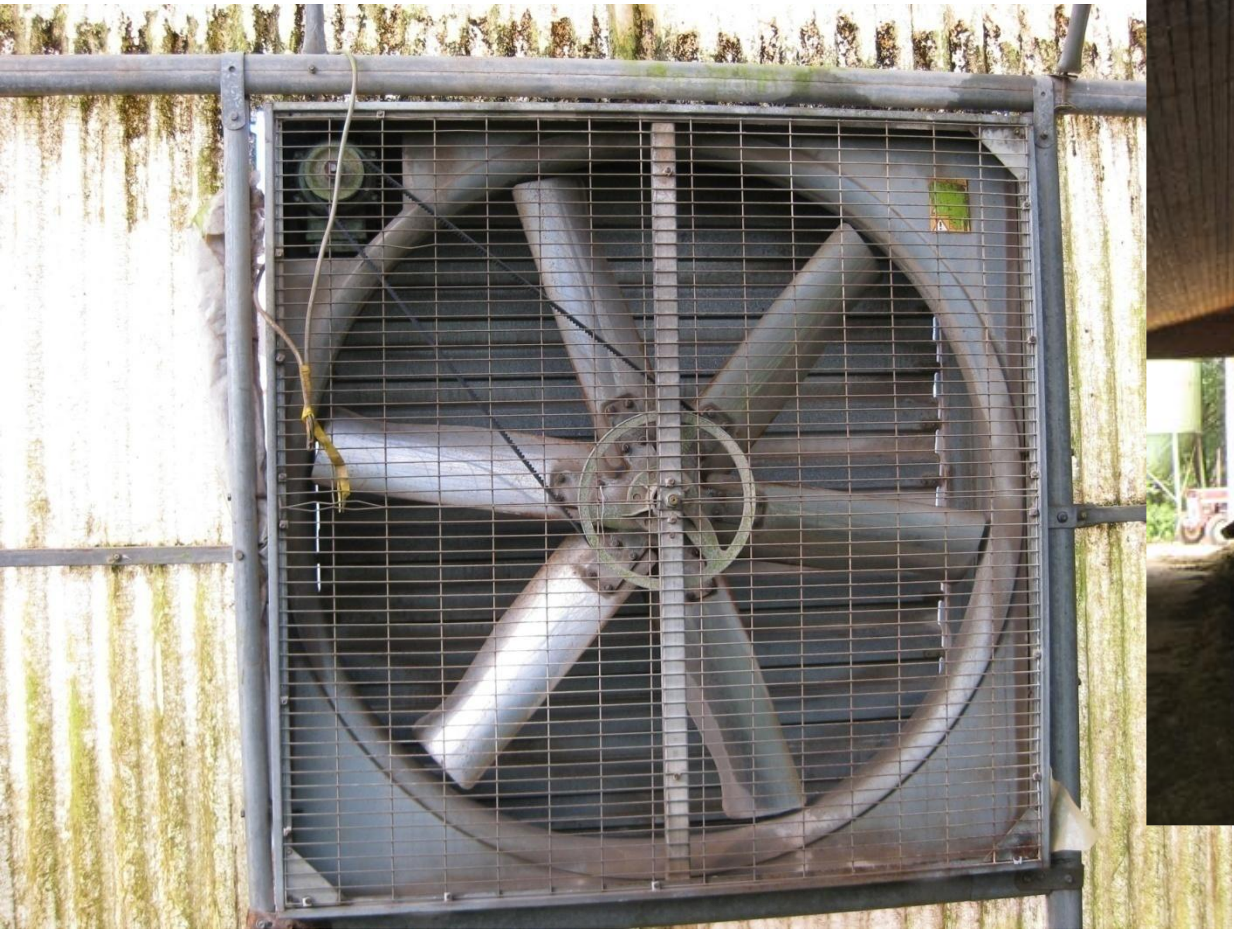


➢ In the tubeaxial fan (and also the vaneaxial) the larger hub blocks this path of shortcircuiting, permitting higher total pressure differences to be generated.

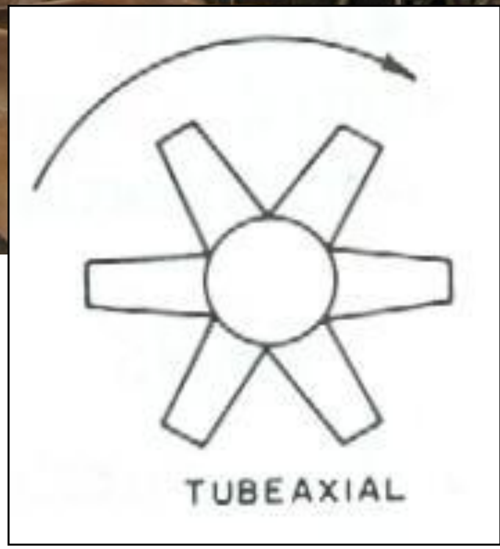
Tubeaxial Fans



A Tubeaxial Fan in a Dairy Barn



A Tubeaxial Fan in a Greenhouse

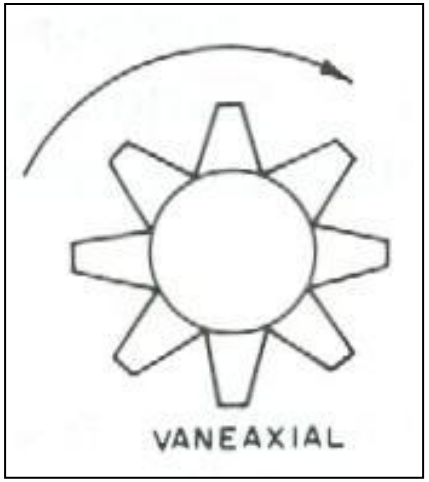


Vaneaxial Fans

- For even higher total pressure applications, vane axial fans are used. These fans often have 6 to 12 blades with an airplane wing cross sectional shape and a relatively large hub (over 50 percent of the fan blade diameter).

- Vaneaxial fans compete with centrifugal fans in terms of pressure relationship, but are more compact and often operate with less noise.

- Both tubeaxial and vaneaxial fans may be used as aeration fans in crop and grain dryers because they can operate at the static pressure required to force air through beds of the materials.



- Because such applications generally require substantial air flow rates in addition to significant total pressure differences, large motors are needed (compared to propeller fans).

Vaneaxial Fans

A Vaneaxial Fan in a Greenhouse

Shutters/Louvers

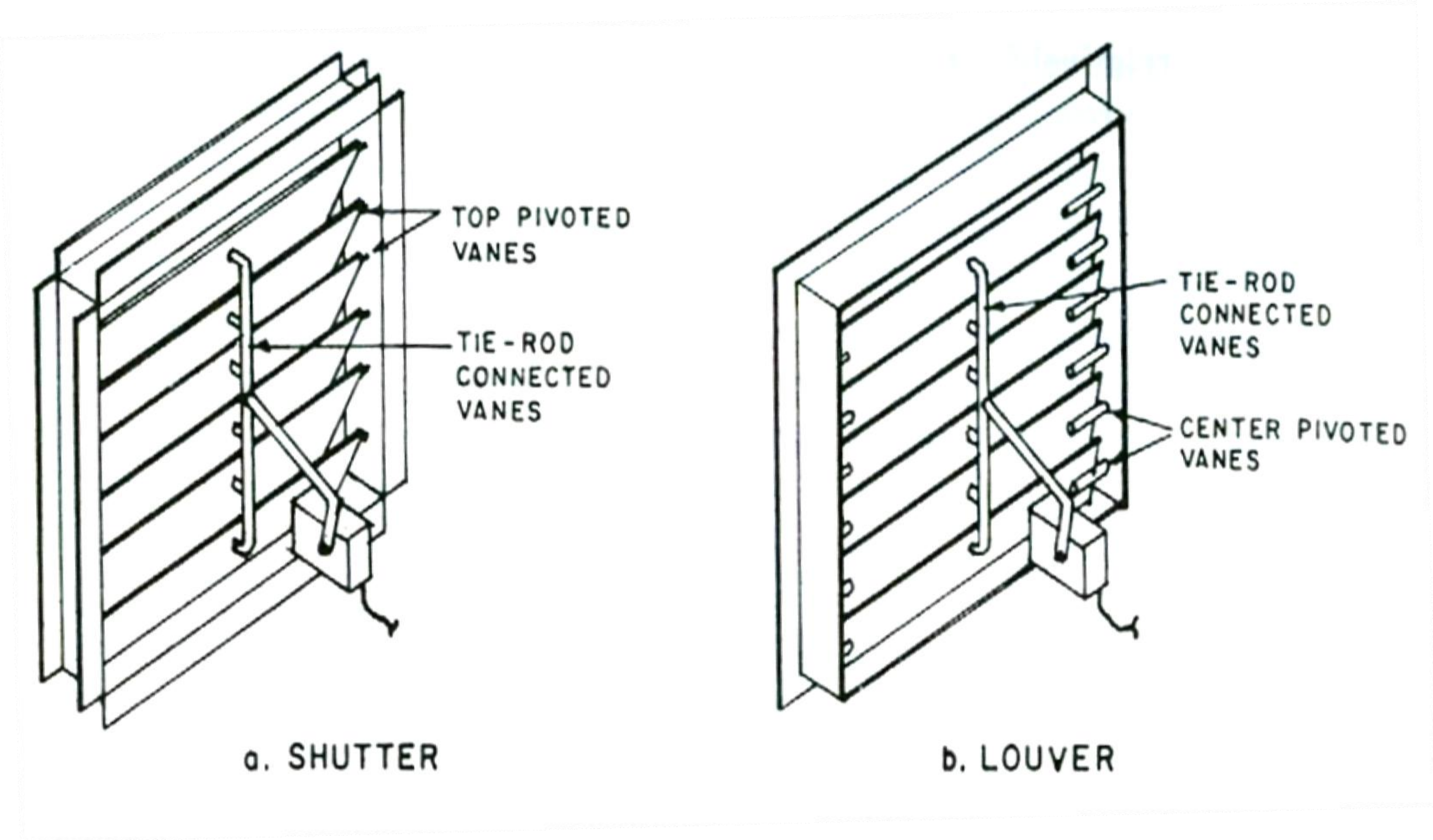
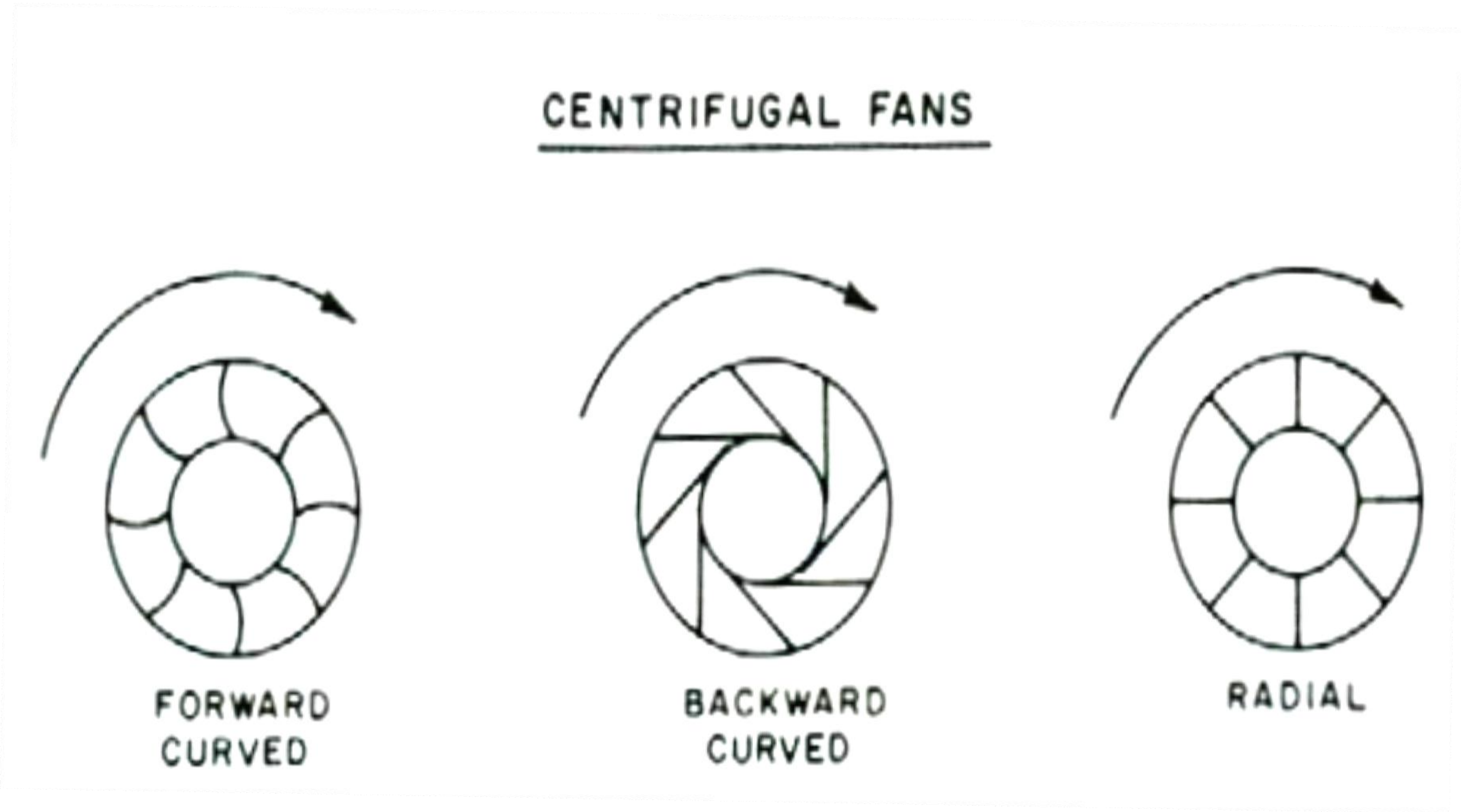


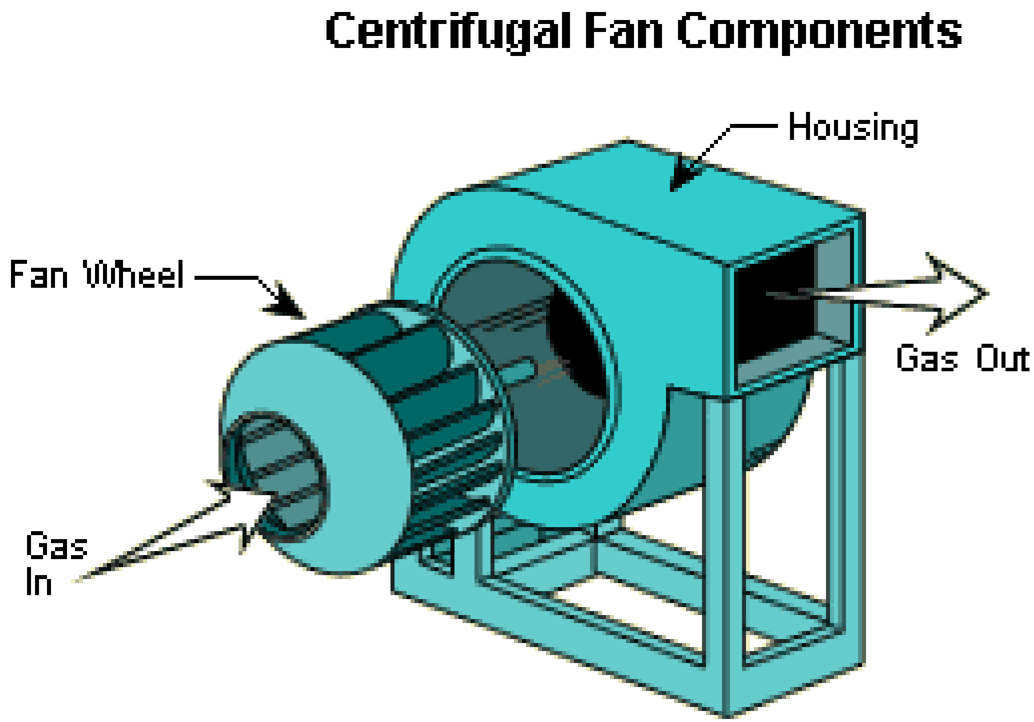
Figure 4.8: Shutters/Louvers

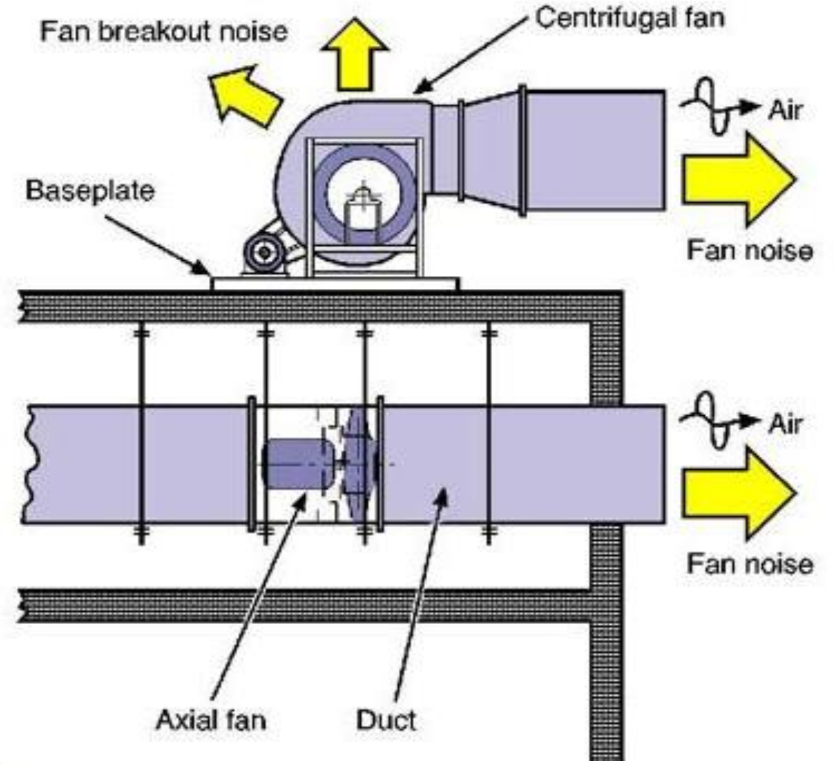
Centrifugal Fans

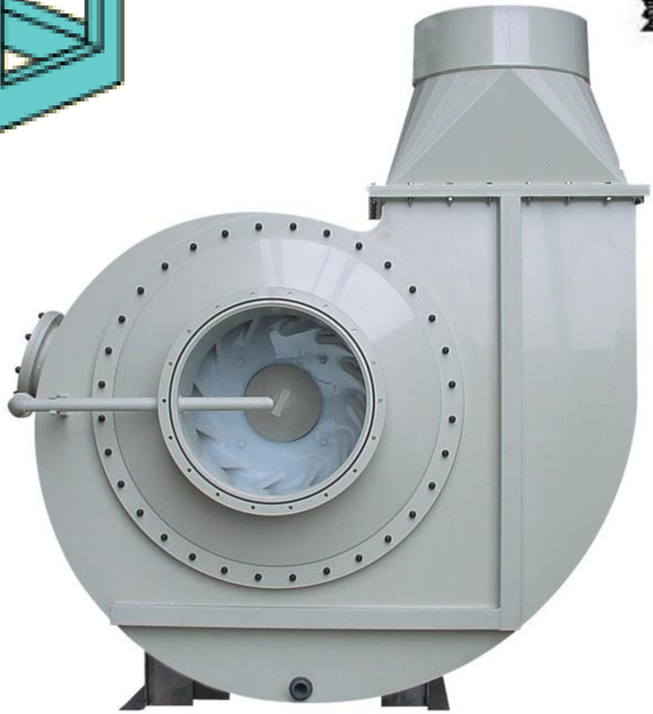


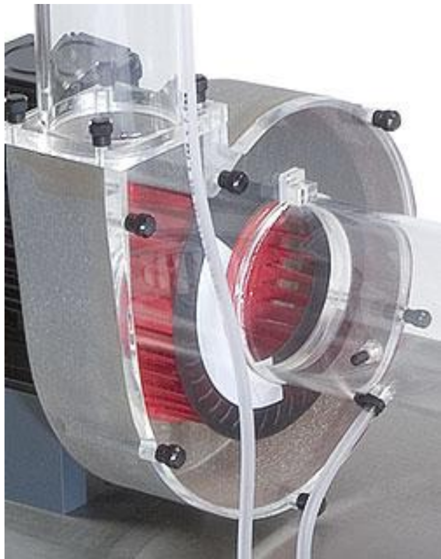
Types of Centrifugal Fans

Centrifugal Fans









Centrifugal Fans

- Centrifugal fans **(centrifugal blowers)** generally have 10-16 blades, and are classified by blade inclination: forward, backward and radial.

- The three types of blades provide differing fan characteristics (air flow rates as a function of total pressure difference). However, all centrifugal fans operate effectively with significant total pressure differences (one or more kilopascals).

- Centrifugal fans generate a total pressure difference in two ways. The centrifugal action of the rotating blades creates a static pressure difference, and the velocity imparted to the air by the blades adds kinetic energy, which increases the total pressure difference.

Centrifugal Fans

- The velocity of the air leaving the impeller is the vector sum of the velocity of the impeller plus the velocity of the air relative to the impeller.

- When the blades are inclined backward, the two velocities are in opposite directions; when inclined forward the two velocities are in the same direction.

- Thus, forward curved blades deliver a greater air flow rate, although with a somewhat smaller total pressure difference.

- The most efficient centrifugal fans are those with backward inclined blades, which generally operate at higher speeds. Air flow rates are affected less by total pressure difference than is the case with forward curved or radial blades.

Fan Rating

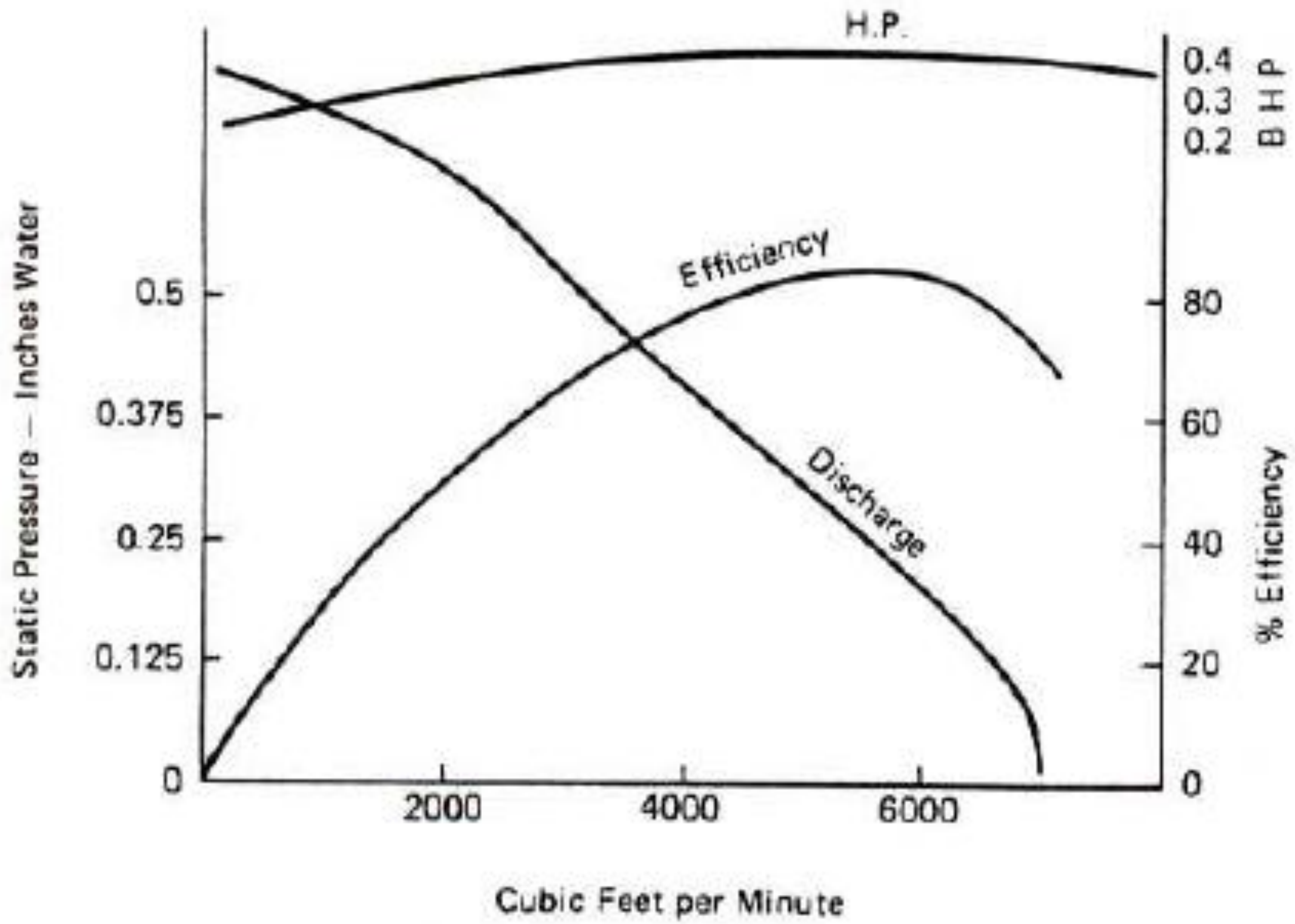
- All fans have slippage, which is to say no fan is completely efficient in transferring energy to air.

- The best fans reach perhaps 80 percent total efficiency, although propeller fans are seldom more than 40 percent efficient.

- This slippage leads to the necessity for experimentally determining fan characteristic curves.

- A number of characteristics can be plotted as functions of the flow rate: static pressure difference, velocity pressure difference, total pressure difference, static efficiency, mechanical efficiency, and power input to the fan.

Fan Performance Curves



Fan Performance Curves (Lindley and Whitaker, 1996).

Fan Performance Curves

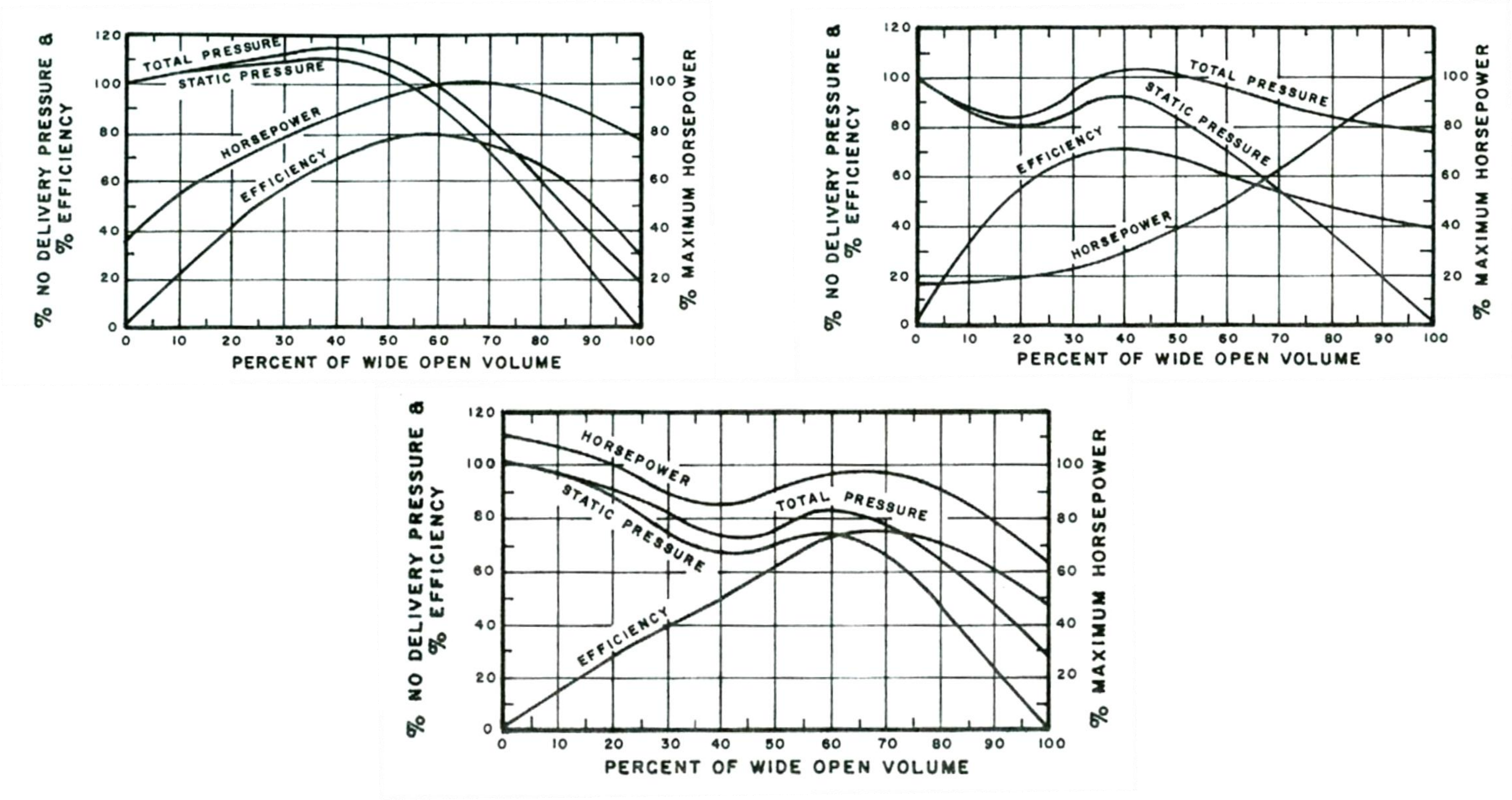


Figure 4.2: Typical fan performance curves (Normalized fan curves).

Fan Laws

➢ The fan laws can be used to predict air flow rate (Q), power (W), and pressure difference (ΔP) as functions of fan diameter (D), air density (ρ) and rotational speed (rpm):

$$Q_2 = Q_1 \left(\frac{RPM_2}{RPM_1}\right)\left(\frac{D_2}{D_1}\right)^3 \quad [4.1]$$

Where, state 1 refers to the fan for which data are known, and state 2 refers to the fan for which characteristics are to be computed

$$W_2 = W_1 \left(\frac{RPM_2}{RPM_1}\right)^3 \left(\frac{D_2}{D_1}\right)^5 \left(\frac{\rho_2}{\rho_1}\right) \quad [4.2]$$

$$P_2 = P_1 \left(\frac{RPM_2}{RPM_1}\right)^2 \left(\frac{D_2}{D_1}\right)^2 \left(\frac{\rho_2}{\rho_1}\right) \quad [4.3]$$

Note: Although the "laws" are not sufficiently detailed for highly accurate predictions, they are adequate for most applications when used within certain limitations.

Fan Laws

Problem 1: Using the fan laws, suppose a belt driven propeller fan is rated at an air flow rate of 4 m^3/s with a total pressure difference of 12 Pa, a power input of 400 W (to the fan blade, not the electric power consumed by the motor), and a rotational speed of 800 rpm. The fan is to be modified, with a different set of pulleys, so the rotational speed is 900 rpm. Everything else is to remain the same. What is the predicted air flow rate and power input after modification?

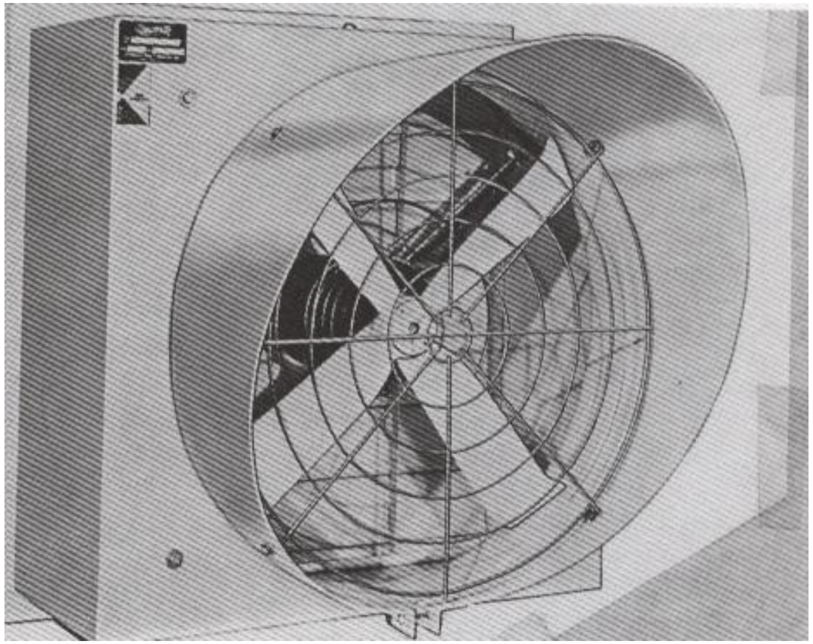
1. $$Q_2 = Q_1 \left(\frac{RPM_2}{RPM_1}\right)\left(\frac{D_2}{D_1}\right)^3 \longrightarrow Q_2 = 4\left(\frac{900}{800}\right)(1)^3 = 4.5\ m^3/s$$

2. $$W_2 = W_1 \left(\frac{RPM_2}{RPM_1}\right)^3\left(\frac{D_2}{D_1}\right)^5\left(\frac{\rho_2}{\rho_1}\right) \longrightarrow W_2 = 400\left(\frac{900}{800}\right)^3(1)^5\ (1) = 570\ \text{watts}$$

At a total pressure differential of:

3. $$P_2 = P_1 \left(\frac{RPM_2}{RPM_1}\right)^2\left(\frac{D_2}{D_1}\right)^2\left(\frac{\rho_2}{\rho_1}\right) \longrightarrow P_2 = 12\left(\frac{900}{800}\right)^2(1)^2\ (1) = 15.2\ \text{Pa}$$

Fan Laws



For the continuous ceiling baffle inlet:

$$Q = 0.0013W^{0.98}P^{0.49}\left(\frac{D}{T}\right)^{0.08}\exp[-0.867W/T]$$

For wall inlet:

$$Q = 0.0012W^{0.98}P^{0.49}$$

Where:

Q= airflow rate (m^3/s per meter length of slot opening).

W= slot width (mm).

P= pressure drop across the inlet (Pa).

D= baffle width (mm).

T= width of ceiling opening (mm).

See Problem 2

Fan Efficiency Ratings

- When fans are tested for rating, static and mechanical efficiencies are often computed. These terms have meaning to fan design engineers and are important in designing industrial type ventilation systems.

- However, for most agricultural applications (especially for ventilating greenhouses and animal housing) the primary measure of fan efficiency meaningful to the buyer is the ratio of what comes out of a fan that is useful when compared to what goes into the fan that must be paid for. What comes out is an air flow rate and what goes in is electricity. For many years this has been called the "cfm/W ratio“ i.e. “cubic feet per minute per Watt ratio”.

- In SI equivalents, it could be the "cubic meters per second per Watt ratio“ i.e. “m^3/s per W”. It has also been termed the Ventilating Efficiency Ratio (VER), a term which parallels the Energy Efficiency Ratio (EER) used to describe the energy use efficiencies of air conditioners.

Fan Costs

Problem 3: Typical VER data range from approximately 5 m^3/s per kW (and lower) to approximately 10. If two fans with VER ratings of 5 and 10 m^3/s per kW, both rated at 4 m^3/s, are compared in typical operation, and operated with a yearly average duty factor (fraction of time running) of 0.65, what is the cost of electricity for both fans at an electricity cost of 8 cents per kWh? What can be inferred?

Fan 1:

$$\text{Cost} = \left(\frac{8¢}{\text{kWh}}\right)(0.65)\left(4\frac{\text{m}^3}{\text{s}}\right)\left(24\frac{\text{hr}}{\text{day}}\right)\left(365\frac{\text{days}}{\text{yr}}\right) / \left(5\frac{\text{m}^3/\text{s}}{\text{kW}}\right)$$
$$= \$364 \text{ per year}$$

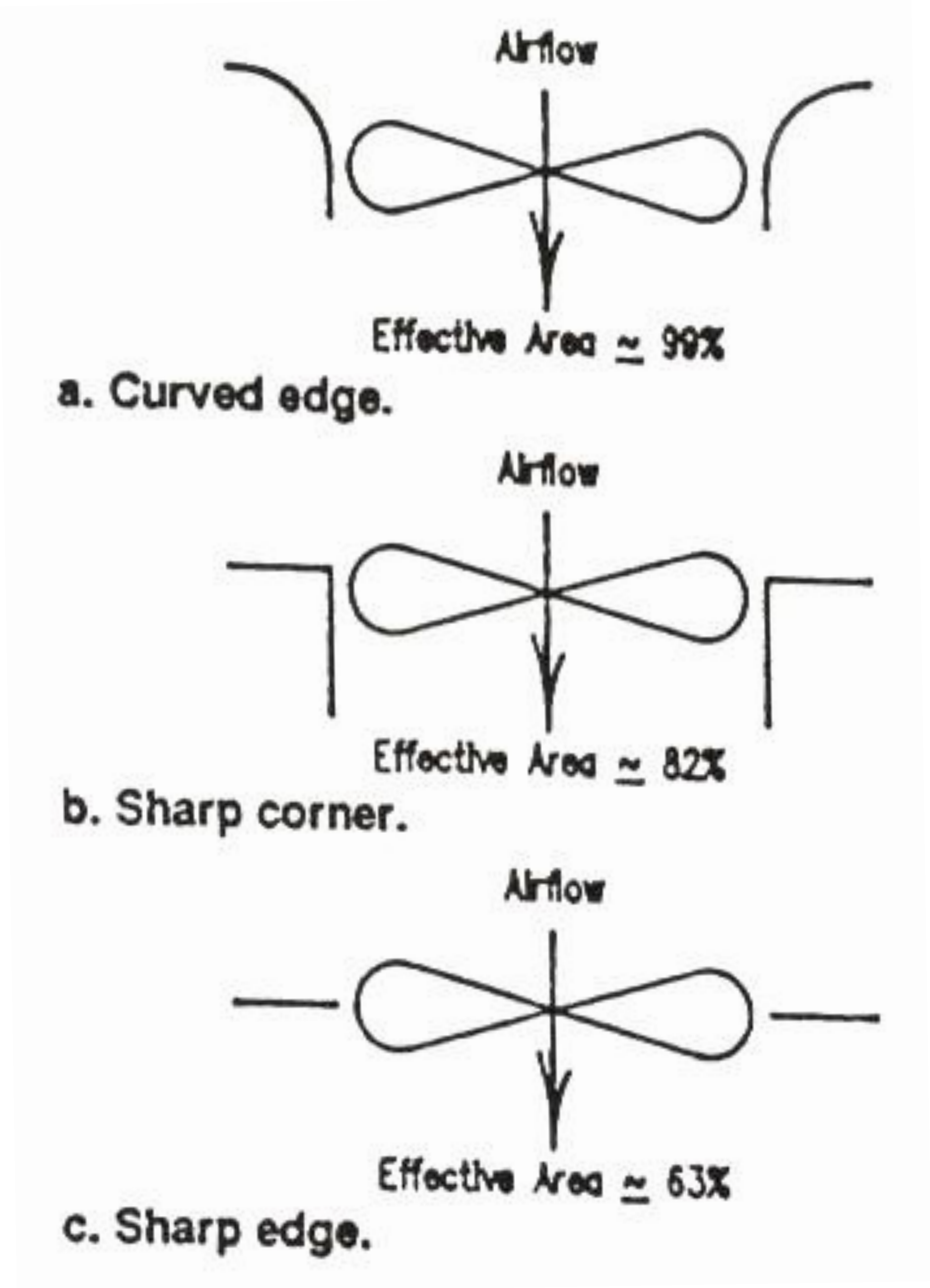
Fan 2:

$$\text{Cost} = \left(\frac{8¢}{\text{kWh}}\right)(0.65)\left(4\frac{\text{m}^3}{\text{s}}\right)\left(24\frac{\text{hr}}{\text{day}}\right)\left(365\frac{\text{days}}{\text{yr}}\right) / \left(10\frac{\text{m}^3/\text{s}}{\text{kW}}\right)$$
$$= \$182 \text{ per year}$$

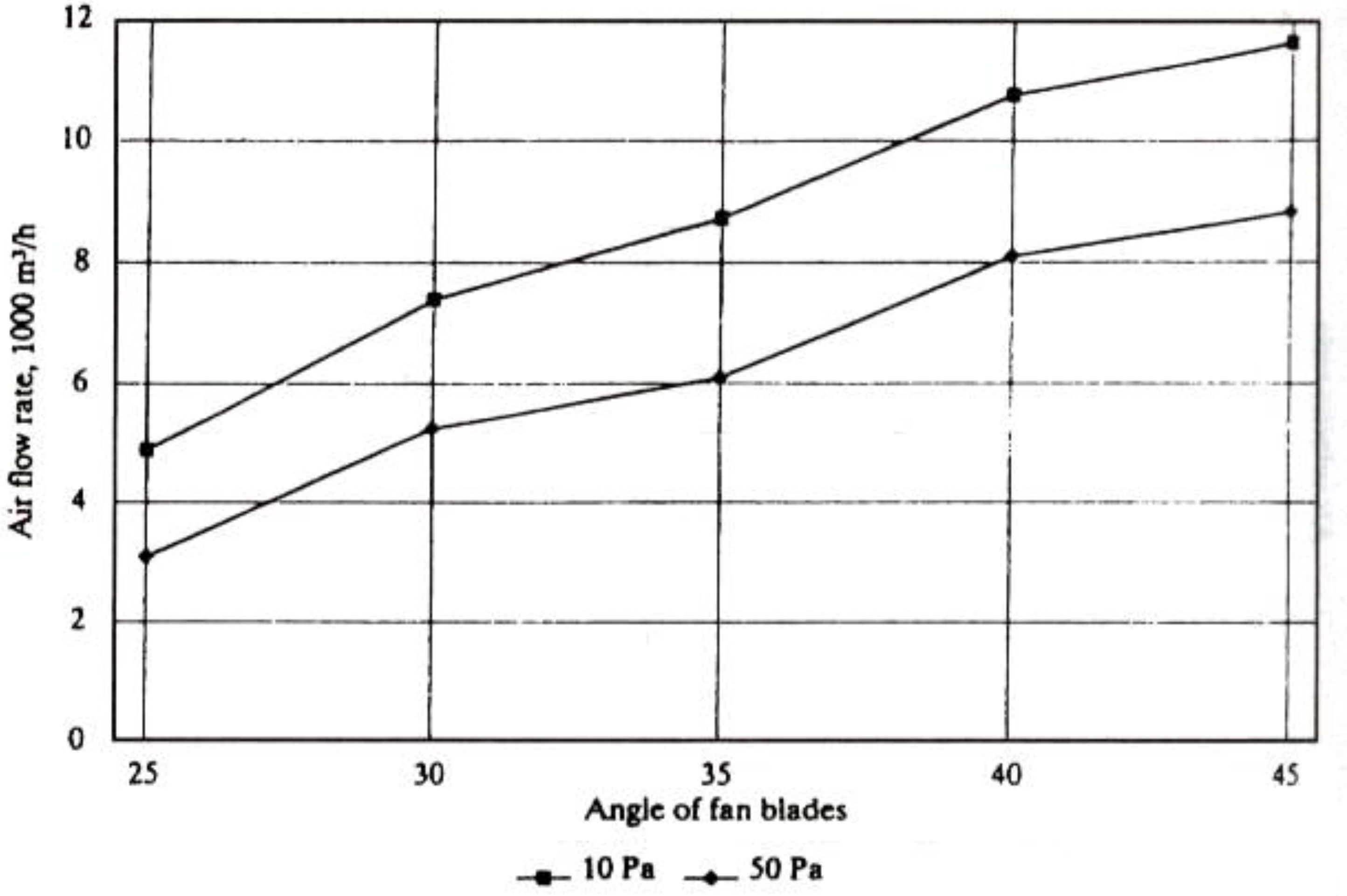
For the fan with a VER = 10, the cost is half, with a yearly savings of $182. If the fans last 10 years, the total savings will exceed the original purchase price of either fan. The ever increasing cost of electricity will further increase the potential savings.

Important Factors

Effect of fan housing on fan capacity
(Lindley and Whitaker, 1996)

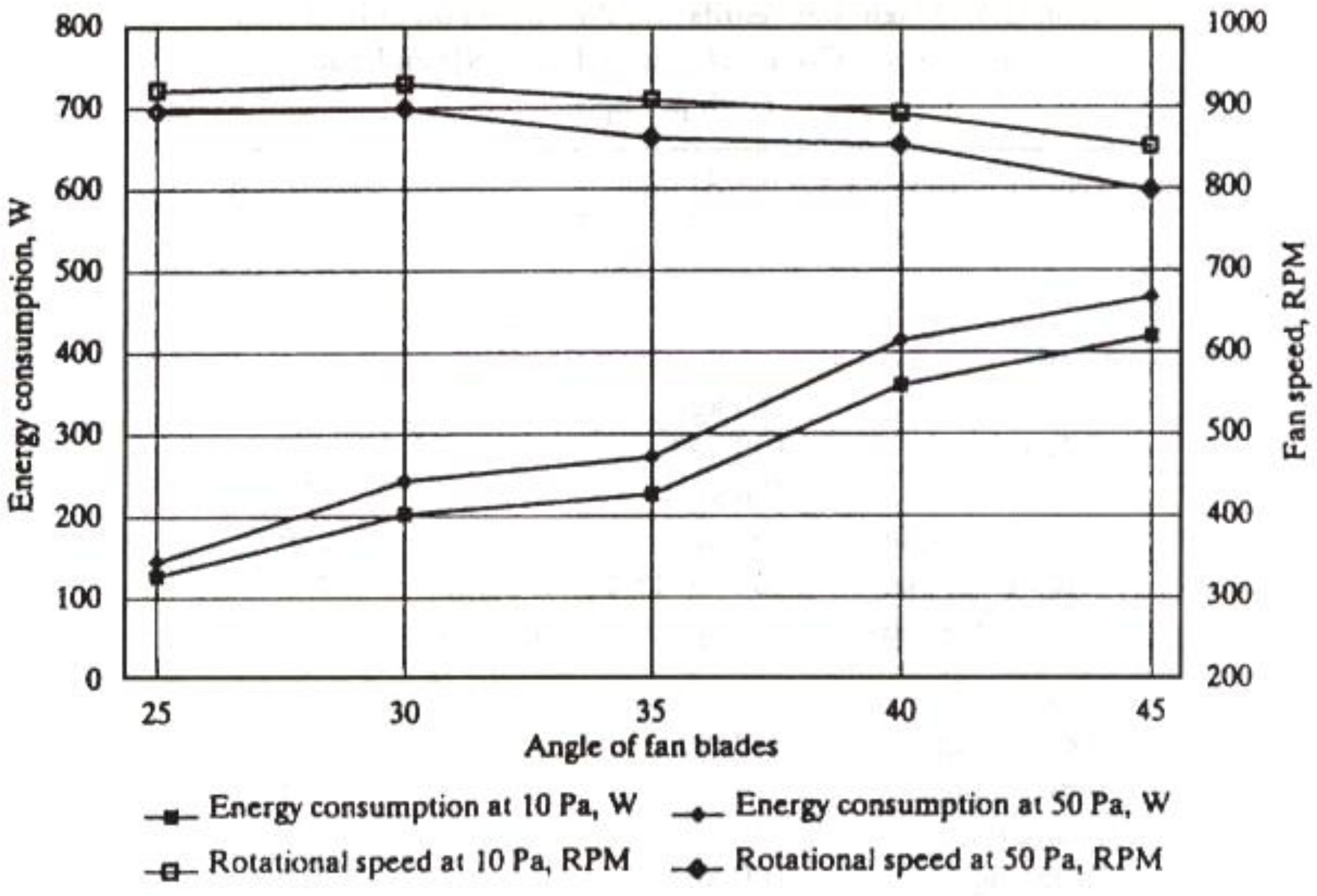


Important Factors



Airflow rate for exhaust fan with different blade angles (Pedersen, 1999).

Important Factors



Power consumption and speed of the fans (Pedersen, 1999).

Thermostat

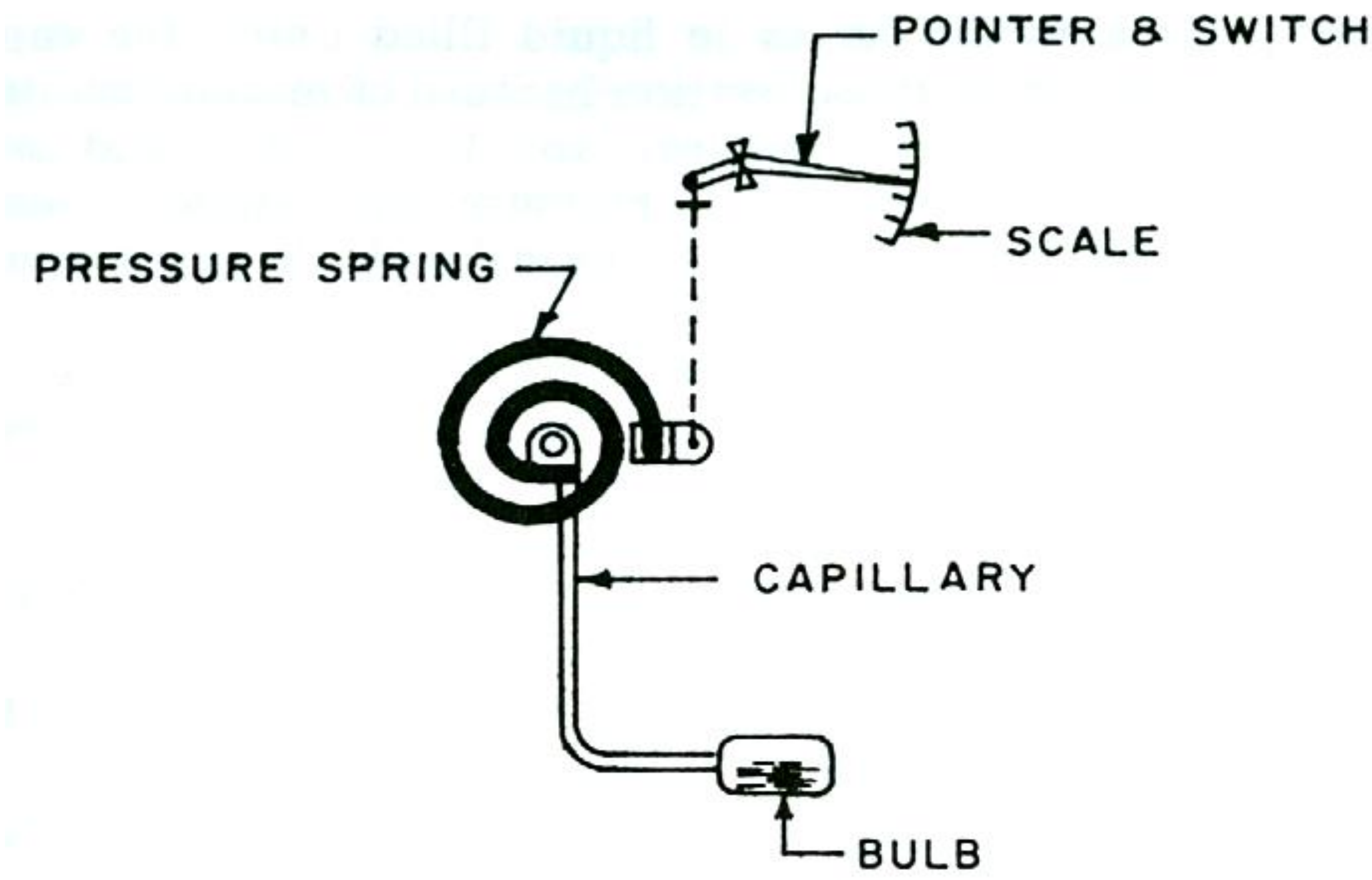


Figure 4.4: Liquid or vapor activated thermostat.

Timers

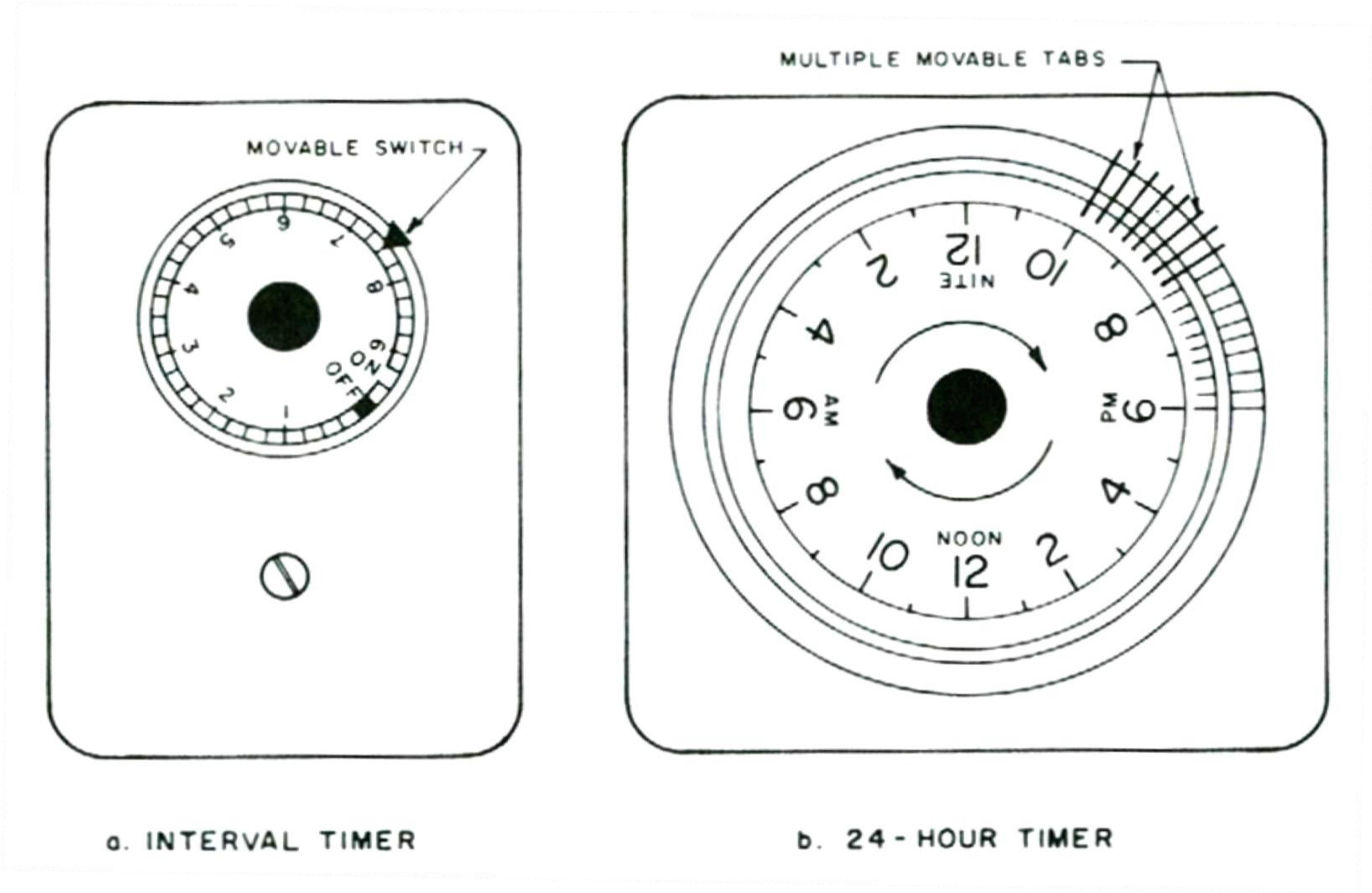
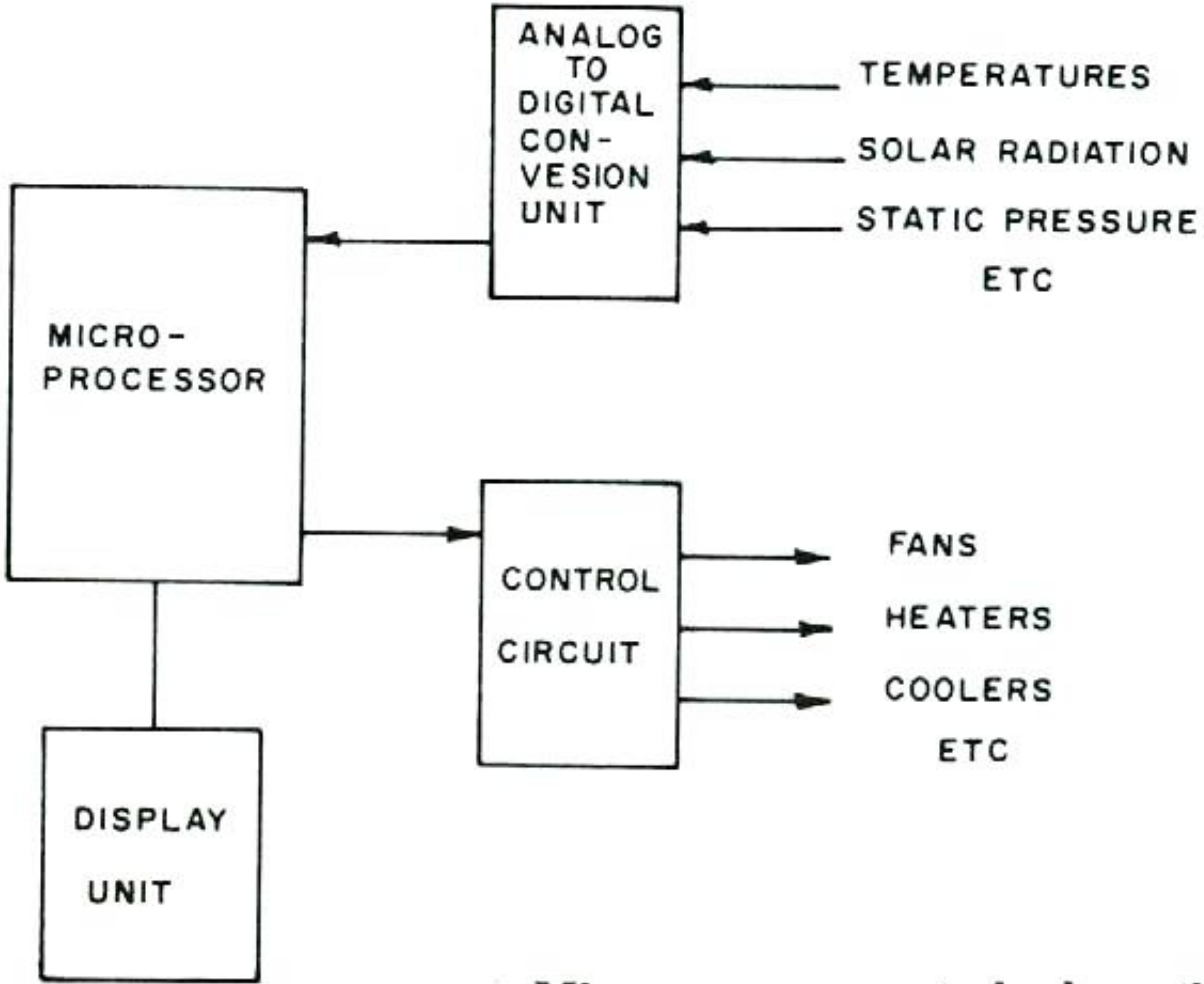


Figure 4.5: Typical times used in agricultural ventilation application.

Ventilation Control



Microprocessor control schematic

Heating Systems

- Heating Systems:

1. Warm Air Systems
2. Hot Water and Steam Systems
3. Electric Heating Systems
4. Heat Exchangers
5. Solar Collectors
6. Special Heating Systems for Agriculture (e.g. floors)

Thank You