6. ENERGY PERFORMANCE ASSESSMENT OF FANS AND BLOWERS

6.1 Introduction

This section describes the method of testing a fan installed on site in order to determine the performance of the fan in conjunction with the system to which it is connected.

6.2 Purpose of the Performance Test

The purposes of such a test are to determine, under actual operating conditions, the volume flow rate, the power input and the total pressure rise across the fan.

These test results will provide actual value for the flow resistance of the air duct system, which can be compared with the value specified by supplier.

6.3 Performance Terms and Definitions

Static Pressure: The absolute pressure at a point minus the reference atmospheric pressure.

Dynamic Pressure: The rise in static pressure which occurs when air moving with specified velocity at a point is bought to rest without loss of mechanical energy. It is also known as velocity pressure.

Total Pressure: The sum of static pressures and dynamic pressures at a point.

Fan Shaft Power: The mechanical power supplied to the fan shaft

Motor Input Power: The electrical power supplied to the terminals of an electric motor drive.

Fan Efficiency: The air power static divided by impeller power

$$\textbf{Static Fan Efficiency \%} = \frac{\text{Volume in } m^3/\text{Sec x total pressure in mmwc}}{102 \text{ x Power input to the shaft in (kW)}}$$

6.4 Scope

The procedure describes field testing of centrifugal fans and blowers for assessing performance and efficiency.

6.5 Reference Standards

British Standard, BS 848 - Fans for general purposes Part 1, Methods of testing performance

6.6 Field Testing

6.6.1 Instruction for Site Testing

Before site tests are carried out, it should be ensured that:

- Fan and its associated equipment are functioning properly, and at the rated speed
- Operations are at stable conditions, e.g. steady temperatures, densities, system resistance etc.

6.6.2 Location of Measurement Planes

General: The flow measurement plane shall be located in any suitable straight length, (preferably on the inlet side of the fan) where the airflow conditions are substantially axial, symmetrical and free from turbulence. Leakage of air from or into the air duct shall be negligible between the flow measuring plane and the fan. Bends and obstructions in an air duct can disturb the airflow for a considerable distance downstream, and should be avoided for the purposes of the test.

Test length: That part of the duct in which the flow measurement plane is located, is termed the 'test length' and shall be straight, of uniform cross section and free from any obstructions which may modify the airflow. It shall have a length equal to not less than twice the equivalent diameter of the air duct (i.e. $2D_e$). For rectangular duct, equivalent diameter, D_e is given by 2 LW/(L + W) where L, W is the length and width of the duct. For circular ducts D_e is the same as diameter of the duct.

Inlet side of the fan: Where the 'test length' is on the inlet side of the fan, its downstream end shall be at a distance from the fan inlet equal to atleast $0.75D_e$. See figure 6.1. In the case of a fan having an inlet box , the downstream end of the test length shall be at a distance from the nearest part of the inlet cone of the fan equal to at least $0.75D_e$.

Outlet side of the fan: Where the 'test length' is on the outlet side of the fan, the upstream end of the 'test length' shall be at a distance from the fan outlet of at least $3D_e$. See figure 6.2. For this purpose, the fan outlet shall be considered as being the outlet of any expander on the outlet side of the fan.

Location of the Flow Measurement Plane within the 'Test Length': The flow measurement plane shall be located within the 'test length' at a distance from the downstream end of the 'test length' equal to at least 1.25De.

Location of Pressure Measurement Plane: For the purpose of determining the pressure rise produced by the fan, the static pressure shall be measured at planes on the inlet and/or the outlet side of the fan sufficiently close to it to ensure that the pressure losses between the measuring planes and the fan are calculable in accordance with available friction factor data without adding excessively to the uncertainty of fan pressure determination.

If conveniently close to the fan, the 'test length' selected for air flow measurement should also be used to pressure measurement. Other planes used for pressure measurement should be

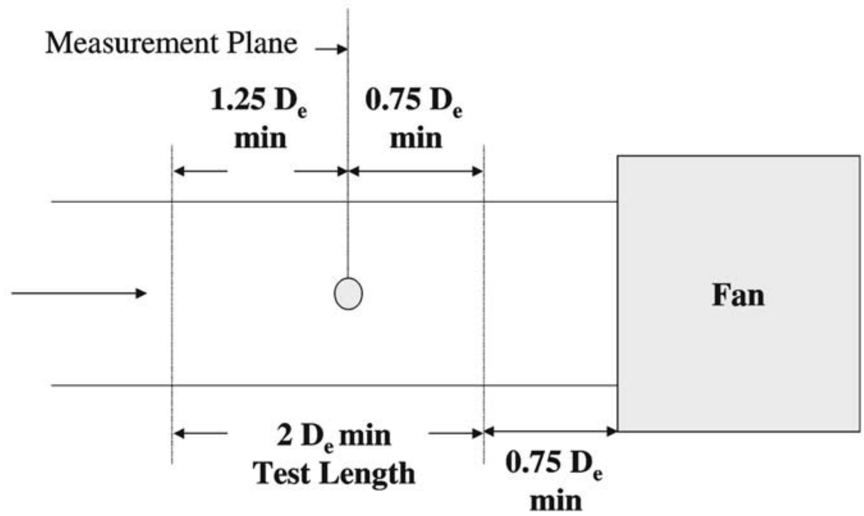


Figure 6.1 Test length on inlet side of fan

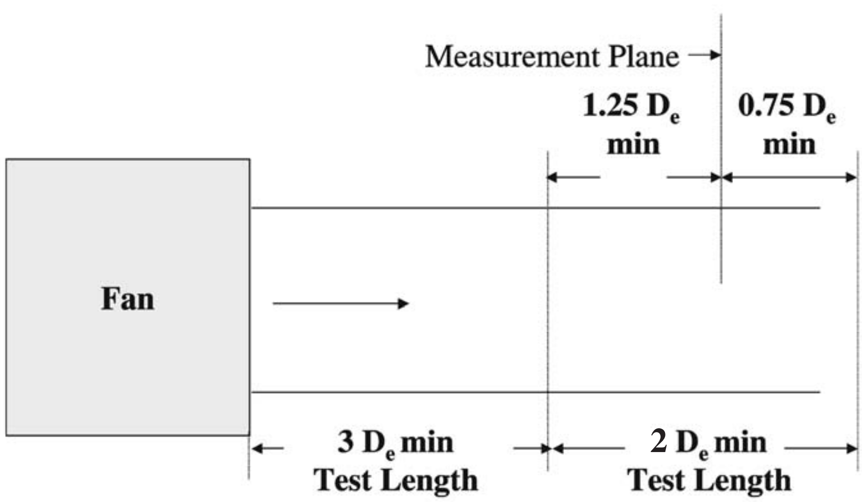


Figure 6.2 Test length on outlet side of fan

no closer than $0.25D_e$ from the fan inlet and no closer than $4D_e$ from the fan outlet. The plane of pressure measurement should be selected at least $4D_e$ downstream of any bend, expander or obstruction which are likely to cause separated flow or otherwise interfere with uniformity of pressure distribution.

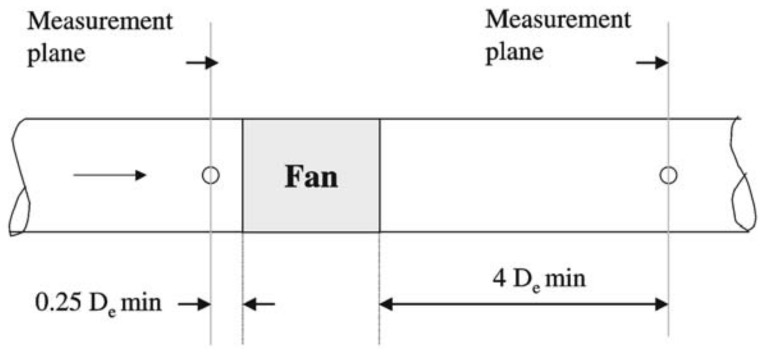


Figure 6.3 Location of pressure measurement planes for site testing

6.6.3 Measurement of Air Velocity on Site

Velocity shall be measured by either pitot tube or a rotating vane anemometer. When in use, the pitot tube shall be connected by means of airtight tubes to a pressure measuring instrument. The anemometer shall be calibrated before the test.

Pitot Tube: In Figure 6.4, note that separate static connections (A) and total pressure connections (B) can be connected simultaneously across a manometer (C). Since the static pressure is applied to both sides of the manometer, its effect is canceled out and the manometer indicates only the velocity pressure.

In practice this type of measurement is usually made with a Pitot tube which incorporates both static and total pressure sensors in a single unit. Essentially, a Pitot tube consists of an impact tube (which receives total pressure input) fastened concentrically inside a second tube of slightly larger diameter which receives static pressure input from radial sensing holes around the tip. The air space between inner and outer tubes permits transfer of pressure from the sensing holes to the static pressure connection at the opposite end of the Pitot and then, through connecting tubing, to the low or negative pressure side of a manometer. When the total pressure tube is connected to the high pressure side of the manometer, velocity pressure is indicated directly. See Figure 6.5.

To ensure accurate velocity pressure readings, the Pitot tube tip must be pointed directly into (parallel with) the air stream. As the Pitot tube tip is parallel with the static pressure outlet tube, the latter can be used as a pointer to align the tip properly. When the Pitot tube is correctly aligned, the pressure indication will be maximum.

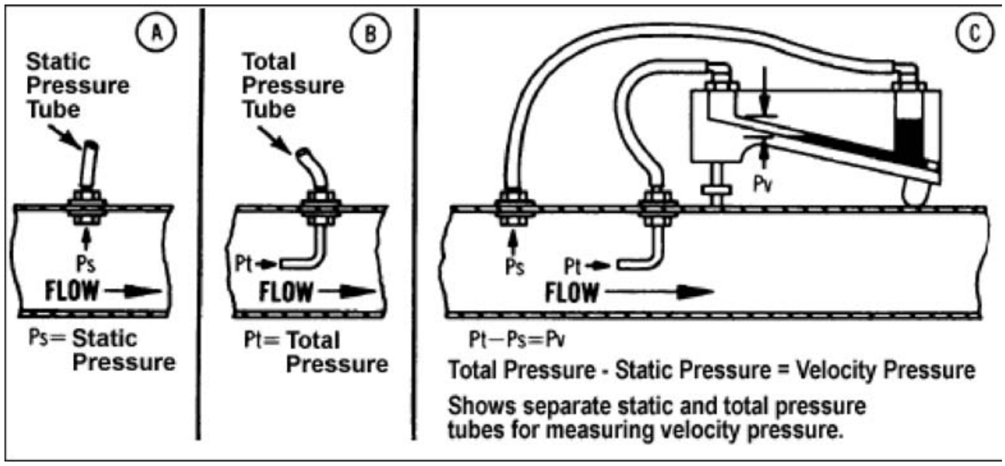


Figure 6.4 Types of Pressure Measurement

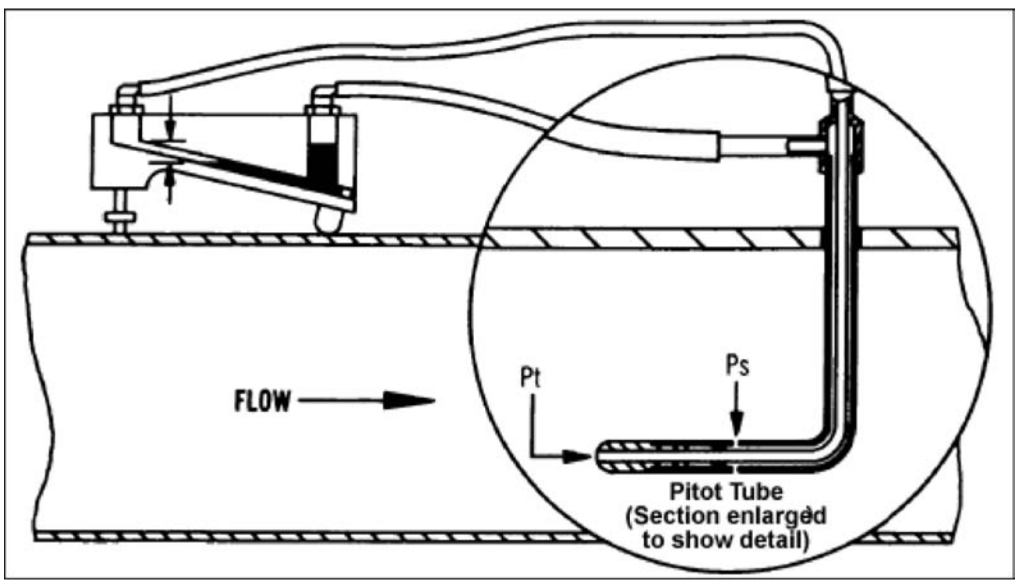


Figure 6.5 Pitot tube senses total and static pressure. Manometer measures velocity pressure (Difference between total and static pressures)

Traverse readings: In practical situations, the velocity of the air stream is not uniform across the cross section of a duct. Friction slows the air moving close to the walls, so the velocity is greater in the center of the duct.

To obtain the average total velocity in ducts of 100 mm diameter or larger, a series of velocity pressure readings must be taken at points of equal area. A formal pattern of sensing points across the duct cross section is recommended. These are known as traverse readings. Figure 6.6 shows recommended Pitot tube locations for traversing round and rectangular ducts.

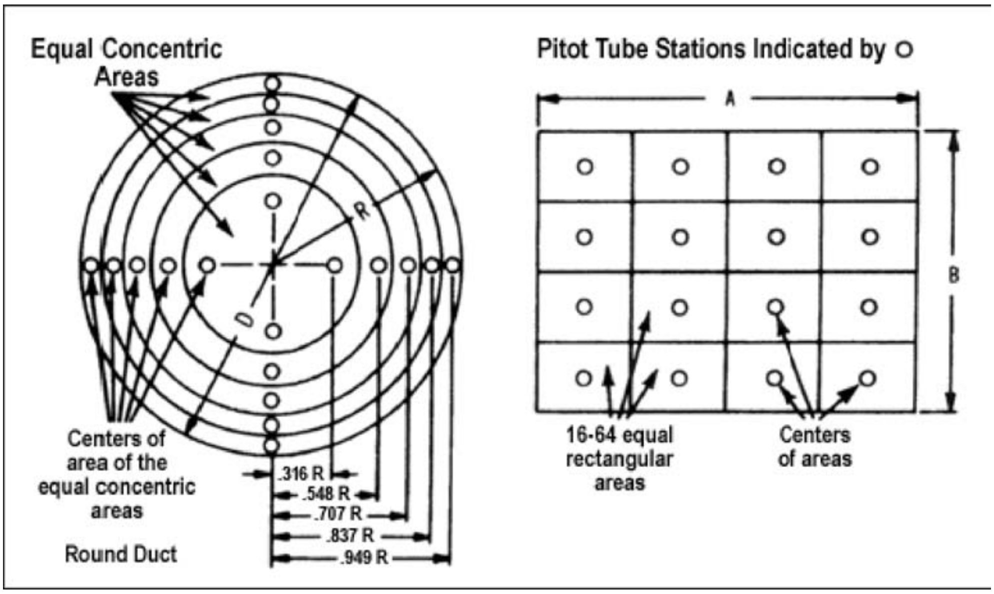


Figure 6.6 Traverse on Round and Square Duct Areas

In round ducts, velocity pressure readings should be taken at centers of equal concentric areas. At least 20 readings should be taken along two diameters. In rectangular ducts, a minimum of 16 and a maximum of 64 readings are taken at centers of equal rectangular areas. Actual velocities for each area are calculated from individual velocity pressure readings. This allows the readings and velocities to be inspected for errors or inconsistencies. The velocities are then averaged.

By taking Pitot tube readings with extreme care, air velocity can be determined within an accuracy of ± 2%. For maximum accuracy, the following precautions should be observed:

Example-Traverse point determination for round duct

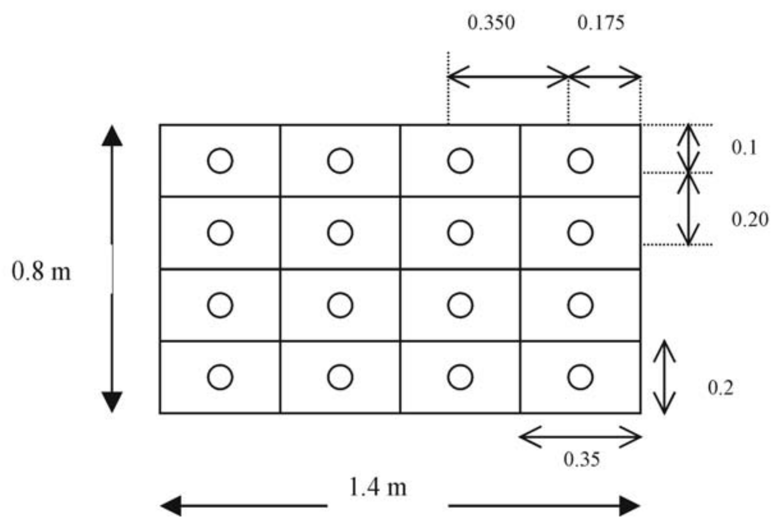
Round duct: Let us calculate various traverse points for a duct of 1 m diameter. From Figure 6.4, for round duct of 1 m diameter (D). The radius, R is 0.5 m. The various points from the port holes are given below:

0.5 – 0.949 x 0.5	0.0255
0.5 – 0.837 x 0.5	0.0815
0.5 – 0.707 x 0.5	0.1465
0.5 – 0.548 x 0.5	0.226
0.5 – 0.316 x 0.5	0.342
0.5 + 0.316 x 0.5	0.658
0.5 + 0.548 x 0.5	0.774
0.5 + 0.707 x 0.5	0.8535
0.5 + 0.837 x 0.5	0.9185
0.5 + 0.949 x 0.5	0.9745

Example-Traverse point determination for rectangular duct

Rectangular duct: For 1.4 m x 0.8 m rectangular duct, let us calculate the traverse points. 16 points are to be measured.

Dividing the area 1.4 x 0.8 = 1.12 m^2 into 16 equal areas, each area is 0.07 m^2. Taking dimensions of 0.35 m x 0.20 m per area, we can now mark the various points in the rectangular duct as follows:



In small ducts or where traverse operations are otherwise impossible, an accuracy of ± 5% can frequently be achieved by placing Pitot in center of duct.

Calculation of Velocity: After taking velocity pressures readings, at various traverse points, the velocity corresponding to each point is calculated using the following expression.

$$\text{Velocity (m/s)} = C_p \times \frac{\sqrt{2 \times g \times \Delta P \times \gamma}}{\gamma}$$

Where C_p = The pitot tube coefficient (Take manufacturer's value or assume 0.85)

ΔP = The average velocity pressure measured using pitot tube and inclined manometer by taking number of points over the entire cross-section of the duct, mm Water Column

γ = Gas density, kg/m^3 corrected to normal temperature

Anemometer: The indicated velocity shall be measured at each traverse point in the cross section by holding the anemometer stationary at each point for a period of time of not less than 1 minute. Each reading shall be converted to velocity in m/s and individually corrected in accordance with the anemometer calibration. The arithmetic mean of the corrected point velocities gives the average velocity in the air duct and the volume flow rate is obtained by multiplying the area of the air duct by the average velocity.

6.6.4 Determination of Flow

Once the cross-sectional area of the duct is measured, the flow can be calculated as follows:

Flow, (m^3/s) = Area (m^2) x Velocity (m/s)

$$\textbf{Volume (flow)} = A \times Cp \times \sqrt{\frac{2 \times 9.81 \times \Delta p \times \gamma}{\gamma}}$$

6.6.5 Determination of Fan Pressure

General: Precautions shall be taken so that the measurements of the static pressure on the inlet and outlet sides of the fan are taken relative to the atmosphere pressure.

Measurement of Static Pressure: This shall be done by using a manometer in conjunction with the static pressure connection of a pitot tube or a U tube manometer.

When using a pitot tube it is necessary to carry out a traverse in the pressure measurement plane taking individual point pressure readings in a manner similar to that for determining flow rate. In general, a smaller number of readings will be found adequate where individual readings do not vary by more than 2% from each other. The average of all the individual readings shall be taken as the static pressure of that section.

6.6.6 Determination of Power Input

Power Measurement: The power measurements can be done using a suitable clamp- on power meter. Alternatively by measuring the amps, voltage and assuming a power factor of 0.9 the power can be calculated as below:

$$P = \sqrt{3} \times V \times I \times \cos\Phi$$

Transmission Systems: The interposition of a transmission system may be unavoidable introducing additional uncertainties. The following values shall be used as a basis for transmission efficiency in the case of drives rated at 20 kW and above unless other reliable information is available:

Properly lubricated precision spur gears	98% for each step
Flat belt drive	97%
V-belt drive	95%

Other Prime Movers: When the fan forms one unit with a non-electric prime mover it is recommended that the fuel consumption (oil, steam, compressed air etc.) should be specified and determined in place of the overall power.

$$\text{Power Input to fan shaft} = \text{Power input to the motor} * \eta \text{ of motor at the corresponding loading} * \text{transmission system } \eta$$

$$\text{Fan efficiency} = \frac{\text{Volume in } m^3/\sec * \text{total pressure in mmWC}}{102 * \text{power input to fan shaft in kW}}$$

6.7 Example: Performance Test Report on Cooling Air Fan

The following is a typical report on measurements taken and calculations made for a **double inlet fan** in a palletizing plant.

A. Design Parameters:

Volume = 292 m^3/sec.
Static Pressure = 609.6 mmwc

B. Measurements:

Temperature = 32°C
Speed = 740 RPM

Inlet Damper Position %	Suction Pressure (-) mmwc	Outlet Pressure (+) mmwc	Measured Velocity Pressure (Δ p), mmwc	Volume m^3/Sec.	Amps (I)	Power Consumption (kW)
80%	**ONE SIDE** 25, 22, 20 Average=22.33	455, 462, 480,478 Avg.=468.75	Average = 70	166.6	**220**	2127 KW
	ANOTHER SIDE 15, 18, 23, 21 **Average=19.25**	459, 464, 473 479, 480, 470 **Avg.=470.83**	Average = 70			

Instruments used

a) Suction pressure, outlet pressure = 'U' tube manometer
b) For differential pressure = Inclined tube manometer
c) For temperature = Mercury in glass thermometer
d) Fan speed = Tachometer
e) Line current = Tong tester

C. Performance calculations:

a) Gas Density (Corrected to NTP)

$$= \frac{273 \times 1.293}{273 + T°C \text{ (at site condition)}}$$

$$= \frac{273 \times 1.293}{273 + 32°C \text{ (at site condition)}}$$

$$= 1.15 \text{ kg/m}^3$$

b) Volume = **Cp** x $A \sqrt{\frac{2 \times 9.81 \times \Delta p \times \gamma}{\gamma}}$

Cp = Pitot tube constant, 0.85

A = Area of rectangular duct in m^2, 1.029 x 5.502

Δp = Average velocity pressure measured by pitot tube by taking measurement at number of points over the entire cross section of the duct.(see Table)

γ = Density at test condition, 1.15 kg/m^3

Flow (v) = $\frac{0.85 \times 1.029 \times 5.502 \sqrt{2 \times 9.81 \times 70 \times 1.15}}{1.15}$

v = 166.6 m^3 / Sec

c) (P_1) = Power input to the motor (kW) = $\frac{\sqrt{3} \times V \times I \times \cos\varnothing}{1000}$

= $\frac{\sqrt{3} \times 6600 \times 220 \times 0.9}{1000}$

= 2263 kW

d) P = Power input to the fan shaft

= Power input to the motor (kW) x Efficiency of motor (%) at the operating load x transmission efficiency

Motor efficiency = 0.94

P = 2263 x 0.94 x 1 (as motor was direct coupled)

= 2127 kW

e) Fan Efficiency % = $\frac{\text{Volume in } m^3 / \text{Sec} \times \text{total pressure in mmwc}}{102 \times \text{Power input to the shaft in (kW)}}$

Where 102 is a conversion constant

For **double inlet fan,**
The total Volume of air, m^3 / Sec = 166.6 x 2 = 333.2

Total static pressure, mmwc (Δp_{Static}, across the fan) = 468.75 – (–22.33) = 491

$$\textbf{Fan Efficiency} = \frac{333.2 \times 491}{102 \times 2127} \times 100$$

Static Fan Efficiency = 75%

6.8 Factors that Could Affect Performance

- Leakage, re-circulation or other defects in the system;
- Inaccurate estimation of flow resistance;
- Erroneous application of the standardized test data;
- Excessive loss in a system component located too close to the fan outlet;
- Disturbance of the fan performance due to a bend or other system component located too close to the fan inlet;
- Error in site measurement

QUESTIONS	
1)	What is the relationship between static pressure, dynamic pressure and total pressure?
2)	For determining fan efficiency, why static pressure readings should be taken as close to fan as possible?
3)	What is the significance of having traverse points in velocity measurement?
4)	What is fan efficiency?
5)	Determine various traverse points for a round duct of 0.5 m diameter.
6)	Why flow should not be measured very close to inlet and outlet of fan?
7)	Calculate the flow rate for the following data: Diameter of duct: 0.5 m, differential pressure: 100mmWC, Density of air at 0°C: 1.293, Temperature of air in the duct: 100°C, pitot coefficient: 0.85
8)	How many traverse points you would propose for a rectangular duct of 1 m x 1 m dimensions?
9)	What are the various ways of measuring the flow?
10)	What are the various factors, which can affect fan performance?

REFERENCES

1. British Standard: BS 848 : Part 1 : 1980
2. Energy and Environmental Audit Reports of National Productivity Council