# 1 CHAPTER -1: AIR DISTRIBUTION AND AIRFLOW PRINCIPLES

The Heating, Ventilation and Airconditioning (HVAC) system of a building depends heavily on the ductwork. Although not always obligatory, ducts are frequently the most practical means for air movement. Most applications use galvanized iron (GI) sheet metal for the main ductwork and flexible ducts for the runouts to the air distribution devices.
Broadly, HVAC ducts fall into four designations:

a. **Supply Air:** These ducts deliver heated and cooled air from the central HVAC system to various areas within a building.
b. **Return Air:** Return ducts draw indoor air back to the HVAC equipment for filtering, reconditioning, and redistribution.
c. **Fresh Air:** Fresh air ducts supply outdoor air to ventilate the occupied building space.
d. **Exhaust Air:** Exhaust ducts remove stale indoor air, fumes, heat, odors, and vapors to outdoors. They are connected to areas like toilets, kitchens, laboratories, workshops, and other spaces requiring ventilation.

All these ducts function in tandem to regulate the comfort and indoor air quality of your building.

## 1.1 Duct Design Objectives

The intricate network of ducts within the building structure necessitates meticulous planning during the initial design phase. Post-construction modifications, especially above false ceilings crowded with numerous MEP services, tend to be laborious and often impractical once the building becomes operational.

The importance of well-designed ductwork is underscored by its three key objectives:

a. Ensuring efficient and balanced airflow to each zone of the building,
b. Minimizing HVAC-generated noise for a quieter indoor environment, and
c. Reducing airflow resistance to enhance overall energy efficiency.

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| | *The primary goal of efficient duct design is to deliver the right amount of air to specific locations within a building, at the correct temperature and humidity levels, while using minimal energy and minimum noise.* |

## 1.2 Understanding Airflow

Designing an effective air distribution system and duct layout requires a thorough understanding of fluid dynamics including vital aspects like air velocity, pressure, and the conservation of mass. Starting with the basics, let's start at the most elementary level of airflow fundamentals.

### 1.2.1 Basic Definitions

The following basic terminology is extensively used in this course.

a. CFM: Airflow volume, cubic feet/minute
b. fpm: Air velocity, feet/minute
c. Sq. ft: Duct cross-sectional size, square feet
d. psi: Air pressure, pounds per square inch
e. in. W.G.: Air pressure, inches of water gauge

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| | *Air volume in CFM is calculated by multiplying the air velocity by the cross-sectional area of the duct in square feet (sq. ft).*<br>*CFM = fpm x sq. ft.*<br>*Given any two of these three quantities, the third can readily be determined:*<br>$fpm = \frac{CFM}{Area}$<br>$Area = \frac{CFM}{fpm}$ |
| | *In practical HVAC air distribution applications, pressure measurements are often expressed in inches of water gauge (in. W.G.) rather than psi. This is because the* |

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| | *pressure differences in the ductwork are typically relatively low, and inches of water gauge provide a more convenient and precise unit of measurement for these scenarios.* |

### 1.2.2 Gauge and Absolute Pressures

Gauge pressure (psi) is displayed on the gauge, while absolute pressure is the total of the gauge pressure and atmospheric pressure expressed a psia.

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| | *Absolute pressure is sum of gauge pressure + atmospheric pressure.*<br>*For example, if the gauge reads 10 psi, then the absolute pressure would be 24.7 psia:*<br>*10 psi + 14.7 psi = 24.7 psia* |
| | *1 psi equals 27.7 inches of water gauge. Therefore, a duct pressure of 0.25 inches water gauge is equal to (0.25 divided by 27.7 in. W.G./psi) = 0.009 psi.* |

### 1.2.3 Duct Pressure

Duct pressure has three classifications:

a. Static pressure – air pressure in the duct, used for fan selection.
b. Velocity pressure – pressure generated by the velocity and weight of the air, used for measuring CFM in a system.
c. Total pressure used to find velocity pressure. Static pressure plus velocity pressure equals total pressure.

Pressure in the ductwork is measured in inches of water gauge (in. W.G.).

### 1.2.4 Standard Air Density

The first thing you need to know is that air has weight.
Standard Air has a density of 0.075 lbs/ft$^3$ when measured at 70°F, under sea-level atmospheric pressure of 14.7 psi or 29.92 inches of mercury, and with a relative humidity of 0%.

| | ***Air Density*** |
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| | *System capacity is directly affected by changes in airflow. As air is heated or humidified, its specific volume increases and its density decreases. If the air density is low, more CFM is required to keep the mass flow rate the same.* |
| | *Temperature and altitude changes affect air density, impacting fan performance and efficiency. No density correction is typically needed for air conditioning cooling applications between 40°F to 100°F and up to 1000 ft. elevation.* |

### 1.2.5 Fan Capacity

Fan capacity refers to the ability of a fan to move a specific volume of air within a given period, usually measured in cubic feet per minute (CFM). This remains constant in a system, indicating that the fan moves the same quantity of air regardless of changes in air density. For example, if a fan moves 3,000 CFM at 70°F, it will also move 3,000 CFM at 250°F.

### 1.2.6 Fan Sizing

Fan sizing involves selecting a fan with the appropriate capacity to meet the specific requirements of a system or space. This process considers several factors:

a. **Airflow Requirements:** Calculating the required airflow (CFM) based on the application, considering factors such as room size, ventilation needs, or industrial processes.
b. **Static Pressure:** Evaluating the system's resistance to airflow, often expressed as static pressure, to ensure the fan can overcome the resistance and deliver the required airflow.
c. **Application Specifics:** Considering the environmental conditions, temperature, altitude, and any specific requirements of the application that might impact fan performance.
d. **Efficiency:** Assessing the efficiency of the fan to ensure optimal energy usage and cost-effectiveness over the fan's operational life.
e. **Ductwork and System Design:** Factoring in the design of the ductwork and overall system layout to ensure proper air distribution and efficient fan operation.

## 1.3 Airflow Rate

The airflow rate is expressed either as mass flow rate or volumetric flow rate.

### 1.3.1 Mass Flow Rate

Mass flow rate is the measure of the mass of air moving through a system per unit of time. It is calculated using the formula:

**m = ρ * A * V**

Where:

- m = mass flow rate, lb/min
- ρ is the density of air, lb/ft$^3$
- A is the cross-sectional area of duct, sq. ft.
- V is the velocity of the air, fpm

*Mass flow rate calculations adjust for variations in air density influenced by temperature and pressure within the system.*

### 1.3.2 Volumetric Flow Rate

Volumetric flow rate is the measure of the volume of air moving through a system per unit of time. It is calculated using the formula:

**Q = A * V**

Where:

- Q = Volumetric flow rate, CFM
- A is the cross-sectional area of duct, sq. ft.
- V is the velocity of the air, fpm

*Volumetric flow rate calculations don't directly account for air density variations and consider the cross-sectional area and air velocity.*

HVAC calculations prioritize volumetric flow rate (CFM) over mass flow rate (lbs/hr) due to several reasons:

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| | *Mass flow rate varies with changes in air density due to temperature and pressure fluctuations, whereas volumetric flow rate remains relatively consistent within the standard HVAC operating range.* |
| | *HVAC equipment and components are typically designed based on volumetric flow rate specifications.* |
| | *Measuring and controlling volumetric flow rate is simpler and manageable in HVAC systems using air handling units and fans.* |

### 1.3.3 Estimating Airflow Rates

Estimating airflow rates in HVAC systems is a first step in designing an efficient air distribution system. This involves considering the cooling load in BTU/hr, which is the amount of heat the system must remove to maintain desired conditions. Since we are not conditioning CFMs of air but rather pounds of it, we need a mass-balance equation, which is converted to volumetric airflow rates.

$$Q\left(\frac{BTU}{hr}\right) = m\left(\frac{lb}{hr}\right) * Cp\left(\frac{BTU}{°F.lb}\right) * \Delta T\ (°F)$$

$$Q\left(\frac{BTU}{hr}\right) = CFM * 60\left(\frac{min}{hr}\right) * \rho\left(\frac{lb}{ft^3}\right) * Cp\left(\frac{BTU}{°F.lb}\right) * \Delta T\ (°F)$$

Standard air conditions at 70°F and 1 atmosphere:

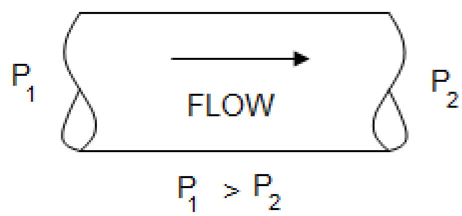
- Density (ρ) = 0.075 lb/ft$^3$
- Specific heat (Cp) = 0.24 BTU/°F.lb

$$Q\left(\frac{BTU}{hr}\right) = CFM * 60\left(\frac{min}{hr}\right) * 0.075\left(\frac{lb}{ft^3}\right) * 0.24\left(\frac{BTU}{°F.lb}\right) * \Delta T\ (°F)$$

$$Q\left(\frac{BTU}{hr}\right) = 1.08 * CFM * \Delta T\ (°F)$$

## 1.4 Air Flow Principles

Much like water, air naturally flows from areas of high to low pressure. In a domestic water system, pressure is typically around 30 psi. When a tap is opened, the pressure drops to zero, causing water to flow. Similarly, air, being a fluid, moves due to pressure differences. To induce airflow, a fan creates a pressure differential, prompting air to move from high to low-pressure zones. The volume and speed of airflow depend on the pressure difference generated and system resistance or friction. The higher the pressure differential, the greater will be the airflow.




Two key concepts governing air flow in ducts are the laws of mass conservation and energy conservation. These principles serve as the foundation for the continuity and pressure equations used in duct system designs.

### 1.4.1 Conservation of Mass

To determine the correct airflow rate within ducts, it is essential to apply the principle of mass conservation. According to the law of mass conservation in steady state flow, the mass flow rate entering a duct should be equal to the mass flow rate exiting that section of the duct, assuming there is no addition or loss of mass (e.g., due to leakage). This concept can be expressed through the following equation:

$m = \rho * A * V = \text{Constant}$

Where:

- m represents the mass flow rate (lb/min).
- ρ stands for air density ($lb/ft^3$).
- A denotes the cross-sectional area of the duct (sq. ft).
- V is the velocity of the airflow (fpm).

### 1.4.2 Continuity Equation

When air density is constant in a duct system, the volumetric flow rate at any duct section is:

Q = A x V

Where:

- Q represents the volume flow rate, typically measured in cubic feet per minute (CFM).
- A is the duct's cross-sectional area, measured in square feet ($ft^2$).
- V is the velocity of the airflow, usually measured in feet per minute (fpm).

This equation allows you to find any one of these properties if you know the other two.

a. Given volumetric flow (Q) and duct cross-sectional area (A), you can calculate duct velocity (V).
b. Given volumetric flow (Q) and duct velocity (V), you can calculate the duct's cross-sectional area (A).

### 1.4.3 Example

Given: Duct diameter (D) = 20 inches and Average velocity (V) = 1,700 feet per minute, calculate airflow.

**Solution**

Calculate the cross-sectional area (A) of the duct section using the formula:

$$A = \pi \frac{D^2}{4} x \frac{1}{144}$$

Where:

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