1 CHAPTER -1: AIR DISTRIBUTION AND AIRFLOW PRINCIPLES

Air ducts, also known as HVAC or AC ducts, are essential pathways that distribute warm or cool air throughout your building, ensuring effective heating, ventilation, and cooling. Connected to the HVAC unit, these conduits deliver air efficiently. HVAC ducts fall into four key categories:

a. Supply Air: Delivers heated or cooled air from the HVAC system to different areas of the building.
b. Return Air: Draws indoor air back to the HVAC unit for filtration, reconditioning, and redistribution.
c. Fresh Air: Supplies outdoor air to ventilate and refresh the indoor environment.
d. Exhaust Air: Removes stale air, fumes, heat, odors, and vapors, commonly from areas like kitchens, restrooms, and workshops.

Together, these ducts work to maintain indoor comfort and air quality in your space.

1.1 Duct Design Objectives

The intricate network of ducts within a building requires careful planning during the initial design phase to ensure seamless integration with architectural and MEP systems. Post-construction modifications, particularly in spaces like false ceilings crowded with MEP services, are labor-intensive and often impractical once the building is operational.

Effective duct design is vital to achieving three primary objectives:

a. Ensuring efficient and balanced airflow delivery to all zones of the building,
b. Minimizing HVAC-generated noise for occupant comfort, and
c. Reducing airflow resistance to enhance energy efficiency.

The primary goal is to deliver right quantity of air at the desired temperature and humidity levels to specific locations while minimizing energy consumption and noise generation.

Table 1. Duct Design Criteria

	Objective/Criteria	**Rules of Thumb**
	Airflow Distribution	Maintain uniform airflow; avoid abrupt size or direction changes to reduce turbulence.
	Duct Velocity	Main ducts: 1000–1500 fpm; branch ducts: 600–900 fpm.
	Pressure Loss	Limit total pressure drop to less than 0.10 in. WG. per 100 ft of duct.

	Objective/Criteria	**Rules of Thumb**
	Noise Control	Use low air velocities and add acoustic insulation or silencers as needed to minimize operational noise.
	Leakage Minimization	Seal ducts according to Class A leakage standards for low-pressure systems and SMACNA standards for high-pressure systems.
	Material Selection	Use galvanized steel for durability, or aluminum for lightweight applications. Consider stainless steel or coated ducts for corrosive environments.
	Energy Efficiency	Optimize duct routing to minimize overall length and avoid sharp bends, reducing fan energy consumption.
	Thermal Insulation	Insulate ducts to minimize heat losses or gains.
	Space Constraints	Design ducts to fit within architectural limitations while maintaining adequate cross-sectional area to prevent excessive velocity or pressure drops. Use round, oval and rectangular in order of preference.
	Code Compliance	Follow local codes, fire safety, ASHRAE, and SMACNA standards.
	Duct Sizing	Use equal-friction or velocity-pressure loss methods for simplified construction. Start with a design friction rate of 0.08 in. WG. per 100 ft for low-pressure systems.
	Accessibility for Maintenance	Provide access points for cleaning and inspection near equipment like VAV boxes, dampers, and AHUs.
	Flex Duct Use	Limit flexible duct runs to under 6 ft to minimize resistance and improve airflow efficiency.

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 terms are fundamental to understanding HVAC air distribution and duct design. These terms form the basis of fluid dynamics and are interconnected to ensure optimal air distribution and system performance.

	Parameters	Description	Rules of Thumb
	CFM (Cubic Feet per Minute)	Represents airflow volume and is calculated by multiplying the air velocity by the cross-sectional area of the duct in square feet (sq. ft). CFM = fpm × area (sq. ft)	Determines the size and layout of ductwork, the selection of fans, and the overall system performance.
	fpm (Feet per Minute)	Measures air velocity in ducts. $\text{fpm} = \frac{\text{CFM}}{\text{Area}}$	Maintain velocity within recommended ranges (e.g., 1000–1500 fpm for main ducts) to minimize noise and energy loss.
	Sq. ft (Square Feet)	Refers to the cross-sectional area of a duct. It is determined by: $\text{sq.ft} = \frac{\text{CFM}}{\text{fpm}}$	Adequate cross-sectional size prevents excessive pressure drops and ensures smooth airflow.
	psi (Pounds per Square Inch)	Denotes air pressure. Typically used for higher-pressure applications, it is related to in. WG. by: 1 psi = 27.7in. WG.	Convert between psi and in. WG. as needed for accurate system design.
	in. WG. (Inches of Water Gauge)	A measure of low-pressure systems commonly used in HVAC ducts.	Keep pressure drops below 0.08–0.10 in. WG. per 100 ft of ductwork to ensure efficiency.

In practical HVAC air distribution applications, pressure measurements are often expressed in inches of water gauge (in. WG.) rather than psi. This is because the 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 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%.

	Parameters	**Rules of Thumb**
	Standard Air Density	Standard density (0.075 lb./ft^3) applies at sea level and moderate temperatures; adjustments may be needed for variations.
	Temperature Impact	Higher temperatures lower air density, affecting airflow, heat transfer, and fan efficiency; systems must adjust accordingly.
	Altitude Impact	Higher altitudes lower air density, requiring increased volumetric flow or equipment resizing.
	Density Correction	For air conditioning applications between 40°F to 100°F and up to 1000 ft elevation, air density changes are minimal, requiring no correction. Adjustments are necessary beyond these limits.

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:

$m = \rho * A * V$

Where:

- m = mass flow rate, lb/min
- ρ is the density of air, lb/ft3
- A is the cross-sectional area of duct, sq. ft.
- V is the velocity of the air, fpm

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

	Parameters	Rules of Thumb
	Mass Flow Rate	Air density affects mass flow rate. As air is heated or humidified, its specific volume increases and density decreases, requiring more CFM to maintain the same mass flow rate. This impacts system sizing and performance.
	Volumetric Flow Rate	Remains stable within standard conditions (40°F-100°F, sea level to 1000 ft); key for HVAC equipment design.
	Design Basis	HVAC equipment and components are typically designed based on volumetric flow rate specifications rather than mass flow, simplifying system design.
	Ease of Measurement	Volumetric flow is easier to measure and control using standard HVAC tools like fans and air handlers.

1.4 Estimating Airflow Rates using Heat Loads

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.

Equation 1. Airflow Rates in lbs/hr. (mass flow rate)

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

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

Equation 2. Airflow Rates in CFM (volumetric flow rate)

Standard air conditions at 70°F and 1 atmosphere:

Density (ρ) = 0.075 lb./ft^3

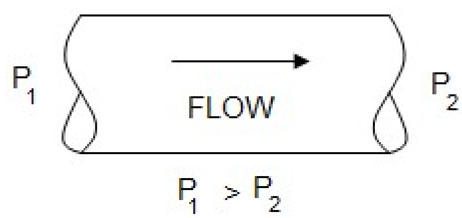
Specific heat (Cp) = 0.24 BTU/°F.lb

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

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

1.5 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.

1.5.1 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).

1.5.2 Continuity Equation

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

$Q = A \times V$

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.

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

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:

- π = pi, 3.14
- D = diameter in inches
- 144 = conversion factor for sq. inch to sq. ft.

Therefore,

$$\text{A} = 3.14 \text{ x } \frac{20^2}{4} \text{x} \frac{1}{144} = 2.18 \text{ sq. ft}$$

Now, we can find the volume flow rate (Q) using the formula:

Q = A x V

Q = 2.18 ft^2 x 1,700 fpm

Q ≈ 3,706 cubic feet per minute (CFM)

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