VENTILATION, INFILTRATION & EXFILTRATION

**Outdoor Air** is assumed to be fresh, clean air made up of the right combination of oxygen (21%), nitrogen (78%), and other gases (1% hydrogen, argon, carbon dioxide, water vapor). People and all animal life need oxygen to live. Nitrogen and the other gases are inert and not harmful to animal life. People breathe in oxygen and breathe out carbon dioxide. The oxygen level in an enclosed occupied space must therefore be replenished by supplying outdoor air. The outdoor air must be cleaned and filtered before it is supplied.

**Indoor Air** in an enclosed occupied space loses its oxygen due to the occupants and it can also be contaminated from within the space with organisms such as bacteria and viruses and with pollutants from the processes that occur in the space. Indoor air must therefore be cleaned and its oxygen content maintained by adding outdoor air. For a typical office building, the outdoor air supply quantity is determined on the basis of the number of occupants and process pollution. For example, 20 cubic feet per minute (CFM) per person. In the case of industrial applications, the outdoor air quantity also depends mainly on the amount of pollutants generated in the space.

**Ventilation Air** can be natural or mechanical. In modern commercial buildings, the term ventilation refers to mechanical ventilation. It is the intentional controlled introduction of outdoor air into an enclosed occupied space. Ventilation is provided using mechanical systems such as fans. The entry of outdoor air through an open door or window is considered infiltration and not ventilation. The total air supplied to a space consisting of outdoor air and indoor recirculation air is not ventilation air either. It is referred to as Supply Air

**Infiltration Air** is the unintentional and uncontrolled entry of outdoor air into an enclosed space. Infiltration occurs through cracks in the building envelope and due to pressure differences between inside and outside. The outdoor air entering through open doors and windows is considered infiltration although the purpose of opening the door or window might be ventilation. Infiltration occurs mainly in winter when the air outside is colder and heavier than the air inside. It depends on wind velocity, wind direction and the air-tightness of the building envelope. In the case of high-rise buildings, the stack effect also causes infiltration

**Exfiltration Air** refers to the flow of indoor air from an enclosed building space to the outdoors. Commercial air-conditioned buildings are designed to be air-tight (the windows cannot be opened) and pressurized. In summer the air inside is colder (air-conditioned) and therefore denser (heavier) than the hotter air outside. The natural air flow direction is therefore from inside to outside. Since commercial buildings are pressurized, the air flow leakage is from the inside to the outside. Exfiltration amount is small and usually neglected in HVAC calculations.

**Ventilation (outdoor) Air** requirements are determined using one or more of the following methods.

1. CFM (cubic feet per minute) per person
2. CFM per square foot (area) of the space
3. Air Changes per Hour (ACH)
4. Percent of total supply air

**CFM per Person** is used in most commercial building applications. The purpose of supplying outdoor air is to replenish the oxygen (O2) content of the indoor space which is being converted into carbon dioxide (CO2) by the occupants in the space and also to dilute pollutants generated in the space. CFM/Person for O2/CO2 control is about 5. When pollution is considered, cfm/person can vary from 5 in theaters and indoor stadiums where the occupancy density can be 10 sqft/person to 20 in offices where the occupancy density is 100 sqft/person. For example, 100 sqft of a theater space will hold 10 people and the OA supply is 5 \* 10 = 50 cfm. 100 sqft of an office space has 1 person and the OA supply is 20 cfm. The lower 5 cfm/person in a theatre is therefore to save energy and it takes into account that theatres are occupied for short intervals of time.

**CFM per SQFT** of floor area is similar to CFM/Person since the design number of people in the space is usually based on the area of the space. CFM/SQFT is a constant quantity while the number of people in the space can be unknown or uncertain. Outdoor air quantity is sometimes calculated as the greater of both CFM/Person and CFM/SQFT.

**Air Changes per Hour (ACH)** method in determining outdoor air quantity is used in buildings such as hospitals. The emphasis here is on replacing the entire quantity of indoor air periodically. For example, 2 ACH of OA means that the room air is replaced twice in one hour with outdoor air. ACH method means that the quantity of OA increases with floor to ceiling height or room volume. For example: floor area = 100 ft2 and ceiling height = 10 ft. 2 ACH is 2 \* 100\*10 = 2000 cubic feet in 1 hour or 33.3 cubic feet per minute. If the ceiling height is raised to 20 feet then 2 ACH becomes 4000 cubic feet per hour or 66.6 CFM.

**Percent of Total Supply Air** is used if the other methods produce low outdoor air quantities. This is a judgment decision. For example, the outdoor air quantity should not be less than 10% of the total supply air in order to maintain the freshness of the supply air. Percent outdoor air calculated using the other methods is usually between 10% and 30%.

**Infiltration Air** quantities are determined using one or more of the following methods.

1. CFM per lineal foot of window and door perimeter lengths
2. CFM-1 per sqft of window area and CFM-2 per sqft of wall area (CFM-1 > CFM-2)
3. CFM per sqft of window and wall area
4. CFM per sqft of space floor area
5. Space ACH (air changes per hour)

Infiltration rates vary throughout the year. It is greater in winter when the temperature difference between inside and outside is greater. For example, 75oF inside and 0oF outside in winter and 75oF inside and 95oF outside in summer. Infiltration rates depend on wind velocity and direction and also on the building envelope construction. Construction can vary from porous and leaky to air-tight and impenetrable.

When the building is pressurized (the air supply fan systems are on) summer infiltration can be neglected but there is still some infiltration in winter. The infiltration heating load is significant when the supply air systems are off during unoccupied periods. Infiltration can be a very big component of winter heating energy loads.

## Air Changes per Hour (ACH)

A picture containing sitting

Description automatically generated

1 Air Change per Hour means that the volume V of air in the room is changed or replaced once per hour. The supply air quantity is therefore V cubic feet in one hour (CFH).  
6 Air Change per Hour means that the volume V of air in the room is changed or replaced six times per hour. The supply air quantity is therefore 6\*V cubic feet in one hour (CFH).  
N Air Change per Hour means that the volume V of air in the room is changed or replaced N times per hour. The supply air quantity is therefore N\*V cubic feet in one hour (CFH).  
Supply (or Exhaust) Air (CFH) = N \* V Supply (or Exhaust) Air (CFM) = N \* V / 60

CFM = N \* V / 60     N = CFM \* 60 / V  
CFM = cubic feet per minute of air  
V = Room volume (cubic feet or ft3)  
N = Number of Air Changes per Hour

**Example:**  
Room dimensions: L = 30' W = 20' H = 10'  
Minimum supply air (SA) = 6 ACH (air changes per hour)  
Calculate supply air (SA) in cubic feet per minute (CFM)  
Room Volume (V) = L \* W \* H = 30 \* 20 \* 10 = 6,000 cubic feet (ft3).     N = 6 ACH  
CFM = N \* V / 60 = 6 \* 6,000 / 60 = 600.

**Example:**  
Room dimensions: L = 30' W = 20' H = 10'  
Supply air (SA) = 900 CFM  
Calculate N (Number of Air Changes)  
Room Volume (V) = L \* W \* H = 30 \* 20 \* 10 = 6,000 cubic feet (ft3).     CFM = 900  
N = CFM \* 60 / V = 900 \* 60 / 6,000 = 9.

**Example:**  
Room dimensions: W = 40' L = 50'  
Supply air (SA) = 4,000 CFM  
Minimum Supply Air Changes per Hour (ACH) = 8  
What is the maximum ceiling height (H) ?  
Volume (V) = W \* L \* H = 40 \* 50 \* H = 2,000 \* H. N = 8, CFM = 4,000  
N = CFM \* 60 / V.     8 = 4000 \* 60 / (2000 \* H). H = 15 feet

**Example:**  
Room dimensions: W = 40' L = 50' H = 10'  
Occupancy Criteria: 50 ft2/person (or 1 person per 50 ft2)  
Ventilation Criteria: 25 cfm per person  
Minimum Supply Air (SA) = 15 air changes per hour (ACH)  
Determine:   (1) No. of People, (2) Ventilation CFM, (3) Ventilation ACH  
(4) Supply Air CFM, (5) Supply Air CFM/ft2, (6) Percent Ventilation Air

Room Area (A) = 40' \* 50' = 2,000 ft2, Room Volume (V) = 2,000 ft2 \* 10' = 20,000 ft3.

1. No. of people = 2000 ft2 / 50 ft2per person = 40
2. Ventilation CFM = 40 people \* 25 cfm/person = 1000 cfm
3. Ventilation ACH = 1000 cfm \* 60 min/hr / 20000 ft3 = 3
4. Supply Air CFM = 15 ACH \* 20000 ft3 / 60 min/hr = 5000 cfm
5. Supply Air CFM/ft2 = 5000 cfm / 2000 ft2 = 2.5 cfm/ft2
6. Percent Ventilation Air = 1000 cfm OA / 5000 cfm SA \* 100 = 20%