Lesson
39
Space Air Distribution

The specific objectives of this chapter are to:

1. Requirements of a proper air distribution system, definition of Air Distribution Performance Index and Space Diffusion Effectiveness Factor (*Section 39.1*)
2. Design of air distribution systems, buoyancy effects and deflection of air jets (*Section 39.2*)
3. Behaviour of free-stream jets, definitions of drop, throw, spread and entrainment ratio (*Section 39.3*)
4. Behaviour of circular jets (*Section 39.4*)
5. Behaviour of rectangular jets (*Section 39.5*)
6. Characteristics of different types of air distribution devices, such as grilles, registers, ceiling diffusers, slotted diffusers etc. (*Section 39.6*)
7. Return air inlets (*Section 39.7*)
8. Airflow pattern inside conditioned spaces using different types of air distribution devices (*Section 39.8*)
9. Stratified mixing flow (*Section 39.9*)
10. Cold air distribution (*Section 39.10*)
11. Displacement flow (*Section 39.11*)
12. Spot cooling/heating (*Section 39.12*)
13. Selection criteria for supply air inlets (*Section 39.13*)

At the end of the chapter, the student should be able to:

1. Explain the importance of proper air distribution in conditioned space and define ADPI and SDEF
2. List the factors to be considered in the design of air distribution devices and explain buoyancy effects and deflection of air jets
3. Estimate throw, drop, spread and entrainment ratio of circular and rectangular, isothermal free jets
4. List different types of supply air outlet devices and their characteristics
5. Draw the airflow patterns for ceiling, sidewall and slotted diffusers
6. Explain stratified mixing flow, displacement flow, cold air distribution and spot cooling and heating
7. List the criteria for selection of supply air outlets.

39.1. Introduction

After the required amount of supply air is transmitted to the conditioned space, it is essential to distribute the air properly within the conditioned space. Thus it is important to design suitable air distribution system, which satisfies the following requirements:

a) Create a proper combination of temperature, humidity and air motion in the occupied zone. The **occupied zone** is defined as all the space in the conditioned zone that is from the floor to a height of 1.8 m and about 30 cms from the walls. In the occupied zone, the maximum variation in temperature should be less than $1^{o}C$ and the air velocity should be in the range of 0.15 m/s to 0.36 m/s.

b) To avoid draft in the occupied zone. Draft is defined as the localized feeling of cooling or warmth. Draft is measured above or below the controlled room condition of 24.4 ^{o}C and an air velocity of 0.15 m/s at the center of the room. The effective draft temperature (EDT) for comfort is given by:

$$\mathbf{EDT = (DBT - 24.4) - 0.1276(V - 0.15)} \qquad (39.1)$$

where DBT is the local dry bulb temperature (in ^{o}C) and V is the local velocity (m/s). For comfort, the EDT should be within **–1.7^{o}C to +1.1^{o}C and** the air velocity should be **less than 0.36 m/s.**

39.1.1. Air Distribution Performance Index (ADPI)

The ADPI is defined as the percentage of measurements taken at many locations in the occupied zone of space that meets EDT criteria of –1.7^{o}C to +1.1^{o}C, that is:

$$\mathbf{ADPI = \left(\frac{N_\theta}{N}\right) x100} \qquad (39.2)$$

where N is the total number of locations at which observations have been made, and N_θ is the number of locations at which the effective draft temperature is within **–1.7^{o}C to +1.1^{o}C.**

The objective of air distribution system design is to select and place the supply air diffusers in such a way that the ADPI approaches 100 percent. The ADPI provides a rational way of selecting air diffusers. Studies show that the value of ADPI depends very much on space cooling load per unit area. A large value of space cooling load per unit area tends to reduce the value of ADPI.

39.1.2. Space Diffusion Effectiveness Factor (SDEF)

The effectiveness of air distribution system is sometimes assessed using Space Diffusion Effectiveness Factor (SDEF). It is defined as:

$$\mathbf{SDEF = \frac{T_{ex} - T_s}{T_r - T_s}} \qquad (39.3)$$

where T_{ex} is the temperature of the exhaust air, T_s is the supply air temperature and T_r is the temperature of the room air (at the measuring point). A SDEF value of ≤ 1 implies that some amount of cold supply air has not mixed with the room air and is leaving the conditioned space as exhaust. The space air distribution is considered to be effective if SDEF $\geq$ 1.0.

Table 39.1 shows the recommended supply air velocities for diffusers. Since the air velocity at the supply air outlet is normally much higher than 0.36 m/s and its temperature is much lower than 24.4^{o}C, it has to mix properly with the room air before it reaches the occupancy level. This depends on the effective design of the air distribution system.

Criterion	Application	Supply velocity, m/s
Noise	**Studios, operating theatres**	**3 to 3.5**
	Apartments, office spaces	**4.0 to 5.0**
	Restaurants, libraries	**5.0 to 6.0**
	Supermarkets	**6.0 to 7.5**
	Factories, Gymnasium	**7.5**

***Table 39.1**: Recommended air velocities for supply air diffusers*

39.2. Design of air distribution systems

The objective of air distribution system design is to choose the location and type of supply air diffuser and the location and type of the return air grilles. The parameters that affect air velocity and temperature at a given point in the conditioned space are:

a) Velocity of air at the inlet to the supply diffuser: Noise criteria to be observed

b) Supply to room temperature difference ($T_s–T_r$)

c) Geometry and Position of air supply outlet

d) Position of return air inlet

e) Room Geometry

f) Room surface temperature: Lower the surface temperature (e.g. with glass) stronger are the natural convection currents.

g) Internal heat sources (e.g. people, appliances)

h) Room turbulence

The exact prediction of velocity and temperature profiles inside the conditioned space requires simultaneous solution of mass, momentum and energy equations for the conditioned space. However in general this task is extremely complicated due to the several factors that affect airflow and heat transfer inside the conditioned space. However, a basic understanding of room air distribution requires the understanding of, buoyancy effects, deflection of air streams and behaviour of free-stream jets. Normally the location and type of return air grilles do not affect the air distribution significantly.

39.2.1. Buoyancy effects:

Due to the buoyancy effects, a supply air stream that is cooler than the room air will drop and supply air that is warmer than room air rises. However, from thermal comfort point-of-view, it is important that the supply air stream does not strike at occupancy level. Figure 39.1(a) shows the drop of a supply air jet that is cooler than the room air.

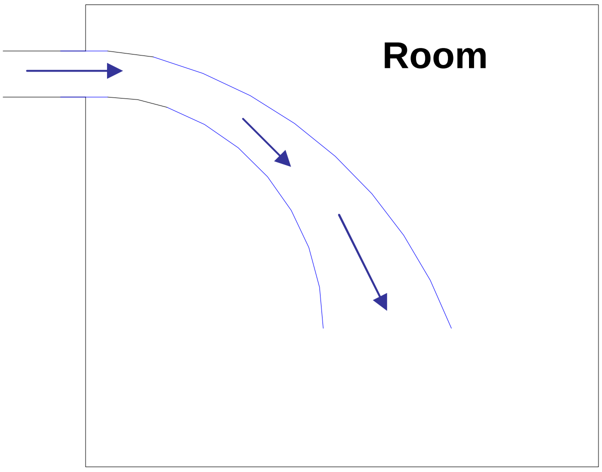


***Fig.39.1(a)**: Drop of a cool air jet*

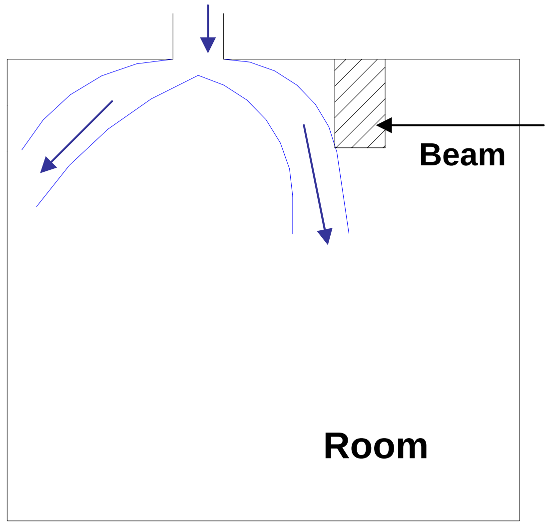


***Fig.39.1(b)**: Deflection of a cool air jet*

It is understood that the buoyancy effects are due to temperature difference prevailing between the supply air and the room air. It can be shown that the velocity of an element at a height 'h' due to buoyancy is given by:

$$V_t^2 = gh\left(\frac{\Delta T}{T_r}\right) \qquad (39.4)$$

where ΔT is the difference between the local temperature of the fluid (T_f) element and the room air (T_r), T_r is the room air temperature in K, g is the acceleration due to gravity and h is the height. For equilibrium at a height H, the velocity of the fluid element should be equal to the entrance velocity of supply air (V_o), i.e.,

$$V_t = V_o \text{ at equilibrium} \qquad (39.5)$$

Then from Eqn.(39.1):

$$V_o^2 = gH\left(\frac{\Delta T_d}{T_r}\right) \qquad (39.6)$$

where ΔT_d is the difference between the temperature of air at supply outlet and the room air.

The **Archimedes number**, Ar is then defined as:

$$\mathbf{Ar} = \frac{\mathbf{gH}}{\mathbf{V_o}^2}\left(\frac{\Delta \mathbf{T_d}}{\mathbf{T_r}}\right) \qquad (39.7)$$

In the above expression for Archimedes number, H may be the height of the room or the hydraulic diameter, D_h of the room given by:

$$\mathbf{D_h} = \frac{\mathbf{4WH}}{\mathbf{2(W+H)}} \qquad (39.8)$$

where W and H are the width and height of the room, respectively. Archimedes number conveniently combines the supply air velocity at the outlet, supply to room temperature difference and the principle dimensions of the room- important factors that define the air distribution in a room. Several studies show that the airflow pattern in a room is largely dependent on the Archimedes number. The Archimedes number can also be viewed as a ratio of Grashof number to the square of Reynolds number ($Ar \approx Gr/Re^2$), thus combining the effects of natural convection due to buoyancy and forced convection due to supply air jet. Archimedes number also affects the heat transfer between the air inside the conditioned space and the surrounding surfaces. To avoid cold drafts in the occupied zone, the Archimedes number should not exceed a maximum value, which depends on the room dimensions. Table 39.2 shows the maximum Archimedes number values as a function of W/H ratio.

W/H	**4.7**	**3.0**	**2.0**	**1.0**
Ar_{max}	**2000**	**3000**	**10000**	**11000**

Table 39.2: Maximum recommended Archimedes number values to avoid draft

39.2.2. Deflection:

When an air stream strikes a solid surface such as a concrete beam or a wall, it deflects. Again from comfort criteria, it is essential to ensure that due to deflection, the supply air does not strike the occupants before it is diffused. Figure 39.1(b) shows the deflection of a supply air jet as it strikes a solid beam.

39.3. Behaviour of free-stream jet:

The following aspects are important in understanding the behaviour of free-stream jets:

Blow or throw:

It is the distance traveled by the air stream in horizontal direction on leaving the supply air outlet and reaching a velocity of 0.25 m/s. The velocity should be measured at a height of 1.8 m above the floor level. In air conditioning, the desirable length of blow is upto 3/4th of the distance to the opposite side of the wall.

Drop:

It is the vertical distance the air moves after leaving the supply outlet and reaches the end of blow.

Figure 39.2 shows the meaning of drop and throw of free-stream jets.

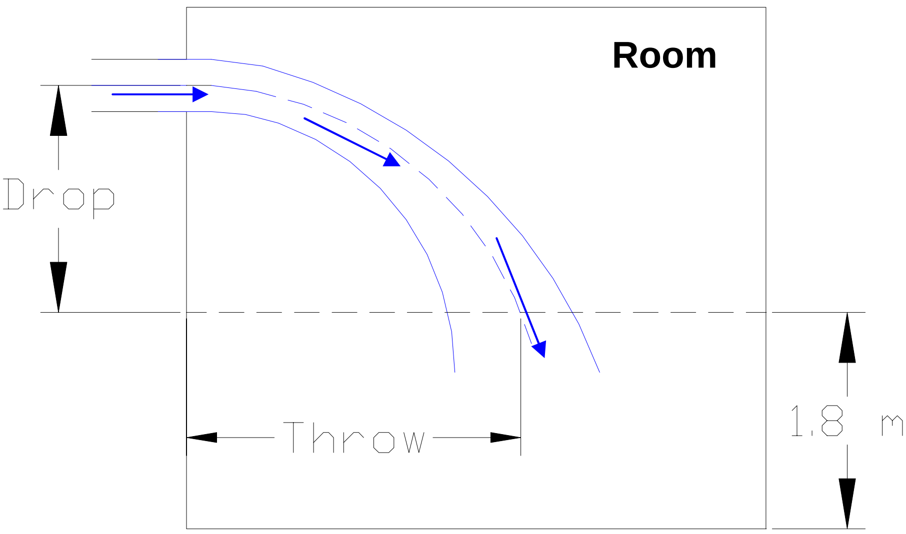


Fig.39.2. *Definition of drop and throw*

Entrainment ratio:

As the high velocity jet (called as primary air) leaves the supply air outlet, it entrains some amount of room air (called as secondary air). Entrainment gives rise to motion of room air. The entrainment ratio at a distance x from the supply outlet is defined as the ratio of volumetric flow rate of air at x to the volumetric flow rate of air at the supply air outlet (x=0), i.e.,

$$\textbf{Entrainment ratio at x,} R_x = \frac{Q_x}{Q_{x=0}} \qquad (39.9)$$

Spread:

It is the angle of divergence of the air stream after it leaves the supply air outlet as shown in Fig.39.3. The spread can be both horizontal as well as vertical. Vanes are normally used in the supply air outlets. These vanes can be straight, converging or diverging. Figure 39.3 shows the outlet with diverging vanes, for which the horizontal spread is $\mathbf{60^o}$ as shown in the figure. For straight vanes and converging the spread is equal to $\mathbf{19^o}$ both in horizontal and vertical directions. Converging vanes yield a blow that is about 15% longer than that of straight vanes, whereas for diverging vanes it is about 50% less than that of horizontal vanes.

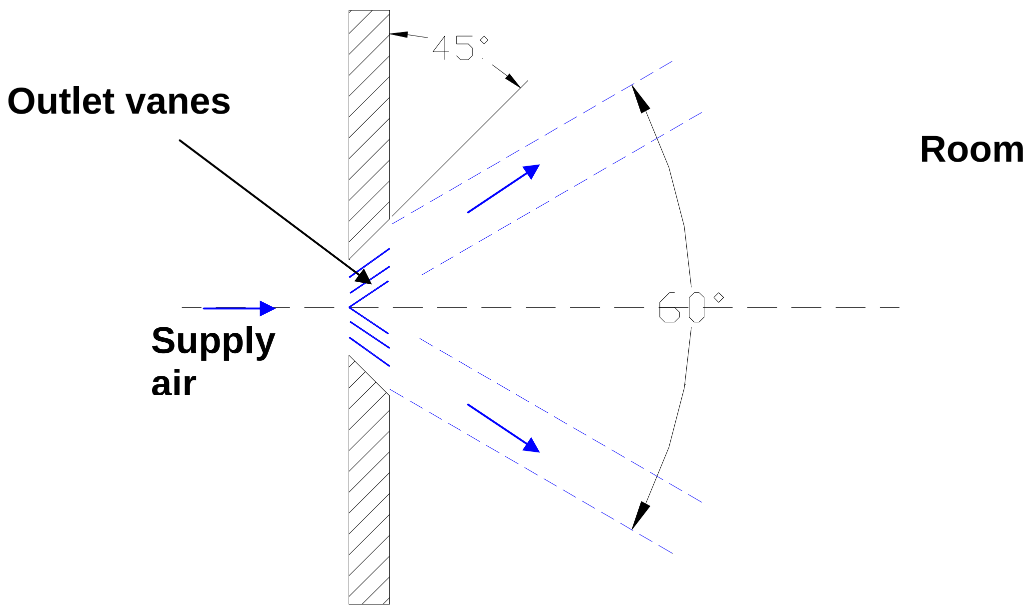


Fig.39.3: *Spread of an air jet with diverging vanes*

39.4.Circular jets:

An understanding of the principle of the simple circular jet can be used to understand the characteristics of most of the commercial supply air diffusers and grilles. Figure 39.4 shows the airflow pattern in a circular jet. As shown in the figure, supply air leaves the outlet at a velocity V_o. The velocity decays as the jet enters the room and entrains the room air. Figure 39.4 also shows the velocity profile. It can be seen that the velocity of air varies as a function of distance, horizontal x from the opening along the centerline and the radial distance from the centerline.

Using the mass and momentum balance equations to the circular jet, it has been shown by Schlichting that the velocity profile for the circular jet is given by:

$$V(x,r) = \frac{7.41 V_o \sqrt{A_o}}{x\left[1 + 57.5\left(r^2 / x^2\right)\right]^2} \qquad (39.10)$$

where V_o is the velocity at the outlet, m/s; V(x,r) is the velocity of air in the jet at x and r, and A_o is the cross-sectional area of the outlet. From the above equation it is easy to predict that the air velocity in the circular jet decreases as x and r increase, and as A_o and V_o decrease. Thus a jet sustains its velocity better as the velocity at the supply outlet increases and/or the area of opening increases. One can also deduce that since the velocity decreases with x and r, the jet spreads as it flows, so that the mass of air is always conserved. And from momentum conservation, it can be deduced that entrainment of room air takes place as the jet moves away from the supply air outlet.

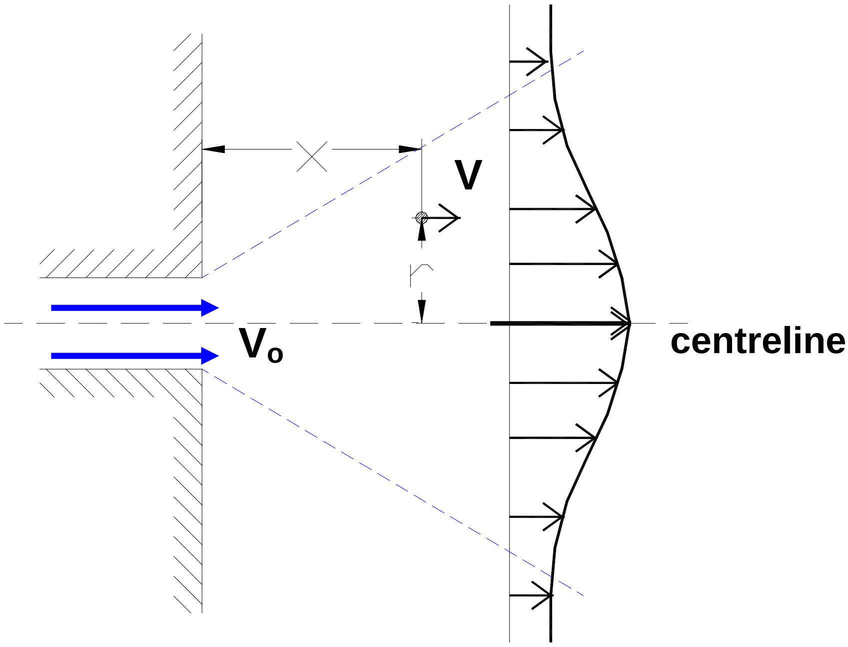


Fig.39.4: *Velocity distribution through a circular jet*

From Eqn.(39.10), the velocity of air in the circular jet along the centerline (r=0) is found to be:

$$\mathbf{V(x,r=0)=\frac{7.41V_o\sqrt{A_o}}{x}} \qquad (39.11)$$

From the above expression, the entrainment ratio R_x for the circular jet can be written as:

$$\mathbf{R_x=\frac{Q_x}{Q_{x=0}}=\frac{\int_{r=0}^{\infty}V(x,r).2\pi r.dr}{A_oV_o}=\frac{0.405\,x}{\sqrt{A_o}}} \qquad (39.12)$$

Large circular openings are rarely used in actual air distribution systems as they travel long distances before mixing with room air. As this can cause discomfort to the occupants, normally diffusers are used in circular jets. These diffusers provide rapid velocity decay and large entrainment.

39.5. Rectangular jets:

Long, rectangular grilles are commonly used for distributing air in conditioned space. These grilles can be modeled using equations of rectangular jet. It has been shown that for a rectangular jet, the velocity distribution is given by:

$$\mathbf{V(x,y)=\frac{2.40\,V_o\sqrt{b}}{\sqrt{x}}\left[1-\tanh^2\left(7.67\,\frac{y}{x}\right)\right]} \qquad (39.13)$$

where b is the width of the opening and y is the normal distance from the central plane. A comparison between circular and rectangular jets shows that the centerline velocity decreases more rapidly for a circular jet compared to a rectangular jet. The rectangular jet entrains less air than a circular jet, as a result it decelerates more slowly.

39.6. Types of air distribution devices:

Grilles and Registers: A grille is an outlet for supply air or an inlet for return air. A register is a grille with a volume control damper. Figure 39.5 shows the front view of a supply air grille with horizontal and vertical vanes. The vanes, either fixed or adjustable are used for deflecting airflow. Grilles have a comparatively lower entrainment ratio, greater drop, longer throw and higher air velocities in the occupied zone compared to slot and ceiling diffusers. Manufacturers specify the performance of the grill in terms of core size or core area, volumetric flow rate of air, effective air velocity, total pressure drop, throw and noise levels. They can be mounted either on the sidewalls or in the ceiling.

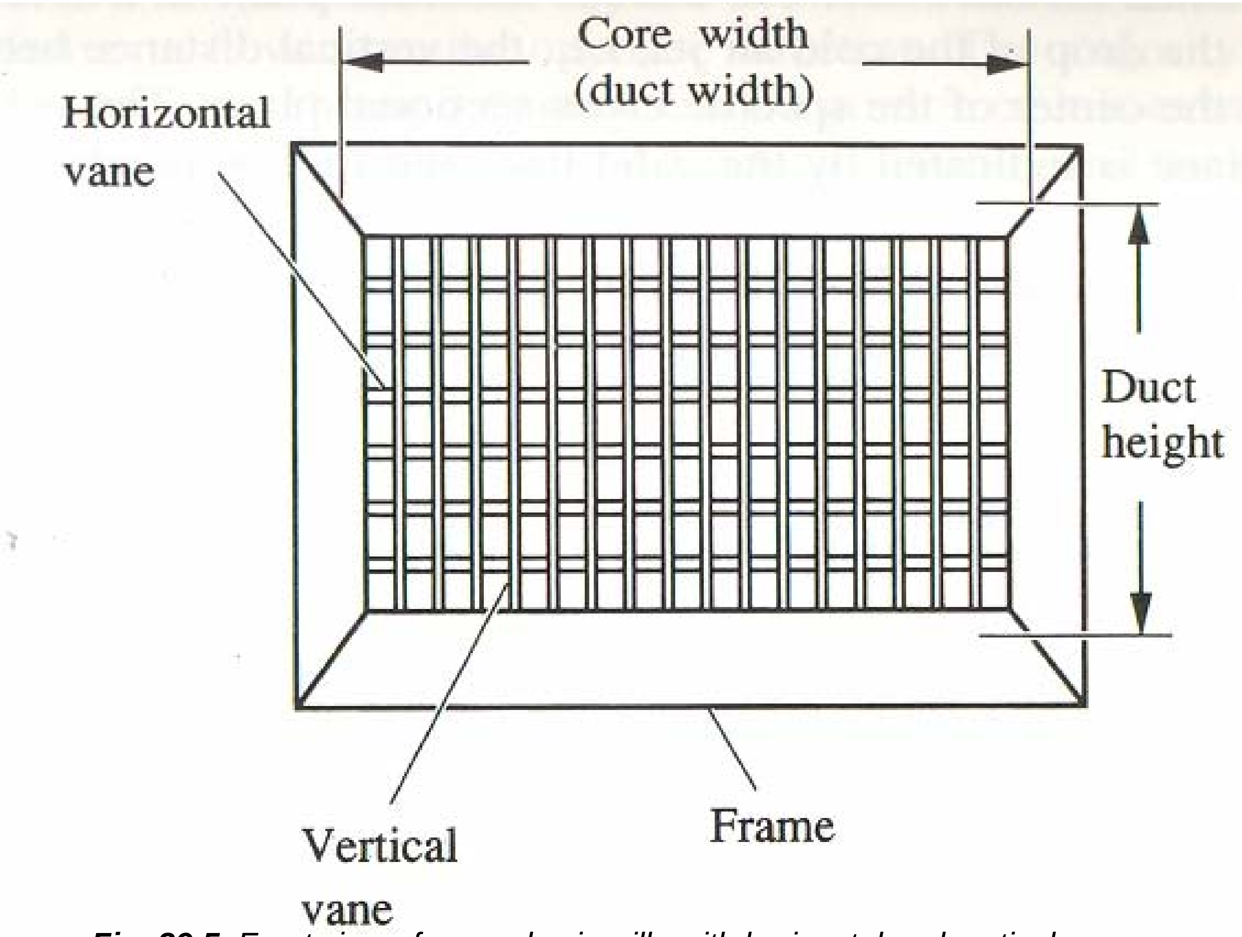


***Fig. 39.5**. Front view of a supply air grille with horizontal and vertical vanes*

Ceiling diffusers: A ceiling diffuser consists of concentric rings or inner cones made up of vanes arranged in fixed directions. Ceiling diffusers can be round, square or rectangular in shape. Figure 39.6 (a) shows square and rectangular ceiling diffuser, and Fig. 39.6(b) shows a perforated diffuser. A square diffuser is widely used for supply air. In the diffusers the supply air is discharged through the concentric air passages in all directions. The air distribution pattern can be changed by adjusting the adjustable inner cones or the deflecting vanes. Ceiling diffusers are normally mounted at the center of the conditioned space. Ceiling diffusers provide large entrainment ratio and shorter throw, hence are suitable for higher supply air temperatures and for conditioned spaces with low head space. Ceiling diffusers can deliver more air compared to grilles and slot diffusers.

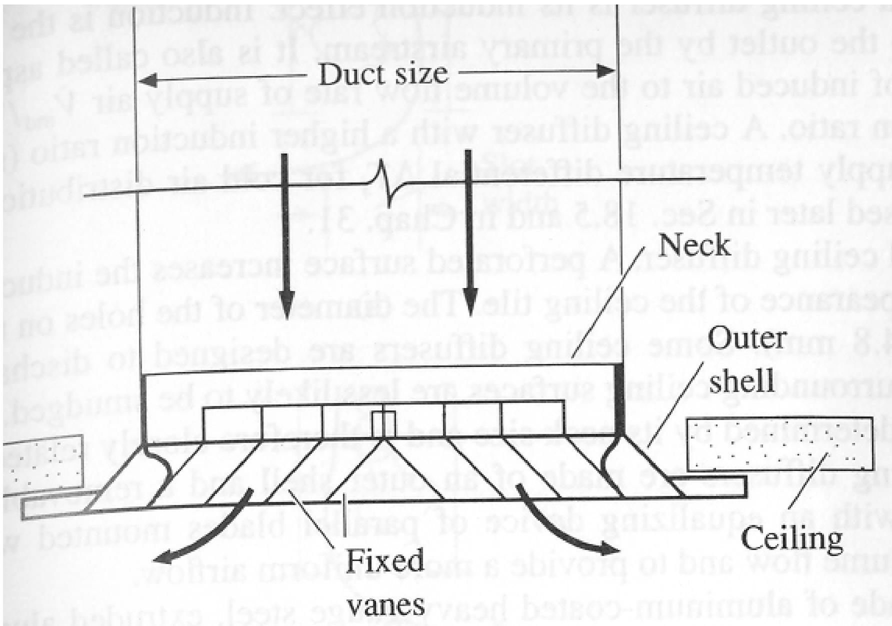


***Fig.39.6(a)**: Schematic of a ceiling diffuser*

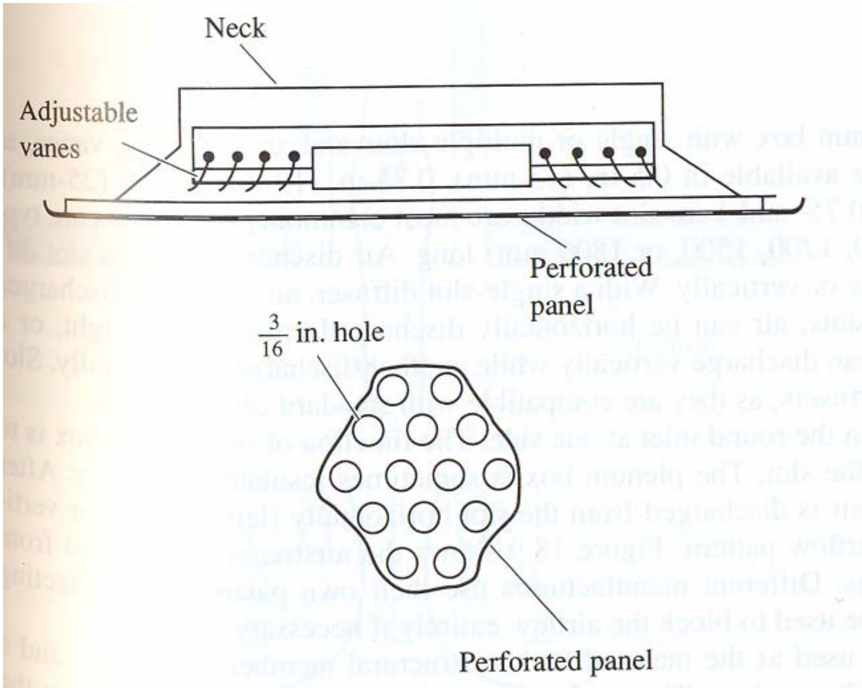


***Fig.39.6(b)**: Schematic of a perforated ceiling diffuser*

Slot diffusers: A slot diffuser consists of a plenum box with single or multiple slots and air deflecting vanes. These are mounted either on the side walls or in the ceiling. Linear slot diffusers mounted on the sidewalls can be as long as 30 meters. These are used for both supply air and return air. Linear slot diffusers are particularly suitable for large open-spaces that require flexibility to suit changing occupant distribution. Figures 39.7(a) and (b) show photograph of conditioned space with linear slot diffusers mounted in the ceiling.

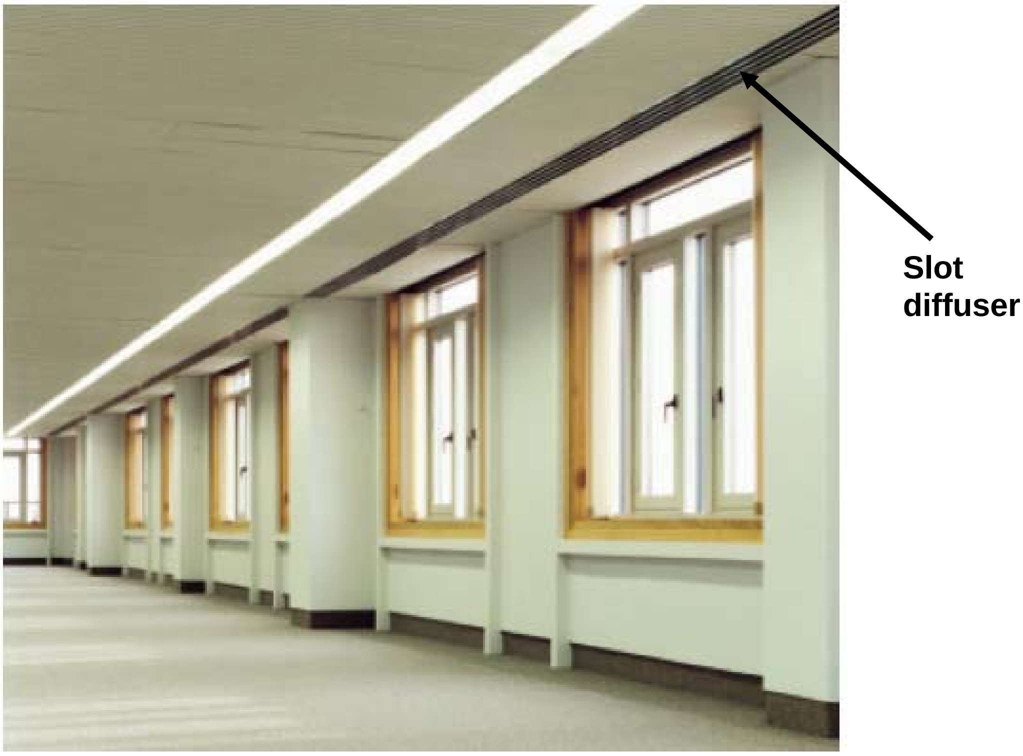


***Fig.39.7(a) and (b)**: Photographs of conditioned space with linear slot diffusers mounted in the ceiling*

Light Troffer-Diffuser: A light troffer-diffuser combines a fluorescent light troffer and a slot diffuser. The slot can be used either as supply air outlet or return air inlet. Light troffer-diffusers offer the following advantages:

a) The luminous efficiency of fluorescent lamps can be increased by maintaining lower air temperature in the light troffer

b) An integrated layout of light troffer, diffuser and return slots can be formed on suspended ceilings

c) Improved aesthetics

d) A combination of light troffer and return slot reduces the space cooling load as the return air absorbs a part of the heat emitted by the lights. However, they should be designed such that the return air does not come in direct contact with the tube so that deposition of dust on the fluorescent tube is prevented

Figure 39.8 shows a light troffer-diffuser slot that combines the light troffer, supply air diffuser and return air slot.

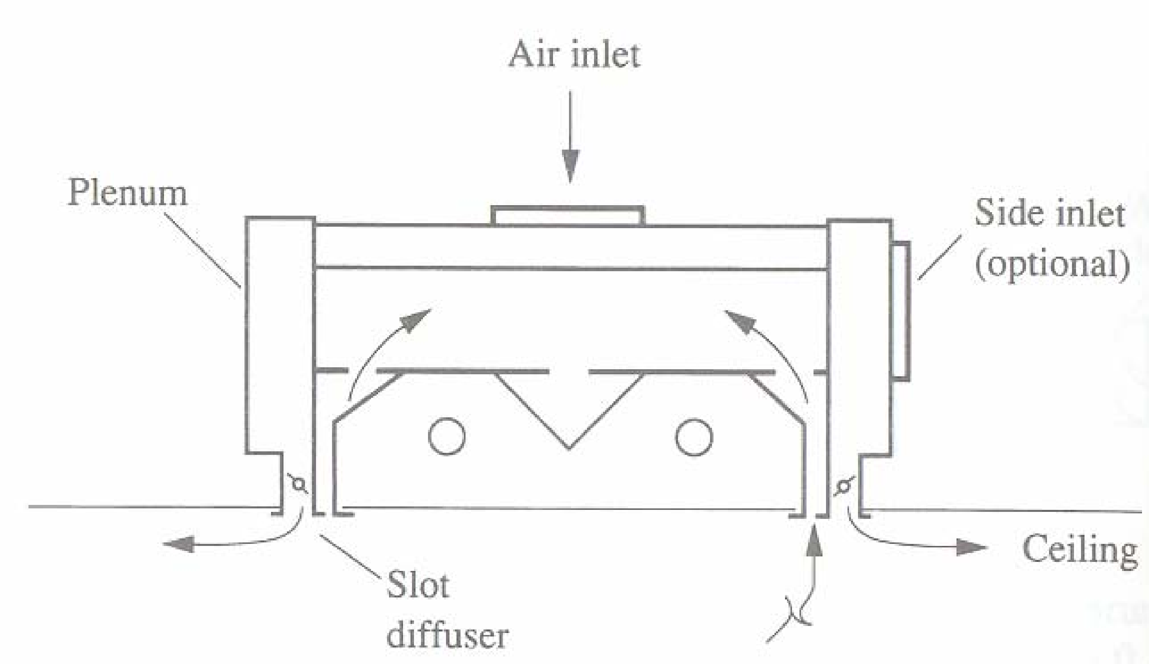


Fig.39.8: *Light troffer-diffuser slot*

In addition to the above air distribution devices, the **floor mounted grilles and diffusers, low-side wall diffusers, nozzle diffusers** etc. are also used for room air distribution.

39.7. Return air inlets:

Different types of return air inlets are used to return the space air to the air handling unit. Requirements of return air inlets are:

a) They should not lead to short-circuiting of supply air

b) Undesirable products such as tobacco smoke, odours etc. should be able to move in their natural direction so that they do not stagnate in the occupied space. To eliminate tobacco smoke, the return air inlets should be placed high in the wall, whereas to remove dust particles etc. the return air inlets should be placed in the floor so that these particles do not float in air.

Similar to supply air outlets, return air inlets can be classified as grilles, registers, diffusers etc. In many commercial buildings the ceiling plenum is used as return air plenum. In this case, return slots are used to draw the return air through the ceiling. In return air inlets the air velocity decreases sharply as the distance from the inlet increases. Based on noise criteria, the air velocity should be within 3 m/s if the return air inlet is inside the occupied space and it should be less than 4 m/s if it is above the occupied space.

39.8. Airflow patterns inside conditioned space:

In most of the air conditioned buildings air is supplied at a temperature between 10 to 15.6^{o}C and with a velocity in the range of 2 to 4 m/s. This air has to mix thoroughly with the room air so that when it reaches the occupied zone its temperature should be around 22.2 to 23.3^{o}C and its velocity is less than 0.36 m/s to avoid draft. The mixing airflow patterns should have the following characteristics:

a) Entrainment of room air to reduce the air temperature and velocity in the occupied zone to acceptable levels

b) Reverse air stream in the occupied zone for an even velocity and temperature distribution

c) Minimization of stagnant areas in the occupied space. A stagnant area is zone in which the natural convective currents prevail and the velocity is less than about 0.1 m/s. Reverse air stream reduces the stagnant areas in the occupied zone

The airflow pattern in the conditioned space is influenced mainly by the type and location of supply air outlets. The high side outlets, ceiling diffusers and slot diffusers are most commonly used in air conditioned buildings.

Figure 39.9 shows the airflow pattern using high side outlets installed on a high sidewall for cooling and heating applications. As the air is discharged from the high side outlet, due to surface effect (**Coanda effect**) the air jet tends to stick to the ceiling as shown in the figure. For cooling applications, the cold supply air entrains the room air and deflects downwards when it strikes the opposite wall. The reverse air stream formed due to entrainment fills the occupied space as shown. If the throw is longer than the length of the room and height of the opposite wall, then the air jet is deflected by the opposite wall and the floor and enters the occupied zone with high velocity. On the other hand if the throw is too small, then the air jet drops directly into the occupied zone before it strikes the opposite wall. Thus both these i.e, a very long or very short throw can cause draft. For heating, a stagnant zone may form as shown due to buoyancy effect. However, if the throw is long, the reverse flow can minimize the stagnant area during heating. For high sidewall outlet, the most suitable location for return air inlet is on the ceiling outside the air jet as shown in the figure.

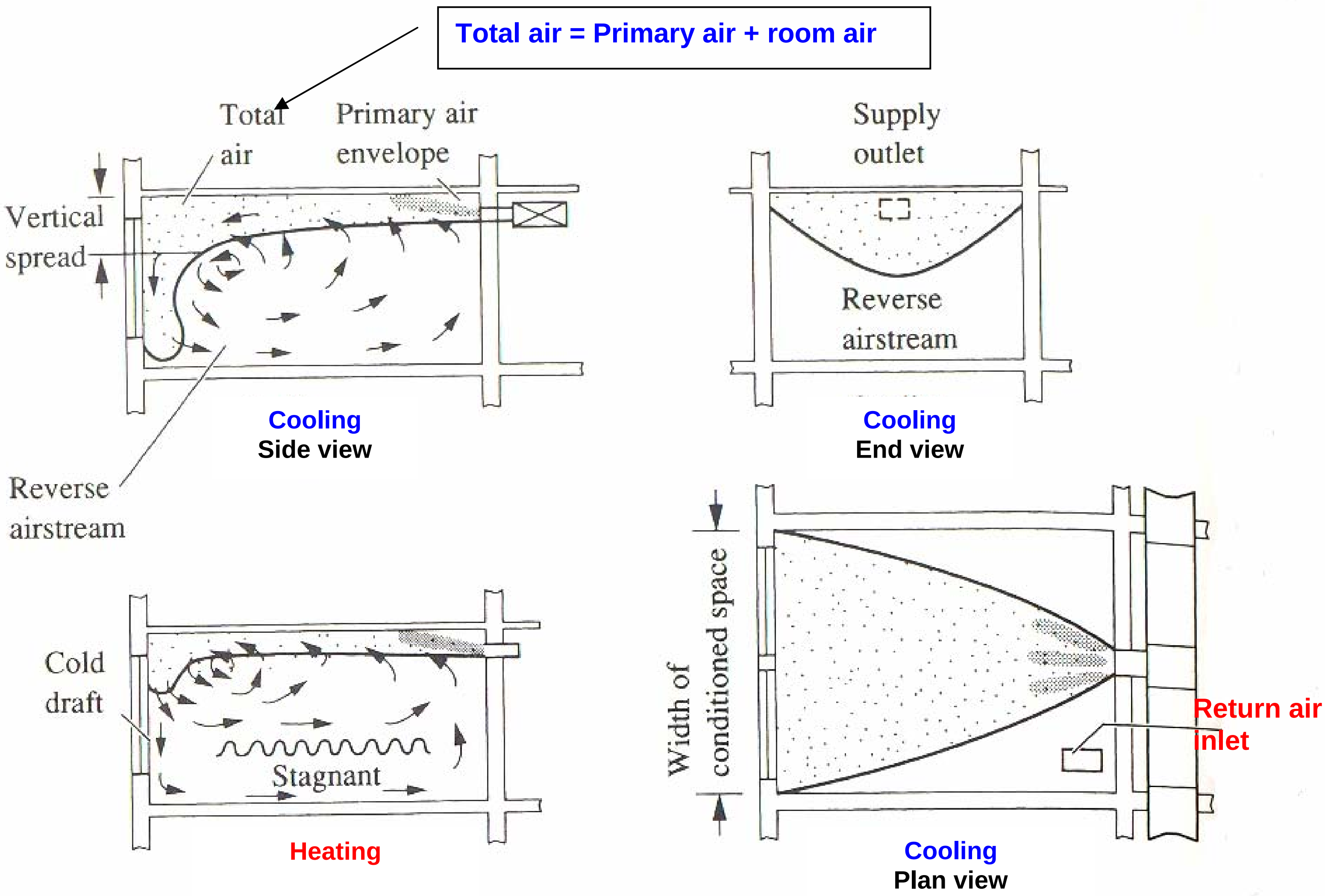


Fig.39.9: Airflow pattern using high side outlets for cooling and heating applications

Figure 39.10 shows the airflow pattern using ceiling diffusers for both cooling and heating applications. It is seen that ceiling diffusers produce a shorter throw, a lower and more even distribution of air velocity and a more even temperature in the occupied zone when used for cooling. However, when used for heating it is seen that a larger stagnant area is formed due to buoyancy effect. Ceiling diffusers are widely used for conditioned spaces with limited ceiling height and are designed to have a large entrainment ratio and are widely used in variable air volume systems.

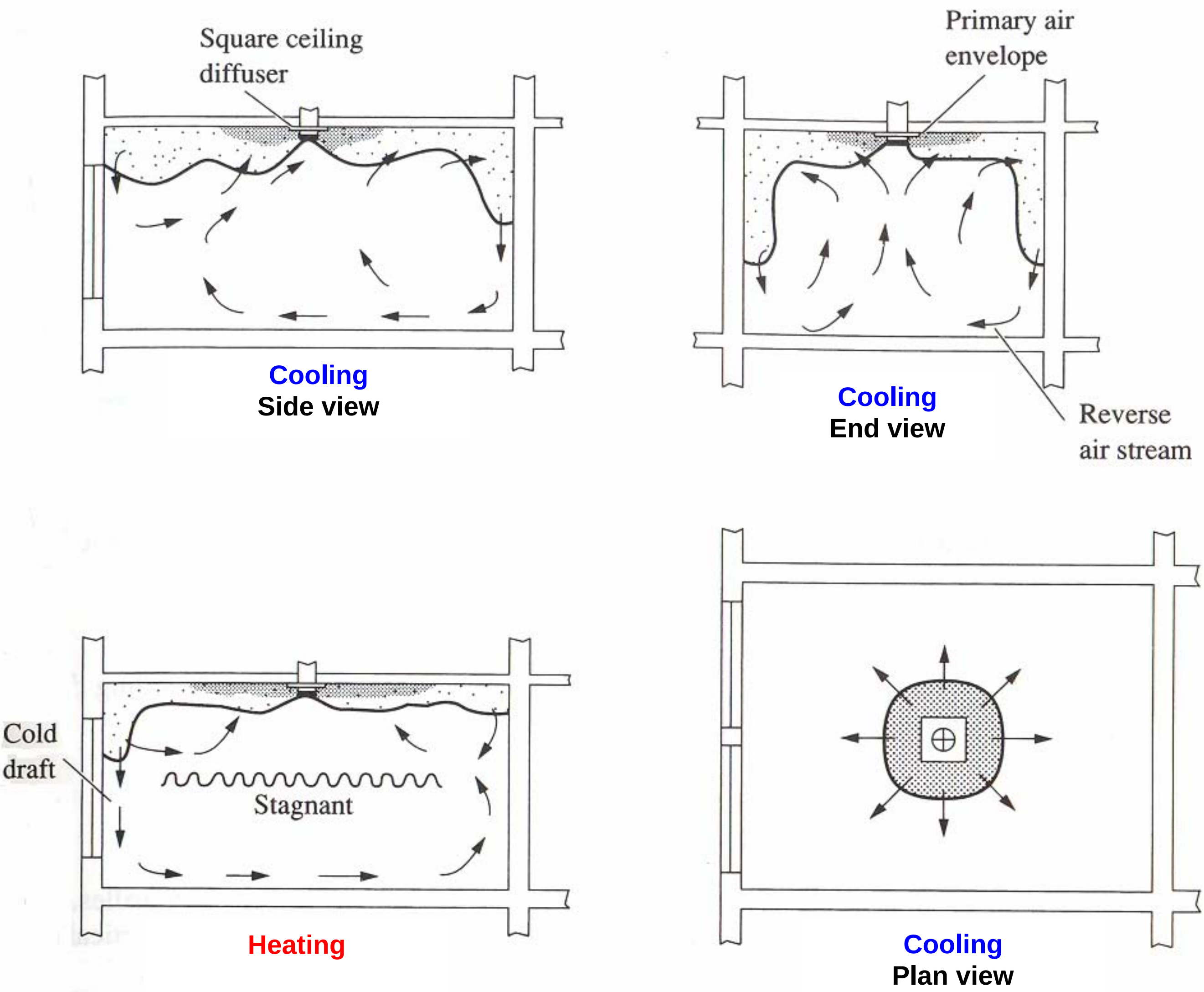


***Fig.39.10**: Airflow pattern using ceiling diffusers for cooling and heating applications*

Figure 39.11 shows the airflow patters obtained using slot diffusers installed in the ceiling in the perimeter and interior zones. The slot diffusers installed in the perimeter zone discharge air vertically downwards and also in the horizontal direction. Due to its better surface effect, the air jet remains in contact with the ceiling for a longer period and the reverse air stream ensures uniformity of temperature and velocity in the occupied zone. Due to their superior characteristics and better aesthetics, slot diffusers are widely used in large office spaces with normal ceiling heights and with VAV systems.

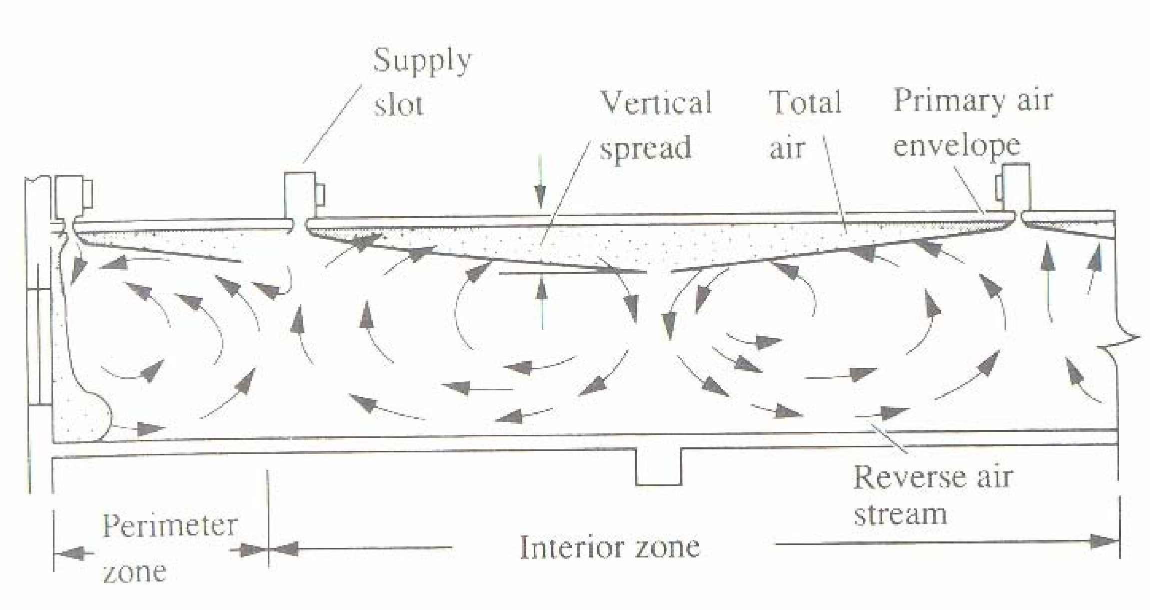


Fig.39.11*: Airflow pattern for cooling using slot diffusers*

39.9: Stratified mixing flow:

In buildings with a high ceiling, it is more economical to stratify the conditioned space into a stratified upper zone and a cooled lower zone. In such cases the supply air outlet is located at the upper boundary of the cooled lower zone and the air jet is projected horizontally. The cold air supply takes care of the cooling load in the lower zone due to windows, walls, occupants and equipment. Radiant heat from the roof, upper external walls and lights installed in the roof enter the occupied zone and are converted into cooling load with a thermal lag.

Stratified mixing flow for summer cooling offers the following advantages:

a) Convective heat transfer from the hot roof is effectively blocked by the higher temperature air in the stagnant upper zone thus reducing the building cooling load
b) Location of the return air inlets affects the cooling load only when they are located in the upper zone

39.10: Cold air distribution:

When chilled water is available at a lower temperature of about 1 to 2^{o}C (e.g. using an ice storage system), the supply air temperature can be reduced to about 4.4 to 7.2^{o}C, instead of the usual temperature of about 13^{o}C. Such a system is called a cold air distribution system. These systems offer the following advantaged when compared with the conventional systems:

a) Due to the lower dew-point temperature, the space humidity can be maintained between 35 to 45 %, as a result the occupied space can be maintained at a slightly higher temperature without causing discomfort

b) Due to the lower supply temperature, the flow rate of supply air can be reduced significantly leading to smaller ducts and hence smaller building space requirement and associated benefits
c) Due to lower flow rates, fan power consumption can be reduced by as much as 40 percent
d) Noise levels in the conditioned space can be reduced due to reduced flow rates

However, due to considerably reduced airflow rates, the air distribution and IAQ may get affected, especially when using with VAV systems. Better insulation and sealing of the ducts may be required to reduce losses and prevent surface condensation.

39.11: Displacement flow:

Displacement flow is a flow pattern in which cold supply air supplied at a velocity that is almost equal to the velocity in the conditioned zone and a temperature that is only slightly lower than the occupied zone, enters the occupied zone and displaces the original space air with a piston like motion without mixing with the room air. Displacement flow when designed properly, provides better Indoor Air Quality (IAQ) with lower turbulent intensity and lower draft in the occupied zone. Displacement flow can be classified into downward unidirectional flow and horizontal unidirectional flow. Figures 39.12(a), (b) and (c) shows the schematic of a downward unidirectional flow system, a horizontal unidirectional flow system and a unidirectional flow system for work stations, respectively. As mentioned before, due to the possibility of achieving superior IAQ, displacement flow systems are used widely in clean rooms, in operation theatres etc. Previously, displacement flow was known as laminar flow. However, in an air conditioned building with forced air circulation, the air flow in the occupied zone is turbulent everywhere except in the boundary layers near the walls (where the flow is laminar), even when the velocities are very low (Reynolds number is usually greater than 10000).

39.12. Spot cooling/heating:

In these systems cold or warm air jet is projected directly into a part of the occupied zone, often called as target zone, so that thermal environment can be controlled locally. Spot cooling/heating offers several advantages such as:

a) Better control of temperature, air purity and movement in a localized area, thus improving the thermal comfort of the occupants
b) Possibility of using greater outdoor air for ventilation
c) Highly localized loads can be handled very efficiently
d) Occupants have greater control of their own personalized environment

However spot cooling/heating have certain disadvantages such as: possibility of draft, discomfort due to air jet pressure, limited area of environment control and a complex air distribution system. Spot cooling systems can be classified into industrial spot cooling systems and desktop task air conditioning systems. As the name implies, industrial spot cooling systems are used in large industrial areas such as large machine shops, steel plants etc. Desktop task air conditioning systems find application in large office buildings.

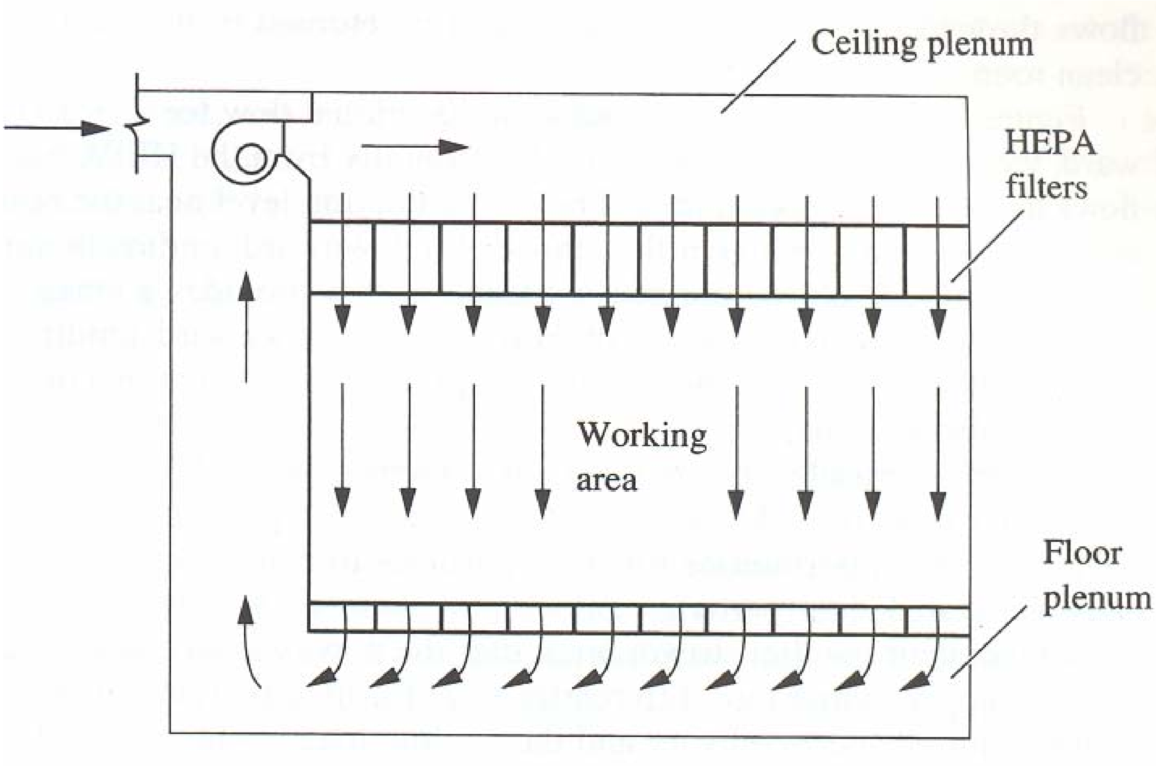


***Fig.39.12(a)**: Downward unidirectional flow*

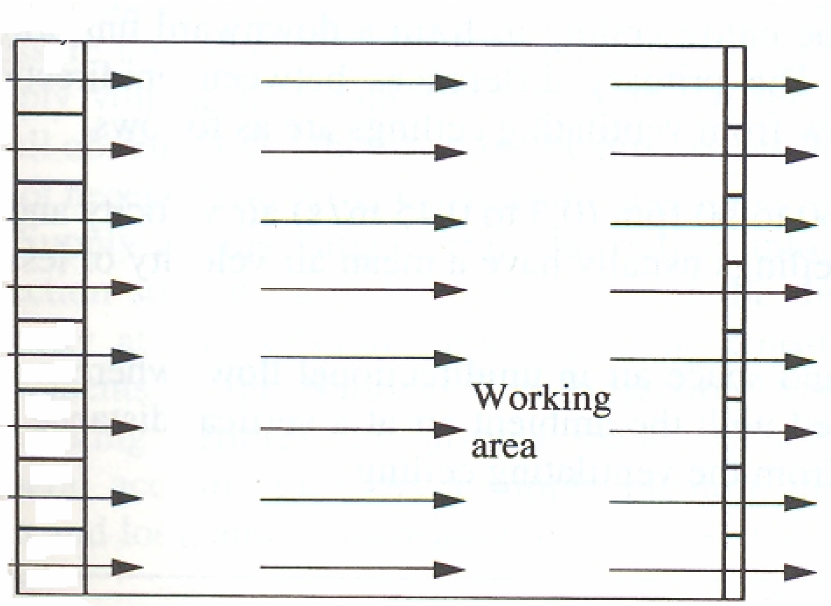


***Fig.39.12(b)**: Horizontal unidirectional flow*

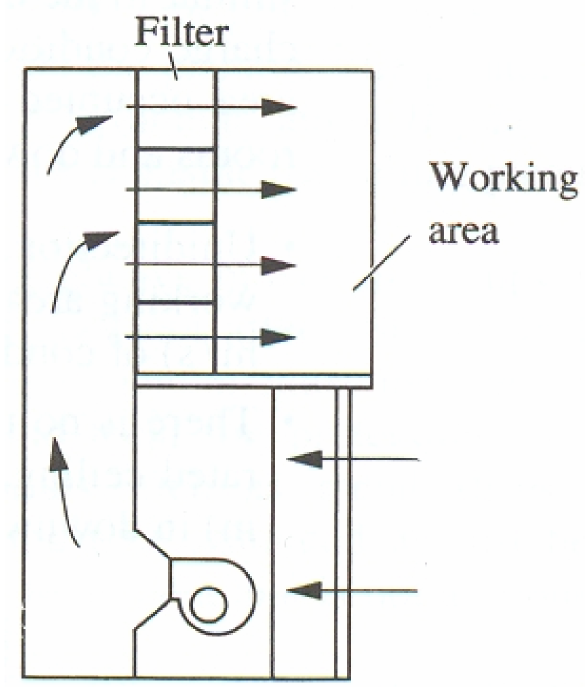


***Fig.39.12(c)**: Unidirectional flow for work stations*

39.13. Selection of supply air outlets:

Selection depends on:

1. **Requirement of indoor environment control:** If the indoor environment requires controlled air movement, then a high side outlet should not be used

2. **Shape, size and ceiling height of the building:** Ceiling and slot diffusers are ideal for buildings with limited ceiling height. For large buildings with large ceiling heights, high side wall mounted outlets are recommended.

3. **Volume flow rate per unit floor area:** Sidewall outlets are limited to low specific volume flow rates as they give rise to higher air velocities in the occupied zone. Compared to slot diffusers, the ceiling diffusers can handle efficiently a larger volumetric flow rates. Table 39.3 shows the specific volume flow rate of different outlets

4. **Volume flow rate per outlet:** The volume flow rate per supply outlet depends on the throw required to provide a satisfactory room air distribution. For linear slot diffusers, the volume flow rate per unit length is important. Its value normally lies between 23 to 62 L/s.m for linear slot diffusers. In a closed office with a floor area of about 14 m^2 and only one external wall, one ceiling diffuser is normally sufficient

5. **Throw:** High side wall outlets have a longer throw than ceiling diffusers. Square ceiling diffusers and circular ceiling diffusers have similar throw

6. **Noise level**

7. **Total pressure drop:** The total pressure loss of supply air as it flows through a slot diffuser of 19 mm width is normally between 12 to 50 Pascals, whereas it is between 5 to 50 Pascals for ceiling diffuser. Normally the pressure loss across the supply outlet should not exceed 50 Pascals

8. **Cost and Appearance:** Finally the cost and appearance of the supply air outlets also have to be considered depending upon the specific application

Performance of various types of supply air outlets are provided by the manufacturers in the form of tables and charts, using which one can select a suitable supply air outlet.

Type of outlet	Specific volume flow rate L/s/m^2 of floor area	Max. ACH for 3-m ceiling
Grilles	3.0 to 6.0	7
Slot diffuser	4.0 to 20.0	12
Perforated Panel	4.5 to 15.0	18
Ceiling diffuser	4.5 to 25.0	30

***Table 39.3**: Specific volume flow rates of different outlet devices*

Questions and answers:

1. State which of the following statements are TRUE?

a) The purpose of an air distribution system is to maintain comfort conditions in the entire conditioned space
b) The purpose of an air distribution system is to maintain comfort conditions in the occupied zone of the conditioned space
c) The effective draft temperature depends on dry bulb temperature and relative humidity of air
d) The effective draft temperature depends on dry bulb temperature and velocity of air

Ans.: b) and d)

2. State which of the following statements are TRUE?

a) The effective draft temperature increases as dry bulb temperature and air velocity increase
b) The effective draft temperature increases as dry bulb temperature increases and air velocity decreases
c) A good air distribution system should yield high value of ADPI and a small value of SDEF
d) A good air distribution system should yield high values of both ADPI and SDEF

Ans.: b) and d)

3. State which of the following statements are TRUE?

a) Due to buoyancy effect a cold air stream rises and a hot air stream drops
b) The buoyancy effects become stronger as the temperature difference between the supply air and room air increases
c) A high Archimedes number indicates a strong buoyancy effect
d) The design Archimedes number should increase as the height of the room decreases

Ans.: b) and c)

4. State which of the following statements are TRUE?

a) The centerline velocity of air from a circular jet increases as the distance from the outlet increases
b) The centerline velocity of air from a circular jet increases as the outlet area decreases
c) The centerline velocity of air from a circular jet increases as the supply air velocity at the outlet increases
d) All of the above

Ans.: c)

5. State which of the following statements are TRUE?

a) Compared to other outlet types, a grille has lower entrainment ratio and greater drop
b) Ceiling diffusers are recommended when the ceiling height is high
c) Sidewall diffusers are generally used in large spaces
d) All of the above

Ans.: a) and c)

6. State which of the following statements are TRUE?

a) A light-troffer-diffuser-slot improves the efficiency of the fluorescent lights
b) A light-troffer-diffuser-slot reduces the room sensible heat factor
c) To eliminate tobacco smoke, return air inlets should be located at a lower height on the wall
d) Design of return air inlet is important from noise point-of-view

Ans.: a), b) and d)

7. State which of the following statements are TRUE?

a) Stratified mixing flows are recommended for buildings with high ceilings
b) Stratified mixing flow reduces the radiant heat load from the ceilings
c) Cold air distribution systems reduce the space requirement and fan power
d) Cold air distribution systems may lead to surface condensation

Ans.: a), c) and d)

8. State which of the following statements are TRUE?

a) Displacement flows are recommended in operation theatres due to better IAQ
b) In displacement flow system, supply air temperature is only slightly different from comfort temperature
c) In displacement flow system, supply air velocity is low
d) All of the above

Ans.: d)

9. State which of the following statements are TRUE?

a) Spot cooling and heating systems are widely used in industrial applications
b) Spot cooling and heating systems provide better individual control
c) Spot cooling and heating systems reduce the total cooling load
d) All of the above

Ans.: d)

10. The following table shows the measurements made at 9 points in the occupied zone of an air conditioned building. Evaluate the design of the air distribution system.

Measuring point	DBT (^oC)	Air velocity (m/s)	EDT (^oC)
1.	21.1	0.30	-3.32
2.	21.7	0.25	-2.71
3.	22.5	0.20	-1.91
4.	23.5	0.21	-0.91
5.	24.1	0.10	-0.29
6.	24.7	0.08	+0.31
7.	23.7	0.11	-0.69
8.	22.8	0.19	-1.61
9.	22.0	0.24	-2.41

Ans.: From the DBT and air velocity (V) data, the Effective Draft Temperature (EDT) for each point is calculated using the equation:

$$\text{EDT} = (\text{DBT}-24.4) - 0.1276(V - 0.15)$$

The calculated EDT values are shown in the table. It is seen from the table that the EDT value varies widely from **–3.31^{o}C to +0.3^{o}C**, indicating improper distribution.

For this space the Air Distribution Performance Index (ADPI) is calculated using the equation:

$$\text{ADPI} = \left(\frac{N_\theta}{N}\right) x100 = \left(\frac{5}{9}\right) x100 = 55.6 \qquad \textbf{(Ans.)}$$

where N_θ is the number of locations at which the effective draft temperature is within **–1.7^{o}C to +1.1^{o}C.**

An ADPI value of 55.6 indicates the need for improving the design of the air distribution system, as it indirectly indicates that only about 56% of the occupied zone meets the comfort criteria, whereas the remaining space gives rise to drafts.

11. The velocity of air issuing from a circular opening is given by the following equation:

$$\mathbf{V(x,r)} = \frac{\mathbf{7.41 V_o \sqrt{A_o}}}{\mathbf{x\left[1 + 57.5\left(r^2 / x^2\right)\right]^2}}$$

where V_o is the velocity at supply air outlet (x=0), A_o is the area of the opening, r is the radial distance from the centerline and V(x,r) is the velocity at point (x,r). An airflow rate of 0.12 m^3/s is supplied through a circular opening at a velocity of 3 m/s. Find the distance from the outlet at which the centerline velocity reduces to 1 m/s. What is the total airflow rate (primary + secondary) at this point?

Ans.: The expression for centerline velocity (r=0,x) is given by:

$$\mathbf{V(x, r = 0)} = \frac{\mathbf{7.41 V_o \sqrt{A_o}}}{\mathbf{x}}$$

Area of the opening, $A_o = Q_o/V_o = 0.12/3 = 0.04\ m^2$

Substituting the values of V(x,r=0) = 1 m/s, Vo = 3 m/s and A_o = 0.04 m_2 in the above expression, we find the value of x as:

$$\mathbf{x} = \frac{\mathbf{7.41 V_o \sqrt{A_o}}}{\mathbf{V(x, r = 0)}} = \frac{\mathbf{7.41 x\, 3\, x \sqrt{0.04}}}{\mathbf{1.0}} = \mathbf{4.446\ m} \qquad \mathbf{(Ans.)}$$

The total airflow rate at x = 4.446 m is obtained from the equation:

$$\mathbf{Q_{x = 4.446\ m} = Q_{x=0}.R_x}$$

Where R_x is the entrainment ratio, given by:

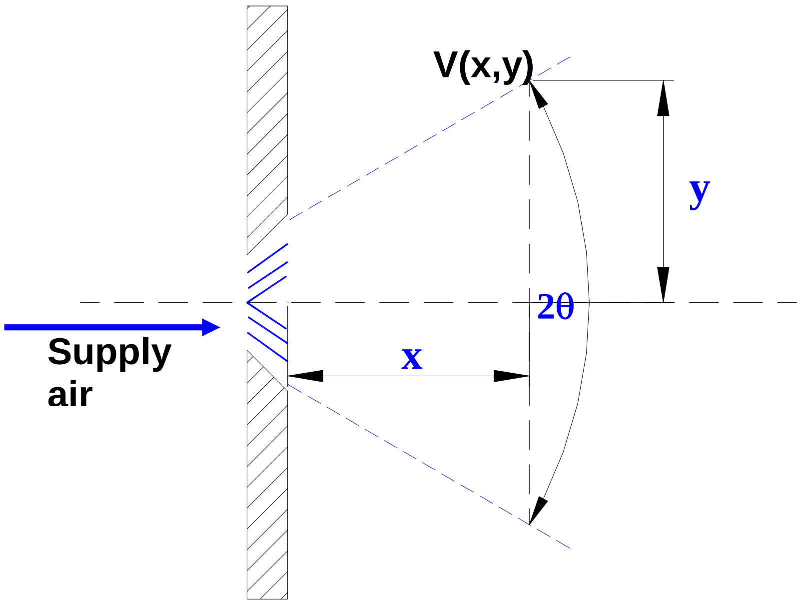
$$\mathbf{R_x} = \frac{\mathbf{Q_{x=4.446}}}{\mathbf{Q_{x=0}}} = \frac{\mathbf{\int_{r=0}^{\infty} V(x,r).2\pi r.dr}}{\mathbf{A_o V_o}} = \frac{\mathbf{0.405\, x}}{\mathbf{\sqrt{A_o}}} = \frac{\mathbf{0.405\, x\, 4.446}}{\mathbf{\sqrt{0.04}}} \approx \mathbf{9.0}$$

hence, $\mathbf{Q_{x = 4.446} = Q_{x=0}\ x\ 9.0 = 0.12\ x\ 9.0 = 1.08\ m^3/s}$ **(Ans.)**

12. The velocity distribution of air from an air jet issued from a long, narrow slot is given by the following equation:

$$V(x,y) = \frac{2.4\,V_o\sqrt{b}}{\sqrt{x}}\left[1 - \tanh^2\left(7.67\,\frac{y}{x}\right)\right]$$

where V_o is the velocity at supply air outlet (x=0), b is the width of the slot, y is the normal distance from the central plane and V(x,y) is the velocity at point (x,y). Find the ratio of velocity V(x,y) to V(x,y=0) at a plane x at which the spread angle is 19^o.



Definition of spread angle (2θ)

Ans.: The spread angle is given by **2θ** as shown in the figure given above.

From the figure,

$$\theta = \tan^{-1}(y/x) = (19/2) = 9.5^o$$

$$\therefore \text{ at } \theta = 9.5^o, \ (y/x) = \tan(9.5) = 0.1673$$

From the expression for V(x,y);

$$\frac{V(x,y)}{V(x,y=0)} = \left[1 - \tanh^2\left(7.67\,\frac{y}{x}\right)\right] = \left[1 - \tanh^2(7.67x0.1673)\right] = 0.265 \qquad \textbf{(Ans.)}$$