CAE 464/517 HVAC Systems Design

Spring 2023

February 16, 2023

Air distribution systems: principles and air jet patterns

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Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

ANNOUNCEMENTS

Announcements

- Do not forget about the Q&A file:

https://docs.google.com/document/d/1m6ezSI6Bi9wGQcjnaYj_iAXY2kzRICPYWkKfayNp5WE

Announcements

- Group project: Add your name to the list

https://docs.google.com/spreadsheets/d/1WwM6L1i8SmpTWU3xYQeNypfnqbloQRglBgCt5E7Kb2s/

Announcements

- Adding interesting and daily application of HVAC systems:

https://docs.google.com/presentation/d/15bvvZ0VVm9SgonCzZ5N07MBvl0YdVRYaph6Z3evveJA/edit#slide=id.p

AIR DISTRIBUTION
(CHAPTERS 20-21 OF THE HANDBOOK)

Air Distribution

- How much is the total airflow requirements? Can we use ASHRAE 62.1 to calculate the entire airflow requirement for a building and design the AHUs?

Air Distribution

CHAPTER 20

SPACE AIR DIFFUSION

ROOM air distribution systems are intended to provide thermal comfort and ventilation for space occupants and processes.

Local temperature and carbon dioxide (CO_2) concentration have similar stratification profiles.

CHAPTER 21

DUCT DESIGN

Air Distribution

Price Industries Handbook

https://www.priceindustries.com/education/engineershandbook

CHAPTER 9

INTRODUCTION TO
MIXING VENTILATION

5.0 PROFESSIONAL DEVELOPMENT HOURS

This chapter provides a concise approach to the proper selection of air distribution outlets with an emphasis on occupant comfort, air quality, and energy conservation.

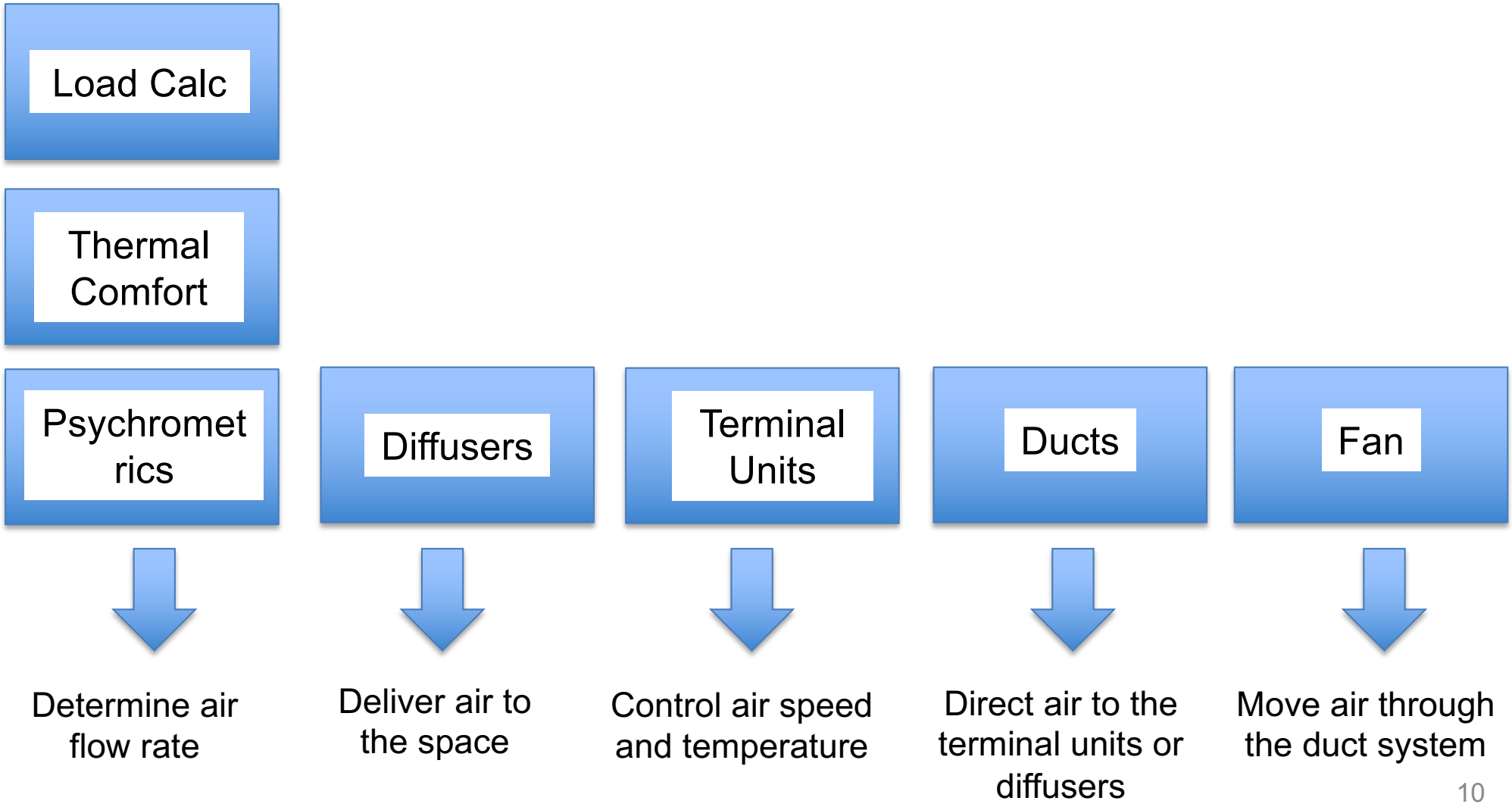
The design and selection of air distribution equipment in today's buildings presents one of the more unique challenges for mechanical designers. Unlike other mechanical equipment required for these environmental systems, the air distribution equipment selection must combine a proper choice of engineered products, efficiently providing conditioned air to the space while adding architectural features that complement the interior design.

Air outlet selection and application is no less important than any other facet of the HVAC system. Much time and money can be spent on the design and purchase of mechanical equipment, controls, piping, and ductwork, but if the air outlets are improperly applied or selected, final system performance will be compromised.

With today's emphasis on occupant comfort, air quality and energy conservation, the proper selection of air outlets is critical. It is the intent of this Mixing Ventilation chapter to provide a concise approach to the proper selection of air distribution outlets.

Air Distribution

- There are a couple of components required for the design of an air distribution



Air Distribution

- Aim to provide a proper room temperature and humidity throughout room by creating air motion

- Avoid drafts and unwanted secondary air flow and noises

- Consider appropriate:
  - ❑ Selection type and location of diffusers
  - ❑ Selection and location of return air grilles
  - ❑ Size of air distribution equipment
  - ❑ Calculation of pressure losses
  - ❑ Noise level

https://www.continentalindustries.com/DD-SupplyRegisters

Air Distribution

- For ”occupied spaces” the goal is to satisfy thermal comfort requirements with a proper combination of:
  - ❑ Temperature
  - ❑ Humidity
  - ❑ Air motion

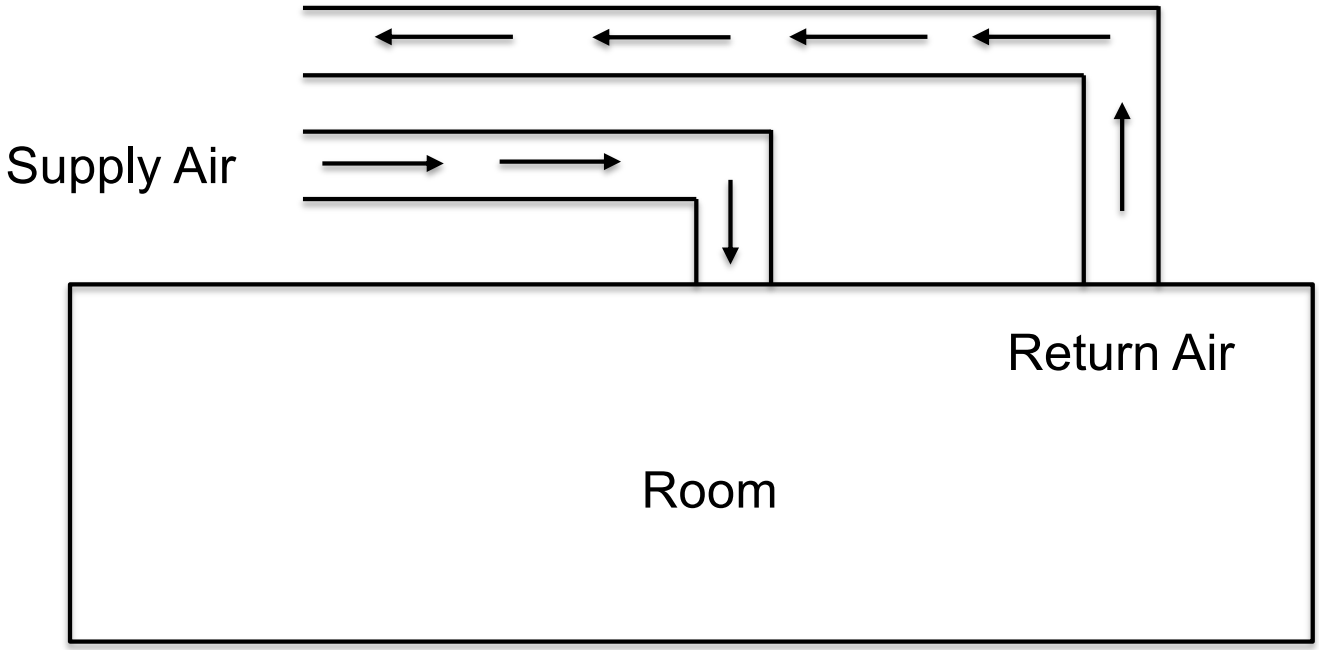
Air Distribution

- For ”unoccupied spaces” the goal is to satisfy the equipment environmental conditions with a proper air circulations with a proper combination of:
  - ❑ Temperature
  - ❑ Humidity

AIR DISTRIBUTION TERMINOLOGY

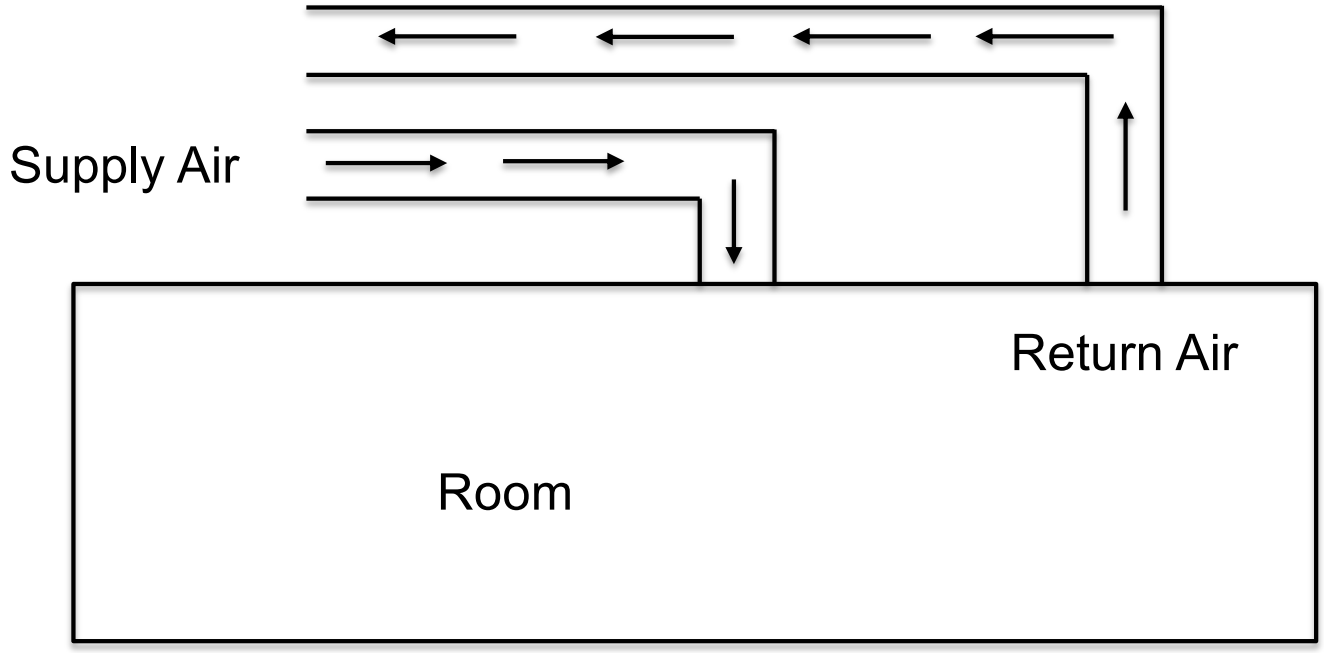
Air Distribution Terminology

- Supply Air (SA): Air entering a space that has been directly delivered from a fan, blower, or air handler. They get distributed through air delivery devices



Air Distribution Terminology

- Return Air (RA): Air removed from a space with the intent or partial or total recirculation. Typically escape through openings or air devices named “register”

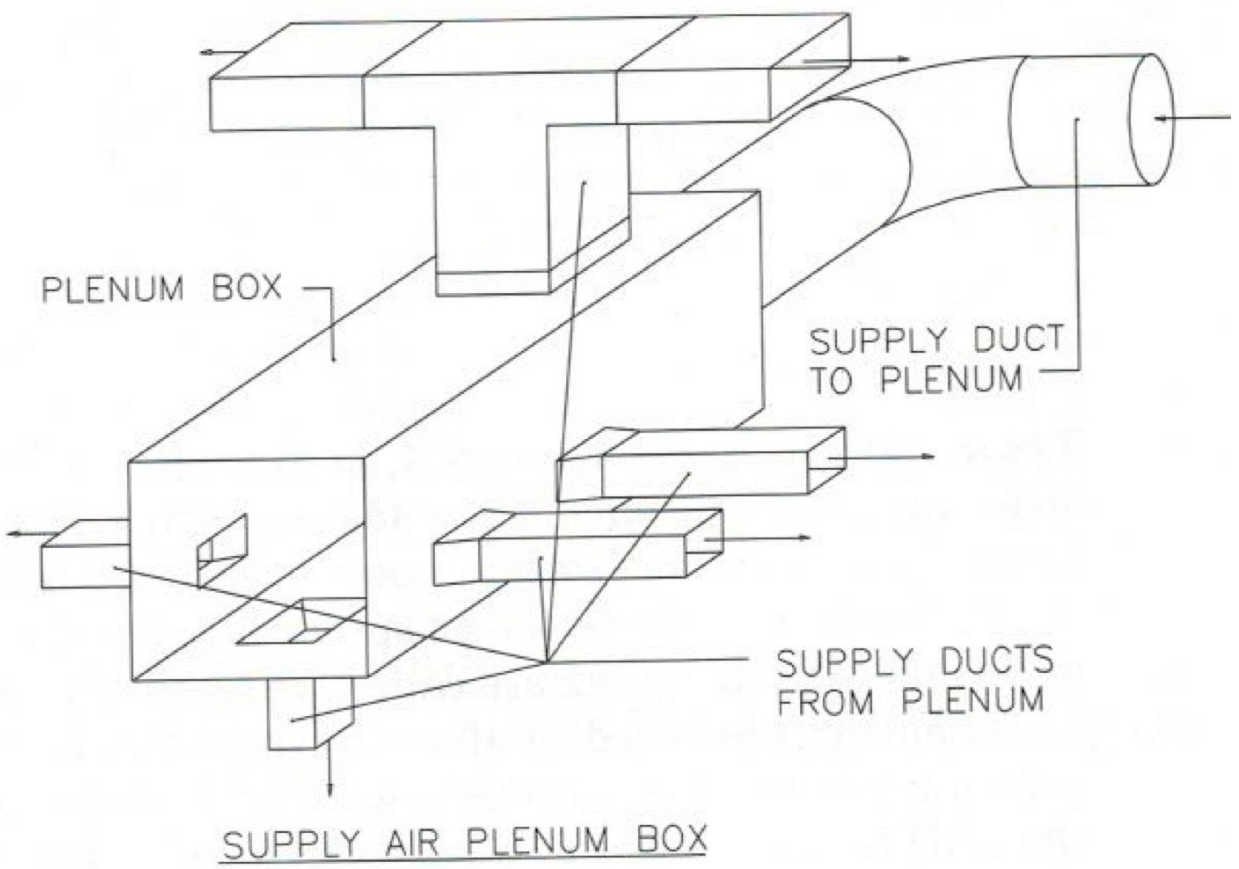


Air Distribution Terminology

- RA removal options:
  - Hard Ducting: A closed system of ducts to direct the air back to the air handler
    - Return air in constant motion
    - No option to store the return air
    - Expensive air return option
    - Code requires that

Air Distribution Terminology

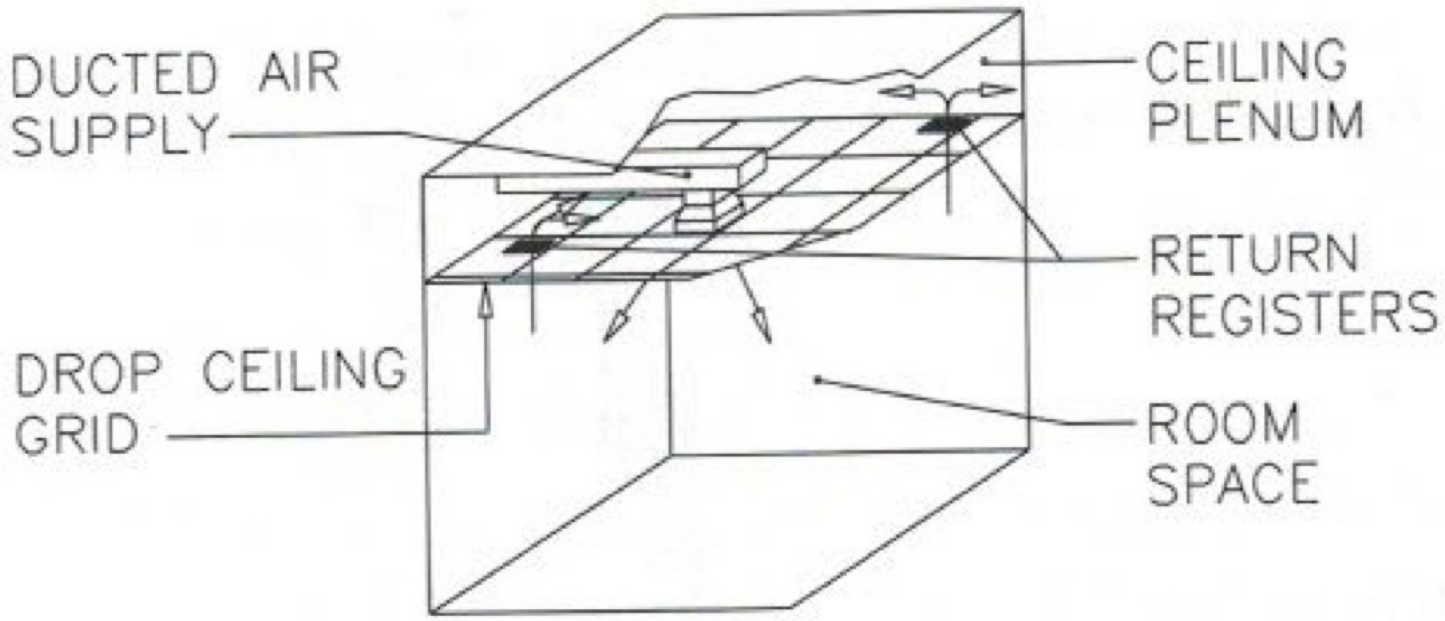
- RA removal options
  - ❑ Duct Plenum or Plenum Box: A plenum is a large enclosure that is used to store air until is needed



Fundamentals of HVAC, Jack Burton

Air Distribution Terminology

- RA removal options:
  - ❑ Ceiling Plenum: Similar to the duct plenum except the space located above the ceiling and below the above floor is used to store air

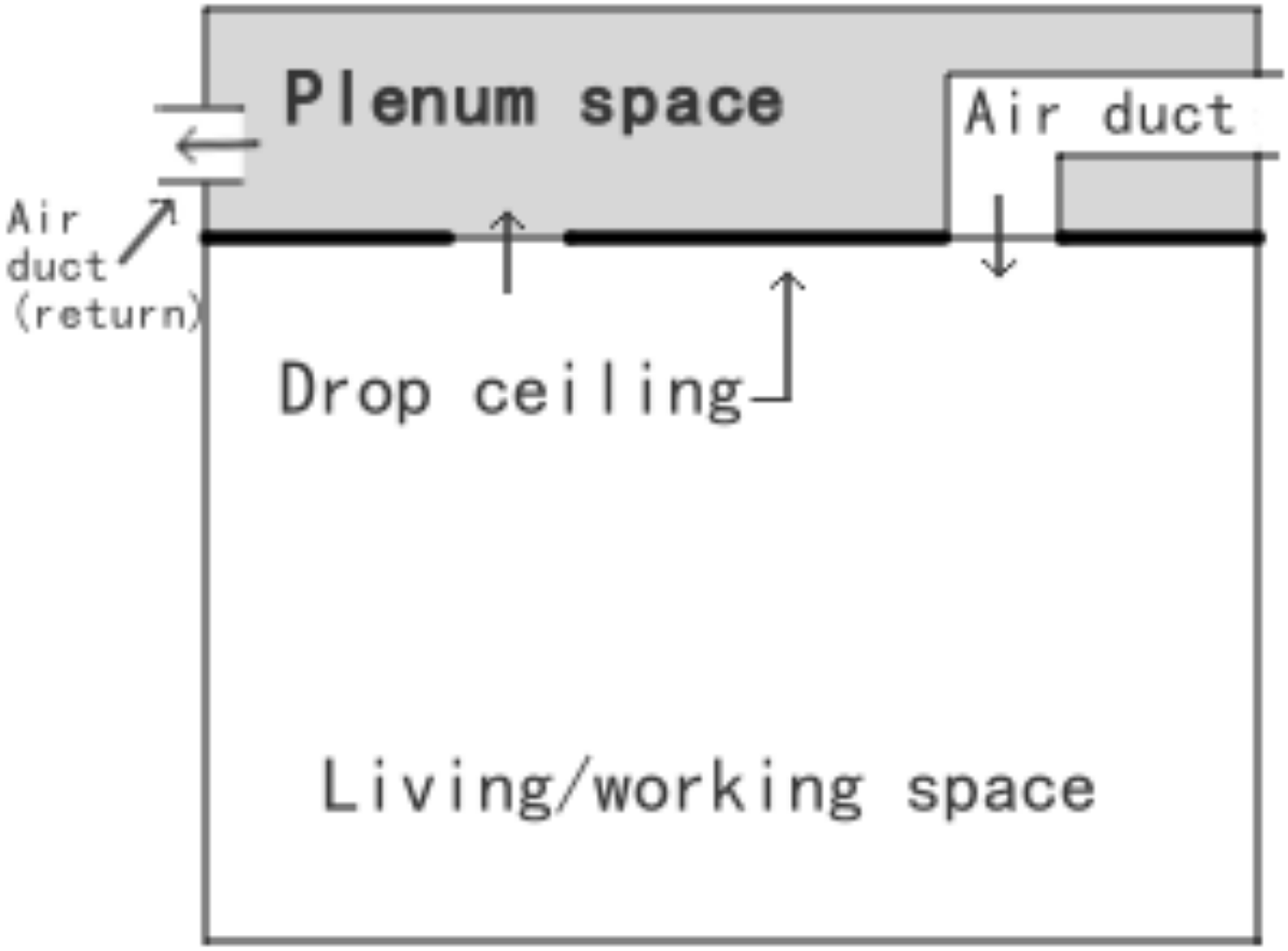


RETURN CEILING PLENUM

Fundamentals of HVAC, Jack Burton

Air Distribution Terminology

- Ceiling plenum options:



https://sewelldirect.com/learning-center/plenum-space

Air Distribution Terminology

- Ceiling plenum options:

https://www.jadelearning.com/blog/passing-an-above-grid-ceiling-inspection/

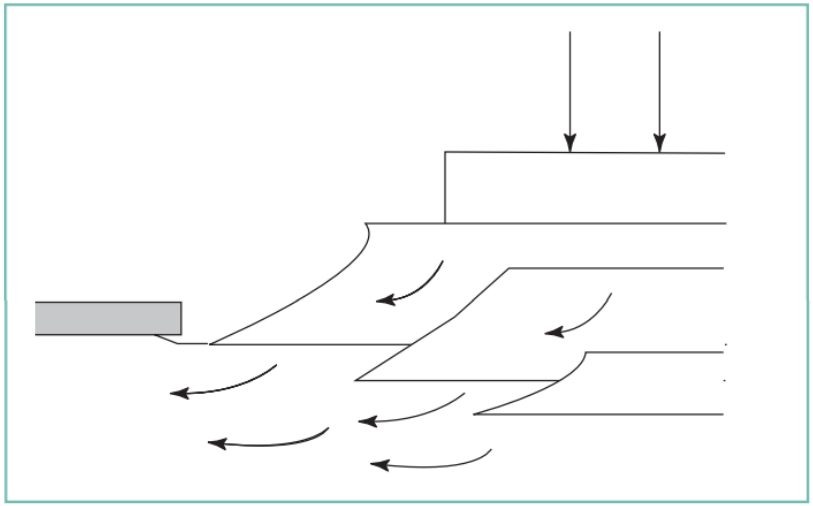
Air Distribution Terminology

- Let's look at three definitions in addition to supply air (SA):
  - Exhaust Air (EA): Any air that is removed directly from a space and derived to the outside of the building. This air is not circulated
  - Make-up Air (MA): Any air that acts as an air supply from a source outside the space which is not forced into the space. It is not filtered, forced, or treated
  - Transfer Air (TA): Any air that acts as a supply to a space that comes from adjacent spaces

Air Distribution Terminology

- Diffusers: Direct air after the ductwork:
  - ❑ Volumetric adjustment: Use dampers
  - ❑ Deflection: Use vanes
  - ❑ Diffusion: Spread air as passes through the diffusers

Air Pattern



Fixed Horizontal Air Pattern

Air Distribution Terminology

- Air register vs. air grille
  - ❑ Grille is used mostly for deflections
  - ❑ Register is a grille plus damper

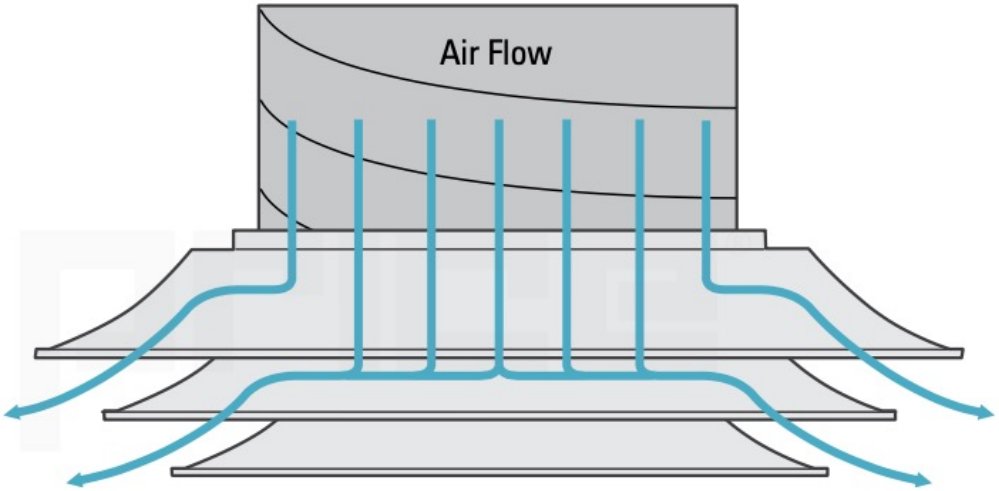
30 in. x 6 in. Return Air Vent Grille, White with Fixed Blades

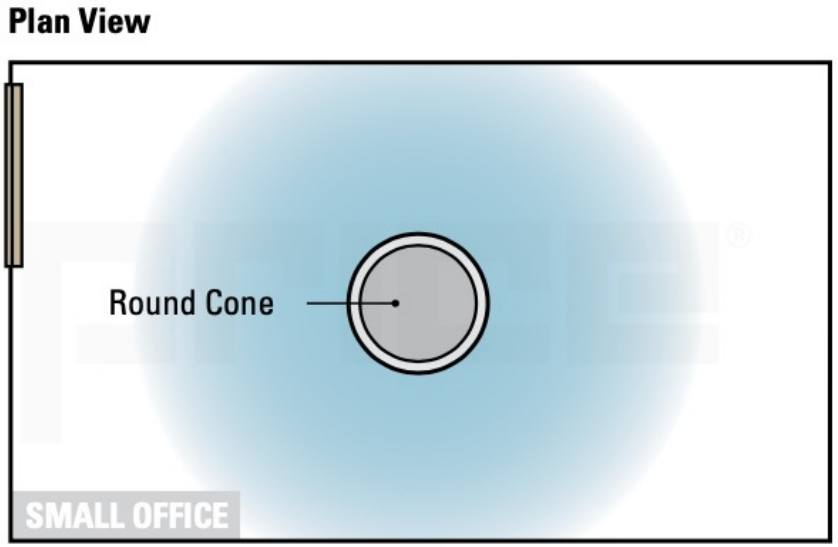
12 in. x 6 in. 3-Way Wall/Ceiling Register

https://www.homedepot.com/p/SPEEDI-GRILLE-30-in-x-6-in-Return-Air-Vent-Grille-White-with-Fixed-Blades-SG-306-RAG/202542239?MERCH=REC-_-PIPHorizontal2_rr-_-203313253-_-202542239-_-N
https://www.homedepot.com/p/Everbilt-12-in-x-6-in-3-Way-Wall-Ceiling-Register-E103M-12X06/300539639

Air Distribution Terminology

- Celling diffusers cross section:

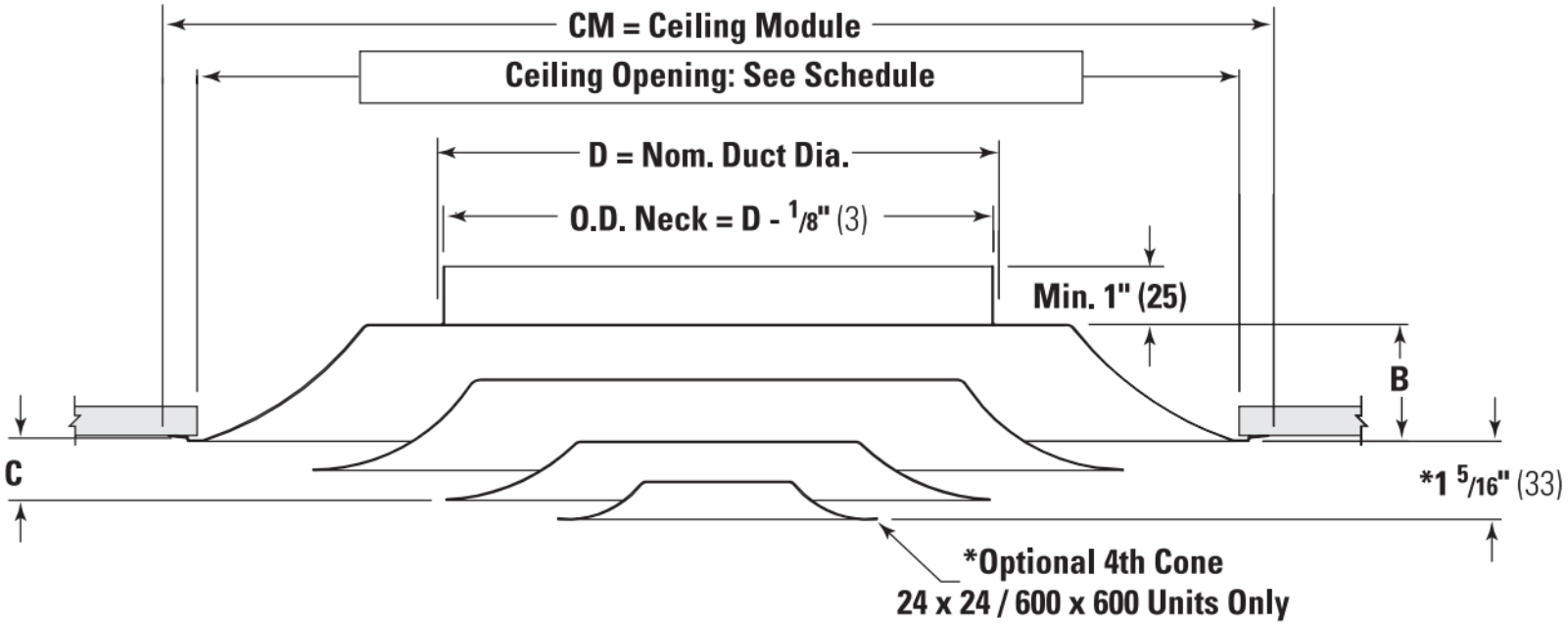




Price Industries, Engineering Handbook

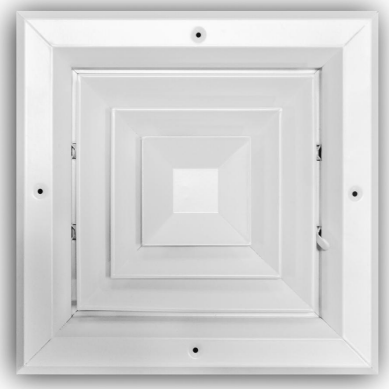
Air Distribution Terminology

- A few common definitions for the diffuser selection:



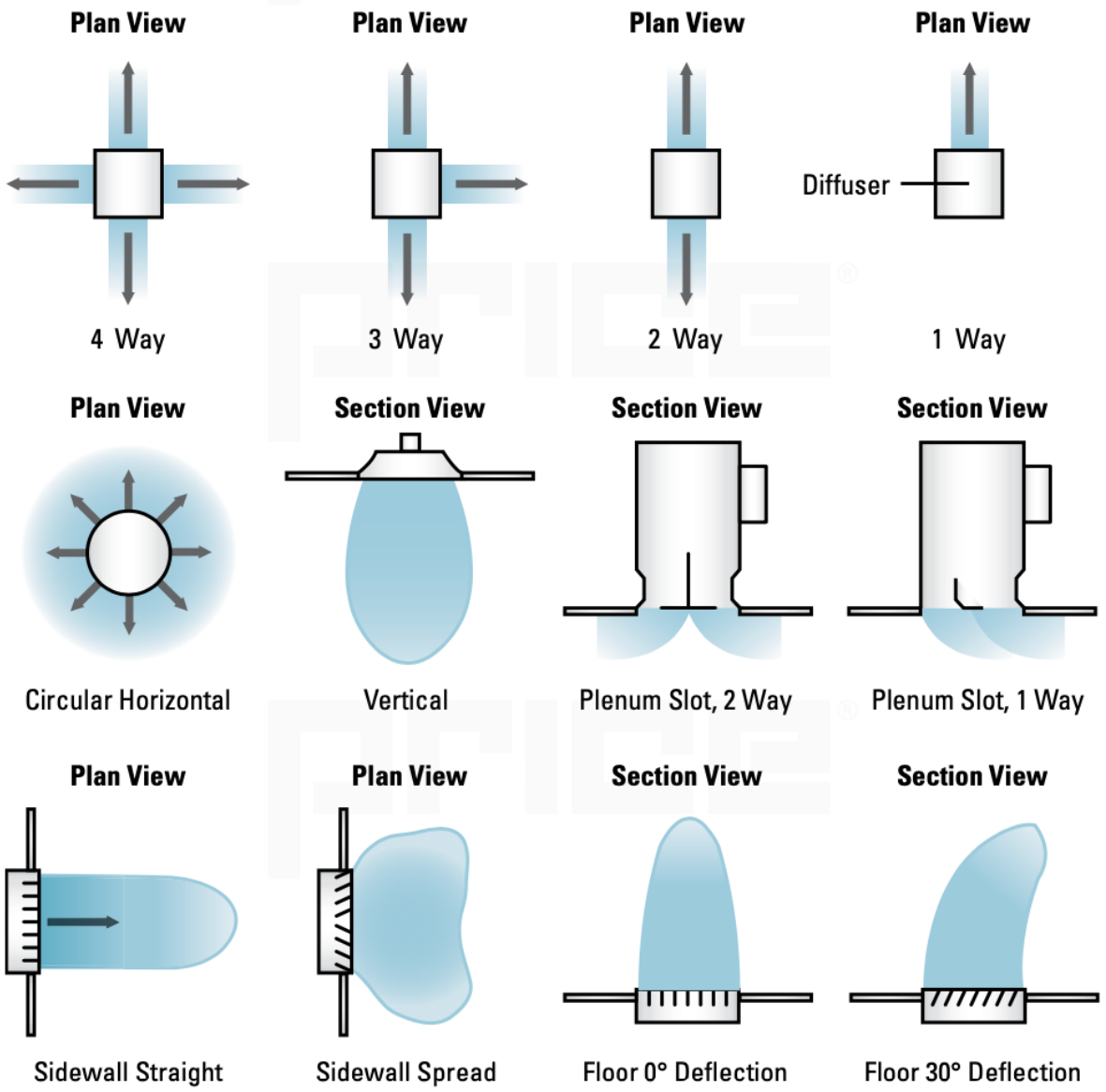
Air Distribution Terminology

- Celling Diffusers can spread air out through:
  - ❑ 2-way
  - ❑ 3-way
  - ❑ 4-way
  - ❑ All-way



https://www.homedepot.com/p/Everbilt-8-in-x-8-in-4-Way-Square-Ceiling-Diffuser-EA504M-08X08/300539275 &. http://grilletech.com.au/product/linear-slot-diffuser/
https://www.homeessentialsdepot.com/truaire-3-way-aluminum-square-ceiling-diffuser-8-in-x-8-in-3562230-3562230/?gclid=EAIaIQobChMIlJTpv7O24AIVBLnACh1SMwM9EAkYAiABEgKBqPD_BwE

Air Distribution Terminology



Price Industries, Engineering Handbook

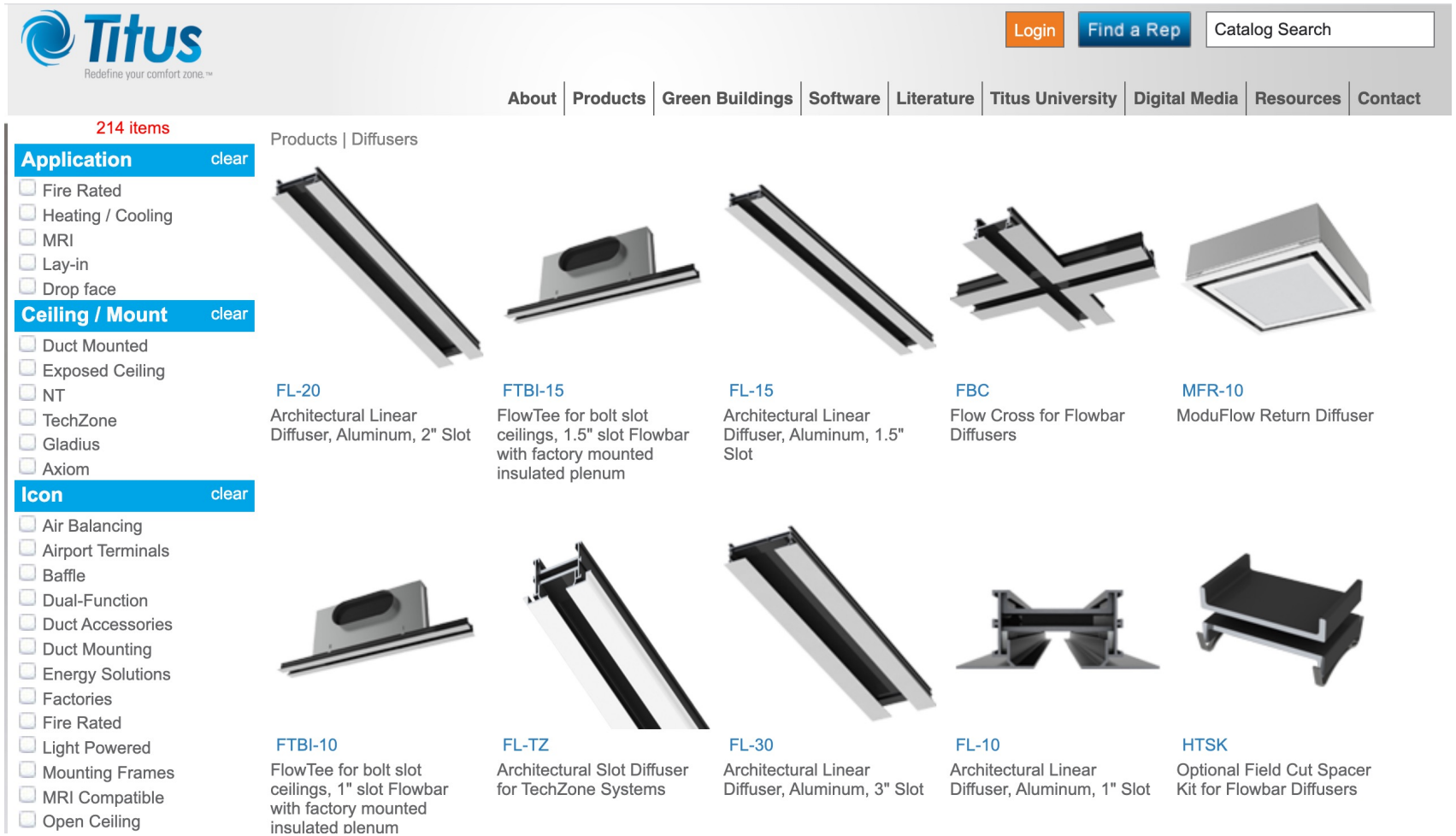
Air Distribution Terminology

- Sometimes we need to use Long, Slender Diffusers (LSD) to deliver air over a greater horizontal distance than a ceiling diffusers

http://www.acutherm.com/product/tlc-linear/
https://www.homedepot.com/p/Everbilt-8-in-x-8-in-4-Way-Square-Ceiling-Diffuser-EA504M-08X08/300539275
https://www.homeessentialsdepot.com/truaire-3-way-aluminum-square-ceiling-diffuser-8-in-x-8-in-3562230-3562230/?gclid=EAIaIQobChMIIJTpv7O24AIVBLnACh1SMwM9EAkYAiABEgKBqPD_BwE
http://grilletech.com.au/product/linear-slot-diffuser/

Air Distribution Terminology

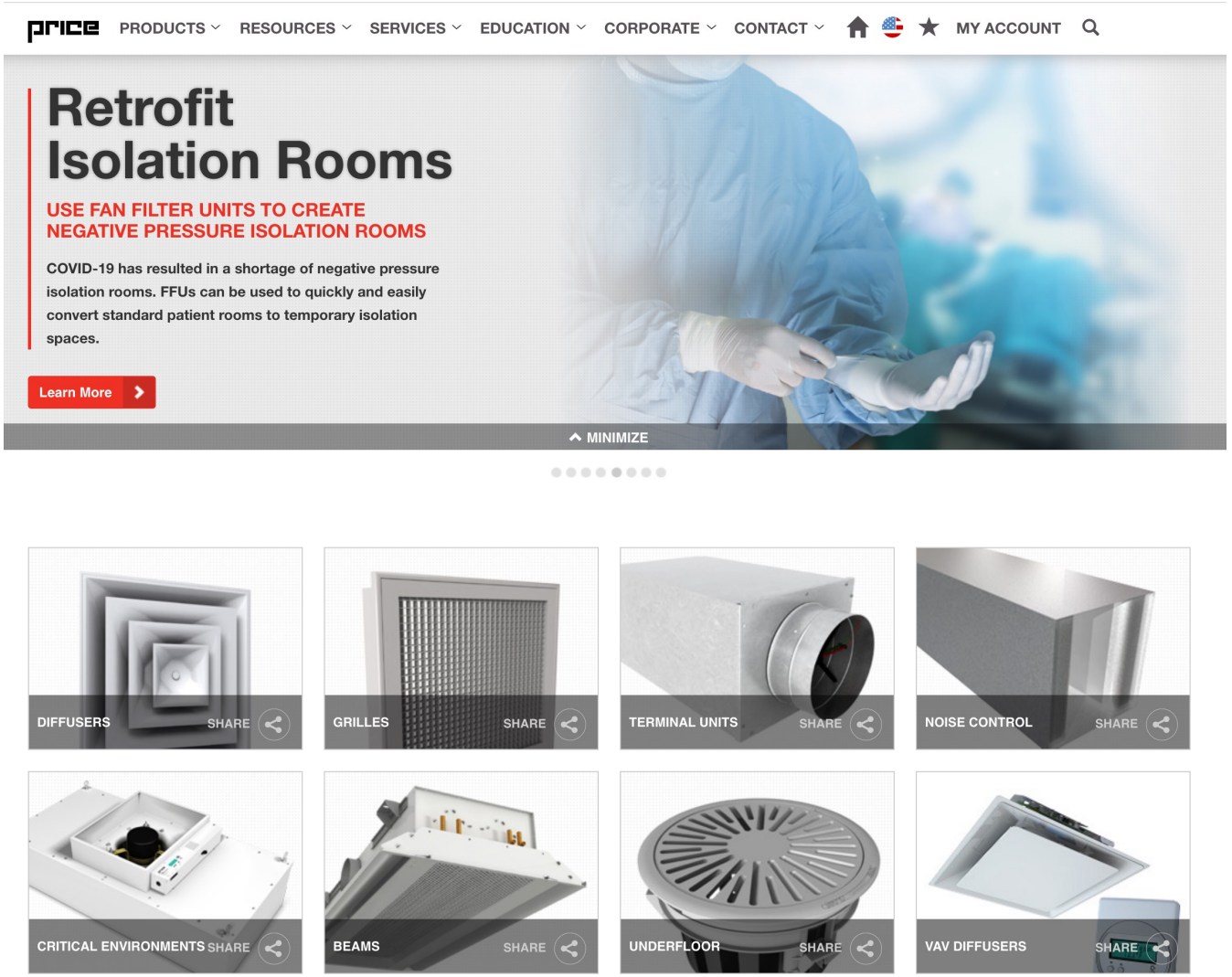
- Please review some diffuser, grille, and register options for the next lectures



https://www.titus-hvac.com/Products/Diffusers

Air Distribution Terminology

- Please review some diffuser, grille, and register options for the next lectures

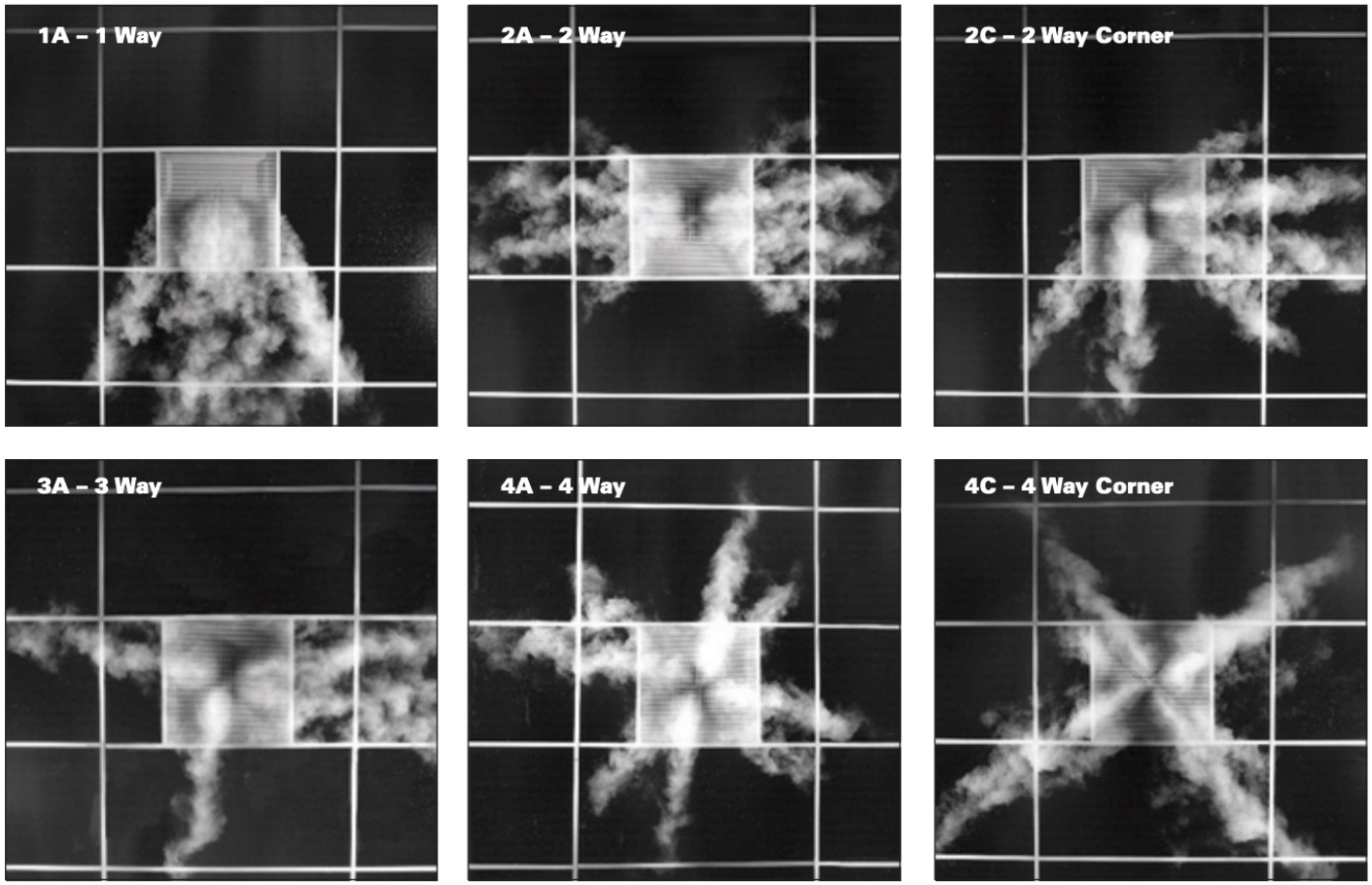


https://www.priceindustries.com/#close

AIRFLOW PATTERNS

Mixed Air Systems

- Air mixing
  - ❑ Leads to space heat transfer and resultant velocity reduction
  - ❑ Needs to occur outside of the occupied zone



C-38

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

https://www.priceindustries.com/content/uploads/assets/literature/catalogs/complete-sections/section%20a/section-c---ceiling-diffusers.pdf

Mixed Air Systems

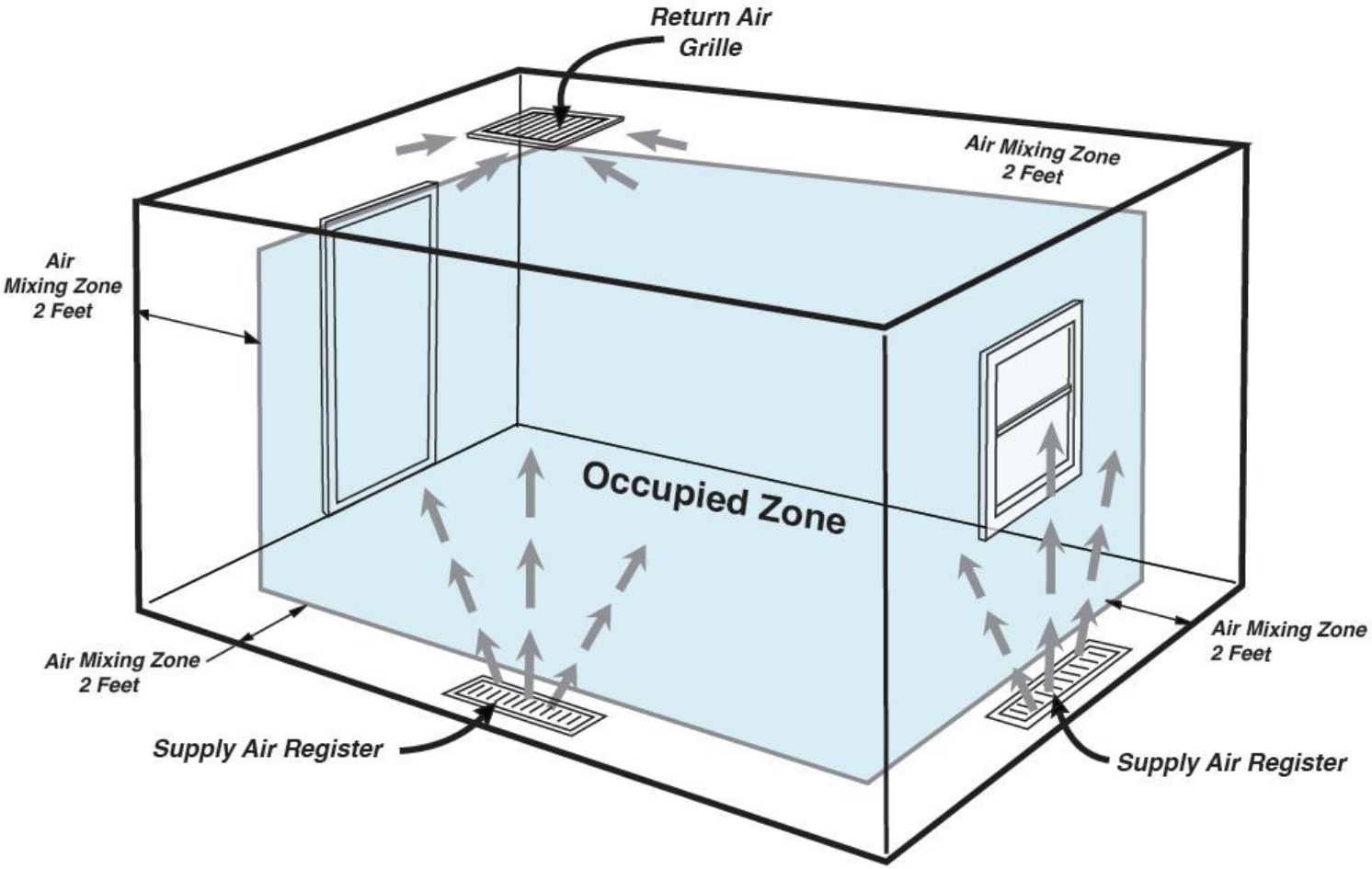
- Occupant thermal comfort occurs through the secondary air flow in the space and not the direct air flow from the outlets

- The goal is to maximize the uniform air temperature and air speed distribution in the occupied zone

- A desirable space air speed is less than 50 fpm (How much is this in SI unit)

Mixed Air Systems

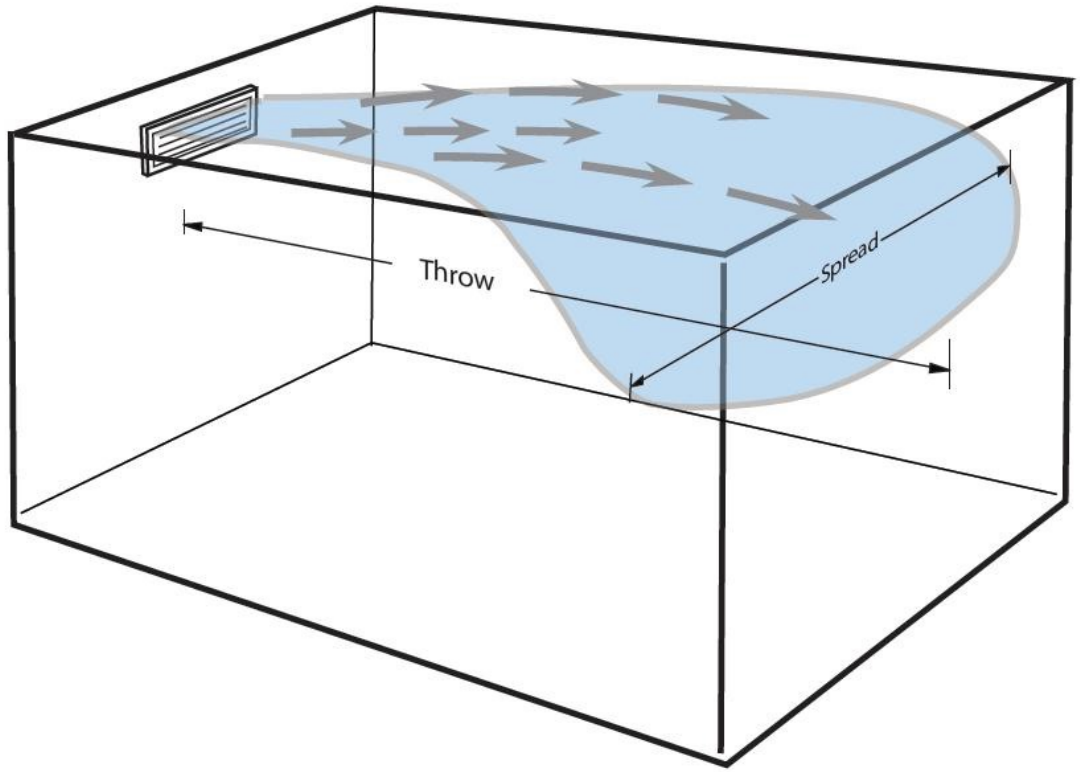
- We are interested in the occupied zone (or breathing zone):
  - ❑ 2 feet from any wall
  - ❑ 6 feet from the floor



https://www.continentalindustries.com/DD-SupplyRegisters

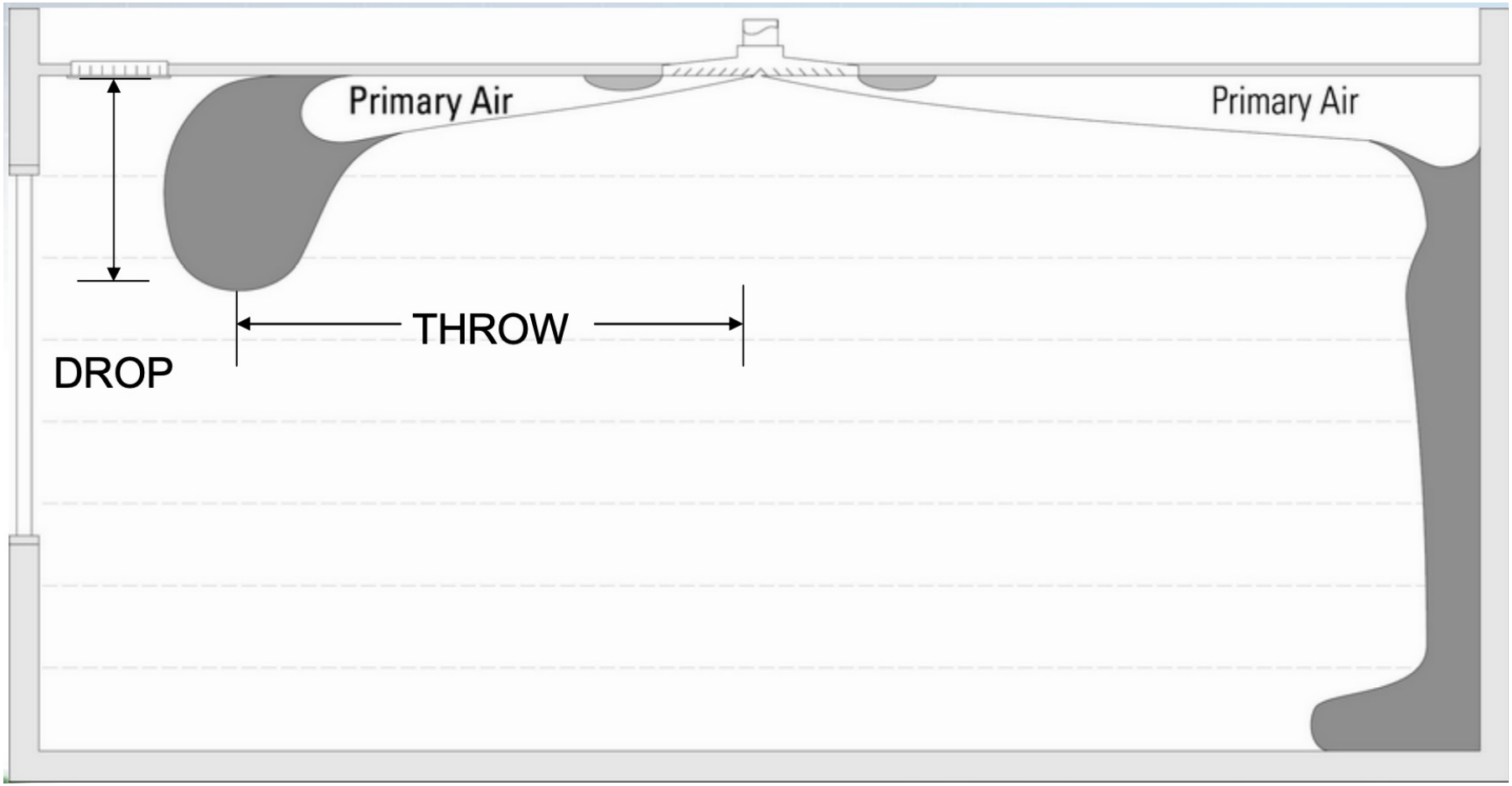
Mixed Air Systems

- Two important factors in the design of a register are:
  - ❑ The distance from the register that the air will travel (Throw)
  - ❑ The maximum width the airstream will travel at a corresponding velocity (Spread)
    - Angle of the vanes (0˚, 22˚ and 45˚)



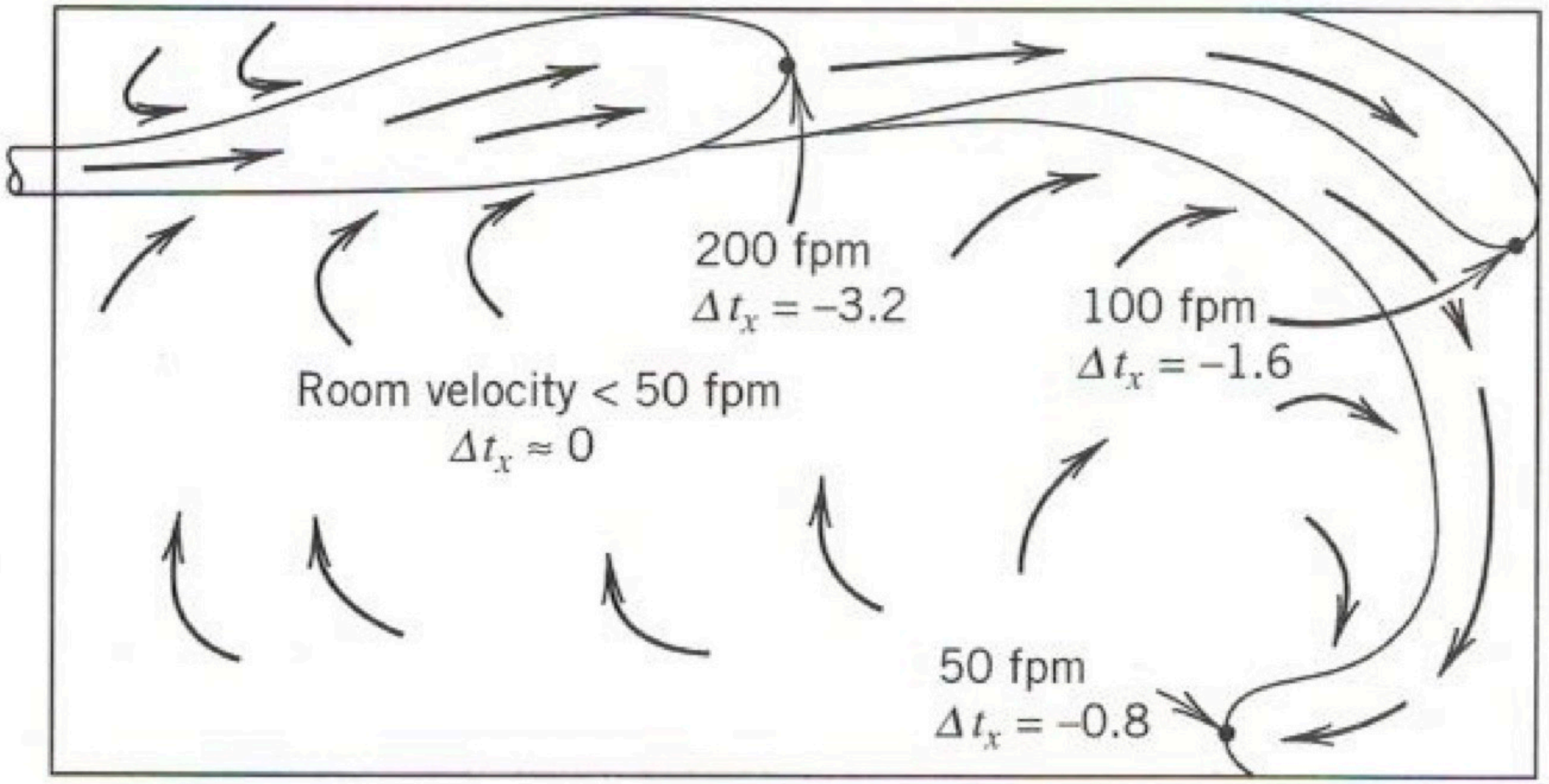
https://www.continentalindustries.com/DD-SupplyRegisters

Mixed Air Systems



https://www.nebb.org/assets/1/7/NEBB_Talk_I_Basics.pdf

Primary, Secondary, and Total Air



Primary, Secondary, and Total Air

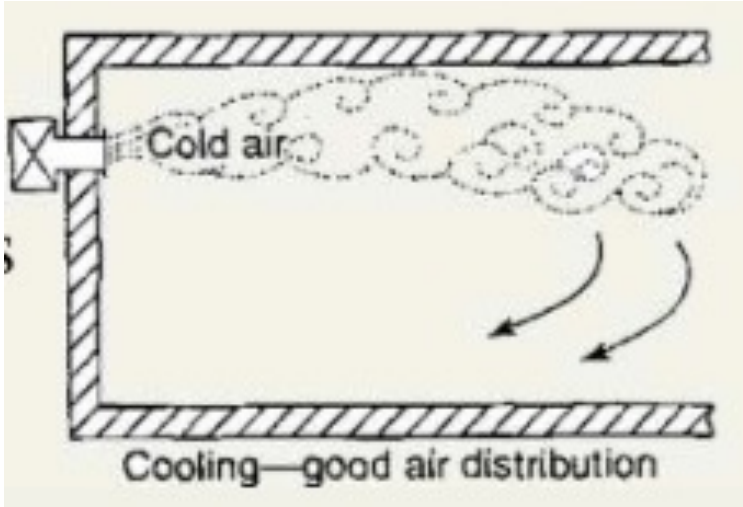
- It is desirable to design a fully mixed system to maintain a constant temperature gradient from the floor to the top of the occupied zone

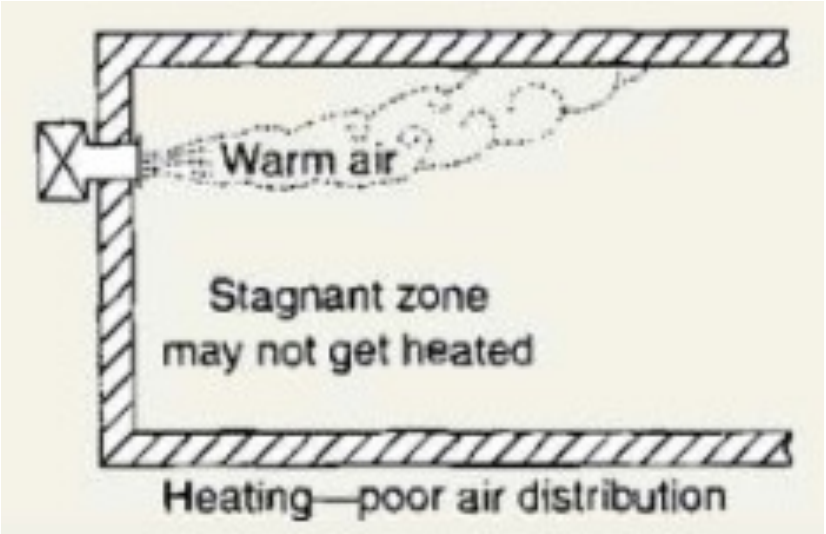
- Displacement ventilation or underfloor systems – not fully mixed

https://www.continentalindustries.com/DD-SupplyRegisters

Basic Flow Patterns

- Location of the air distribution devices has a significant impact on the room flow patterns



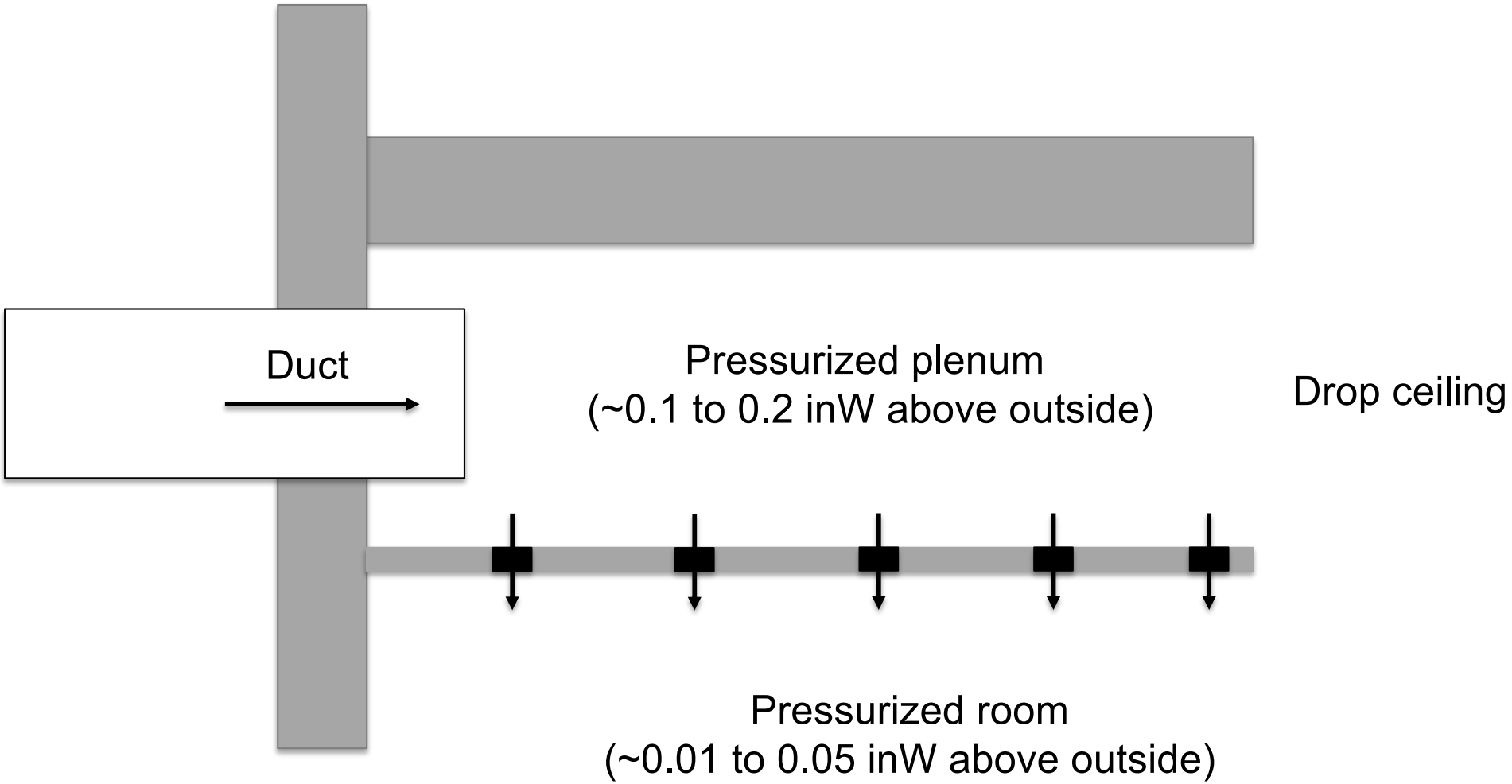


- Good air distribution uses:
  - ❑ Ceiling outlet location for cooling
  - ❑ Floor or sill location under window for heating

https://www.continentalindustries.com/DD-SupplyRegisters

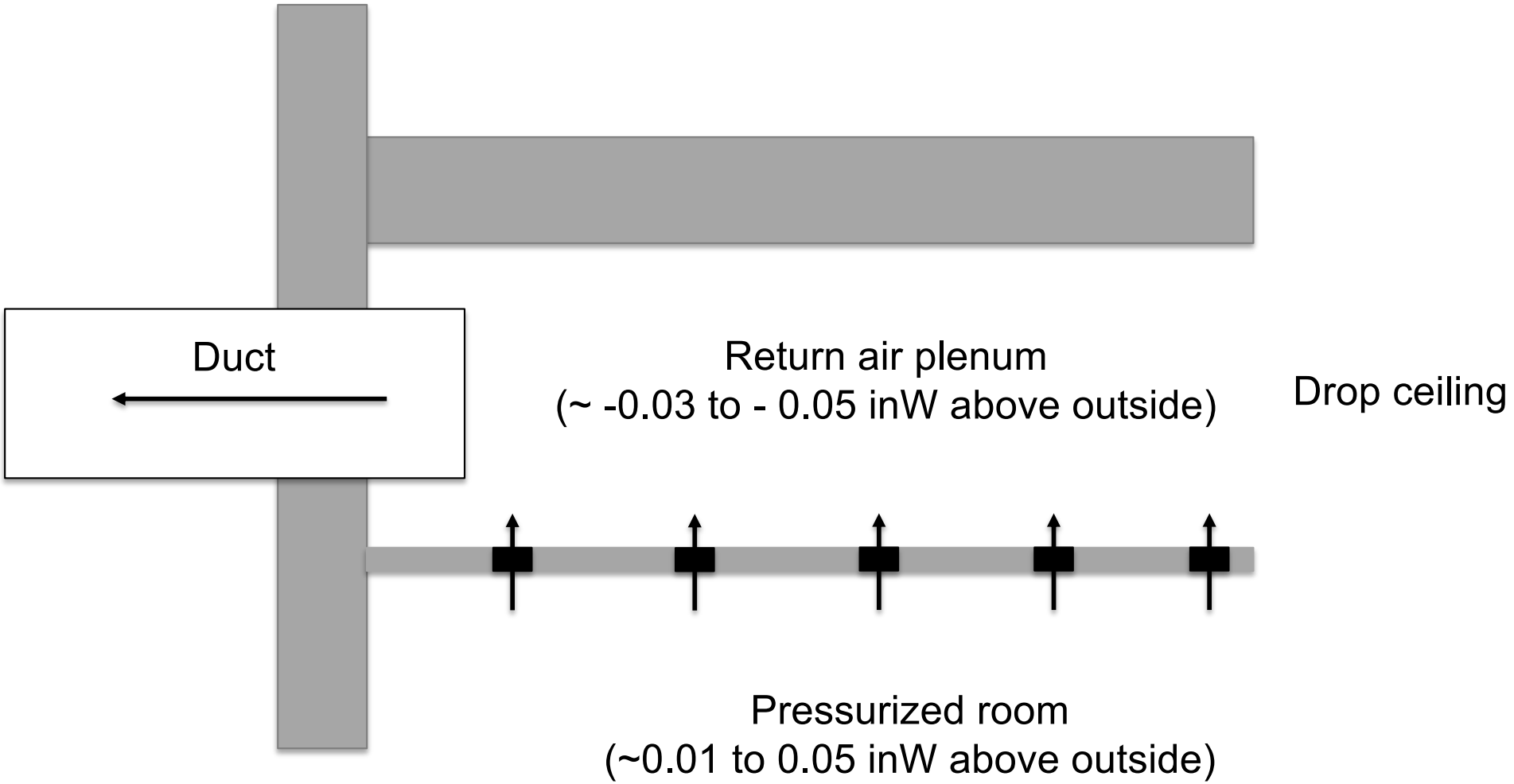
Basic Flow Patterns

- Ceiling plenum (Supply air):



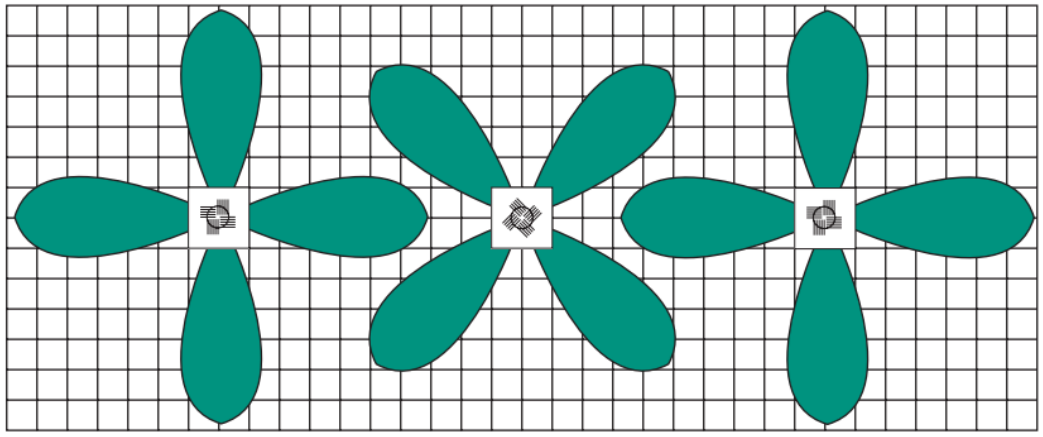
Basic Flow Patterns

- Ceiling plenum (Return air):



Basic Flow Patterns

- For room supply airflow, the major factors are:
  - ❑ Total room supply airflow quantity
  - ❑ Room supply air temperature
  - ❑ Diffuser type
  - ❑ Diffuser throw height (or outlet velocity) or mixing provided by a floor diffuser



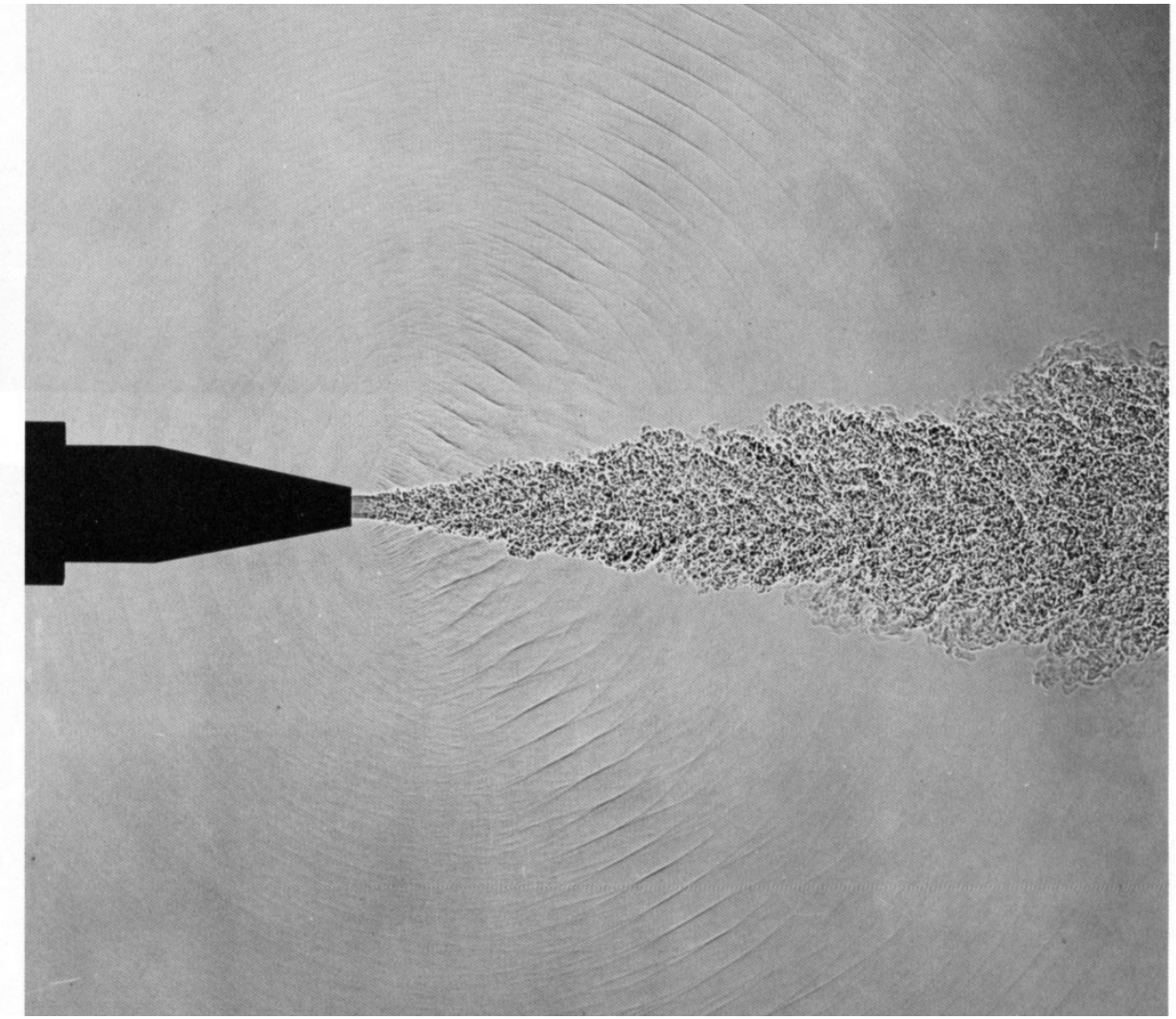
Basic Flow Patterns

- For heat loads, the major factors are:
  - ❑ Magnitude and number of loads in space
  - ❑ Load type (point or distributed sources)
  - ❑ Elevation of load (e.g., overhead lighting, person standing on floor, glazing)
  - ❑ Radiative/convective split
  - ❑ Other heat sources

BEHAVIOR OF JETS

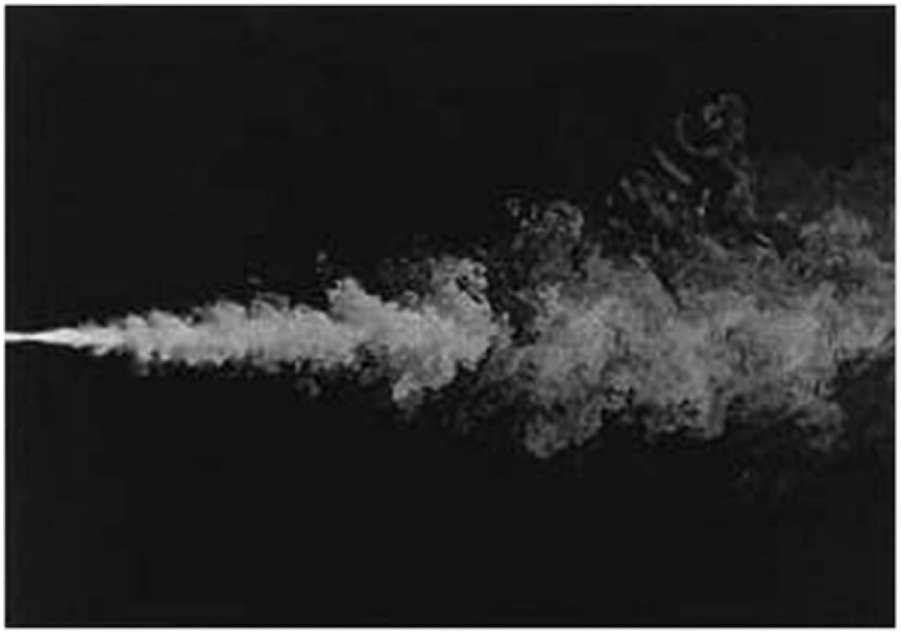
Behavior of Jets

- High speed supply air jets from the outlets mixes with room air to maintain indoor thermal comfort



Behavior of Jets

$0 \leq \frac{X}{D} \leq 200$



$Re = 10{,}000$

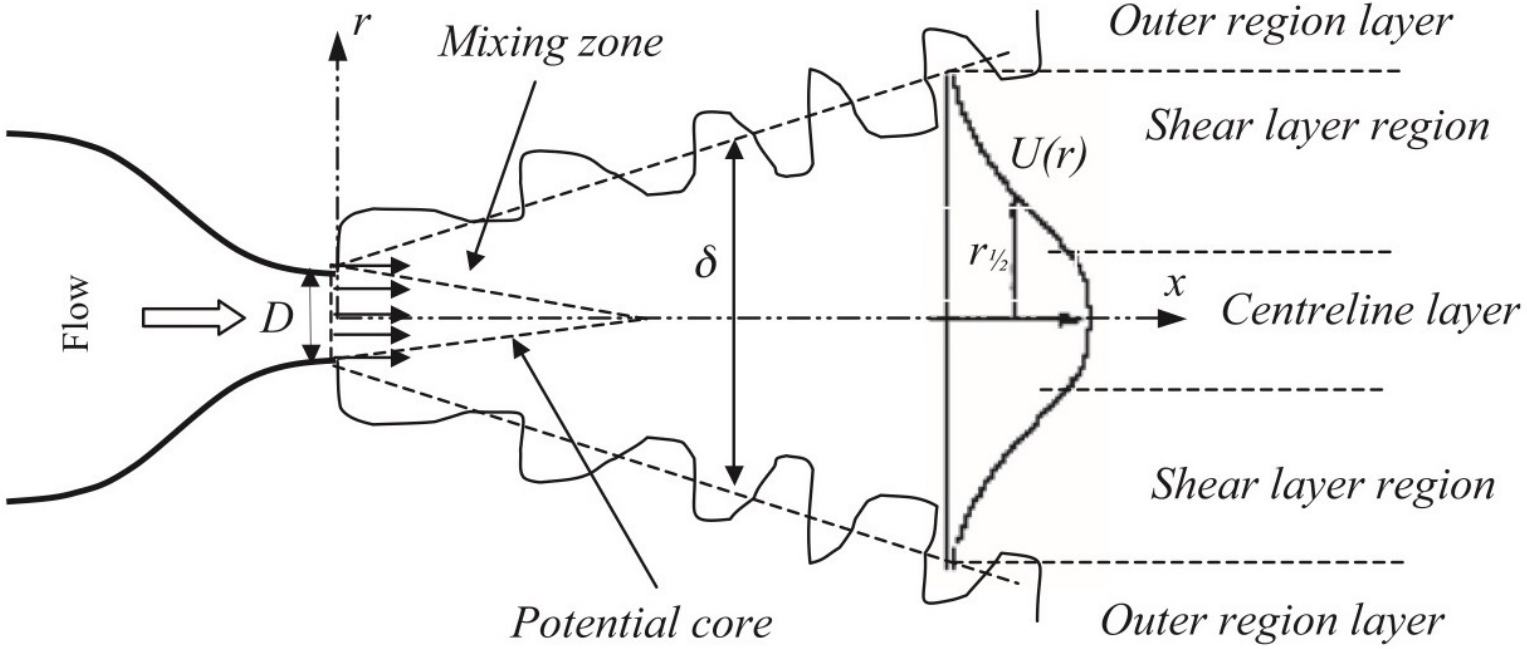
$0 \leq \frac{X}{D} \leq 35$

$Re = 2{,}500$

Ball et al., The flow field in turbulent round free jets

Behavior of Jets

- High speed supply air jets from the outlets mixes with room air to maintain indoor thermal comfort



- This air mixing
  - ❑ Leads to space heat transfer and resultant velocity reduction
  - ❑ Needs to occur outside of the occupied zone

Ball et al., The flow field in turbulent round free jets

Behavior of Jets

- If the supply air temperature is equal to the ambient room air temperature, the air jet is called an *isothermal*

- If the initial temperature of the air jet is different from the ambient air temperature, the air jet is called non-isothermal jet. The air temperature difference affects:

  - ❑ Jet trajectory
  - ❑ Location at which it attaches to and separates from the ceiling/floor
  - ❑ Throw

Behavior of Jets

- If an air jet is not obstructed or affected by walls, ceiling, or other surfaces, it is considered as a *free jet*

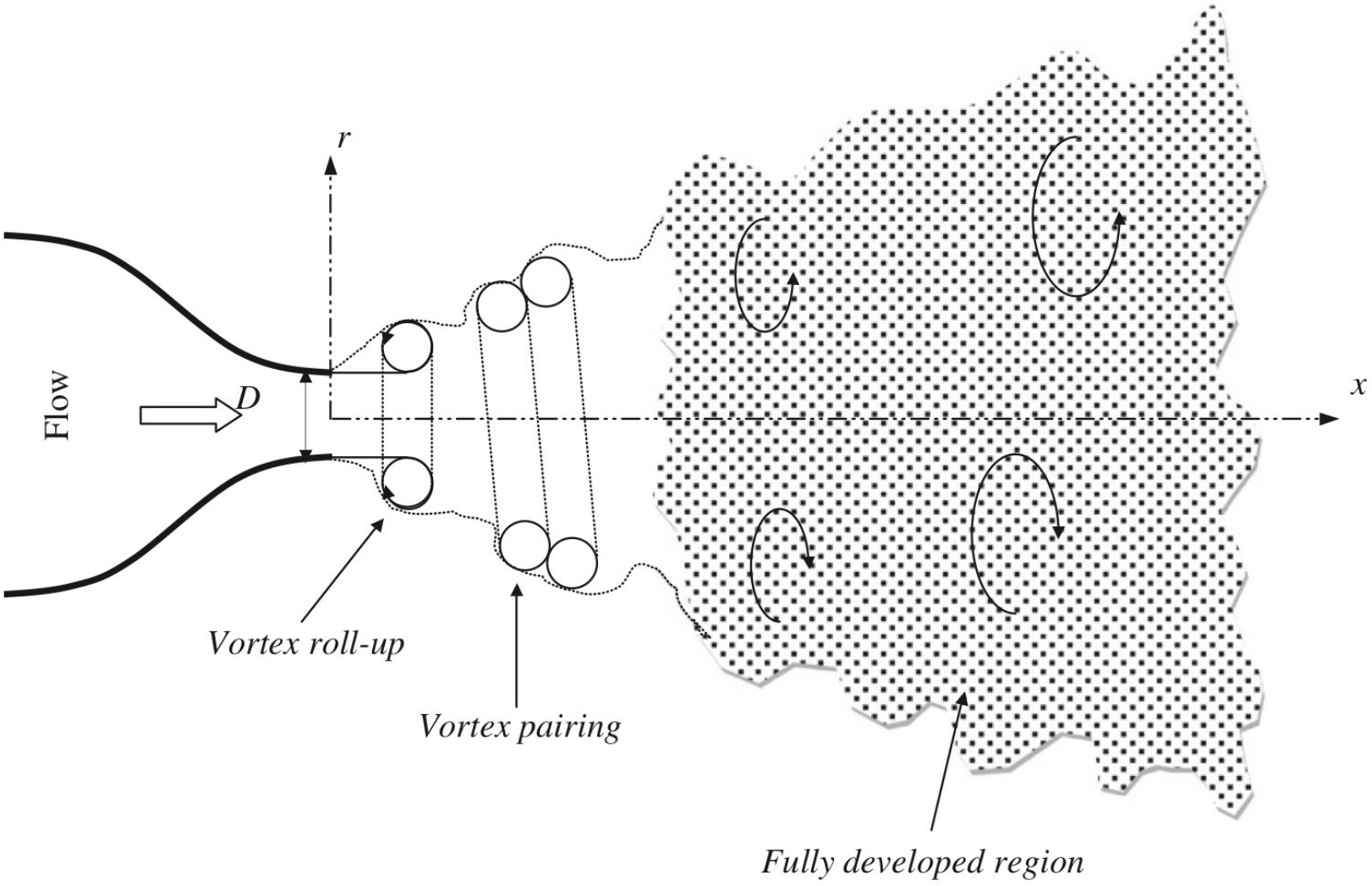
- Usually, the outlet area is small compared to the dimensions of the space normal to air jet. We can consider it free jet as long as:

$$X \leq 1.5\sqrt{A_R}$$

- X: Distance from face of the outlet (ft)
- A_R: Cross-sectional area of confined space normal to jet (ft^2)

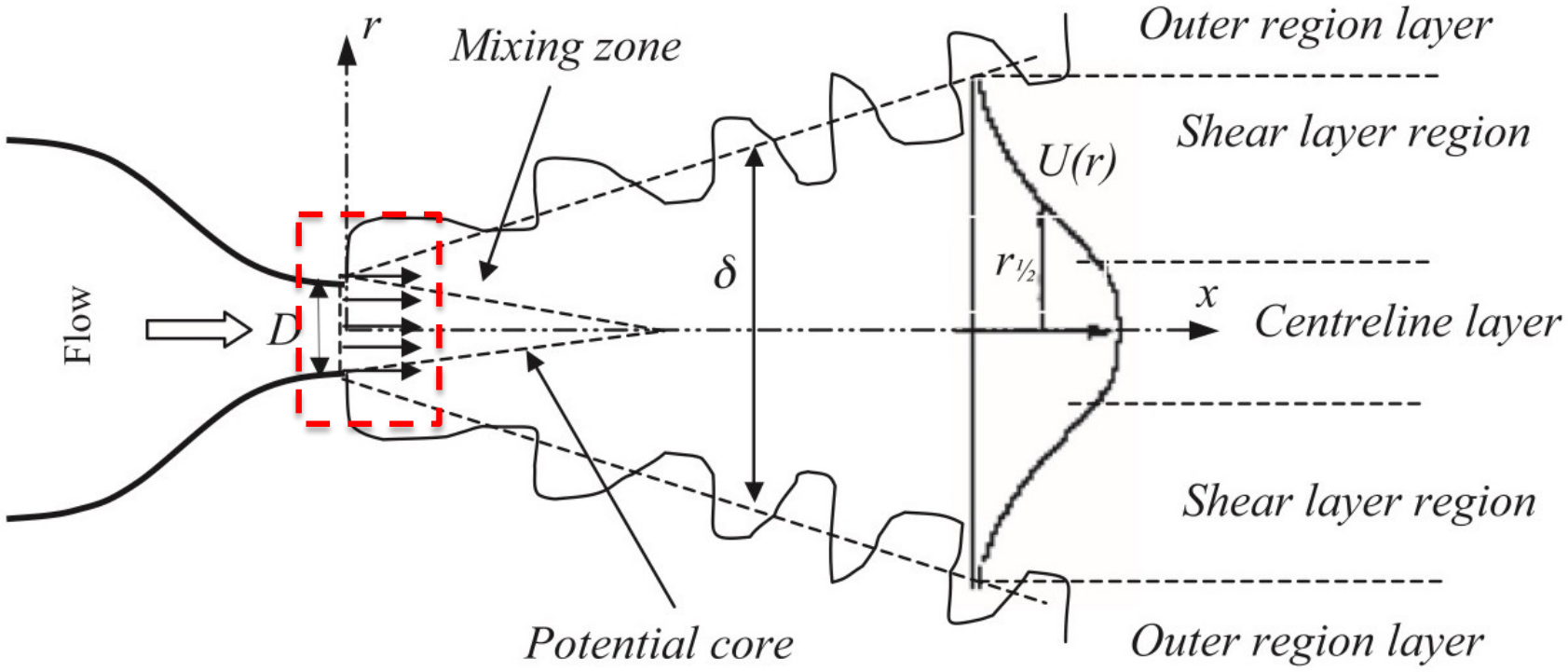
Behavior of Jets

- There are four distinct regions in an air jet.



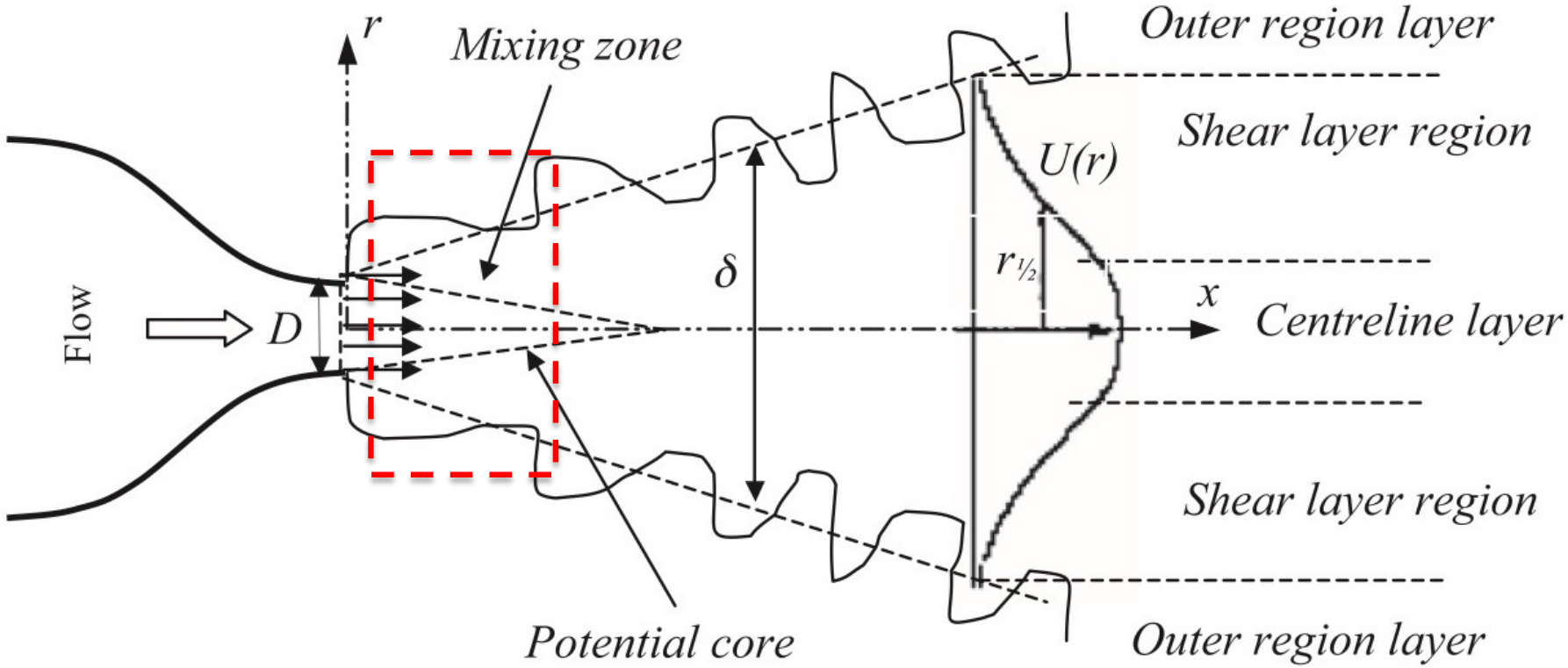
Behavior of Jets

- Zone 1 (Core Zone):
  - ❑ Extend from the outlet face
  - ❑ Velocity and temperature of airstream remains relatively unchanged



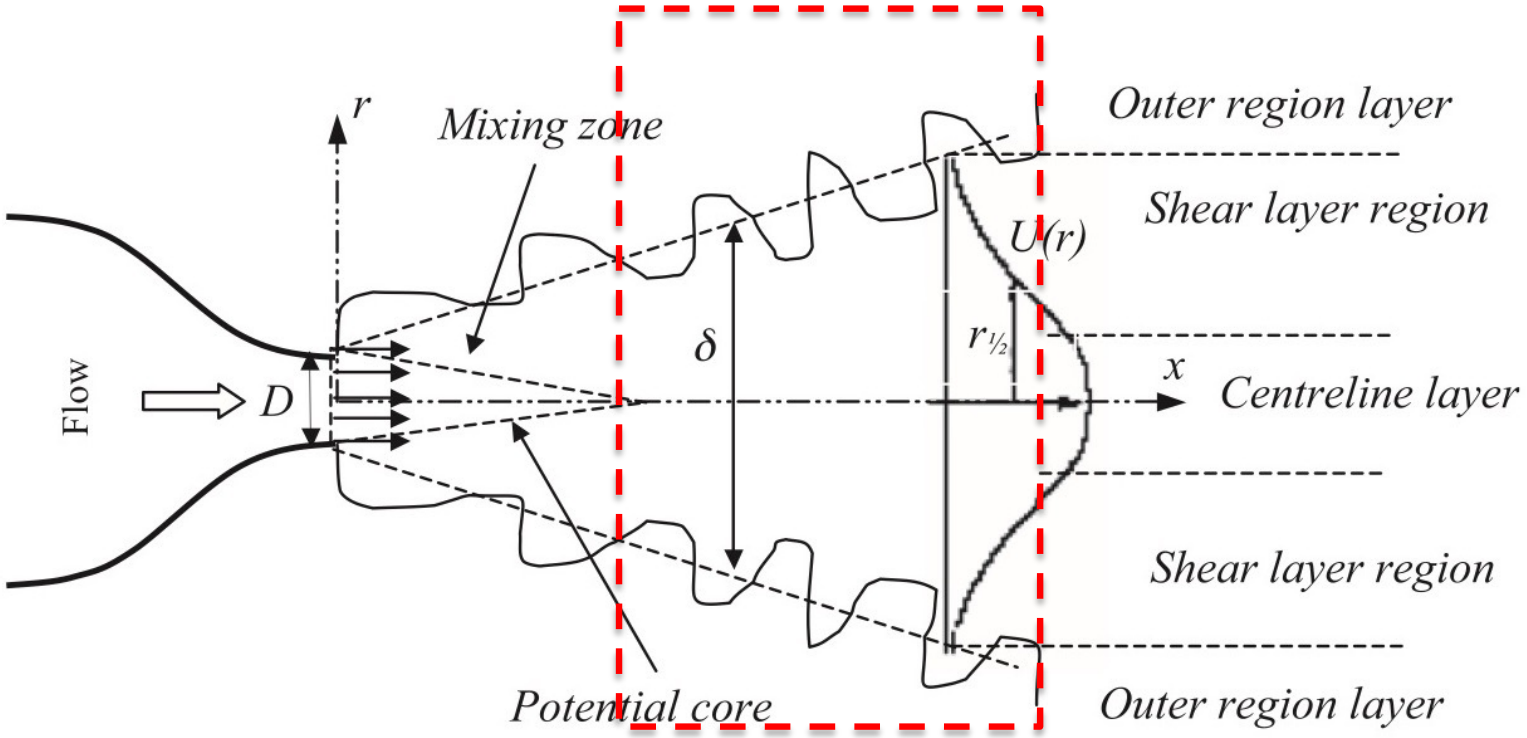
Behavior of Jets

- Zone 2 (Transition Zone):
  - ❑ Transition zone
  - ❑ Length is determined by the type of outlet, aspect ratio of the outlet, initial airflow turbulence



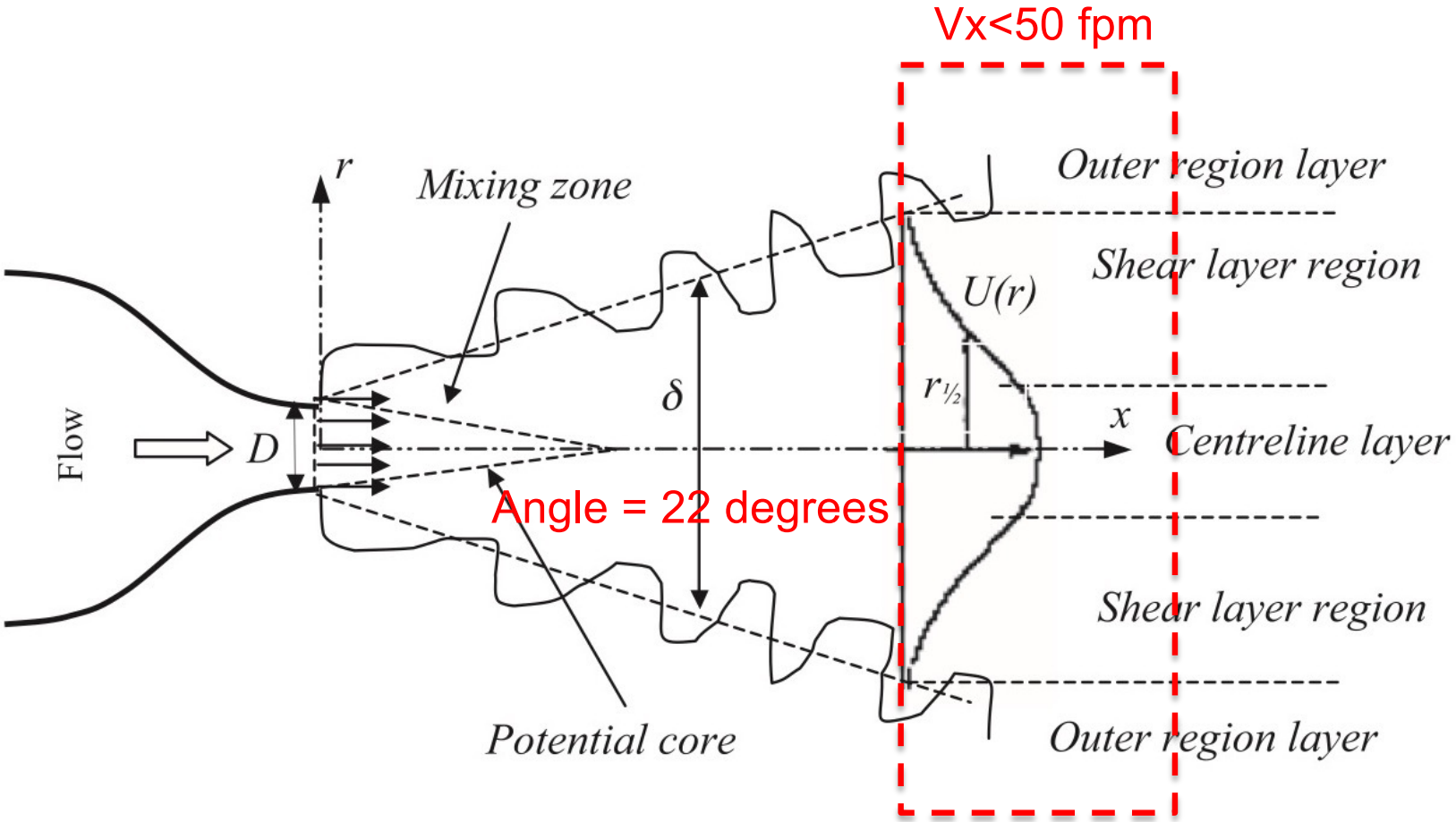
Behavior of Jets

- Zone 3 (Main Zone):
  - ❑ Zone of jet degradation where air velocity/temperature decrease rapidly
  - ❑ Turbulent flow is established and may be 25 to 100 equivalent of the air outlet diameters long
  - ❑ The angle is well-defined (20 degrees to 24 degrees)



Behavior of Jets

- Zone 4 (Terminal Zone):
  - ❑ Most important since it enters the occupied area in this zone
  - ❑ The aim is to have 50 fpm velocity here



Behavior of Jets

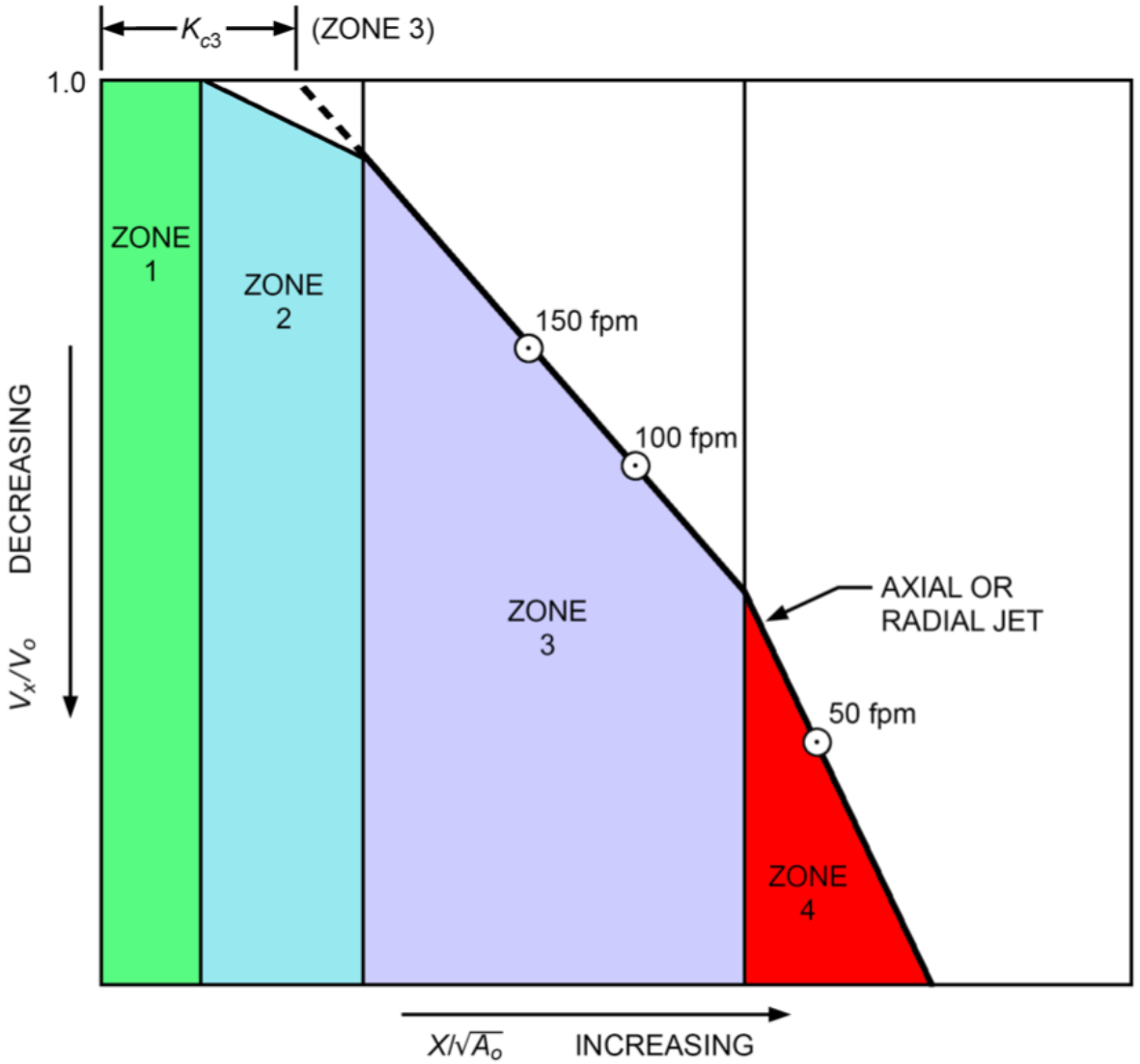


Fig. 11 Zones of Expansion for Axial or Radial Air Jets

Behavior of Jets

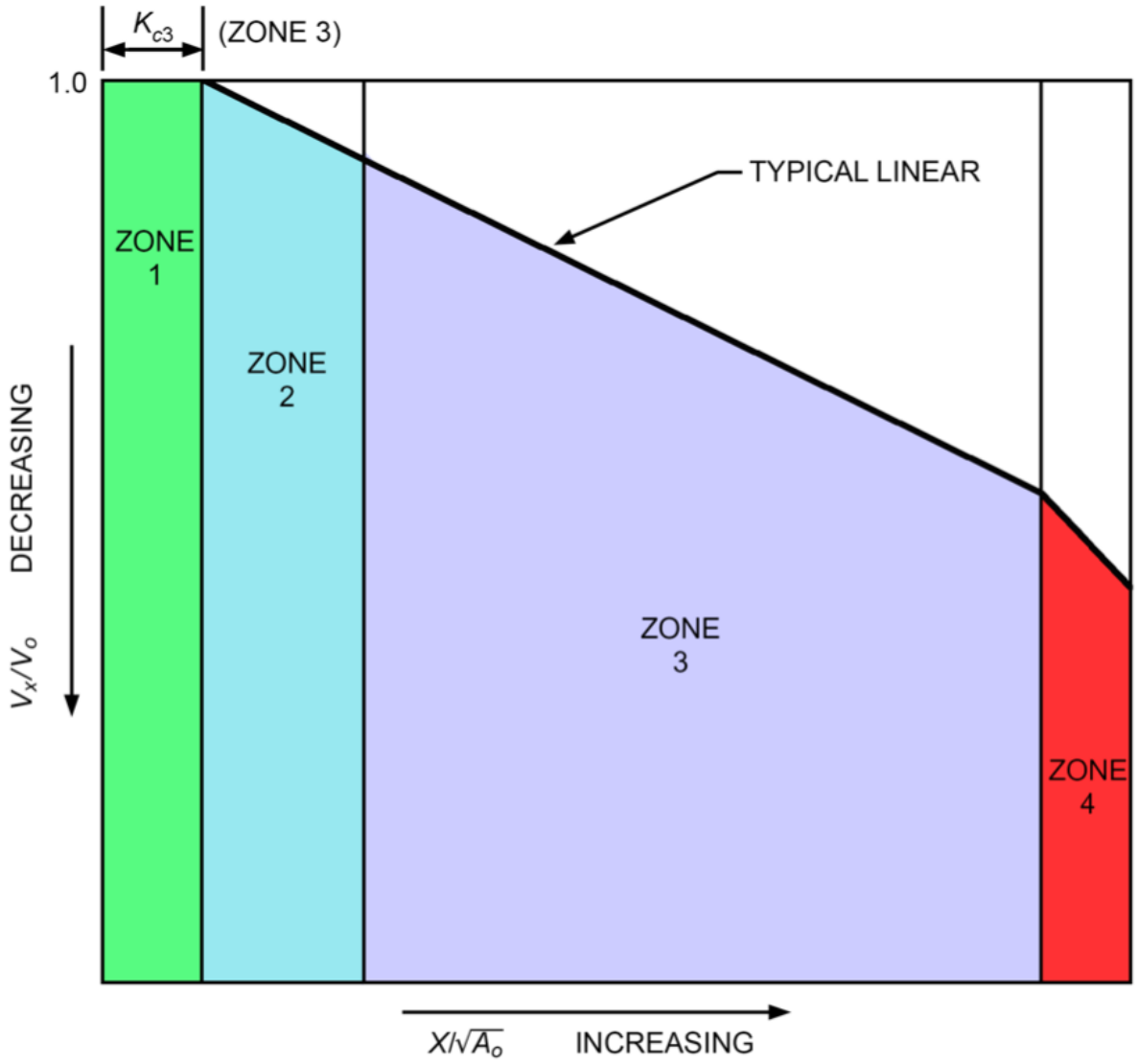
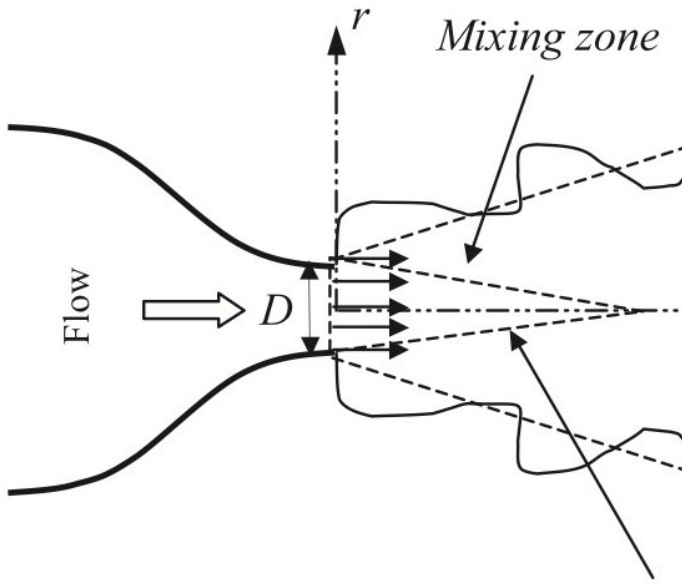


Fig. 12 Zones of Expansion for Linear Air Jets

Behavior of Jets

- Rectangular centerline jet velocity, V_x in Zone III is given by:

$$V_x = \frac{K_{c3} V_o \sqrt{A_o}}{X} = \frac{K_{c3} Q_o}{X\sqrt{A_o}}$$



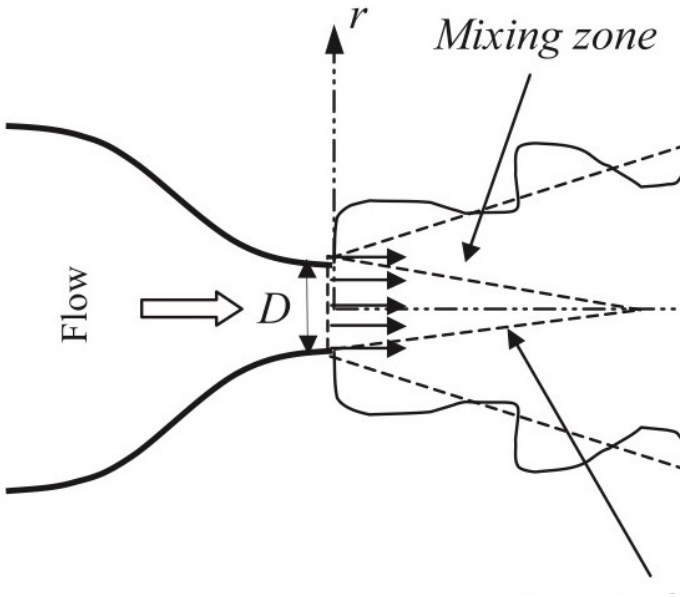
- Where
  - K_{c3}: Centerline velocity constant
  - Q_o: Discharge from outlet (cfm)
  - V_o: Average initial discharge velocity (fpm)
  - X: Distance from outlet to the point of measurement (ft) = Throw
  - A_o: Area corresponding to initial velocity (ft^2)

Entrainment Ratio

- Circular jets and jets from long slots

$$\frac{Q_x}{Q_o} = \frac{2X}{K_{c3}\sqrt{A_o}} \qquad \rightarrow V_x = \frac{K_{c3}Q_o}{X\sqrt{A_o}}$$

$$\frac{Q_x}{Q_o} = 2\frac{V_o}{V_x}$$



- Where
  - Q_x: Total volumetric flow rate at distance X from face of outlet (cfm)
  - Q_o: Discharge from outlet (cfm)
  - X: Distance from outlet to the point of measurement (ft)
  - K_{c3}: Centerline velocity constant
  - A_o: Area corresponding to initial velocity (ft^2)

Behavior of Jets

Table 1 Generic Values for Centerline Velocity Constant K_{c3}[a] for Commercial Supply Outlets for Fully and Partially Mixed Systems, Except UFAD

Outlet Type	Discharge Pattern	A_o	K_{c3}[a]
High sidewall grilles (Figure 4)	0° deflection[b]	Free	5.7
	Wide deflection	Free	4.2
High sidewall linear	Core less than 4 in. high[c]	Free	4.4
	Core more than 4 in. high	Free	5.0
Low sidewall (Figure 7)	Up and on wall, no spread	Free	4.5
	Wide spread[c]	Free	3.0
Baseboard	Up and on wall, no spread	Core	4.0
	Wide spread	Core	2.0
Floor grille (Figure 5)	No spread[c]	Free	4.7
	Wide spread	Free	1.6
Ceiling (Figure 2)	360° horizontal[d]	Neck	1.1
	Four-way; little spread	Neck	3.8
Ceiling linear slot (Figure 3)	Horizontal/vertical along surface[c]	Free	5.5
	Horizontal/vertical free jet[c]	Free	3.9
	Free jet (air curtain units)	Free	6.0

[a]Generic values shown for example purposes only. See manufacturer's data for specific K_{c3} values.
[b]Free area is about 80% of core area.
[c]Free area is about 50% of core area.
[d]Cone free area is greater than duct area.

CLASS ACTIVITY

Class Activity

- **Example (Grille Throw):** Consider a 12” by 18” high sidewall grille with zero deflection and 11.25” by 17.25” core area. The airflow rate is 600 cfm. Calculate the throw to:

  - ❑ 50 fpm
  - ❑ 100 fpm
  - ❑ 150 fpm

Class Activity

- **Solution:**

Throw at 50 fpm:

Table 1 Generic Values for Centerline Velocity Constant K_{c3}[a] for Commercial Supply Outlets for Fully and Partially Mixed Systems, Except UFAD

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High sidewall grilles (Figure 4)	0° deflection[b]	Free	5.7
	Wide deflection	Free	4.2
High sidewall linear	Core less than 4 in. high[c]	Free	4.4

$$X = \frac{K_c Q_o}{V_x \sqrt{A_o}} \ (Zone\ III)$$

$$X = \frac{(5.7)(600\ cfm)}{V_x \sqrt{\frac{11.25 \times 17.25}{144}}} = \frac{2{,}946}{V_x} \qquad X(at\ 50\ fpm) = \frac{2{,}946}{50} = 59\ ft$$

50 fpm is in zone IV. Zone IV is typically 20% to 30% less than the calculated value in Zone III

$$X = 59(0.8) = 47\ ft$$

Class Activity

- **Solution:**

Throw at 100 fpm:

$$X(at\ 100\ fpm) = \frac{2{,}946}{100} = 29.5ft$$

Throw at 150 fpm:

$$X(at\ 150\ fpm) = \frac{2{,}946}{150} = 19.6ft$$