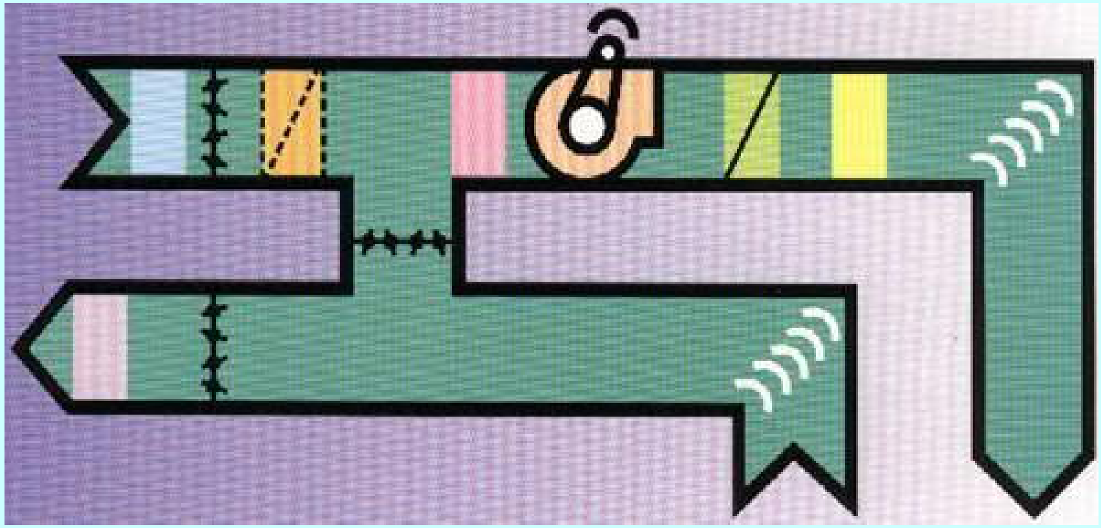
MEBS6008 Environmental Services II

http://www.mech.hku.hk/bse/MEBS6008/



Space Air Diffusion II

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Jan 2015

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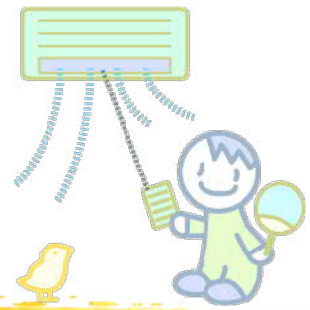
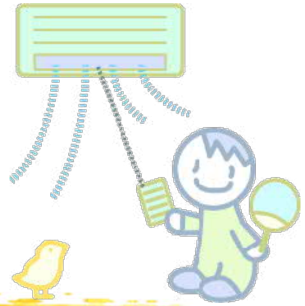
- Cold Air Distribution
- Displacement Flow
- Underfloor Air Distribution
- Unidirectional Flow
- Projecting Flow
- Air Flow Analysis

Cold Air Distribution



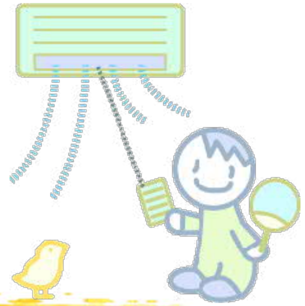
- Lower supply air temp. = 4.4 to 7.2 ^{o}C
- Conventional air distribution = 12.7 to 15.0 ^{o}C
- Applied mainly in conjunction with ice storage systems
  - Lower chw temp. (1.1 to 2.2 ^{o}C) (from ice storage)
- Main advantages:
  - Reduce design supply volume flow (larger ΔT)
  - Air-side components can be downsized
  - Fan energy use can be reduced
  - Reduced fan sound levels
- Drawbacks: dumping of cold air jet & IAQ issues

Cold Air Distribution

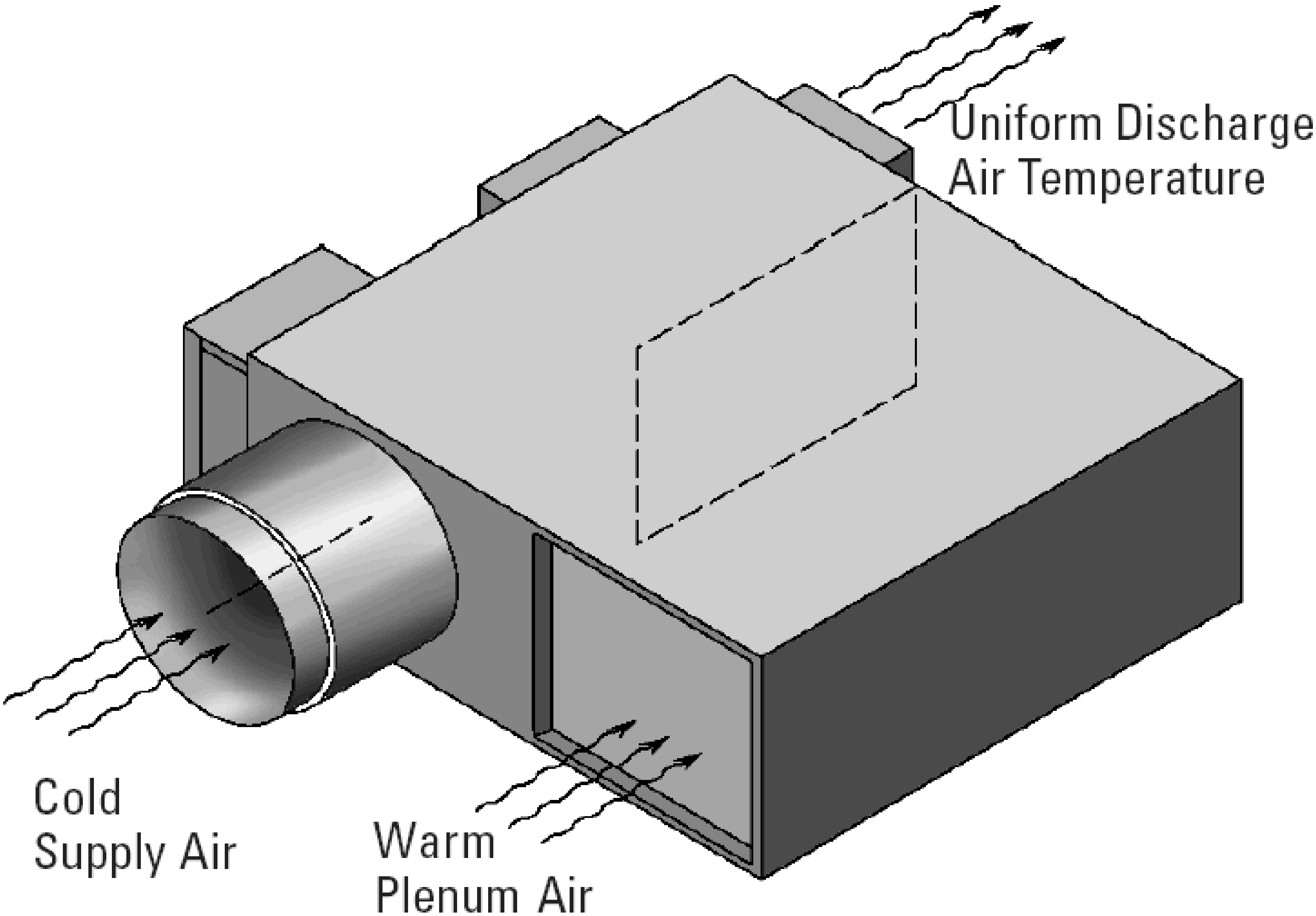


- Design considerations
  - Condensation
    - Cooled surfaces shall be well insulated & sealed
  - Comfort
    - Air supplied at lower velocities: diffuser performance is affected (e.g. dumping & stagnant at low load)
  - Indoor air quality
    - Minimum ventilation flow is required; may need reheat
  - Controls
    - Start-up & shut-down, humidity controls, VAV, etc.

Cold Air Distribution



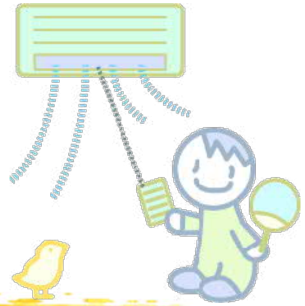
- Two methods for cold air space diffusion
  - High induction nozzle diffusers
    - Direct from AHU or package unit
  - Fan-powered VAV boxes
    - Mix low-temperature supply air with return air before supplied to the conditioned space
- Characteristics of cold air distribution
  - Higher $\sqrt{Ar}$ / Do value
  - Higher supply air velocity & jet turbulence
  - Good surface effect (adequate throw, small drop)
  - ADPI $\geq$ 80 at both design & reduced airflow



Series flow fan power terminal

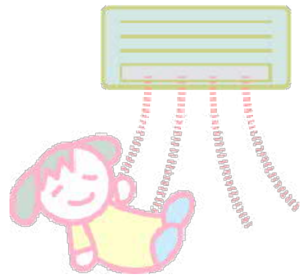
(Source: http://www.price-hvac.com)

Cold Air Distribution



- Design checks
  - Performance of ceiling & slot diffusers
    - Any difference compared with conventional system?
  - Fan-powered VAV boxes
    - In parallel or in series
    - Mixing w/ return air to get suitable supply temp.
    - Provide space air movement
    - Higher noise & more maintenance
  - Surface condensation
    - Sufficient thermal insulation is needed to prevent this

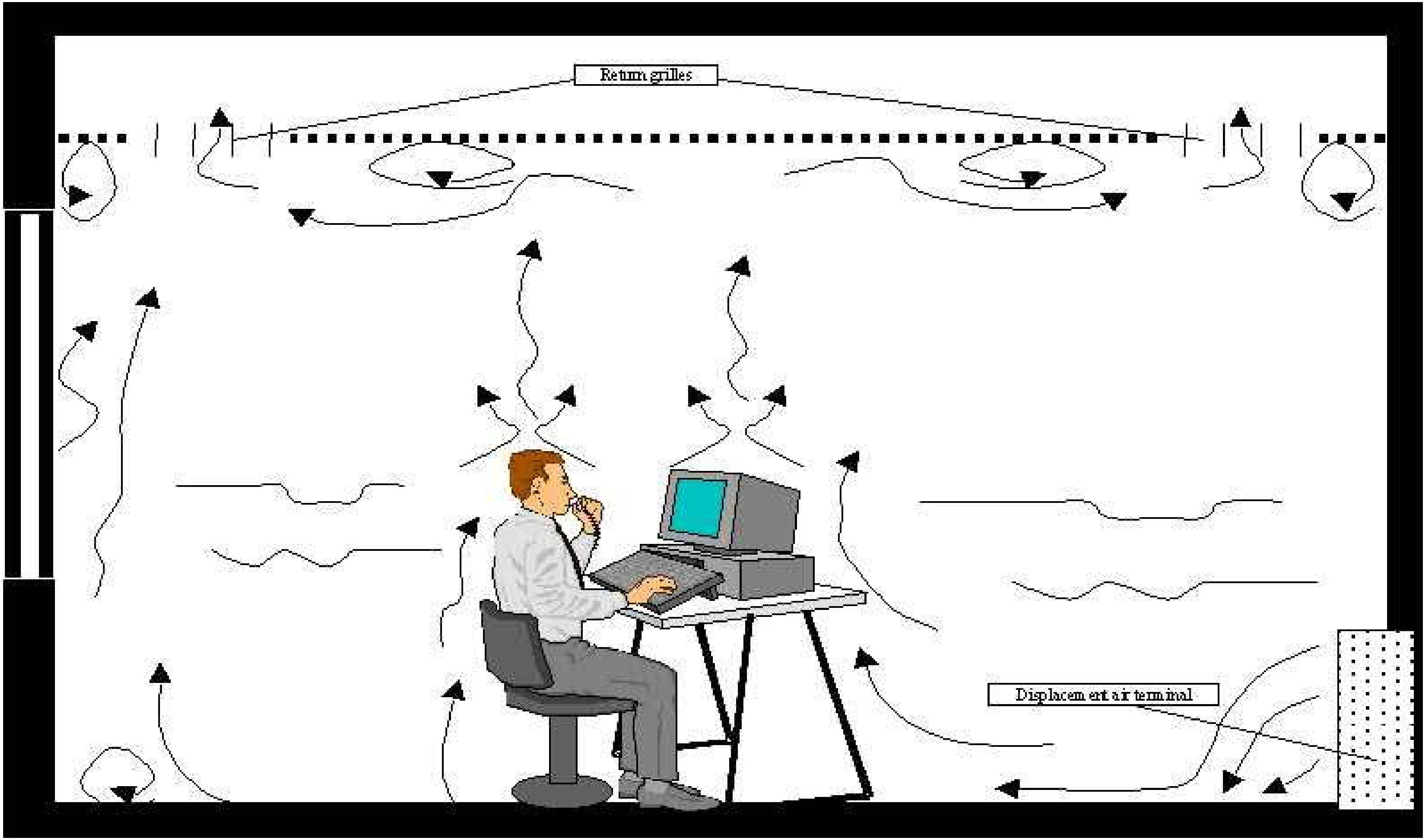
Displacement Flow



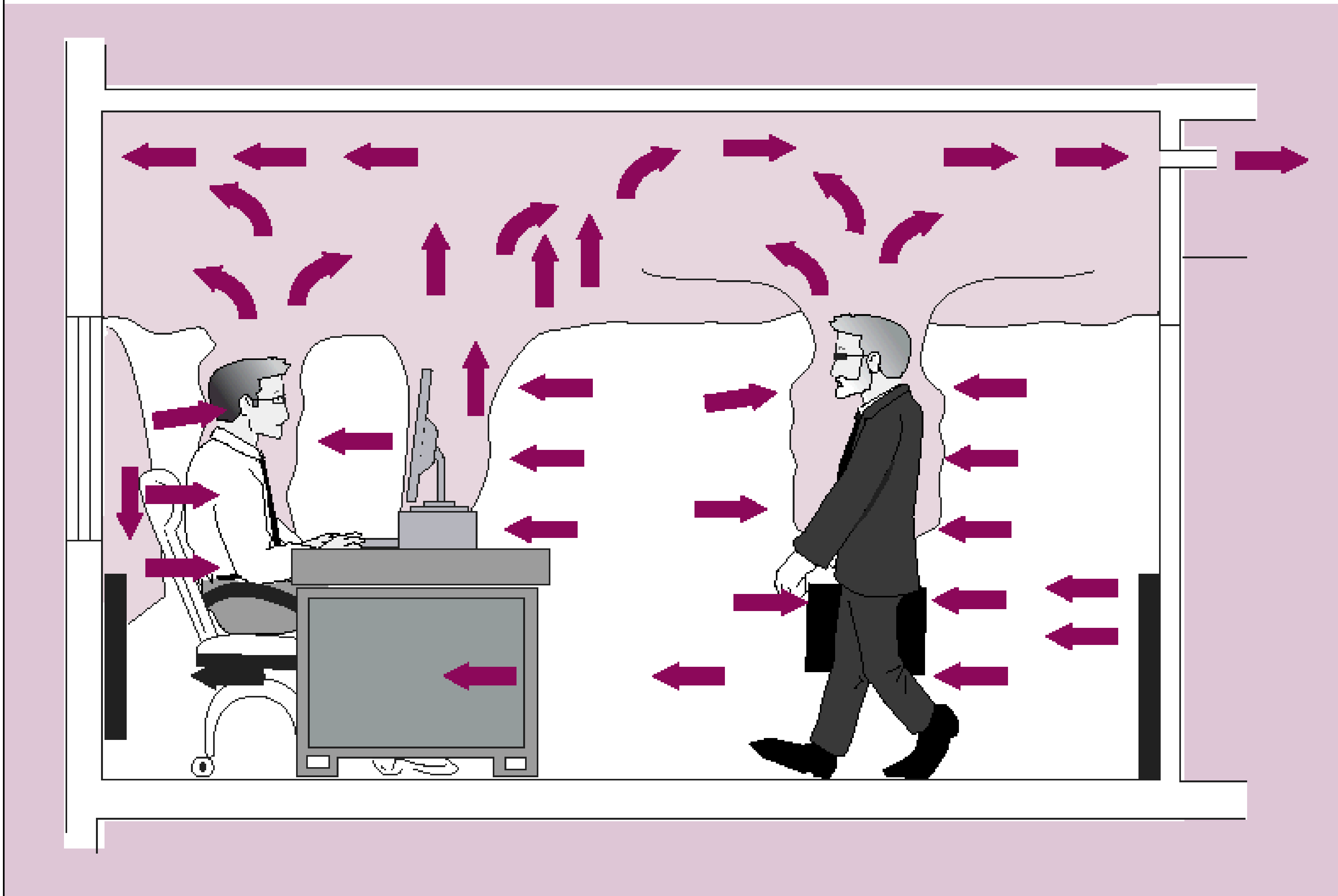
- Displacement flow
  - Cold supply air at a velocity nearly equal to the required velocity and displace the original air with piston-like airflow w/o mixing
  - If properly designed, it can give:
    - Better IAQ in occupied zone
    - Higher space diffusion effectiveness
    - Low turbulence intensities & fewer draft problems
  - Drawbacks:
    - Require greater supply volume flow rate
    - Higher construction cost

Displacement ventilation (DV)

Mixing ventilation (MV)

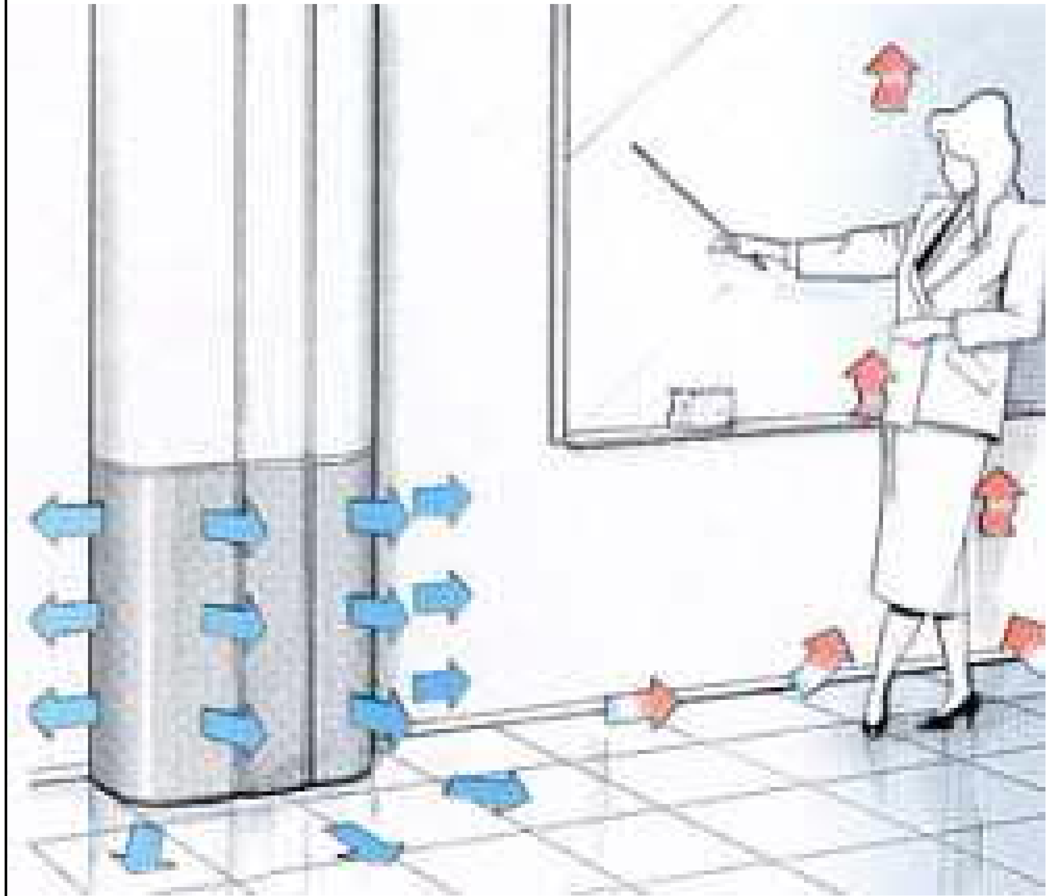


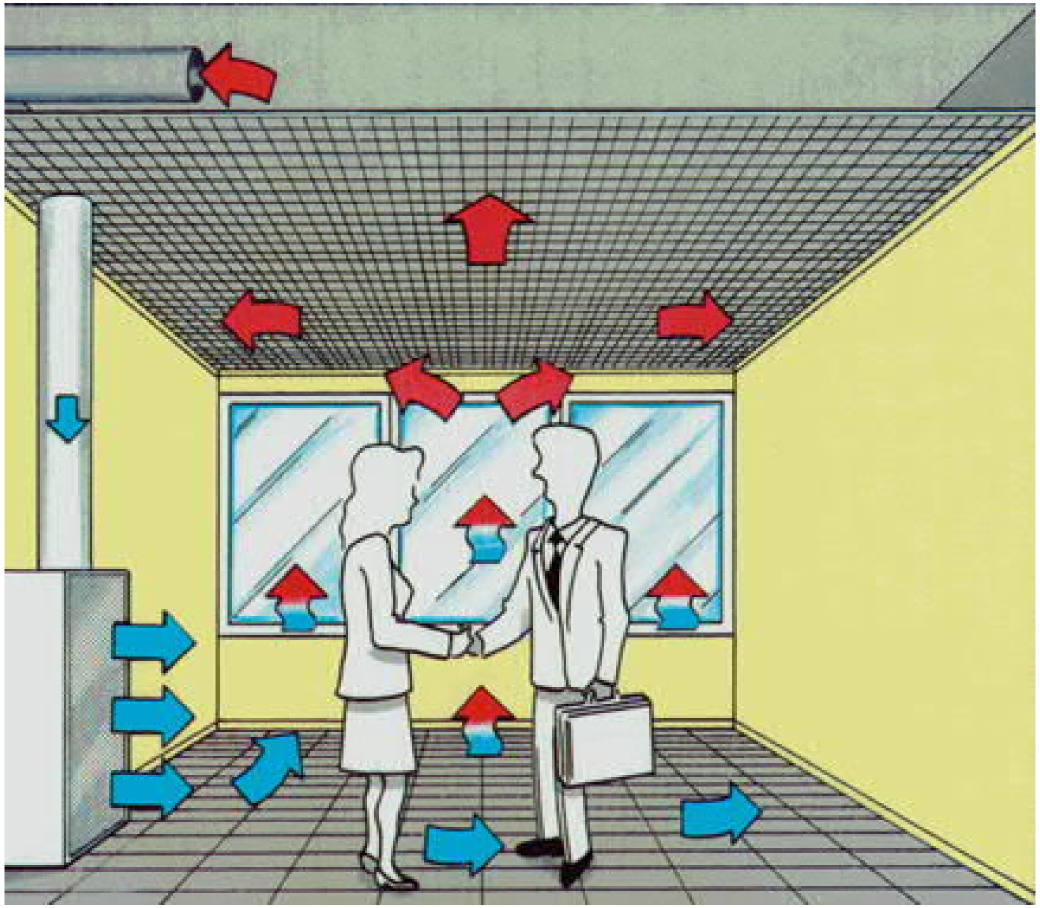
Typical displacement ventilation room layout



Displacement flow characteristics

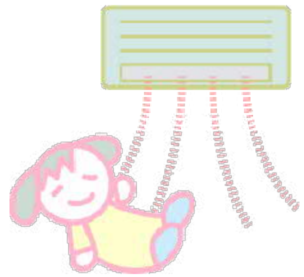
(Source: http://www.price-hvac.com)





Displacement ventilation system

Displacement Flow



- Airflow patterns
  - Because of low discharge velocity, air motion is influenced to a large degree by convection flows
    - Convection flows (or thermal plumes) are created by heat sources, e.g. people, equipment, warm windows
    - Cold sinks (e.g. cold windows) may create flows down
- Airflow penetration
  - Supply air spread across the floor in a thin layer, filling the entire space
  - Flow around & beyond obstructions

Figure 5 - Horizontal Air Movement

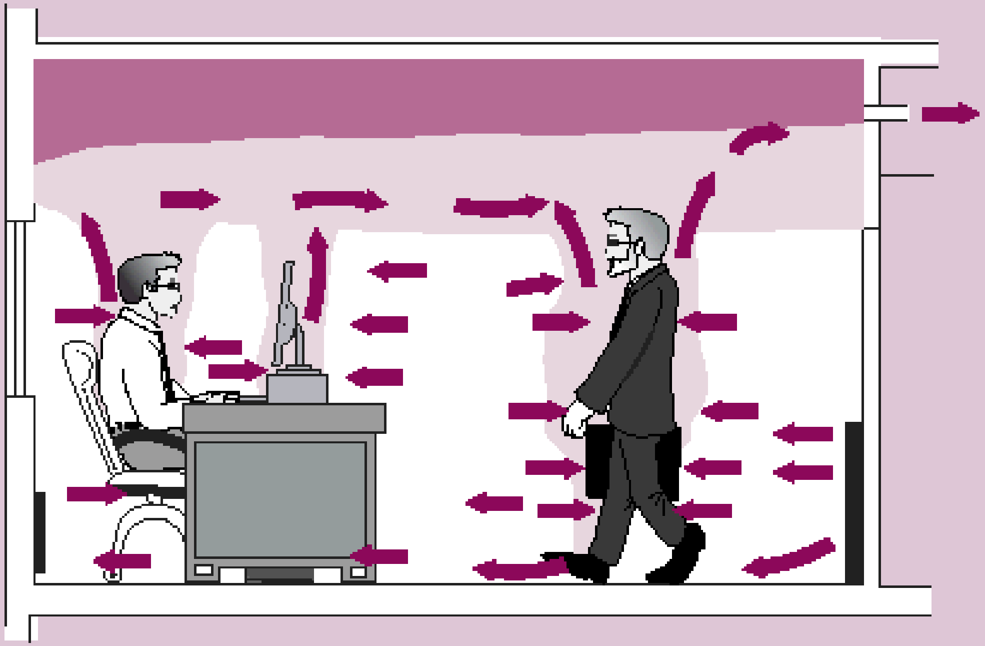
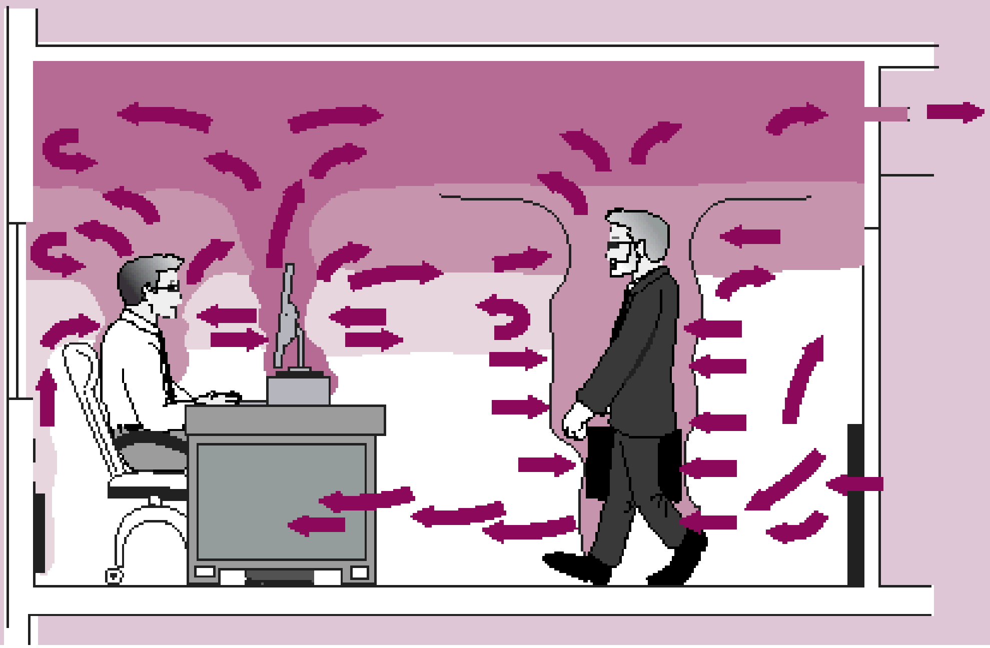
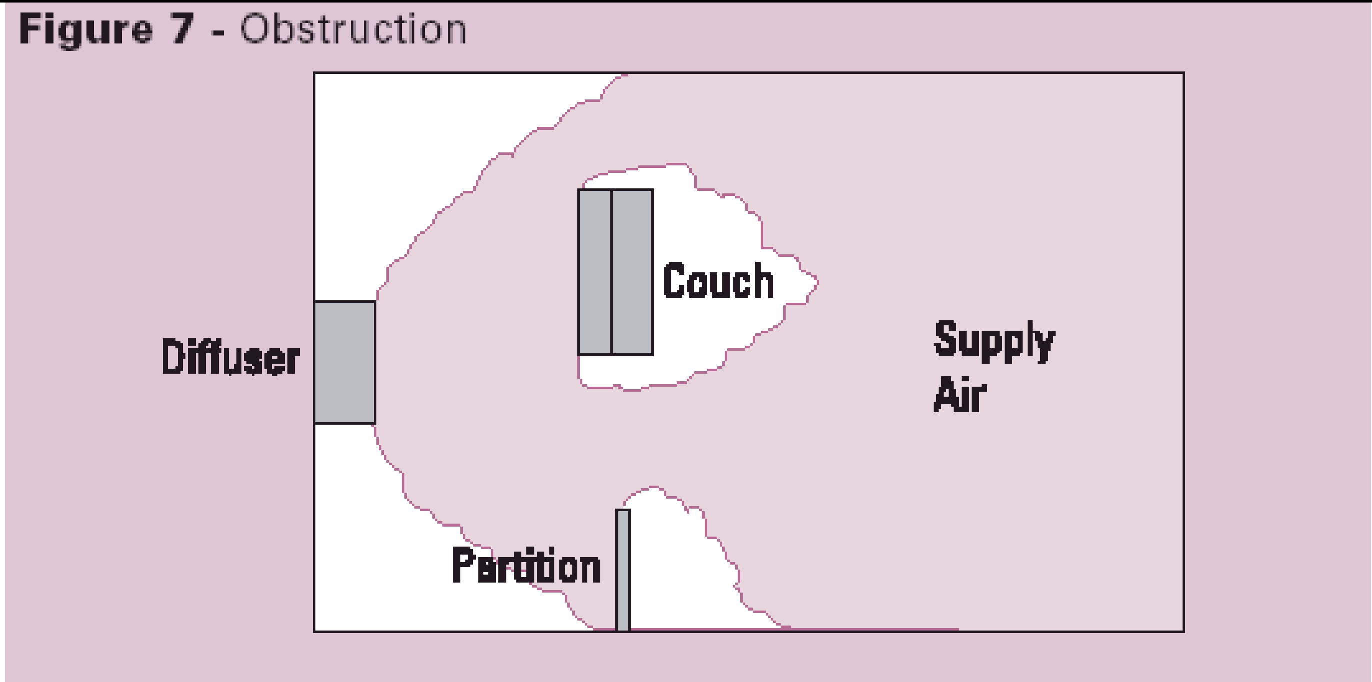


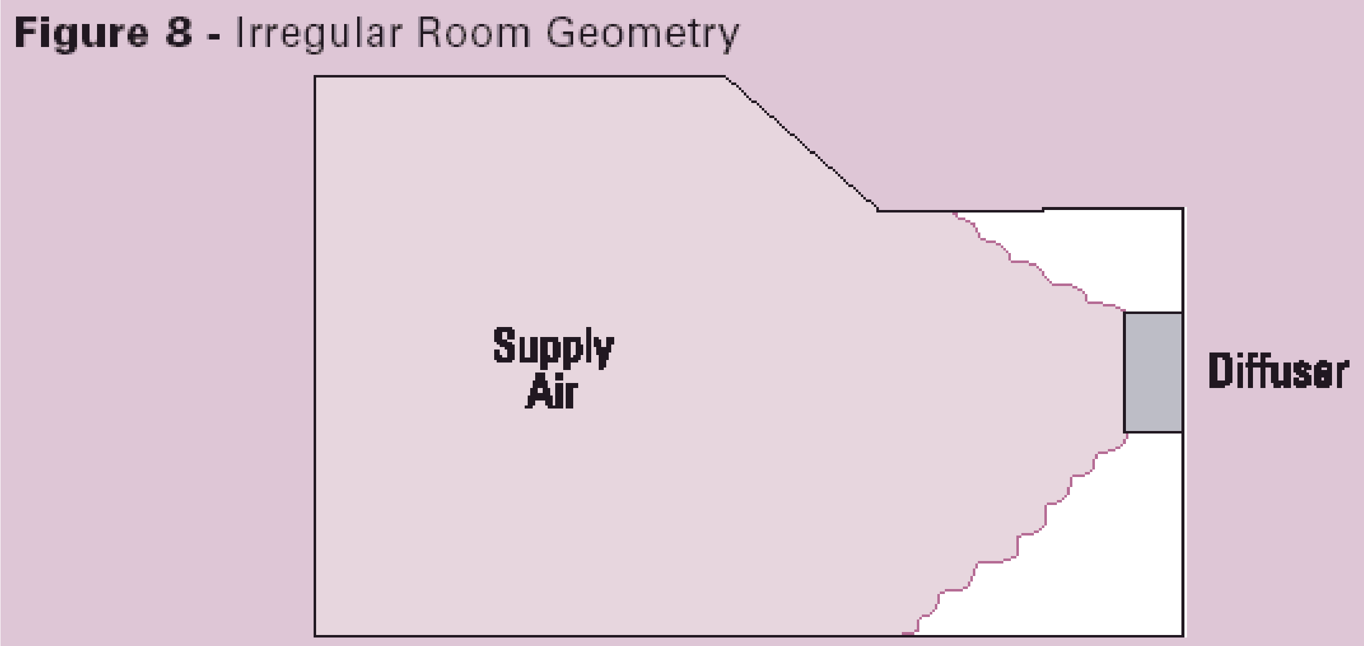
Figure 6 - Vertical Air Movement



Displacement flow patterns

(Source: http://www.price-hvac.com)



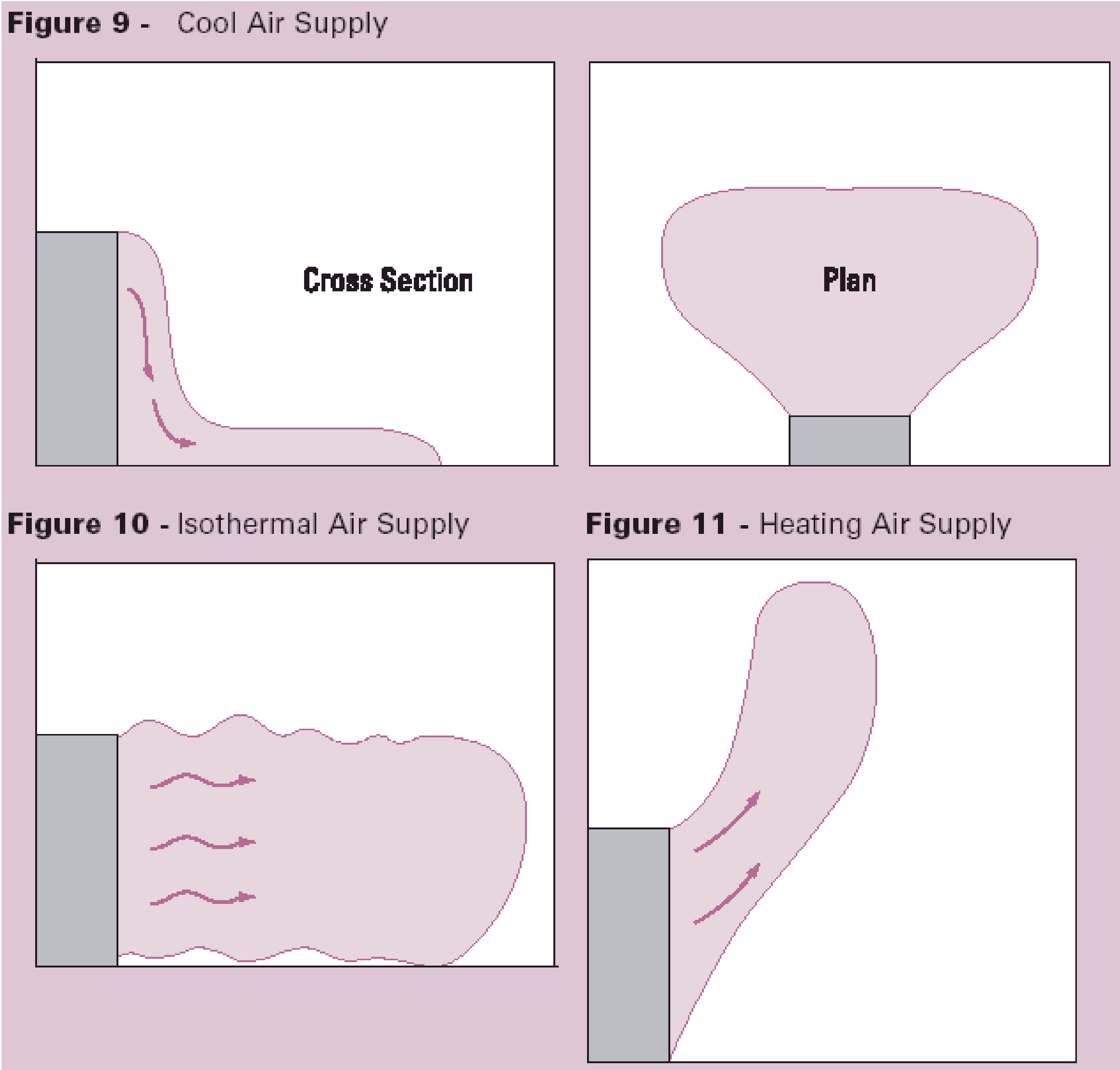


Airflow penetration

(Source: http://www.price-hvac.com)

Displacement Flow

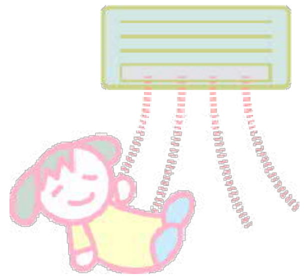
- Diffuser airflow patterns
  - To avoid draft, displacement diffuser shall deliver the supply air uniformly at low velocity
    - With internal equalization baffle & low free area face
  - For cool air supply, it will falls towards the floor
  - For isothermal air, it will distribute horizontally
  - For heated air, the discharge air will rise
    - Therefore, it is not recommended to supply heated air



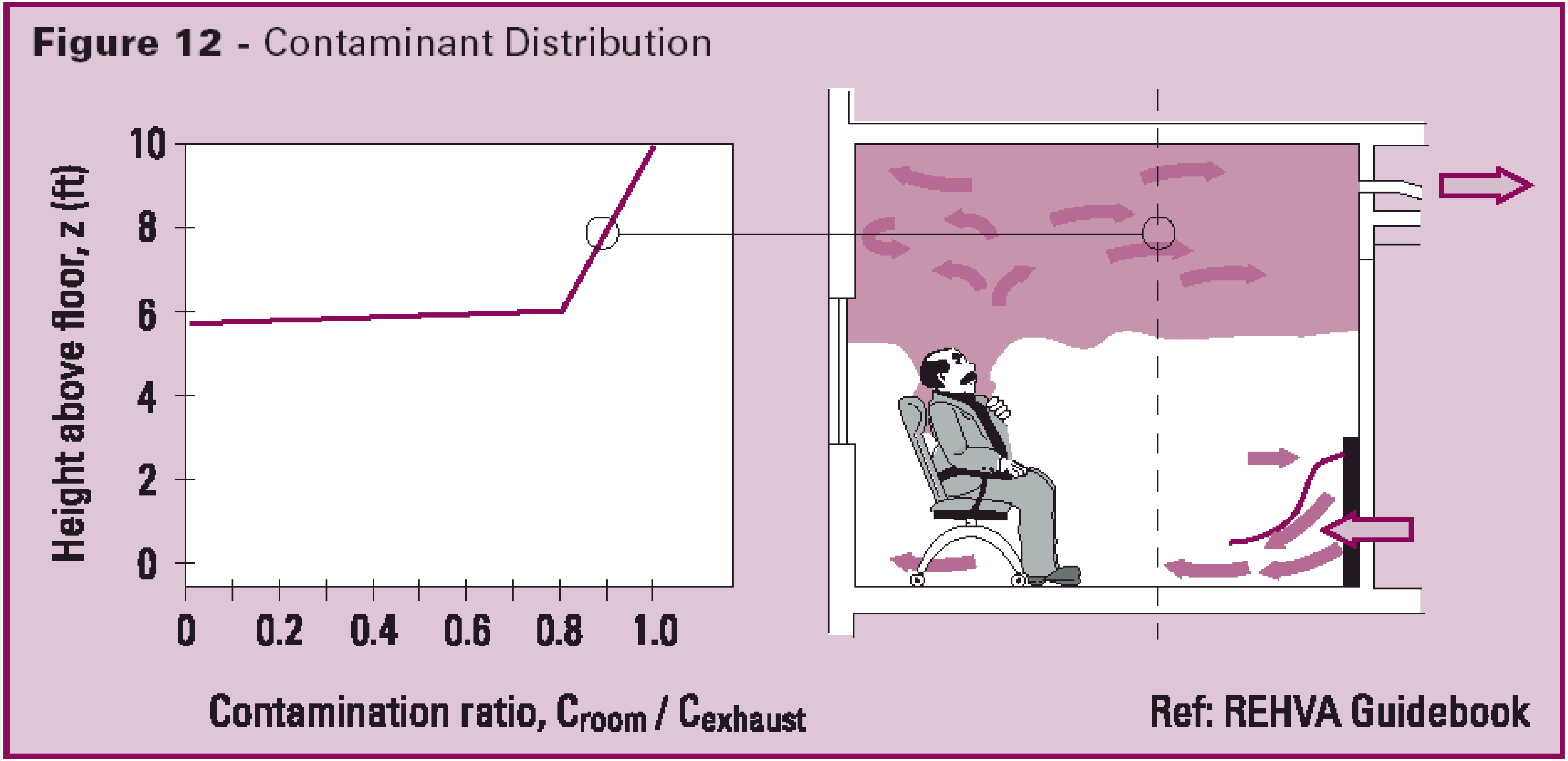
Displacement diffuser airflow pattern

(Source: http://www.price-hvac.com)

Displacement Flow

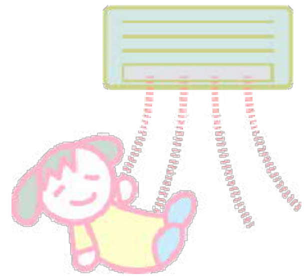


- Contaminant distribution
  - Can reduce contaminant in lower portion of room
  - Actual distribution is influenced by factors e.g. contaminant source type & location, human body convection and space height, strength of thermal plume
- Ventilation effectiveness
  - Displacement can achieve around 1.2-1.4; most mixing systems is around 1.0

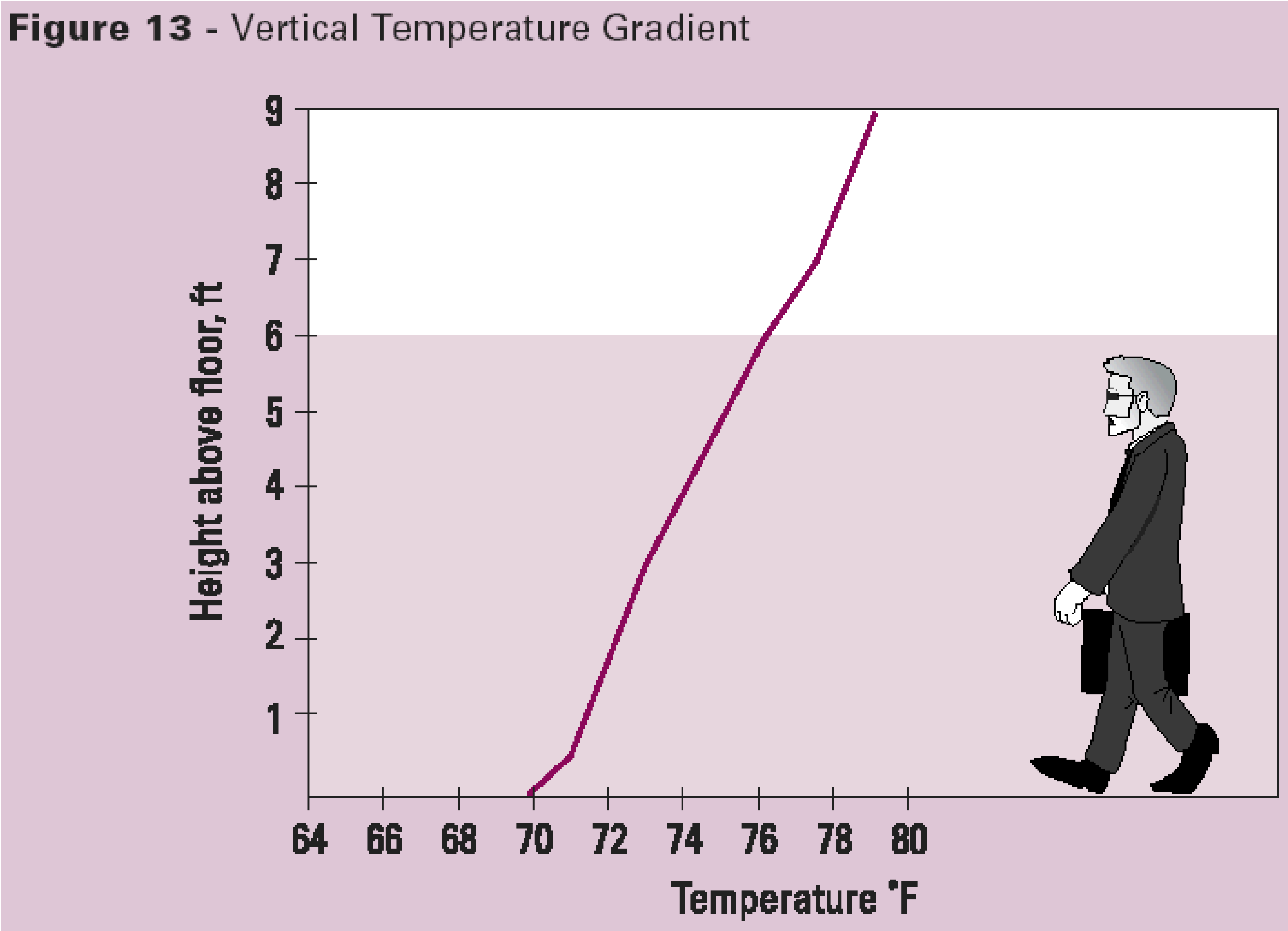


(Source: http://www.price-hvac.com)

Displacement Flow

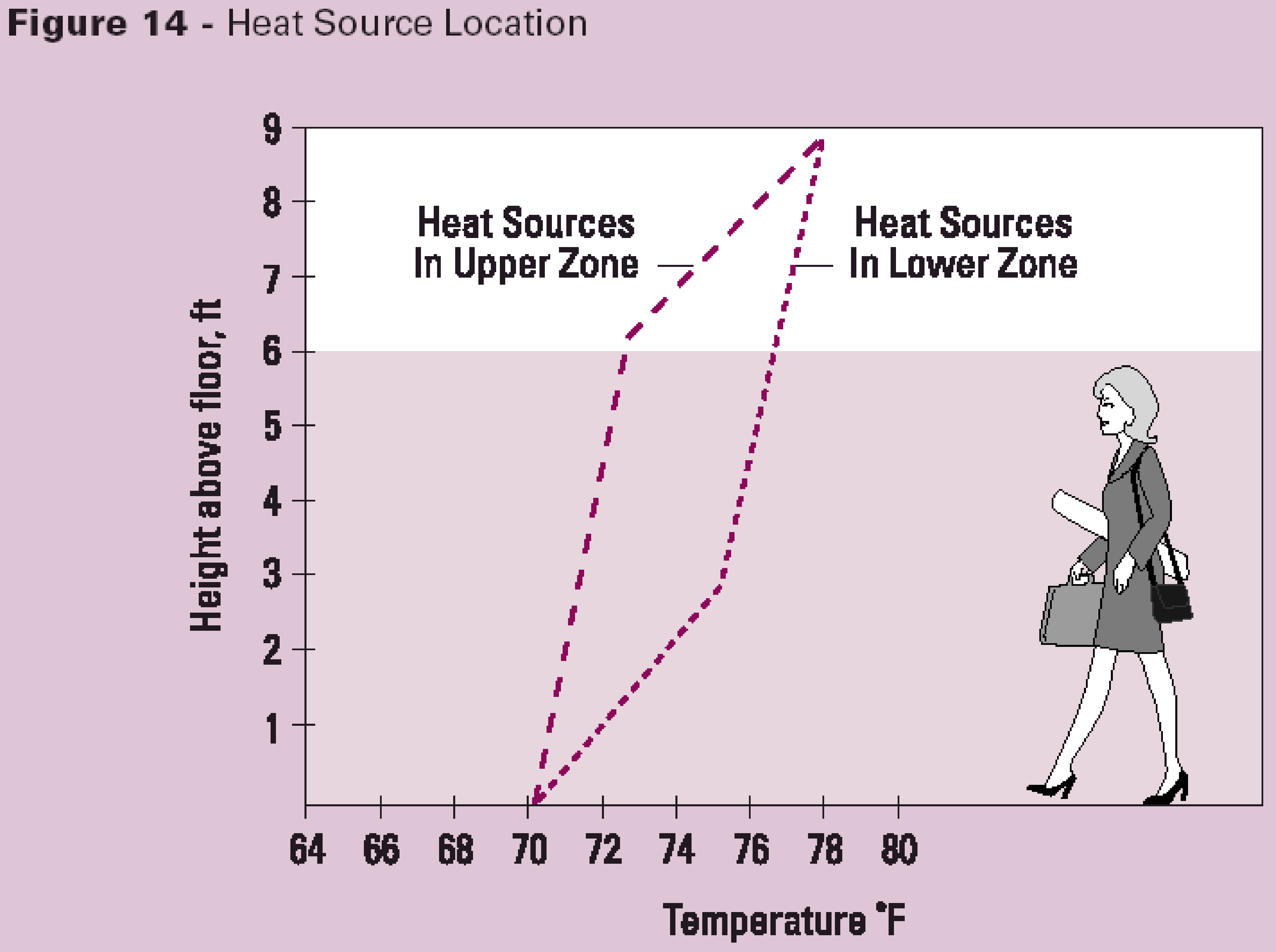


- Temperature distribution
  - Temperature gradient between the floor & ceiling
  - Also known as "Stratification"
  - Affected by factors e.g. supply air volume, room cooling load, location & type of heat source, height of the space
  - Controlling stratification is critical to maintain thermal comfort
- If heating is needed, may use radiator to offset cold downdrafts near the windows



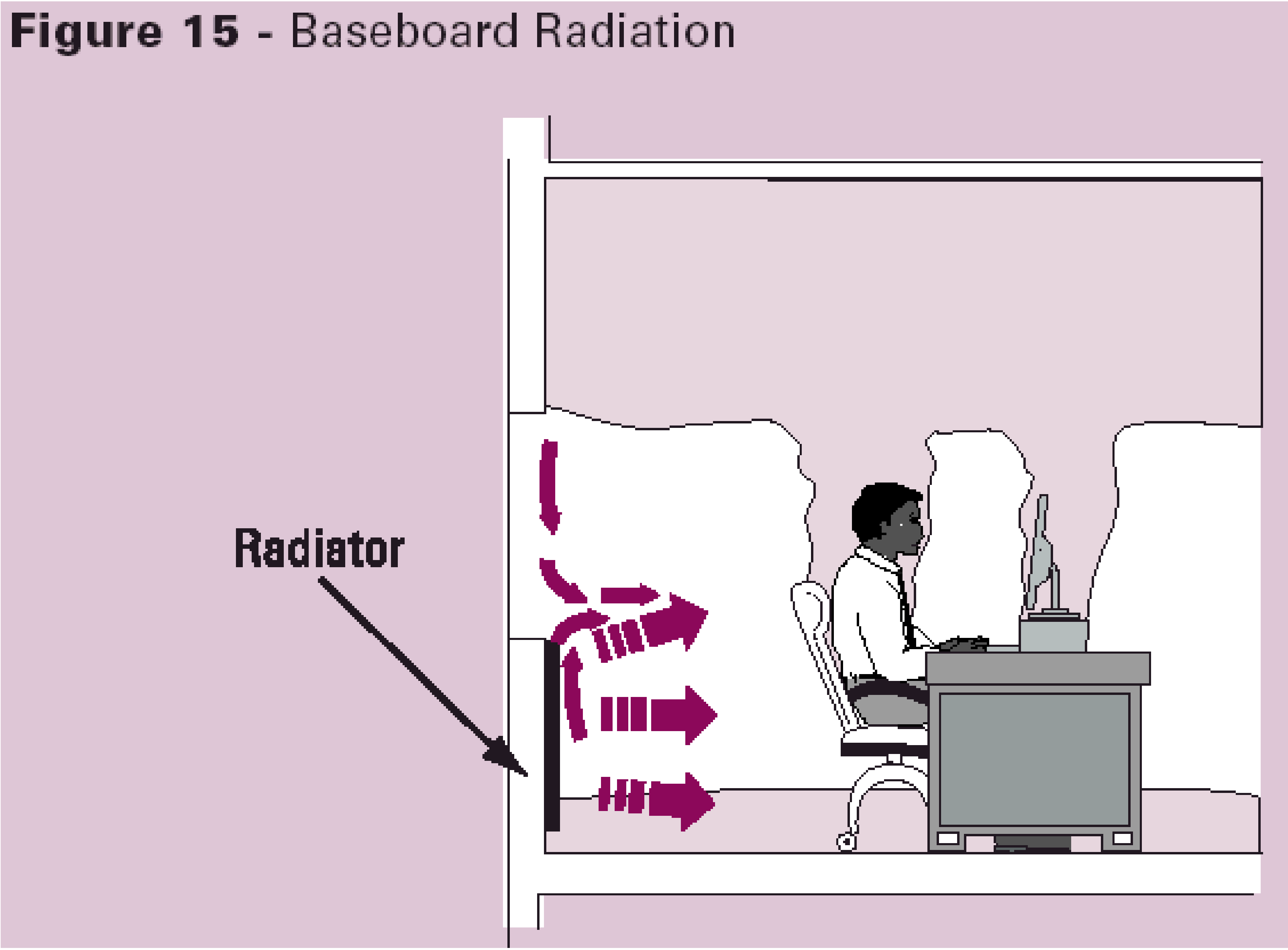
Displacement ventilation – temperature gradient

(Source: http://www.price-hvac.com)



Displacement ventilation – temperature gradient

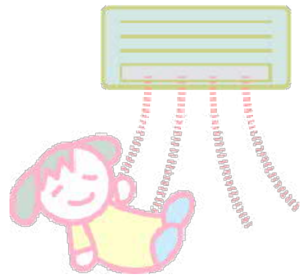
(Source: http://www.price-hvac.com)



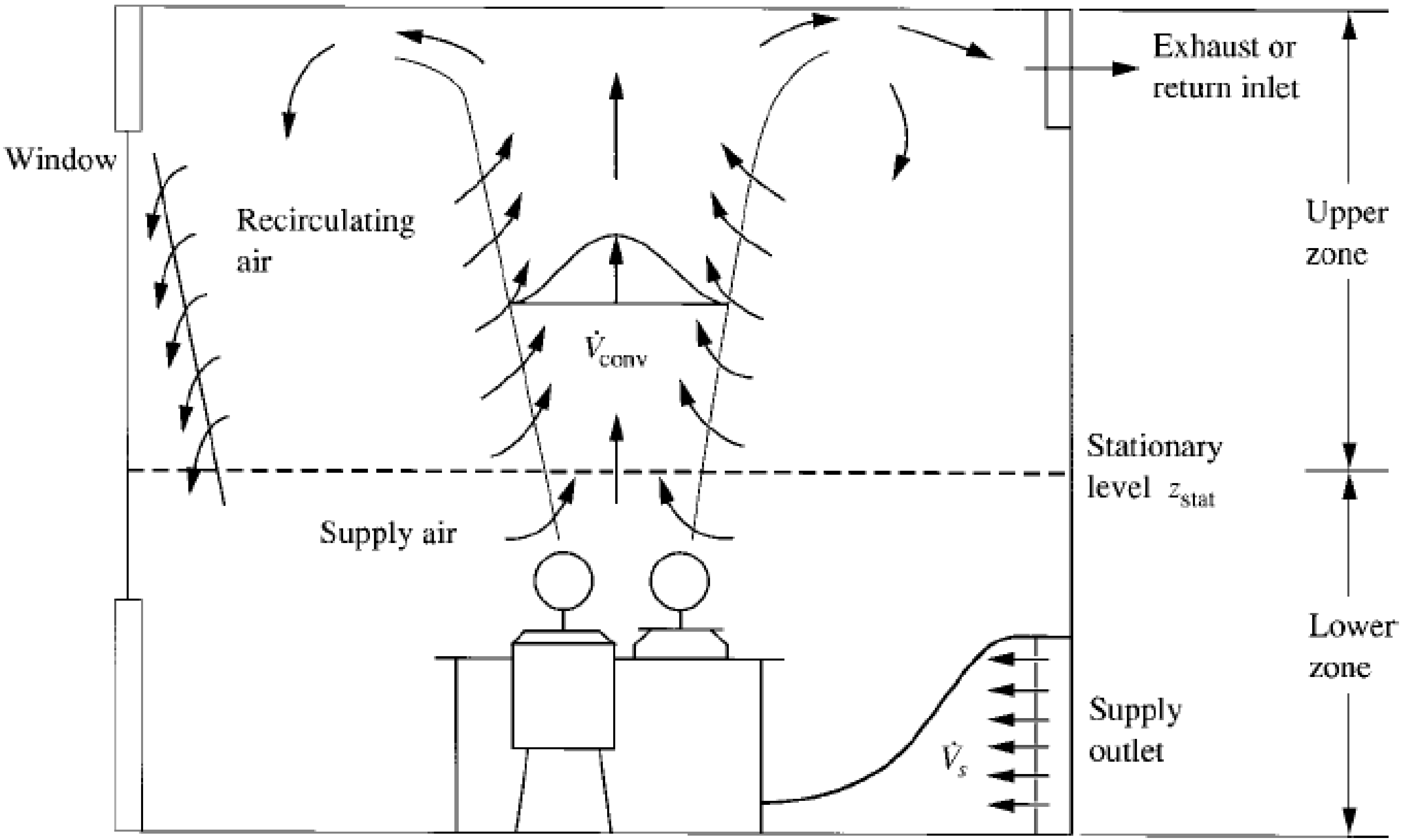
Displacement ventilation and radiator

(Source: http://www.price-hvac.com)

Displacement Flow

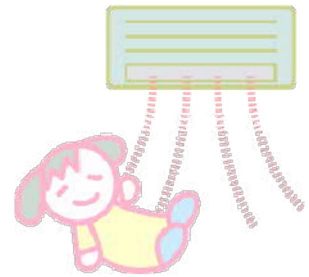


- Stratified displacement flow
  - First introduced in Scandinavian countries
  - Low-level supply outlet
  - Above heat & contaminated sources
    - Heated air rises upward due to buoyancy effect
    - Supply air is entrained into the upward convective flow
    - Stationary level: upward flow = supply flow
    - Two-zone stratified model: upper zone & lower zone



Stratified displacement flow in a typical room

Displacement Flow



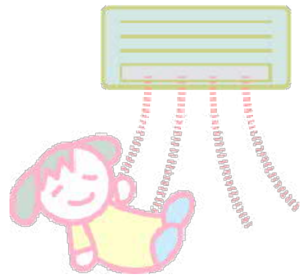
- Characteristics of stratified displacement flow
  - Cold air supply of usually 100% outdoor air
  - Air must be supplied at low velocity (< 0.3 m/s) & at a height less than 0.54 m above floor
  - Cold air supplied at 2.8 to 5 ^{o}C lower than occupied zone
  - Height of lower zone shall be higher than a seated occupant (1.4 m); all air is supply air in lower zone
  - Smaller cooling load density (max. 41 W/m^2)
  - Return or exhaust inlets located near ceiling level

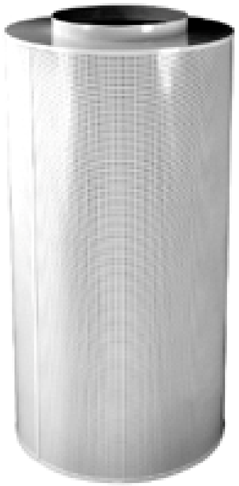
Displacement Flow

- Design procedure
  - Step 1: determine summer cooling load
    - Occupants, lights, equipment, envelope
  - Step 2: determine cooling load ventiln. flow rate
    - Equation from the ASHRAE design guide
  - Step 3: determine flow rate of fresh air
  - Step 4: determine supply air flow rate
    - Max {Step 2, Step 3} flow rates
  - Step 5: determine supply air temperature
  - Step 6: determine exhaust air temperature

Displacement Flow

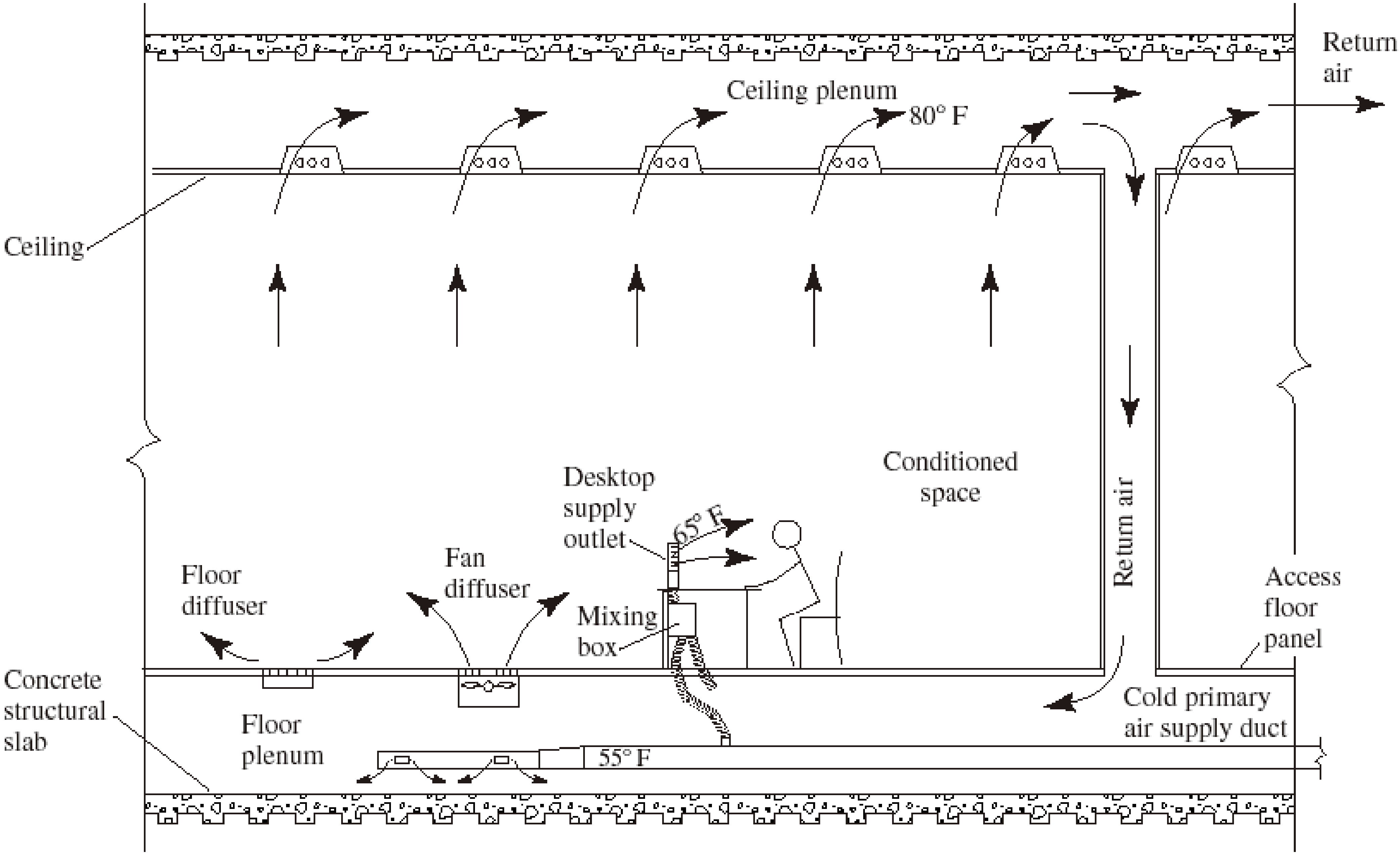
- Common diffuser types
  - Rectangular units
  - Corner units
  - Semi-circular units
  - Circular units
  - Floor mounted units



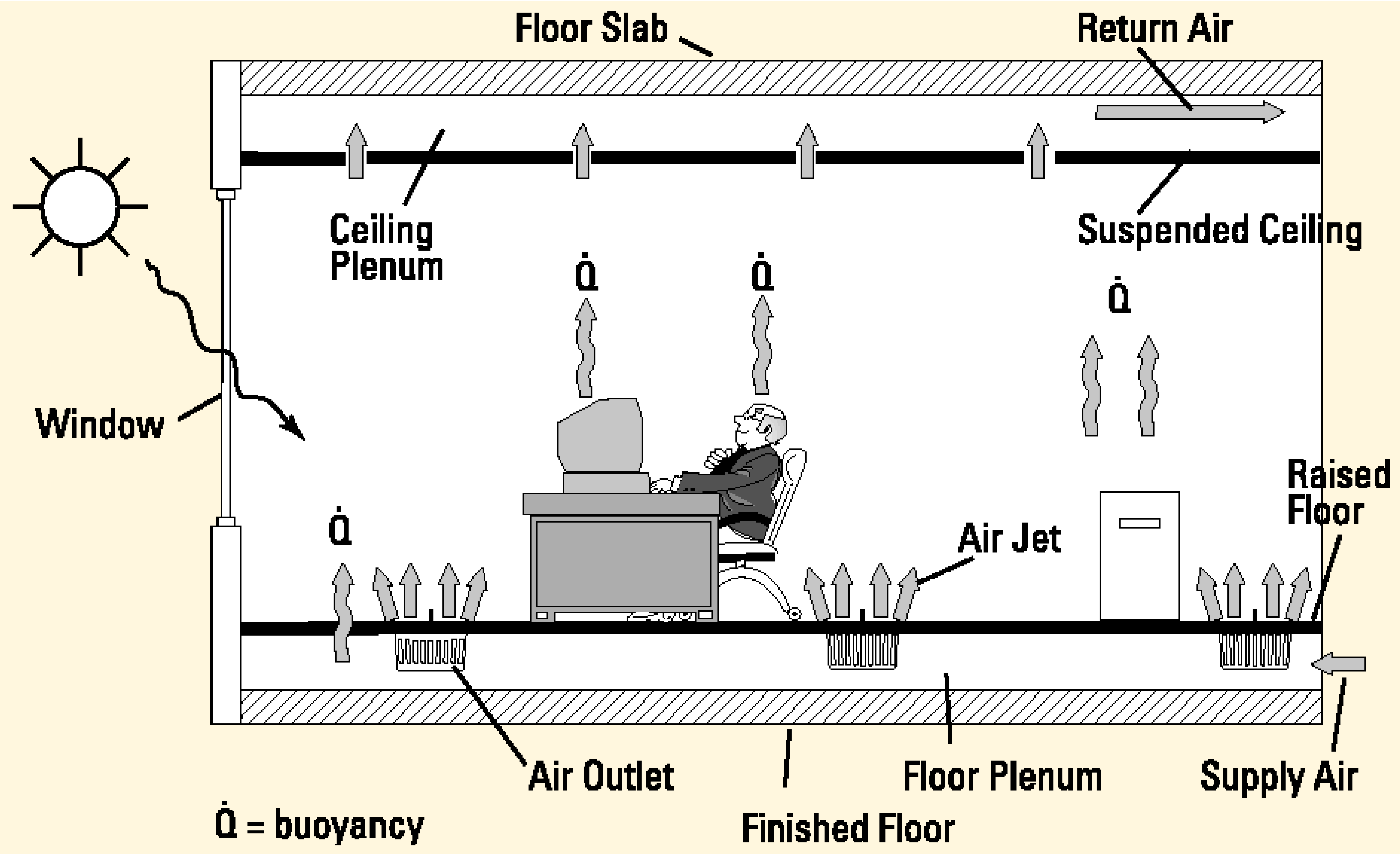


Underfloor Air Distribution

- Upward flow underfloor air distribution
  - Conditioned air from floor plenum (0.3-0.45 m)
    - Usually ductless (air duct has also been used in the past)
  - Supply outlets
    - Floor diffusers, fan-driven units, desktop units, supply outlets from fan coil units and water-source heat pumps
    - Often partial displacement & partial mixing
  - Cool primary air from AHU
  - Applications of underfloor air distribution
    - Computer rooms air conditioning
    - Commercial buildings (w/ access raised floor systems)

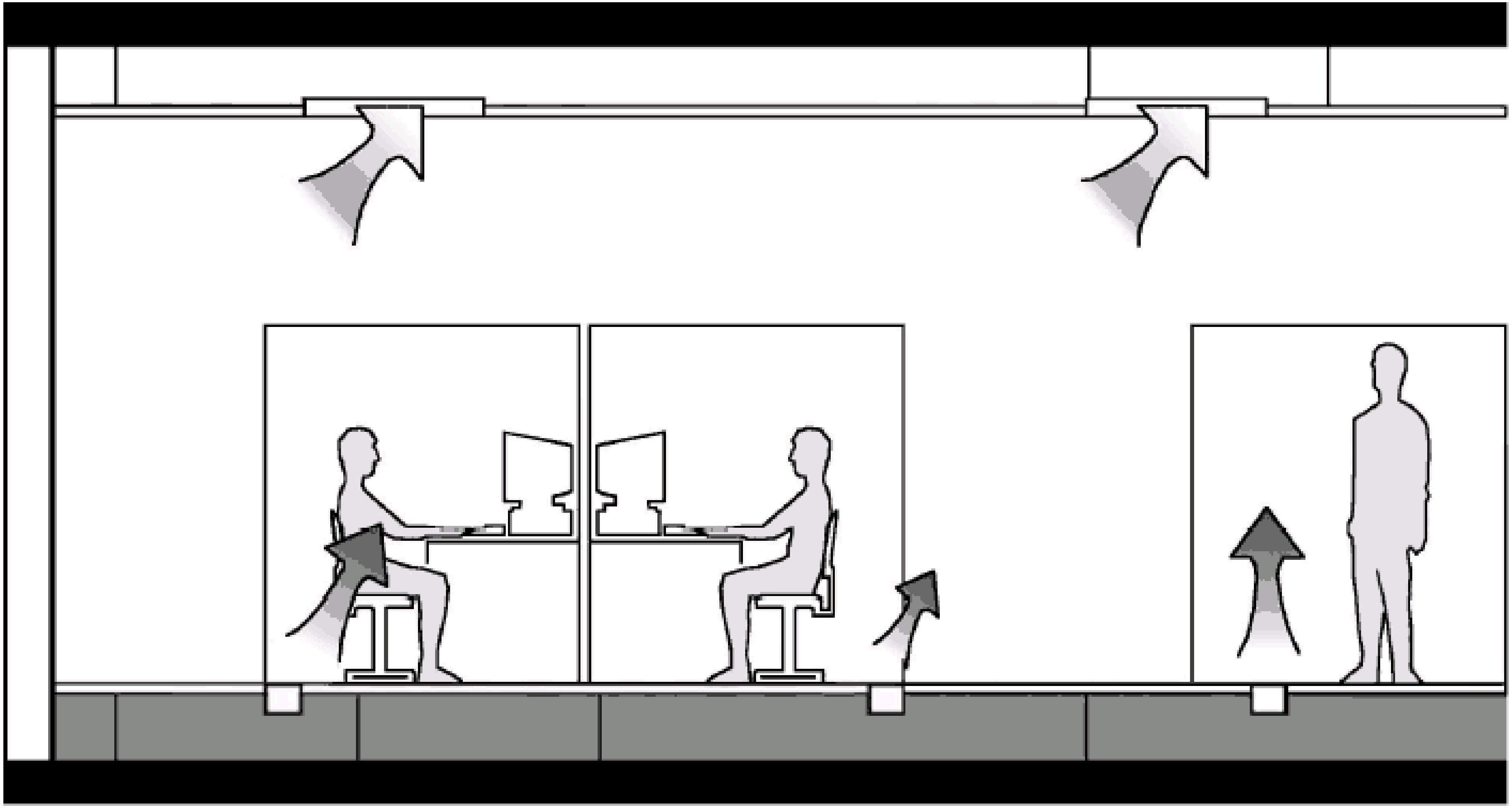


Upward flow underfloor air distribution system



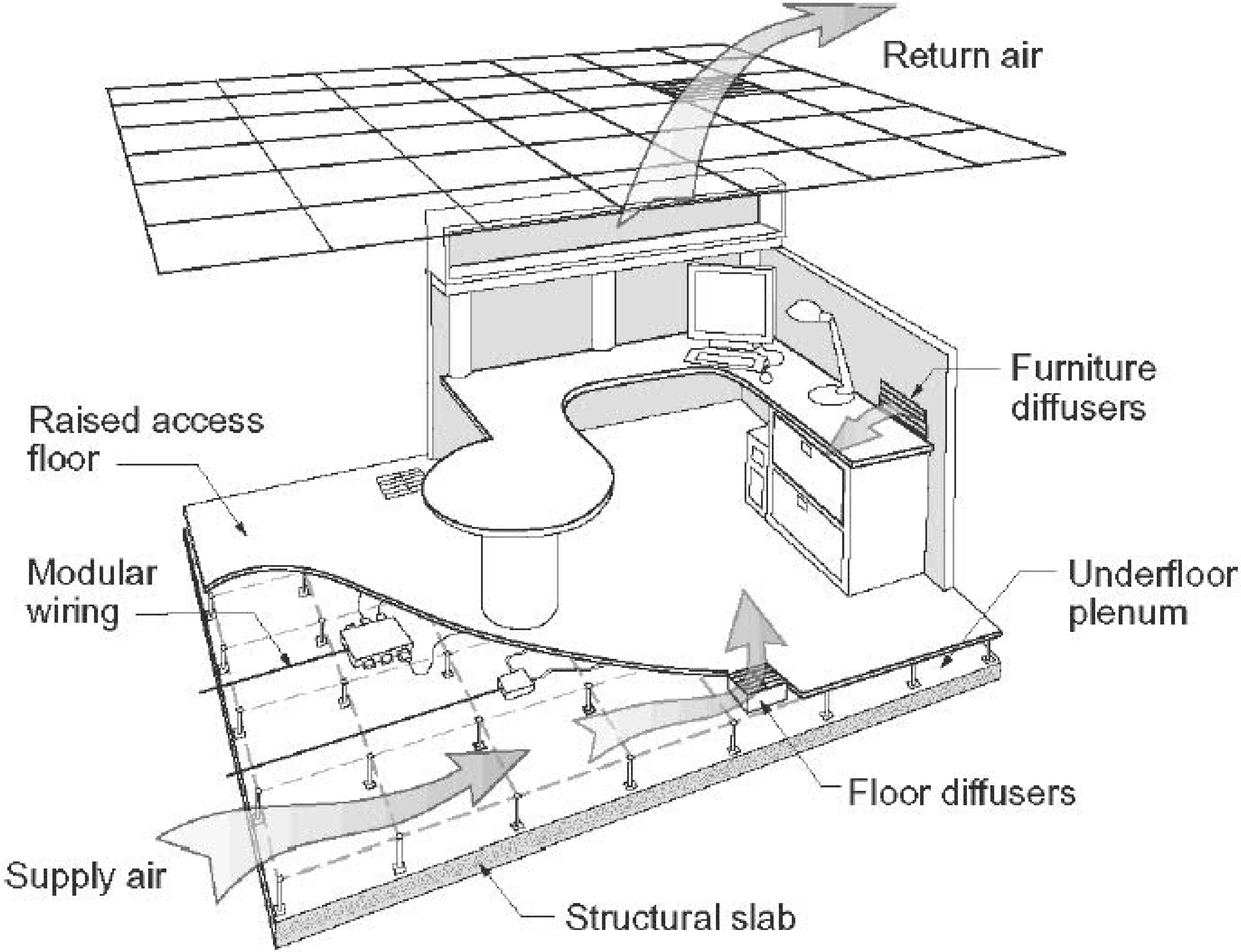
Underfloor air supply

(Source: http://www.price-hvac.com)



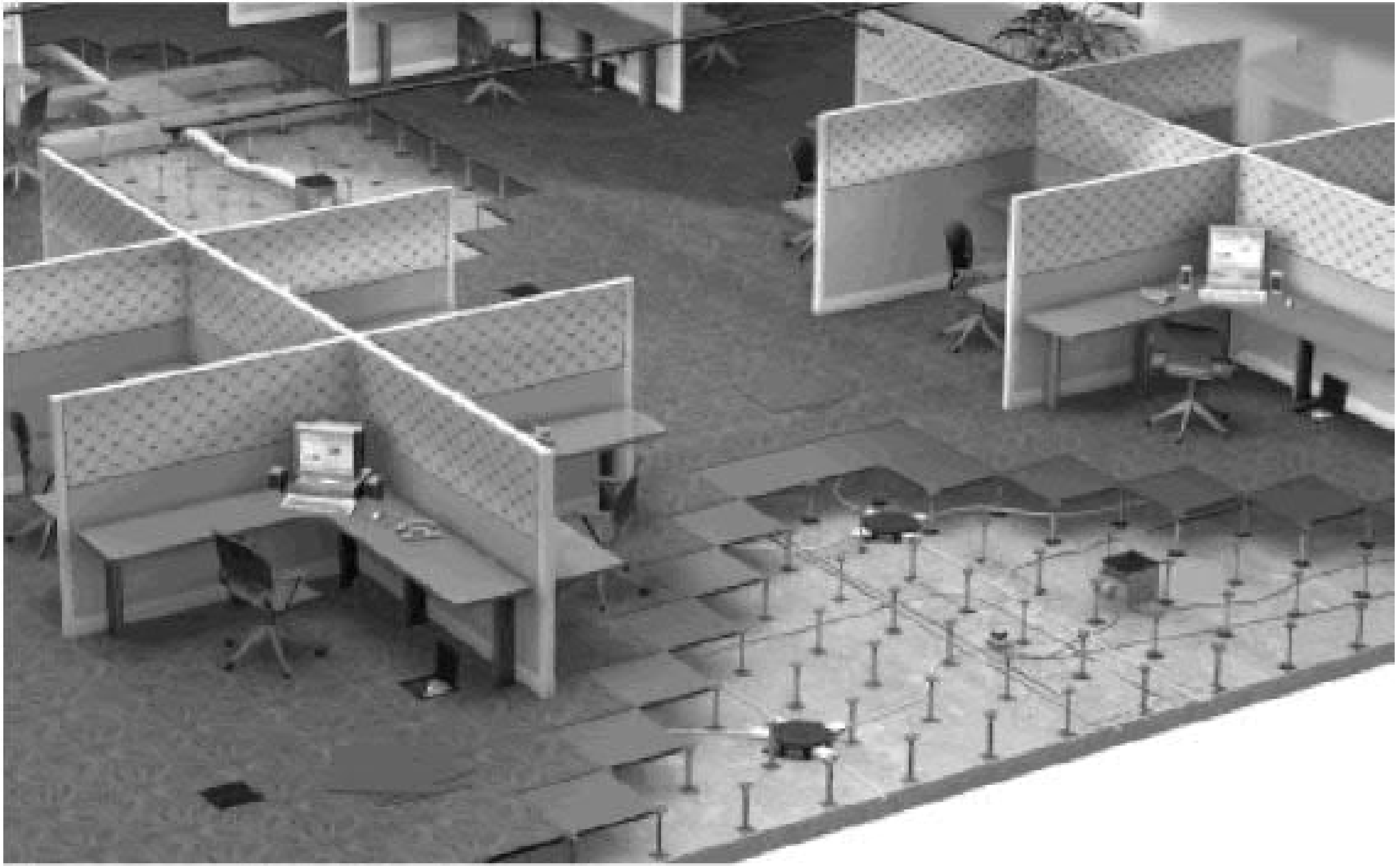
Underfloor air distribution system

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)



Office space with underfloor air distribution & task air-conditioning

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)



Installation of raised floor system in open plan office

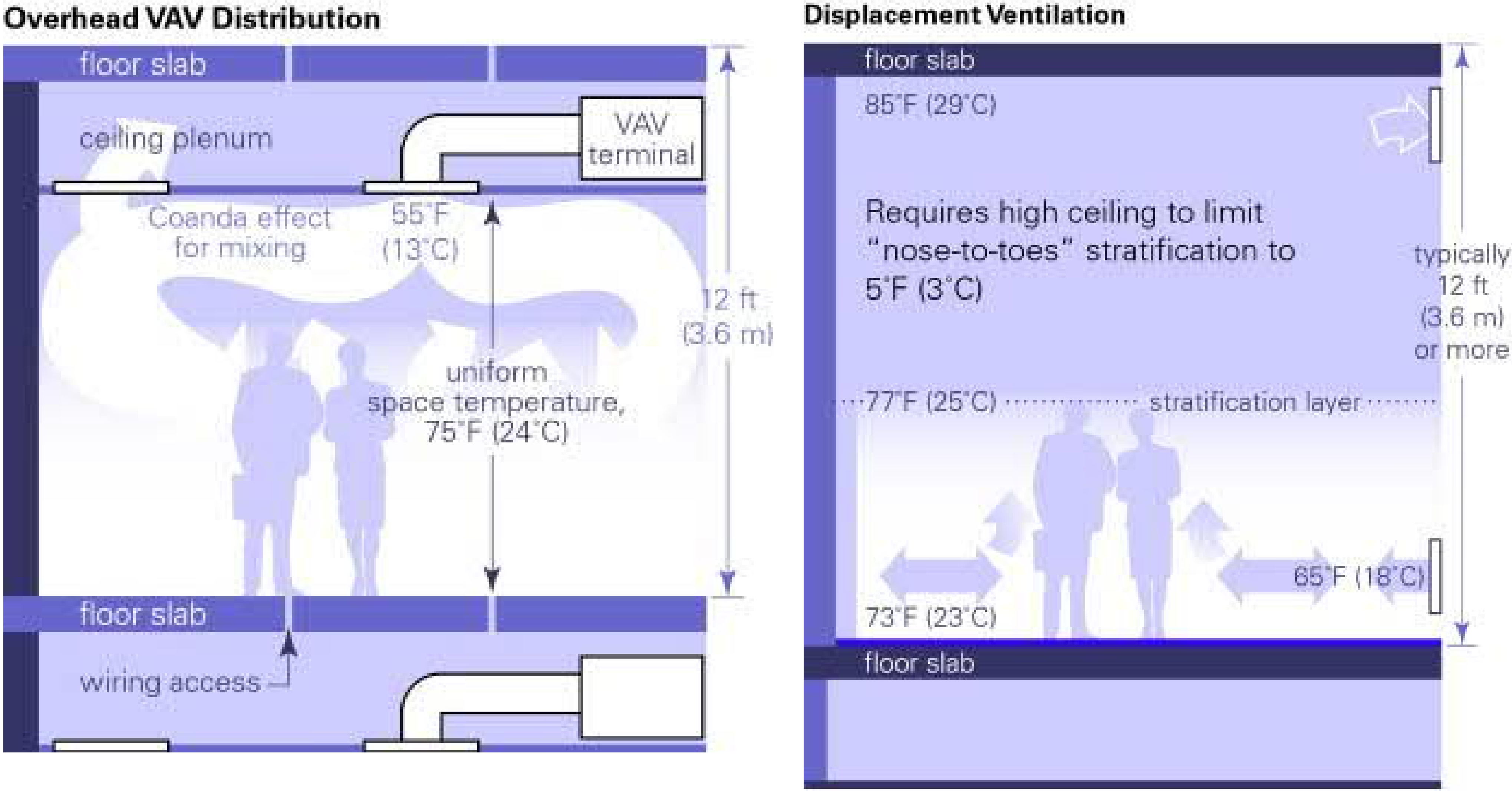
(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

Underfloor Air Distribution

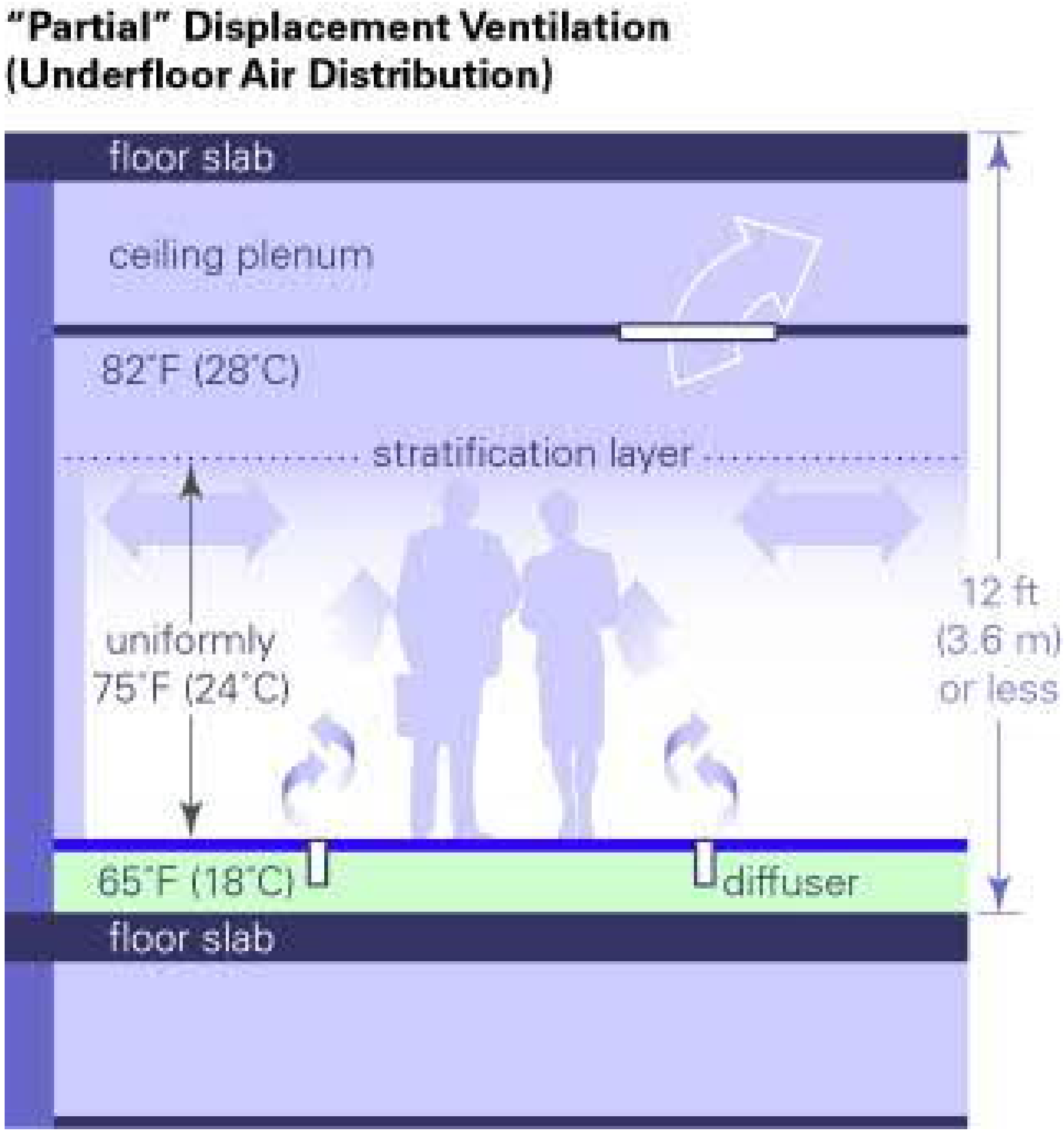
- Design factors of underfloor air distribution
  - Thermal storage of floor plenum
    - Primary air in direct contact with concrete floor slab
  - Heat unneutralised
    - Upward air flow lifts the heat unneutrailised to ceiling
    - Greater capability to capture/exhaust heat thru’ ceiling
  - Maintaining a consistent access plenum temp.
    - Blending air for suitable temperature; travel distance
  - Master zone air temp. control
    - Important for VAV system to response to load changes

Underfloor Air Distribution

- Advantages of underfloor air distribution
  - Integrated well with raised floor plenum
  - Can be very flexible for future changes/relocations
  - Conditioned air is supplied directly to occupants
  - Stagnant air can be reduced (if ceiling return)
  - Upward flow lifts some unneutralised heat
  - It can utilise thermal mass of access floor & slab to reduce peak demands
- Disadvantages
  - Higher initial costs
  - Need for raised floor system & floor diffusers



(Source: UC Berkeley)



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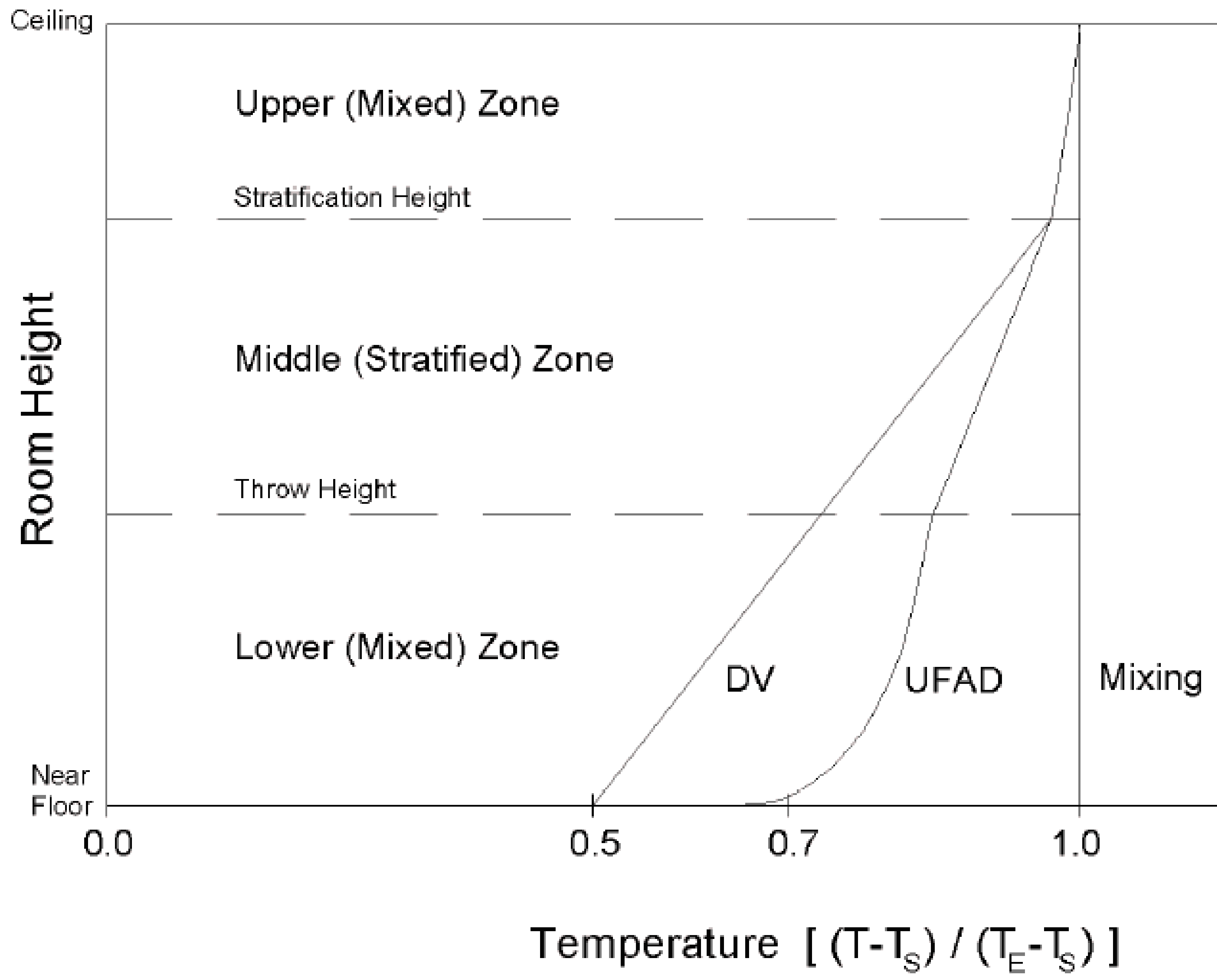
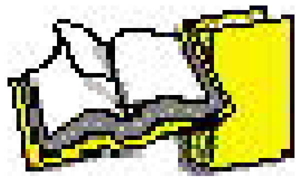


Comparison of typical vertical temperature profiles

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

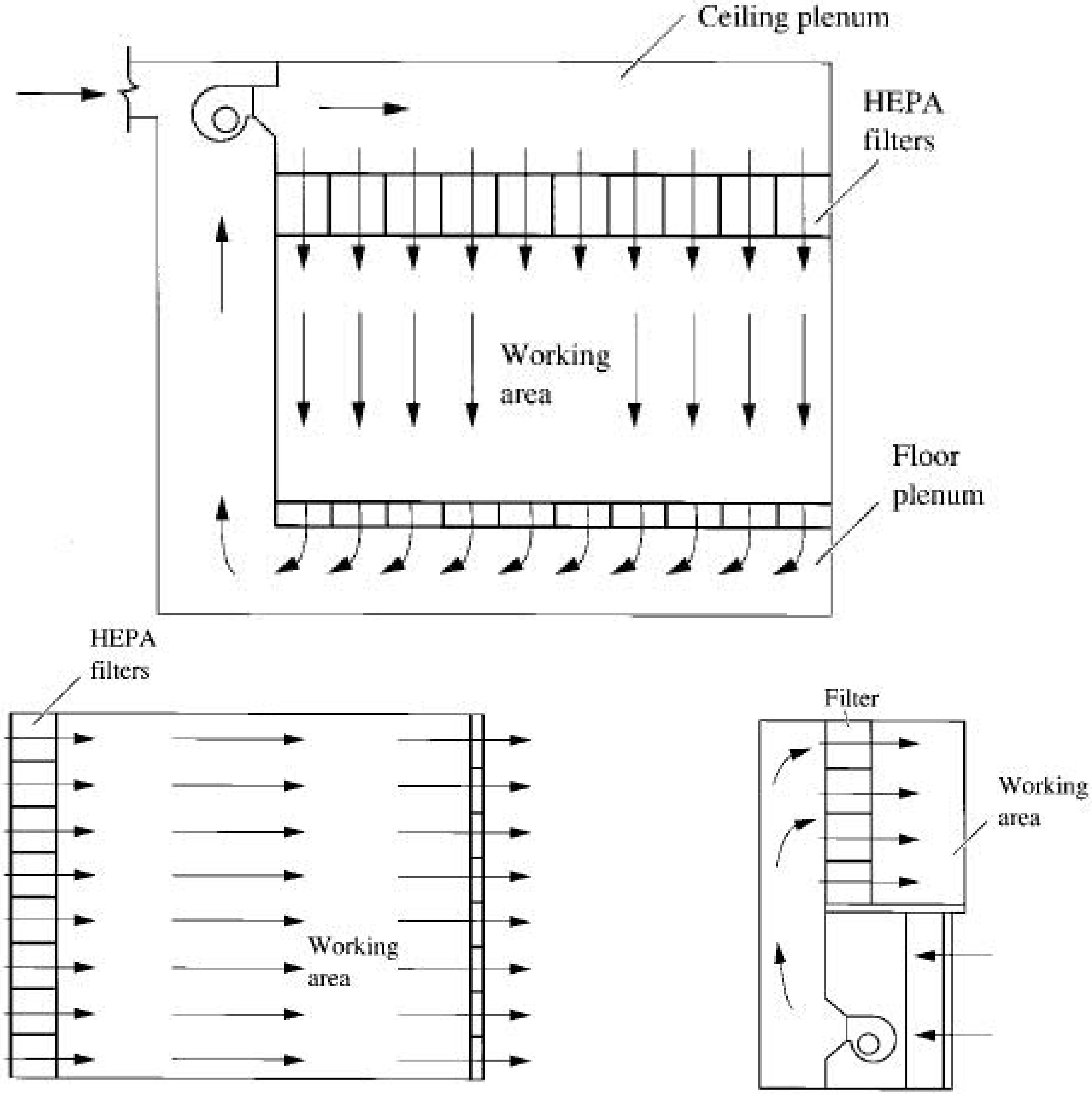
References



- ASHRAE design guides:
  - ASHRAE, 2013. *UFAD Guide: Design Construction and Operation of Underfloor Air Distribution Systems*
  - Bauman, F. S. and Daly, A., 2003. *Underfloor Air Distribution Design Guide*
  - Chen, Q. and Glicksman, L., 2003. *System Performance Evaluation and Design Guidelines for Displacement Ventilation*
- Suppliers information:
  - http://www.priceindustries.com
  - http://www.flexiblespace.com

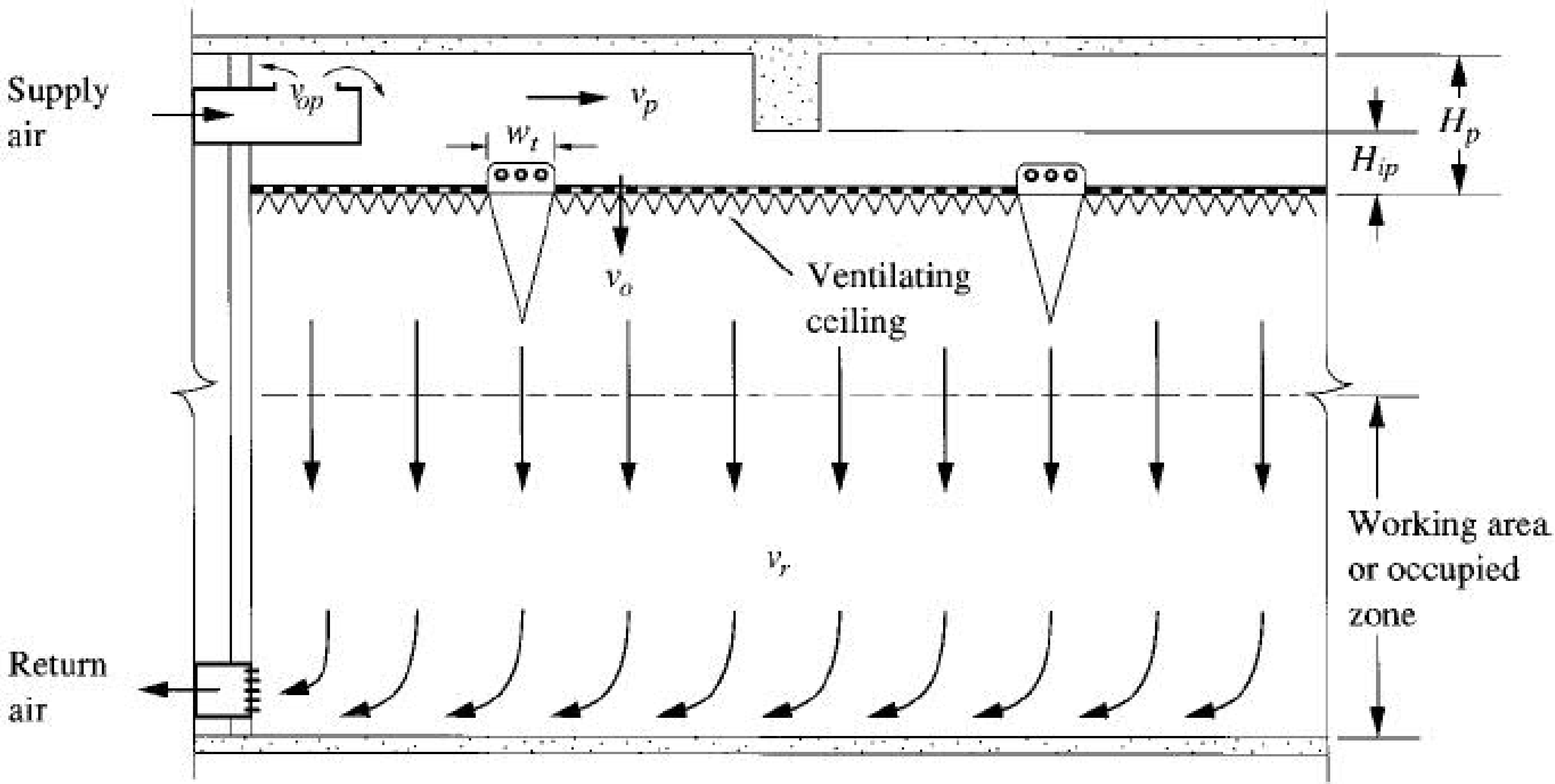
Unidirectional Flow

- Unidirectional flow
  - Airstream flows in the same direction as uniform airflow showers the entire working area or occupied zone (known as "laminar flow")
  - Examples:
    - Clean rooms (downward or horizontal flow)
    - Ventilating or perforated ceiling
  - Advantages:
    - Contaminants generated cannot move laterally
    - Dust particles will not be carried to higher levels



Unidirectional flow for clean rooms

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)



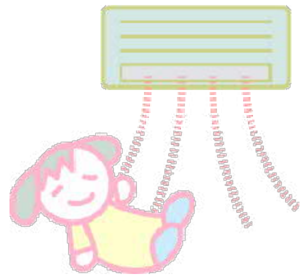
Ventilating ceiling

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Ventilating ceiling: an example for kitchen

(Source: *http://www.reven.de*)

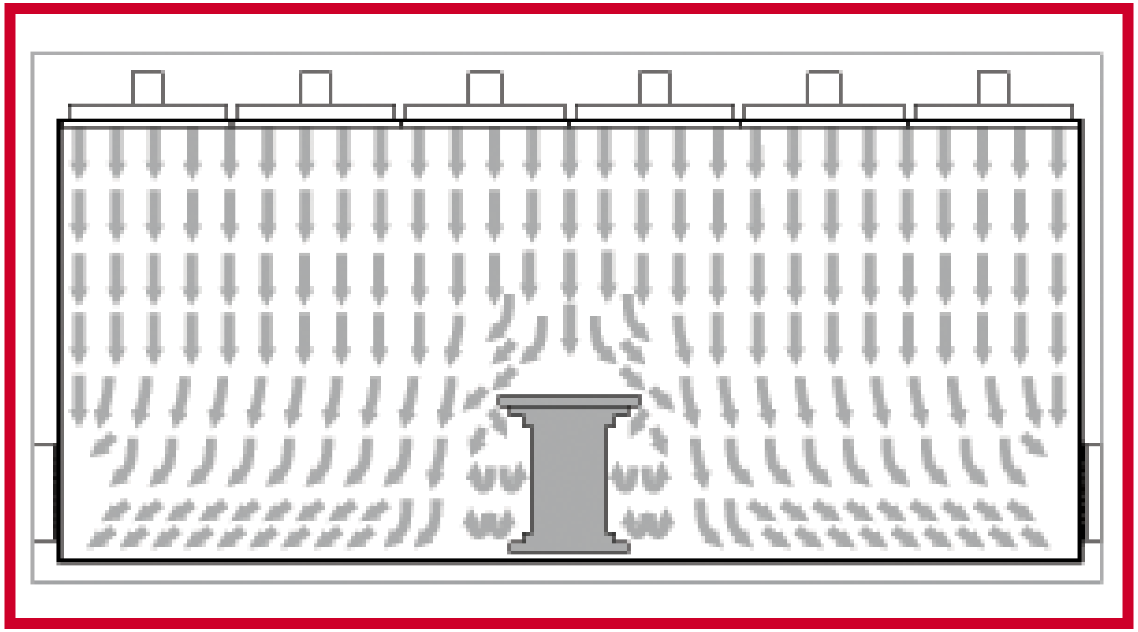
Unidirectional Flow



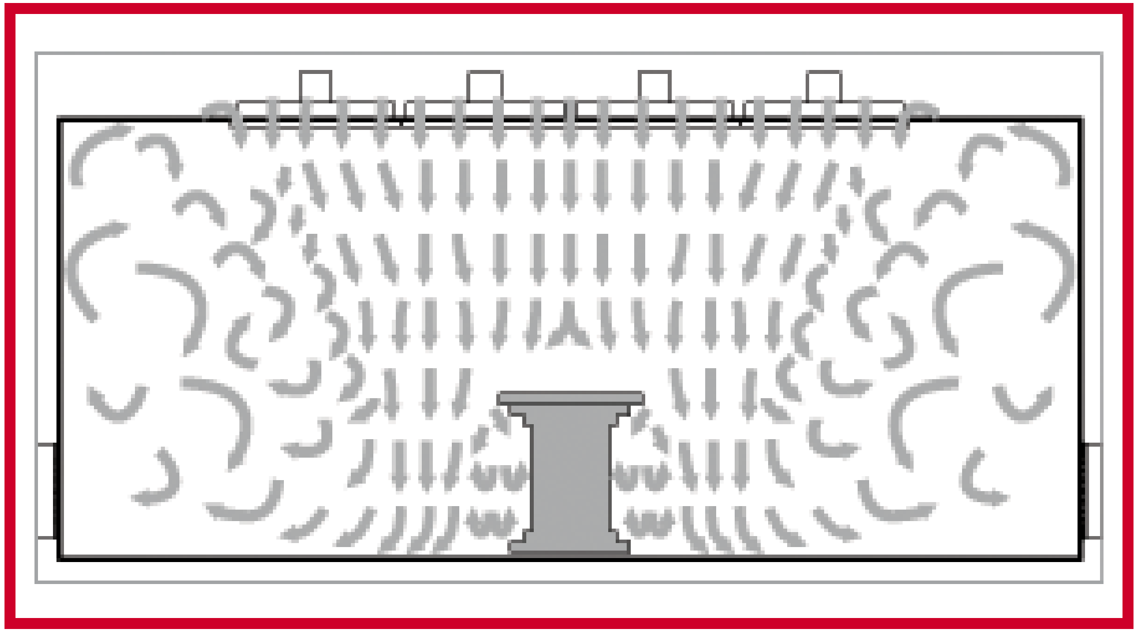
- Ceiling plenum & supply air velocity
  - To create a more uniform supply air velocity, the max. air velocity inside the ventilating ceiling plenum shall be low
  - If sufficient plenum height & few obstructions, distributing ductwork inside is not needed
- Applications of ventilating ceiling
  - Industrial process
  - Indoor sports stadium for badminton (< 0.2 m/s)

Unidirectional Flow

- Hospital applications (more critical)
  - Main purpose: control of airborne contaminants
  - Such as operating theatre and isolation wards
- Operating theatre
  - Large fresh air ventilation (100% outdoor air)
  - Large volume of supply air
  - At low uniform velocity to promote stable downward flow of air



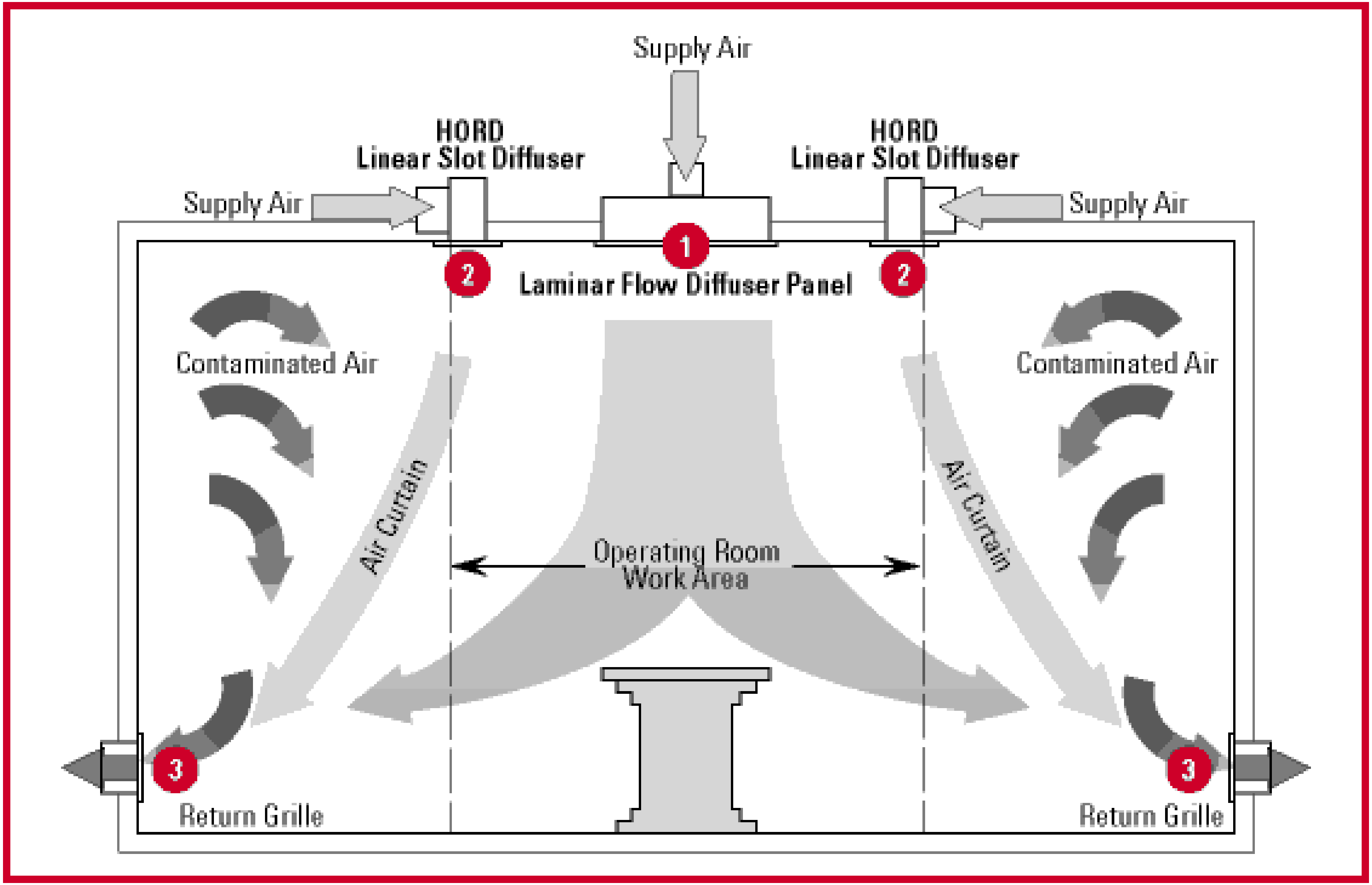
Laminar flow - full ceiling supply



Laminar flow - partial ceiling supply

Flow patterns in hospital operating theatre

(Source: http://www.price-hvac.com)



Hospital operating theatre (laminar flow with air curtains)

(Source: http://www.price-hvac.com)

Hospital operating theatre (typical design)

(Source: http://www.price-hvac.com)

HORD

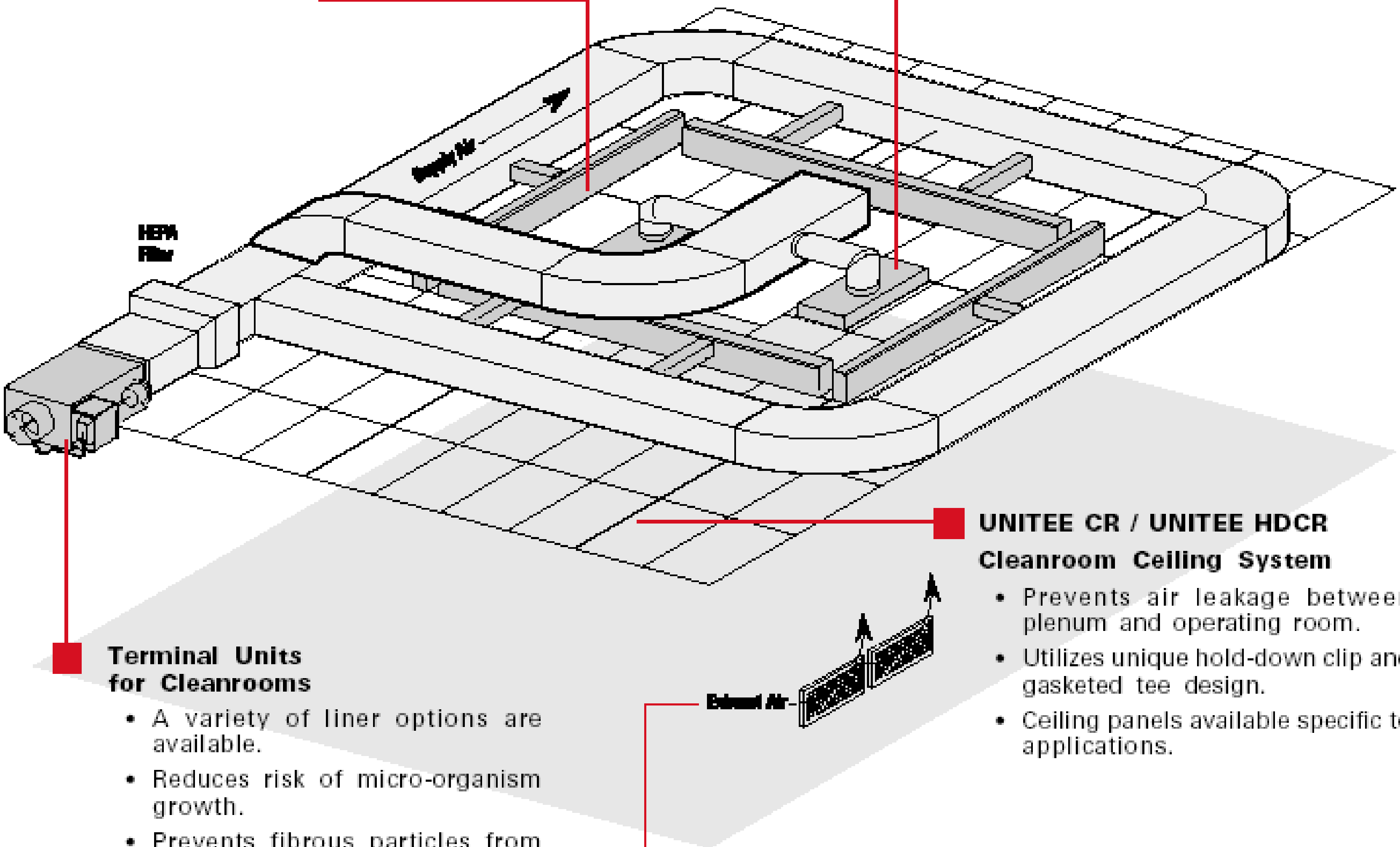
Hospital Operating Room Diffuser

- Linear slot discharges vertical curtain of clean air.
- Creates a "room within a room" around perimeter of operating table work area.
- Single or multiple side feeds from supply air plenum.

LFD / LFDSS / LFD2

Laminar Flow Diffuser

- Perforated face discharges non-aspirating (non-mixing) vertical flow of clean air.
- Air pattern "flows" over the operating table on its way to the floor.
- Creates a "washing" and "rinsing" effect.



Terminal Units for Cleanrooms

- A variety of liner options are available.
- Reduces risk of micro-organism growth.
- Prevents fibrous particles from entering supply air stream.

UNITEE CR / UNITEE HDCR

Cleanroom Ceiling System

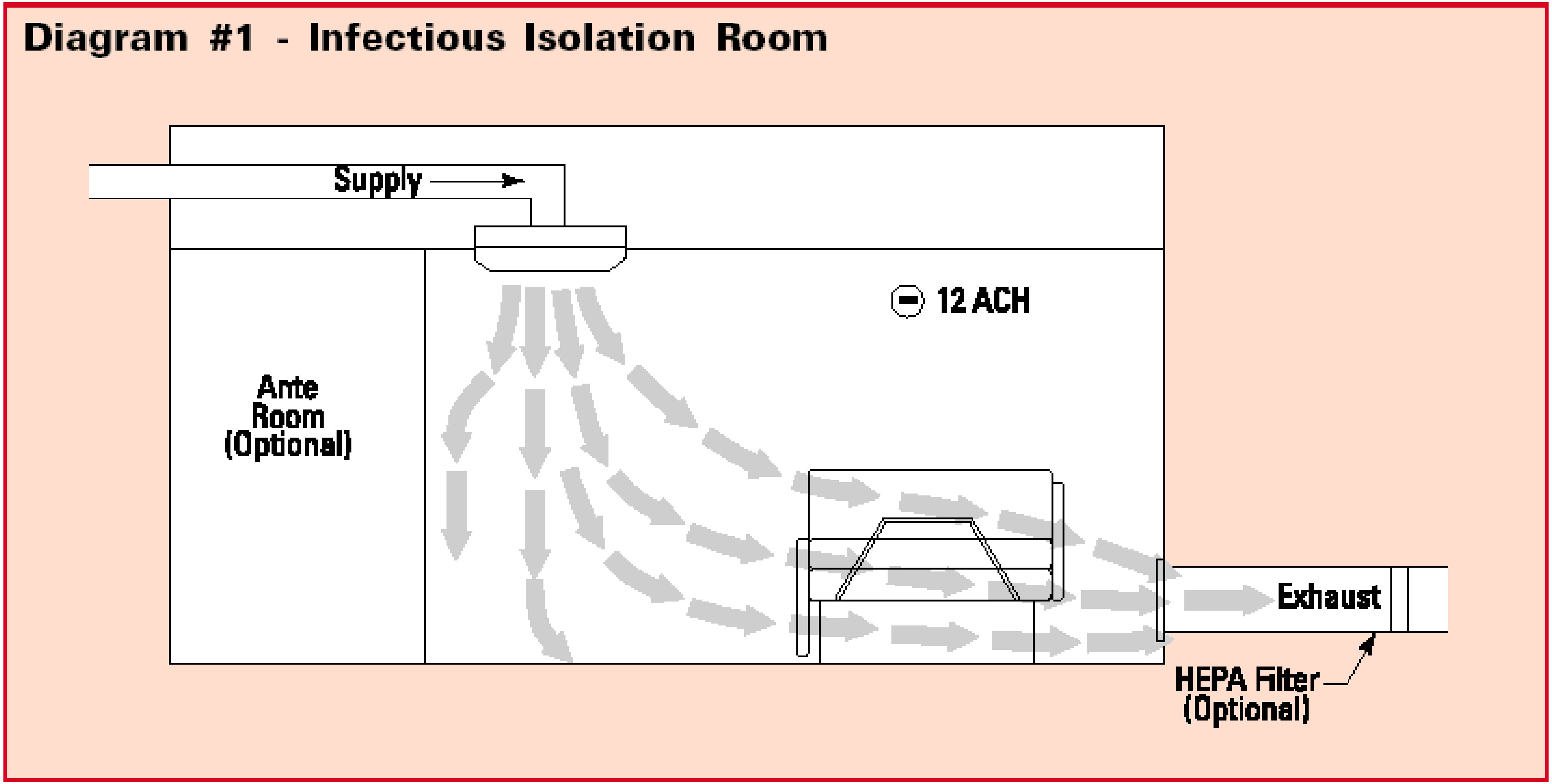
- Prevents air leakage between plenum and operating room.
- Utilizes unique hold-down clip and gasketed tee design.
- Ceiling panels available specific to applications.

Hospital operating theatre (typical design)

(Source: http://www.price-hvac.com)

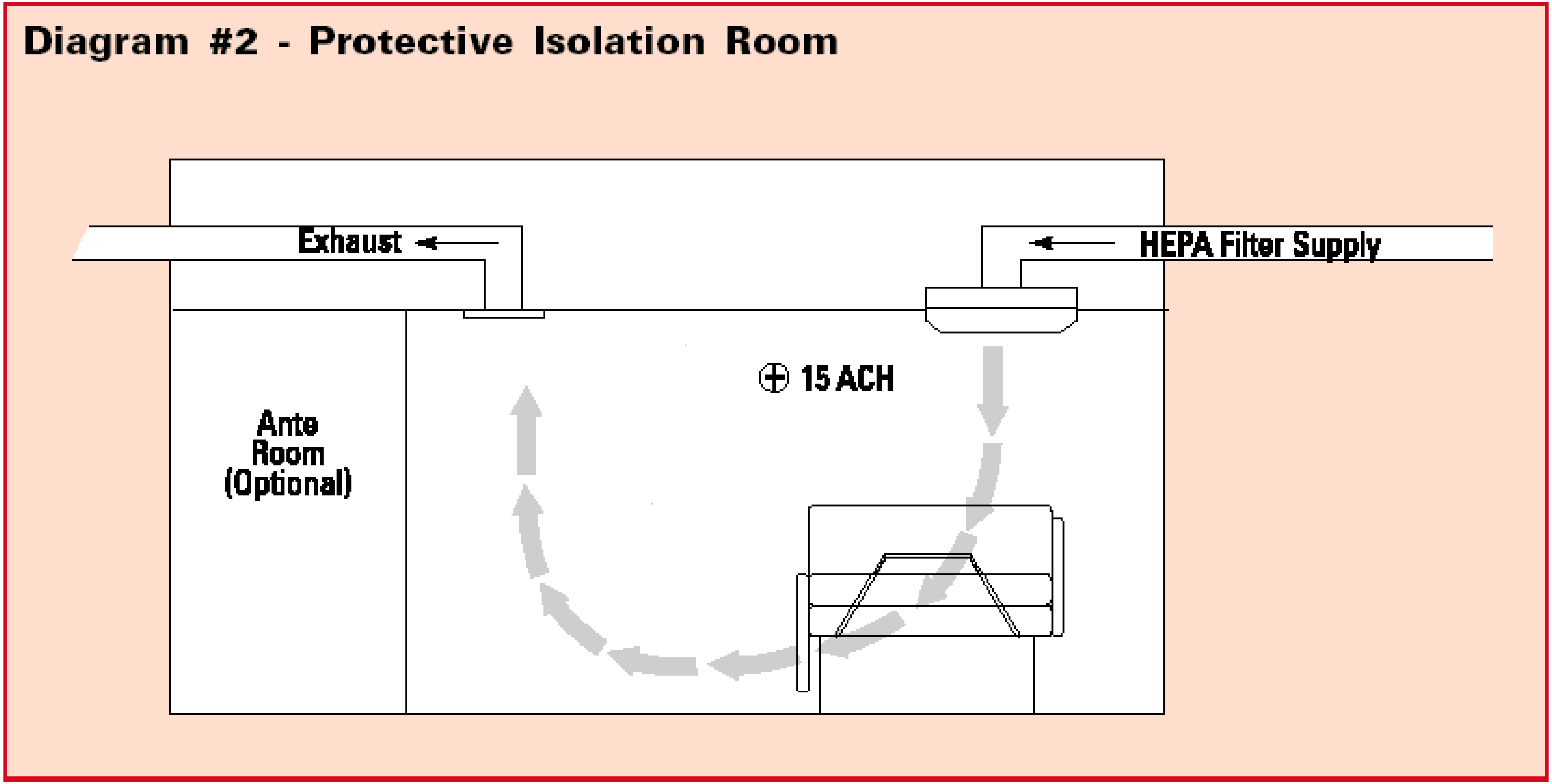
Unidirectional Flow

- Hospital applications - isolation wards
  - Infectious isolation rooms
    - Patients with infectious diseases
    - Kept at a negative pressure
  - Protective isolation rooms
    - Patients with a high susceptibility to infection
    - Kept at a positive pressure
  - HEPA filters will be used
  - Ante rooms are recommended to minimize exchange of air between a hallway and the isolation room
  - Airflow pattern: protect health care staff or patient



Infectious isolation room

(Source: http://www.price-hvac.com)



Protective isolation room

(Source: http://www.price-hvac.com)

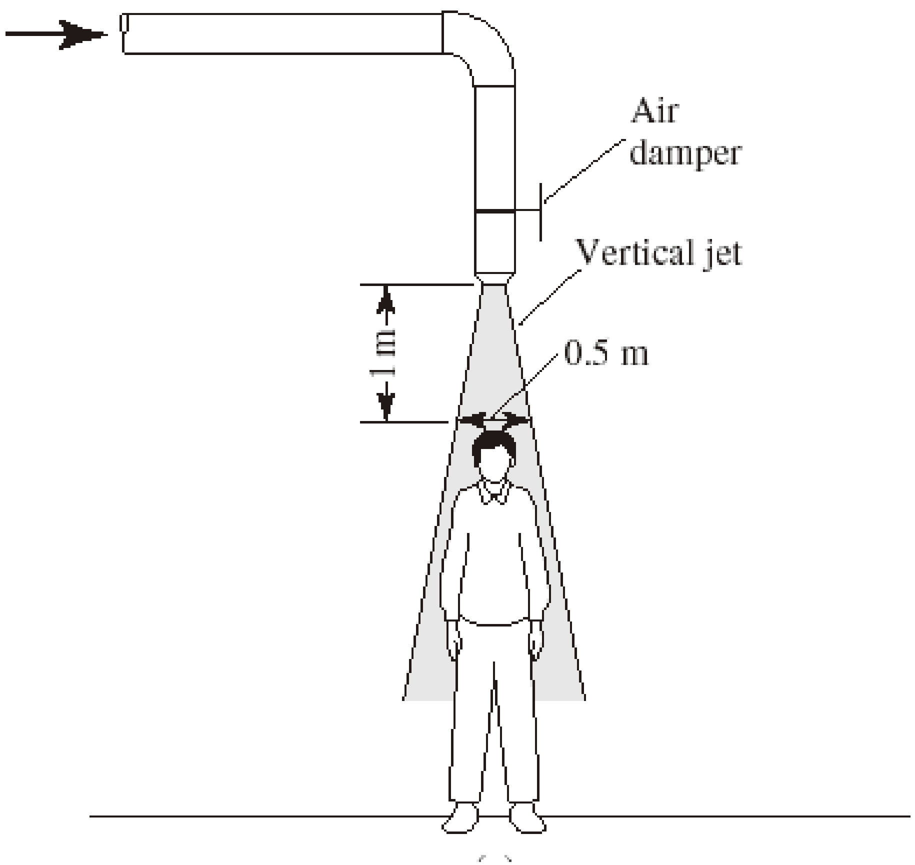
SARS test chamber (inside HKU BSE Lab)

Projecting Flow

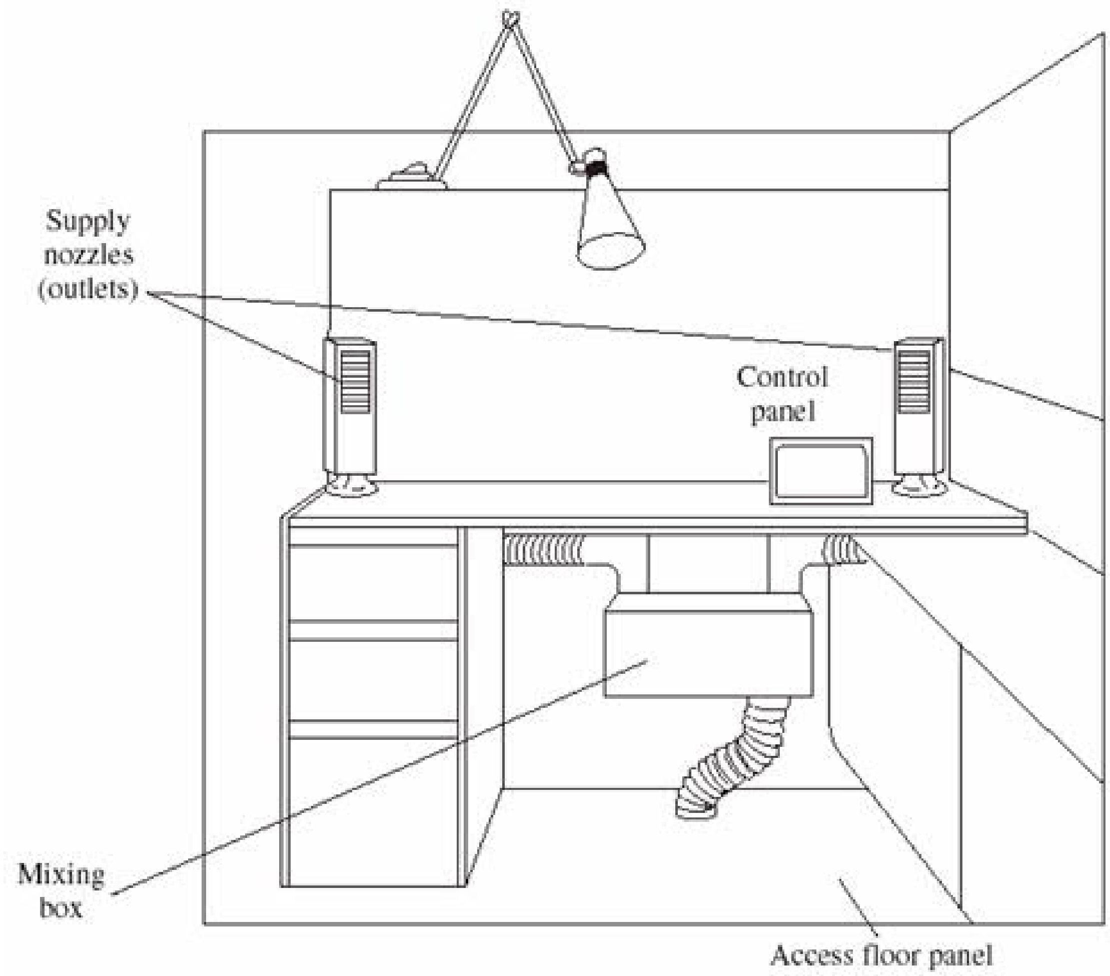
- Cold or warm air jet projected to target zone
- Benefits of projecting flow
  - Better control of temp., air cleanliness & air movement in a localised environment
  - Spot cooling improve occupants' thermal conditions & reduce heat stress
  - Greater direct outdoor air supply
  - Direct & efficient handling of local loads
  - Greater control of their own micro-environment

Projecting Flow

- Disadvantages of projecting flow
  - Draft discomfort or pressure air jet
  - Limited area of environmental control
  - More complicated space air diffusion design
- Usually free jets with high entrainment ratios
  - Long-throat round nozzles are often used
- Two types of projecting flow
  - Industrial spot cooling systems
  - Desktop task air conditioning systems



Industrial spot cooling system



Desktop task air conditioning

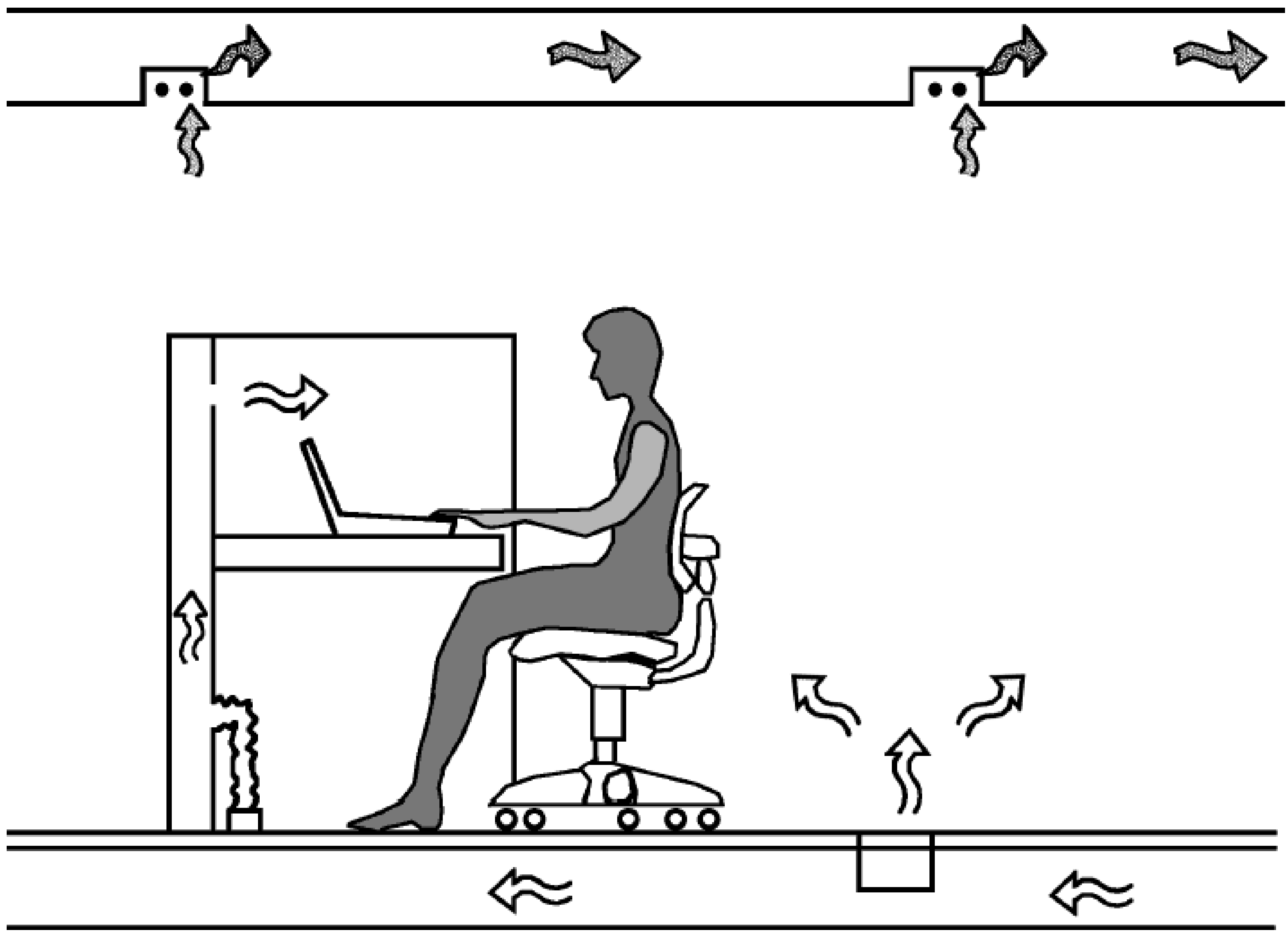
(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Projecting Flow

- Industrial spot cooling systems
  - Temperature difference between target zone & the room air is often 2.8 ^{o}C or greater
  - Distance between target zone & supply outlet
  - Vertical vs horizontal jet
  - Target velocities
  - Thermal sensation
    - Of whole body & for individual parts (local)
  - Allow occupants to have individual control

Projecting Flow

- Desktop task conditioning systems
  - Also task/ambient conditioning (TAC)
  - Typical design: self-powered mixing box, small supply fans, desktop supply outlets (nozzles), flexible ducts + control panel
  - Also integration with furniture or partitions
  - Advantages:
    - Allow occupants to fine-tune the local environment
    - Possible to off the unit when unoccupied to save energy
    - Direct supply of primary air to occupants



(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

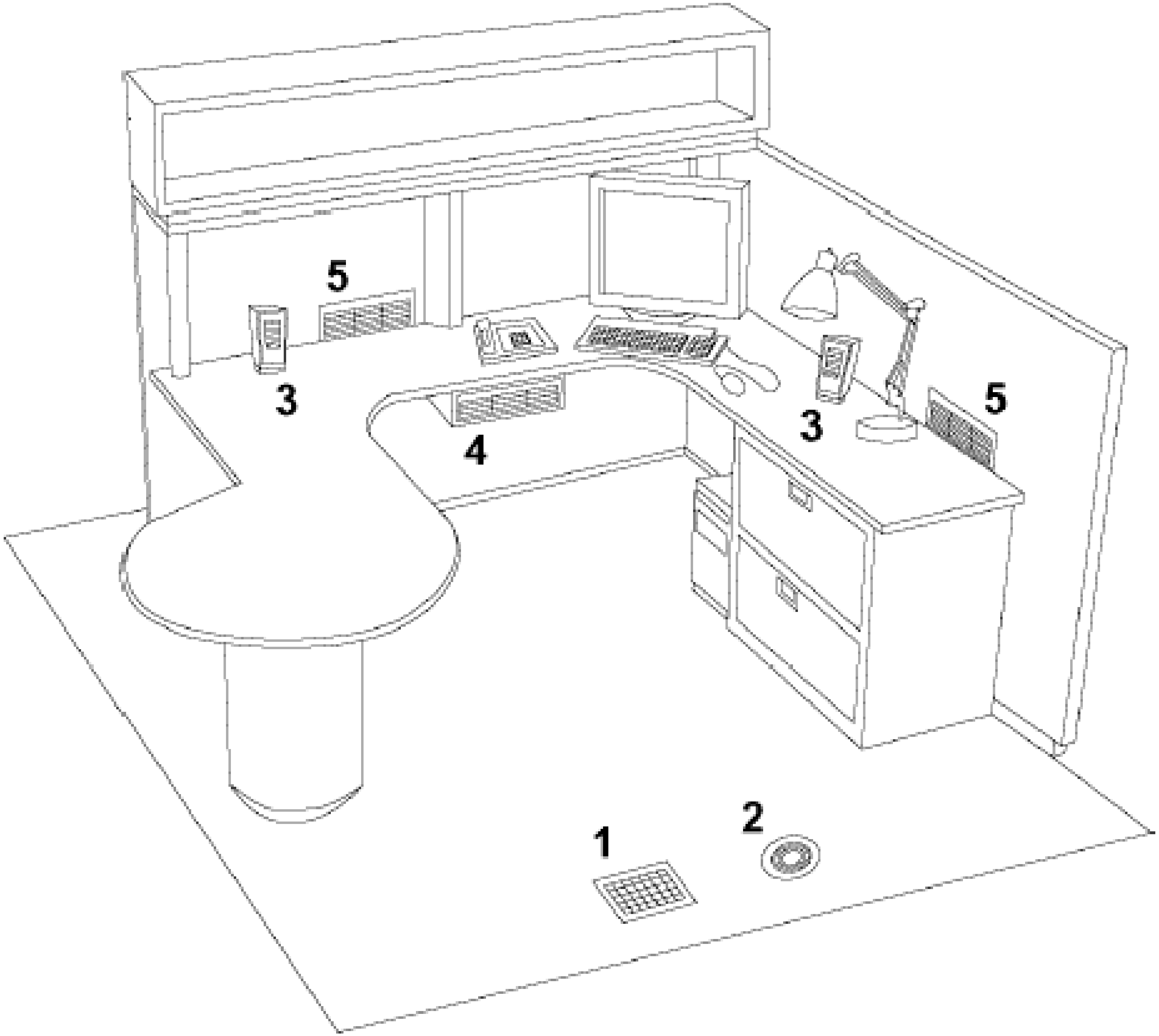


Figure 5.1 UFAD and TAC diffuser locations in a workstation.

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

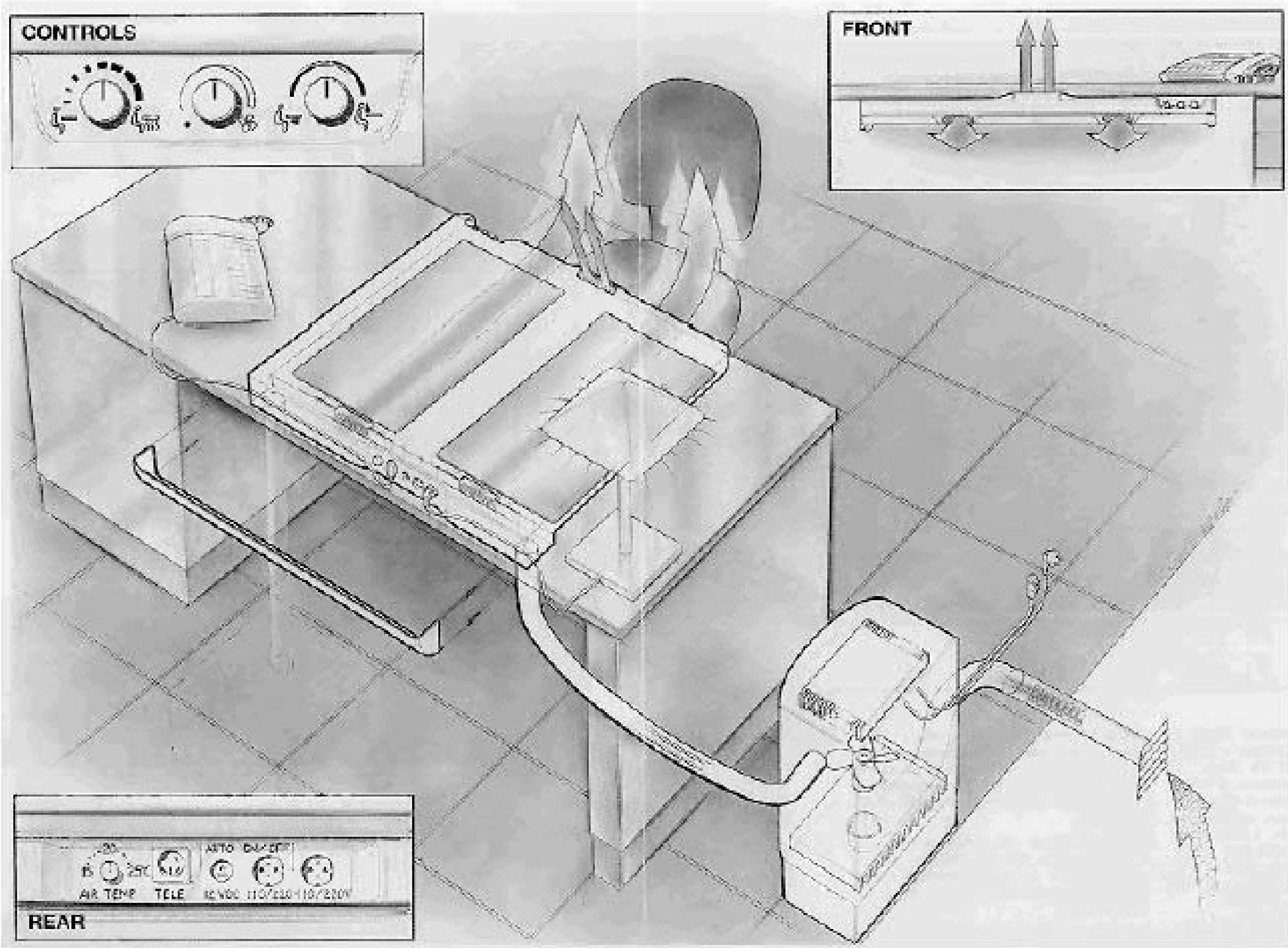


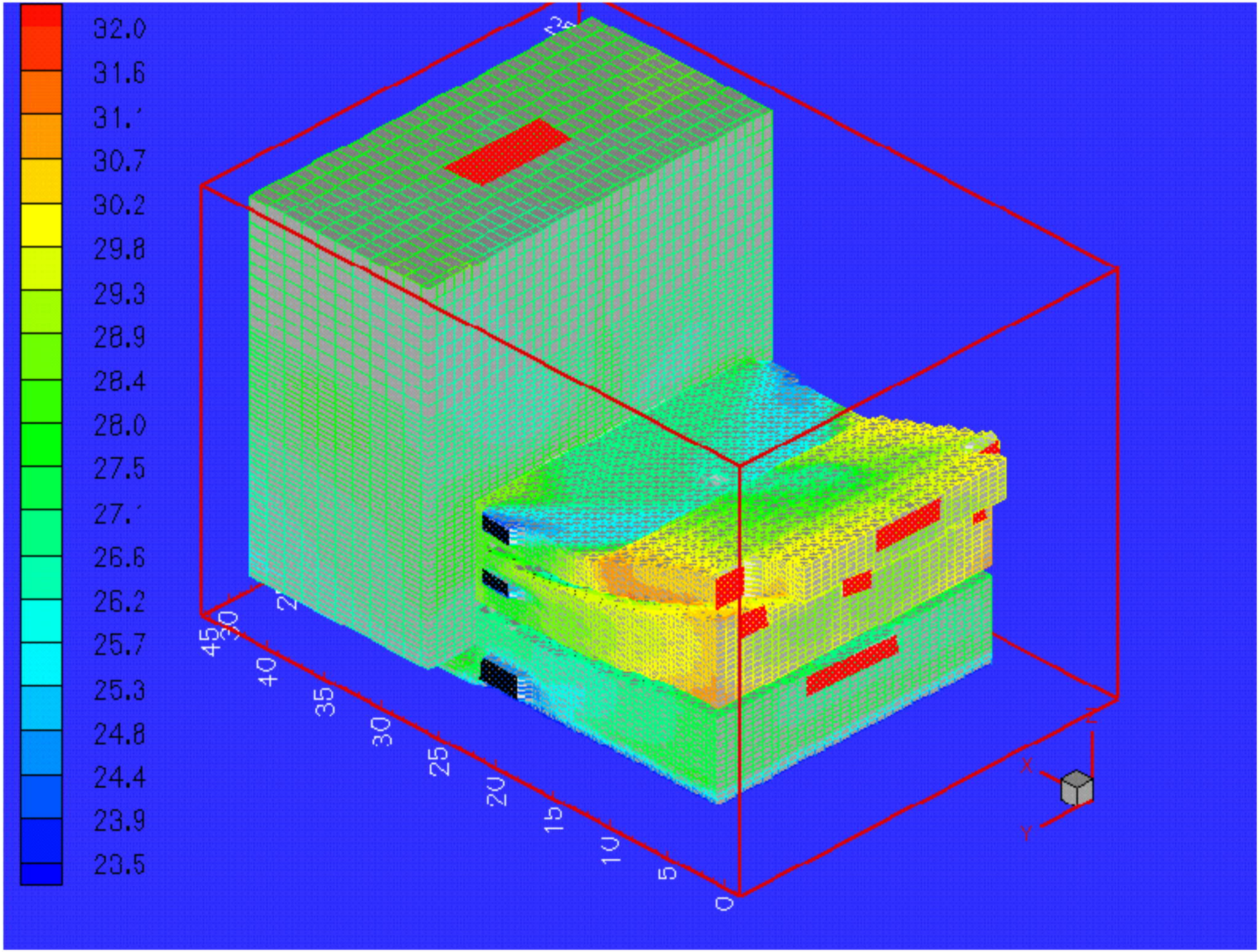
Figure 5.12 Underdesk TAC supply unit [Johnson Controls 2002].

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

Air Flow Analysis

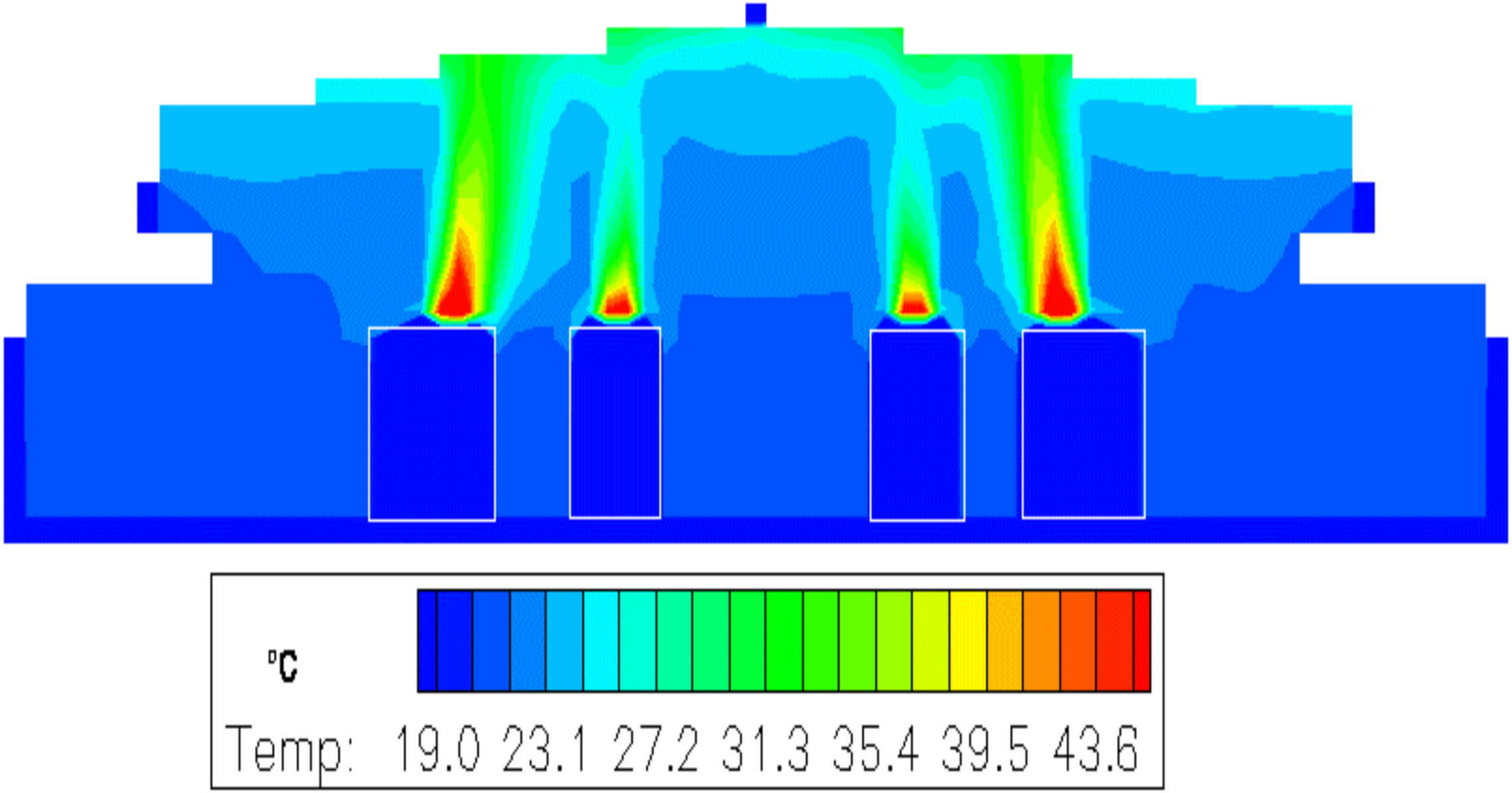
- Computational fluid dynamics (CFD)*
  - Computing technique for analysis & prediction of fluid motion and heat transfer
    - Using Navier-Stokes & thermal equations
  - Become more and more popular for study of air flow patterns, indoor temperature distribution & indoor contaminants
  - Useful tool for studying space air diffusion

* Video: Computational Fluid Dynamics (CFD) (3:32) https://www.youtube.com/watch?v=hzTCCcsOTg8
http://www.learnengineering.org/2013/05/What-is-CFD-computational-fluid-dynamics.html



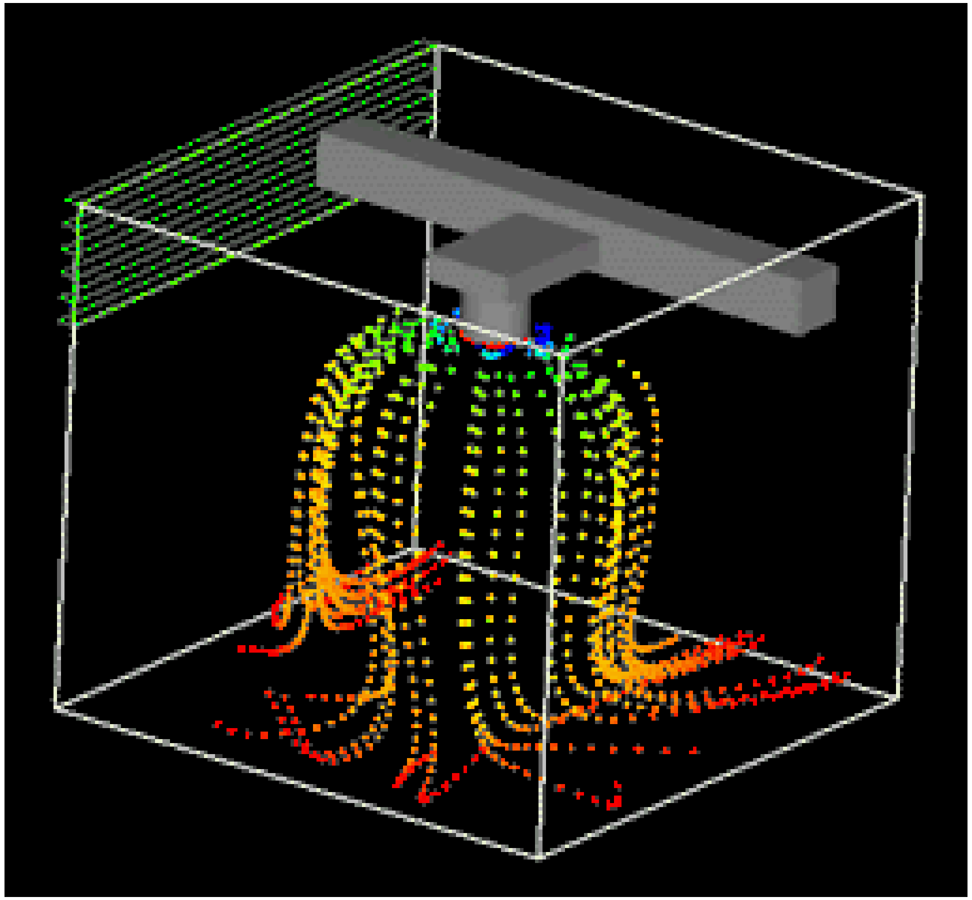
CFD visualisation – temp. distribution (St. James Theatre, Australia)

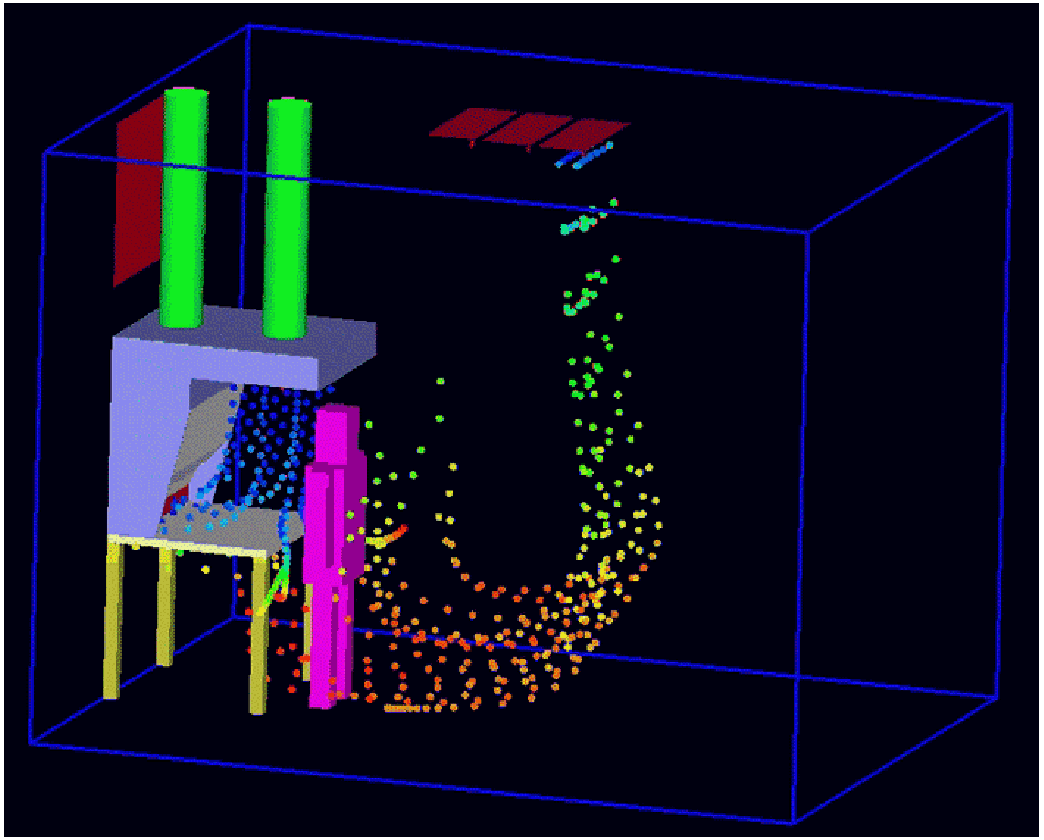
(Source: Dr. Yuguo Li, Dept of Mech Engg, HKU)



CFD visualisation – temp. distribution (Sydney Fruit Market)

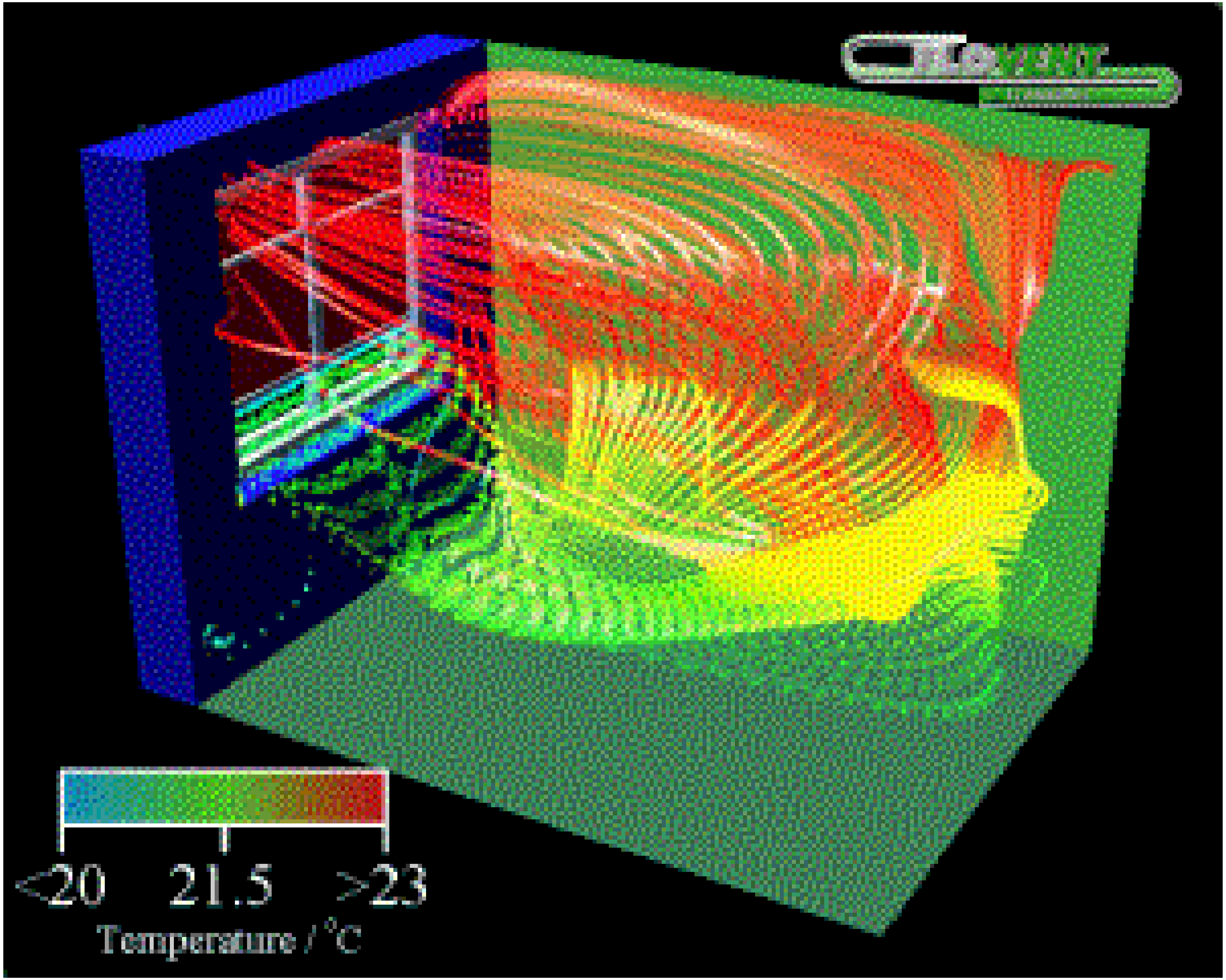
(Source: Dr. Yuguo Li, Dept of Mech Engg, HKU)





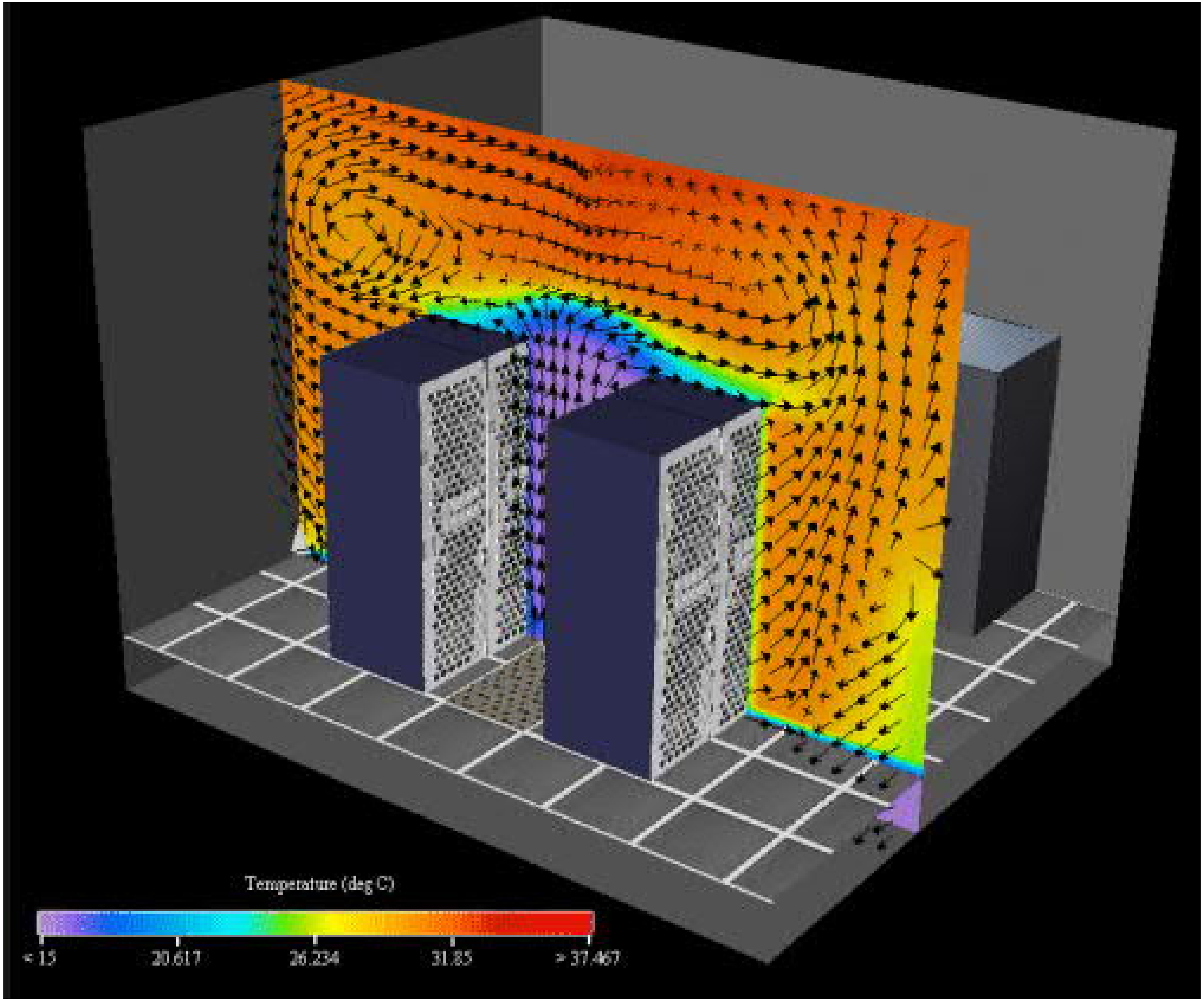
Computational fluid dynamics (CFD) applied to airflow study

(Source: http://www.fluent.com/)



CFD applied to naturally ventilated buildings

(Source: *http://www.flovent.com*)



CFD applied to data centre design study

(Source: *http://www.flovent.com*)

Air Flow Analysis

- Computational fluid dynamics (CFD)
  - Turbulence modelling methods
    - Correlations, e.g. drag as a function of Re
    - Integral methods
    - Reynolds average models (κ-ε models)
      - Large eddy simulation (LES)
      - Direct numerical simulation (DNS)
  - Time average Navier-Stokes equations*
    - Incompressible form of the momentum equation
    - Full and general set of partial differential equations governing fluid motion

* Video: Computational Fluid Dynamics (CFD) | RANS & FVM (5:21) https://www.youtube.com/watch?v=YGuLvNWKk2k
http://www.learnengineering.org/2013/05/computational-fluid-dynamics-rans-fvm.html

Air Flow Analysis

- Computational fluid dynamics (CFD)
  - Governing equations:-
    - Mass balance:

Fluid density (ρ) — Velocity (U, V, W)

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho U)+\frac{\partial}{\partial y}(\rho V)+\frac{\partial}{\partial z}(\rho W)=0$$

    - Momentum:

x-momentum
y-momentum
z-momentum

Viscosity (μ)

$$\frac{\partial}{\partial t}(\rho U)+\frac{\partial}{\partial x}(\rho UU)+\frac{\partial}{\partial y}(\rho UV)+\frac{\partial}{\partial z}(\rho UW)$$
$$=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}(\mu\frac{\partial U}{\partial x})+\frac{\partial}{\partial y}(\mu\frac{\partial U}{\partial y})+\frac{\partial}{\partial z}(\mu\frac{\partial U}{\partial z})+\frac{1}{3}\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}\right)\right]+\rho g_x$$

    - Energy:

$$\frac{\partial}{\partial t}(\rho T^*)+\frac{\partial}{\partial x}(\rho UT^*)+\frac{\partial}{\partial y}(\rho VT^*)+\frac{\partial}{\partial z}(\rho WT^*)=\frac{\partial}{\partial x}(\Gamma\frac{\partial T^*}{\partial x})+\frac{\partial}{\partial y}(\Gamma\frac{\partial T^*}{\partial y})+\frac{\partial}{\partial z}(\Gamma\frac{\partial T^*}{\partial z})$$

Temperature (T^*) — Diffusivity (Γ)

References

- The Basics of Computational Fluid Dynamics Modeling
  - http://www.flow3d.com/CFD-101/CFD101.htm
- Navier-Stokes Equations (Foundations of Fluid Mechanics)
  - http://www.navier-stokes.net/
- FLOVENT Applications
  - http://www.flovent.com/applications/