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Indoor Air Quality (IAQ) Strategies --- Source Control, Ventilation or Air Purification?

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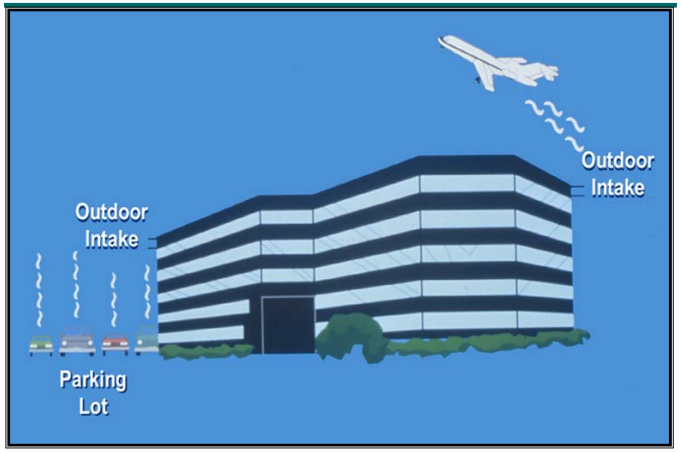
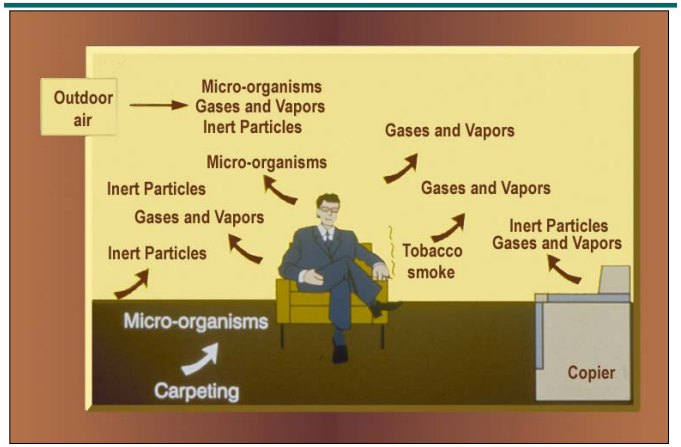
Typical Indoor Air Contaminants

- Inorganic gases
  - CO, CO2, SO2, NOx, O3, etc….
- Organic gases
  - Volatile organic compounds (VOCs)
    - Formaldehyde, benzene, toluene, styrene, 1,4-dichlorobenzene, 4-phenyl cyclohexene (4-PC), nonane, decane, undecane, dodecane, etc….
- Radioactive gases (e.g., Radon)
- Particulate pollutants
  - Bioaerosols derived from
    - Virus, bacteria, fungi, protozoa, dust mites, pollen
    - Asbestos, dusts, etc….

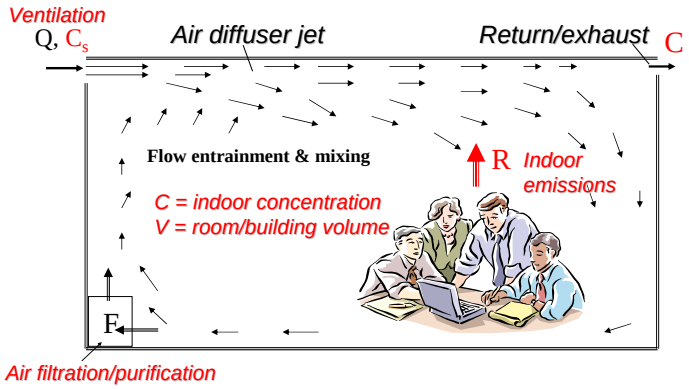
Typical contaminant sources: outdoors



Typical contaminant sources: indoors



Principle of IAQ Control



Principle of IAQ Control

- Goal:

$$C < C_{criteria}$$

- Governing equation:

$$V\,dC/dt = R(t) - Q(t)[C(t) - C_s(t)] - F(t)$$

Rate of contaminant accumulation = *Rate of source emission* − *Rate of dilution by ventilation* − *Rate of reduction by purification*

IAQ Control

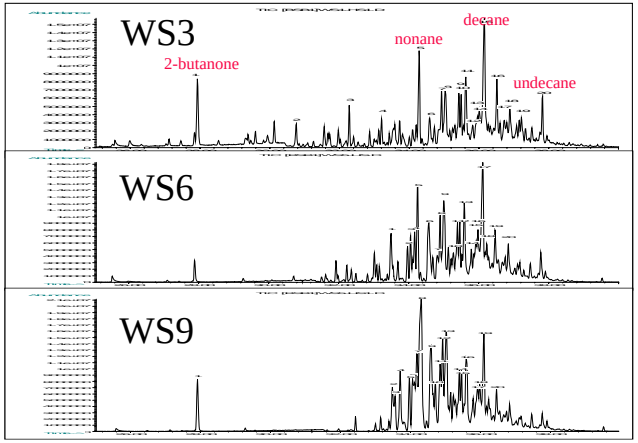
- Goal: $C < C_{criteria}$
- Strategies
  - *Source/emission control*
  - *Ventilation*
  - *Air purification (cleaning/filtration)*

Building Material Emissions

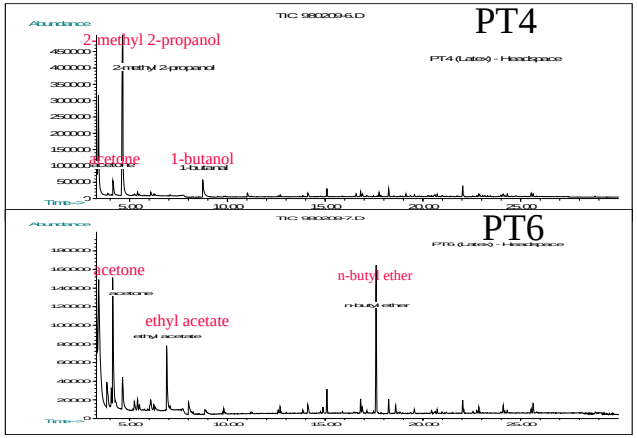
Why Study Material Emissions?

- 300+ VOCs identified (accounts for over 50% indoor contaminants)
- Many VOCs can cause discomfort and adverse health effects
- Indoor VOC concentrations are usually much higher than outdoors

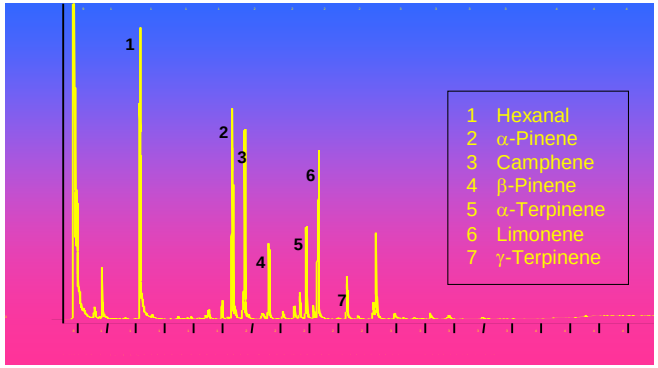
VOCs from Three Oil-based Wood Stains



VOCs from Two Water-based (Latex) Paints



Particleboard (at t=24 h, by GC/FID)



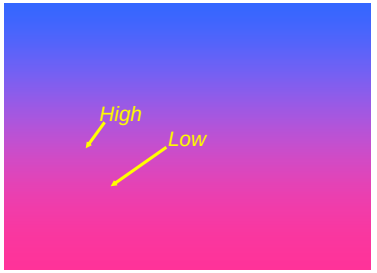
Full-scale Environmental Chambers

Emission Characteristics

"Wet" coating materials:

- High initial emission rates and fast decay rate
- Three emission periods
  - *evaporative controlled initial period*
  - *transition period*
  - *diffusion controlled final period*
- Affected by air velocity

Range of Individual VOC Emission Rates (Zhang et al. 1998)

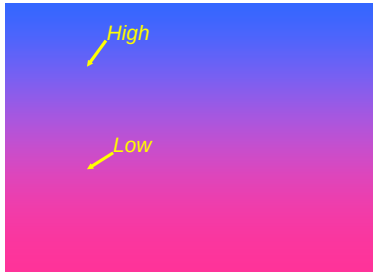


Emission Characteristics

Dry materials:

- Low emission rates and slow decay rate
- Diffusion controlled process
- Not significantly affected by air velocity

Range of Individual VOC Emission Rates (Zhang et al. 1998)



Minimization of Source Emissions

- Material selection
- Pre-conditioning
- Encapsulation/sealing
- Reformulation
  - *Oil versus water-based paints*
- Change of manufacturing processes
  - *Recycled tire materials—temperature control*

Strategies for IAQ Control

- Source/emission control
- Ventilation
- Air purification

Adequate Ventilation for IAQ

- Outdoor air quality
- Amount of outdoor air
- Room air distribution
  - *Delivery of outdoor air to the occupied spaces*

"ASHRAE Standard 62-1999: Ventilation for Acceptable Indoor Air Quality"

Outdoor Air Quality: National Primary Ambient-Air Quality Standards*

	Long Term		Short Term	
	ug/m^3 (ppm)	Averaging	ug/m^3 (ppm)	Averaging
SO_2	80 (0.03)	1 year	365 (0.14)	24 hours
PM10	50	1 year	150	24 hours
CO			40,000 (35)	1 hour
CO			10,000 (9)	8 hour
NO_2	100 (0.055)	1 year		
O_3			235 (0.12)	1 hour
Hydrocarbons			160 (0.24)	3 hour
Lead	1.5	3 months		

* Set by U.S. Environmental Protection Agency (EPA)

Outdoor Air Quality (ASHRAE 62-99)

- Satisfy EPA National Primary Ambient-Air Quality Standards
- Conduct air sample analysis for specific contaminants of importance
- Reduce outdoor air supply temporarily (e.g., during rush-hours)
- Use air purification devices

Amount of Outdoor Air (ASHRAE 62-99)

- Prescriptive procedure

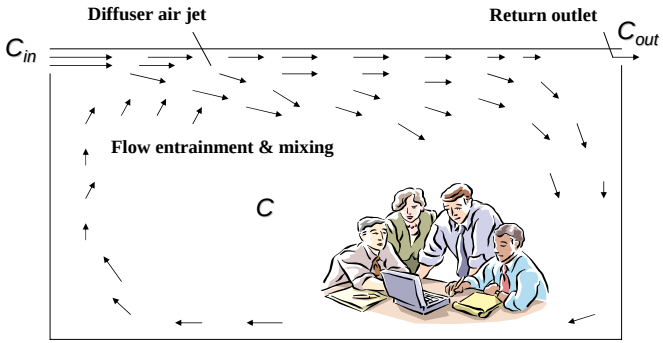
Application	Max. Occupancy (P/1000 ft² or 100 m²)	CFM (L/s) per person
Office space	7	20 (10)
Classroom	50	15 (7.5)
Residential living area:		15 (7.5)
(& not less than 0.35 air changes per hour)		

- IAQ procedure (performance based, allows for integration and optimization)

Adequate Ventilation for IAQ

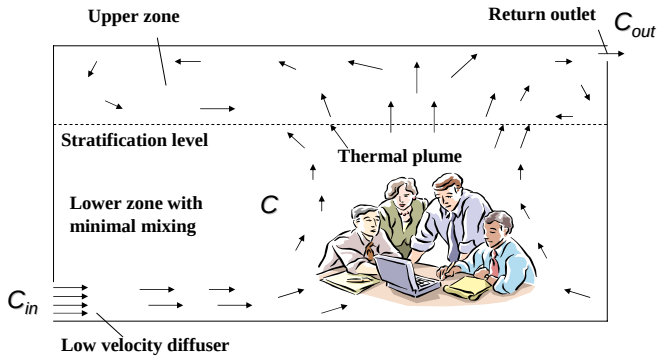
- Outdoor air quality
- Amount of outdoor air
- Room air distribution
  - *Deliver fresh air to occupants*
  - *Remove/dilute contaminants*

Mixing Ventilation



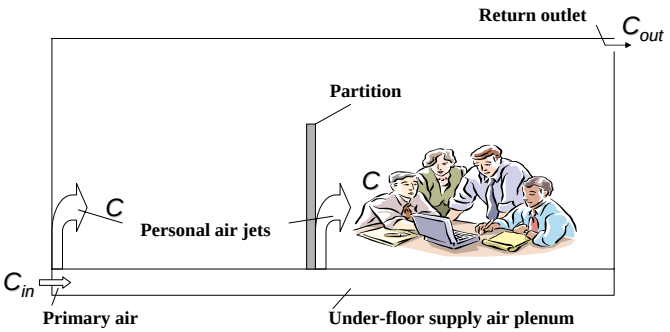
$$\text{Ventilation Efficiency} = (C_{out}-C_{in})/(C-C_{in}) \approx C_{out}/C \approx 1.0$$

Displacement Ventilation



$$\text{Ventilation Efficiency} = (C_{out}-C_{in})/(C-C_{in}) \approx C_{out}/C > 1.0$$

Personal/local Ventilation



$$\text{Ventilation Efficiency} = (C_{out}-C_{in})/(C-C_{in}) \approx C_{out}/C > 1.0$$

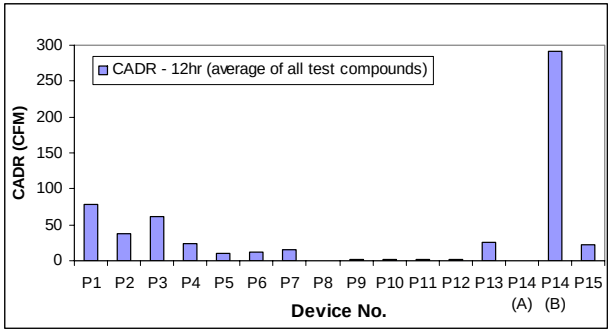
Strategies for IAQ Control

- ☐ Source/emission control
- ☐ Ventilation
- ☐ Air purification

Air Purification Methods

- ☐ Sorption by filter media
- ☐ Photo-catalytic oxidization
- ☐ Others
  - ◆ *Bio-filtration*
  - ◆ *Botanical air cleaning*
  - ◆ *Thermal decomposition*
  - ◆ *Non-thermal plasma decomposition*

Equivalent Clean Air Delivery Rate (CADR12-hr), Chen & Zhang 2004

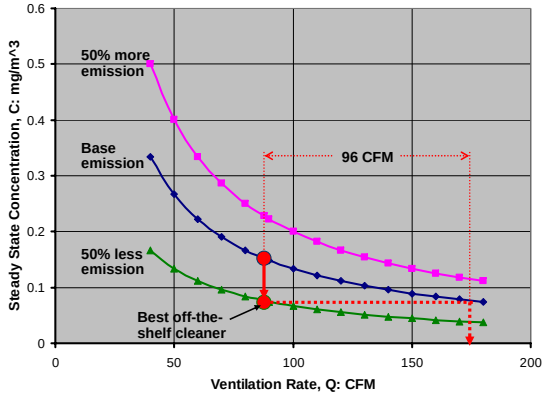


Note: Initial efficiencies of the seven sorption-based air cleaners could be ranked as P1>P3>P2>P4>P7>P6≈P5, according to the average $CADR_{12\text{-}hr}$ (for all the VOCs except dichloromethane, formaldehyde, and acetaldehyde)

Effectiveness of Current Air Cleaning Devices for IAQ Control

- Example case: 240 m² single family detached house (Zhang, 2000)

(Base Case: Cs=0.152 mg/m³, Es=22.7 mg/h Toluene, Nc=0.24 ACH, No air cleaner)



Strategies for IAQ Control

- ☐ Source/emission control?
- ☐ Ventilation?
- ☐ Air purification?

"These strategies should be integrated & optimized in building design and operation."