

Advanced Building Science

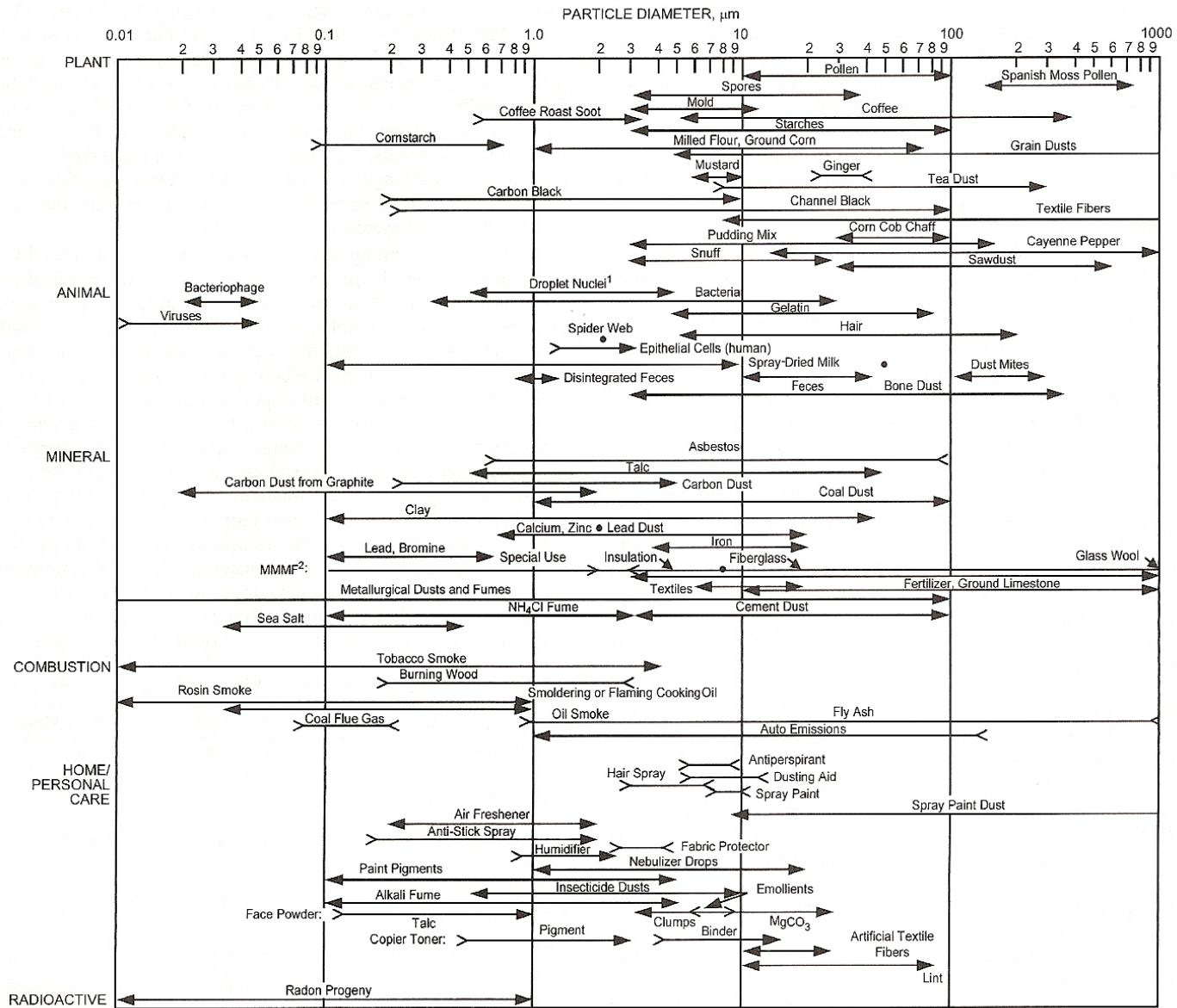
- Air Contaminants
 - Classes of contaminants
 - Indoor
 - Outdoor pollutants
 - Soil gases
- Air Cleaners
 - Equipment types
- Readings
 - HF: Chapter 11 & 12

Classes of Air Contaminants

- Particulate types
 - dust, fume, smoke (mostly solid)
 - mist, fog, smog (mostly liquids)
 - bioaerosols (viruses, bacteria, spores, pollen, animal dander)
- Other particulate definitions
 - coarse, fine, visible, invisible
 - macroscopic, microscopic, submicroscopic
 - Inhalable (respirable)
- Gaseous
 - gases (naturally gaseous under ambient conditions)
 - vapors (from items that are normally solid or liquid)

Particulates

- Anthropogenic vs. Natural - Primary vs. Secondary
- Types of solids
 - dusts => generally 1 to 100 microns
 - fumes => usually smaller than 1 micron
 - bioaerosols => wide range 0.01 to 100 microns
- Types of liquids
 - mists => fine airborne droplets
 - fogs => transition between vapor and mists
- Complex particles
 - smoke => small liquid and solid particles; incomplete combustion
 - ETS => mostly a suspension of fine liquid particles (and gases)
 - smog => mixture of smoke, mists, fogs (and gases)



¹Liquid droplets containing bacteria, etc., sneezed, etc.

²Man-made mineral fibers

Fig. 3 Sizes of Indoor Particles
(Owen et al. 1992)

Source: ASHRAE Handbook
Fundamentals 2013 Chapter 11.4

Airborne Particles

- Sizes
 - Nasal
 - Tracheo-bronchial
 - Pulmonary
- Size distribution in the atmosphere
 - Fine
 - Coarse
- Units of measurement
 - Particle counts (total or by size range)
 - Particle mass (usually total, but can be separate by size)

Outdoor Particulates

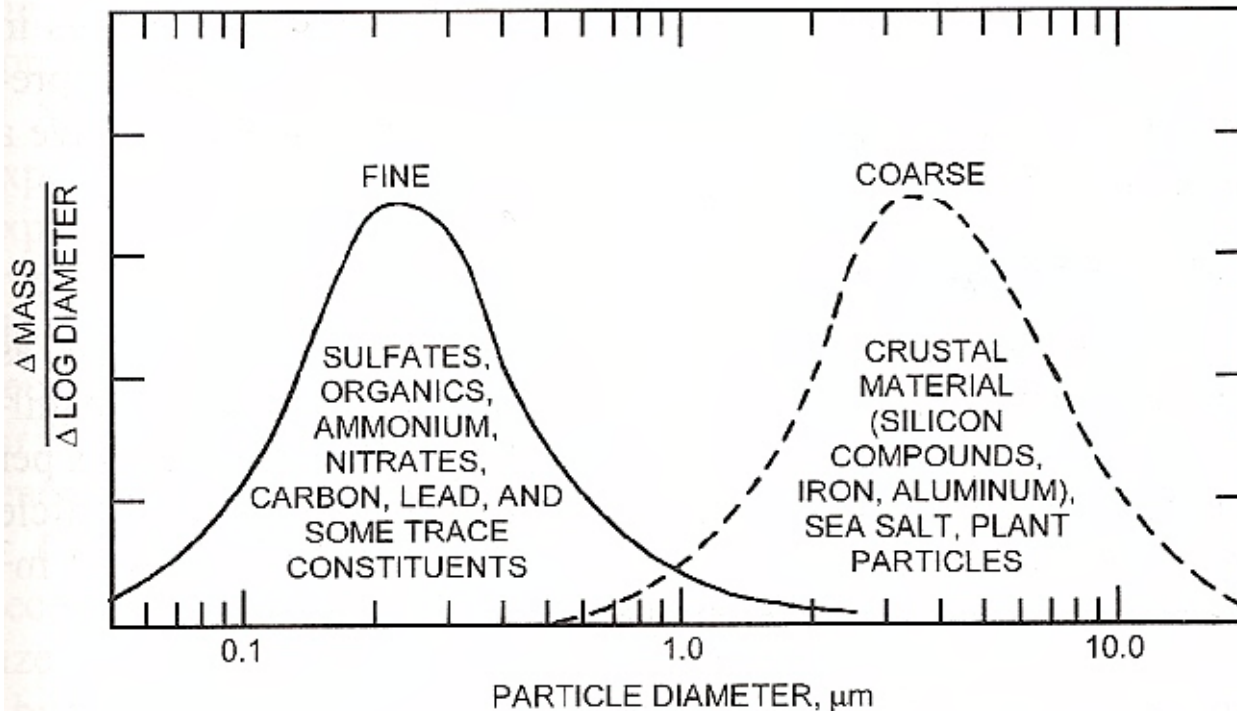


Fig. 1 Typical Urban Aerosol Composition by Particle Size Fraction
(EPA 1982; Willeke and Baron 1993)

Source: ASHRAE Handbook
Fundamentals 2009, Chapter 11.3

Respiratory Deposition

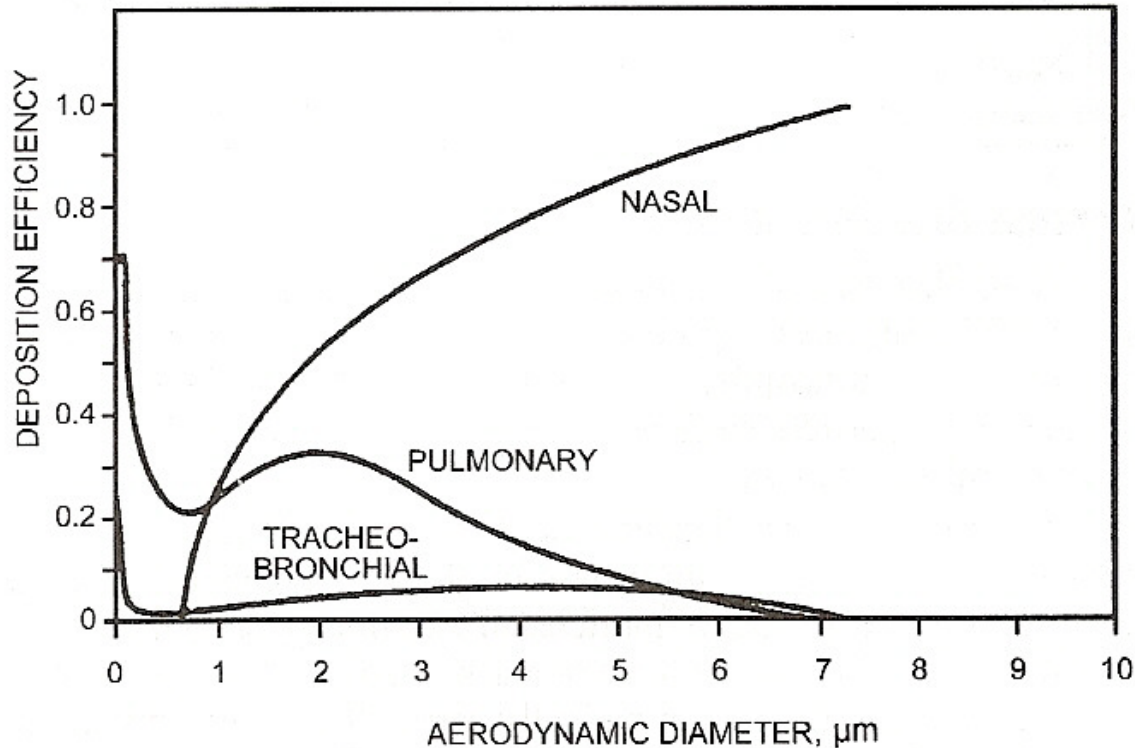
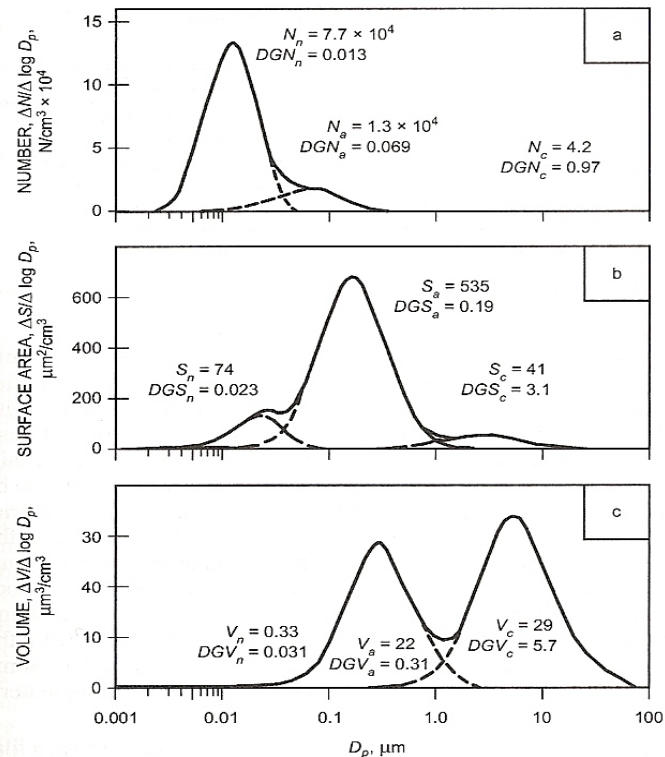


Fig. 2 Relative Deposition Efficiencies of Different-Sized Particles in the Three Main Regions of the Human Respiratory System, Calculated for Moderate Activity Level (Task Group on Lung Dynamics 1966)

Source: ASHRAE Handbook Fundamentals 2013, Chapter 11.3

Outdoor Distributions



Data are plotted by particle number N (plot A), surface area S (plot B), and volume V (plot C). D_p is particle diameter in microns. Legends show geometric mean diameters (DG) for each distribution, and particle number, surface area, or volume in mode.

Fig. 4 Typical Urban Outdoor Distributions of Ultrafine or Nuclei (n) Particles, Fine or Accumulation (a) Particles, and Coarse (c) Particles (Whitby 1978)

Source: ASHRAE Handbook Fundamentals 2013, Chapter 11.5

Indoor Air Pollutants

- Types
- Sources

Bioaerosol Contaminants

Airborne microbiological particulate matter derived from:

- fungi
 - bacteria
 - viruses
 - protozoa
 - algae
 - pollen
 - mites
 - animal dander
-and their cellular or cell mass components

Gaseous Contaminants

- Organic (mostly vapors) vs. Inorganic (mostly gases)
- Harmful effects
 - human toxicity
 - human irritation
 - odors
 - damage to materials
- Units
 - ppm or ppb
 - mg/m³
 - Equation 3* to convert
 - based on molecular mass, temperature, pressure

*See ASHRAE Handbook Fundamentals 2013, Equation 3, page 11.10

Volatile Organic Compounds (VOC)

- As a serious indoor pollutant, they
 - are beginning to attract considerable attention
 - are a tremendous variety of compounds
 - are very difficult and expensive to measure
- Total VOC (or TVOC)
 - useful concept, but
 - some difficulty in measurements and accuracy
 - not all VOCs have similar levels of concern

Volatile Organic Compounds (VOC)

Table 10 VOCs Commonly Found in Buildings

Benzene	Styrene
<i>m</i> -, <i>p</i> -xylene	<i>p</i> -dichlorobenzene
1,2,4-trimethylbenzene	<i>n</i> -undecane
<i>n</i> -octane	<i>n</i> -nonane
<i>n</i> -decane	Ethyl acetate
<i>n</i> -dodecane	Dichloromethane
Butyl acetate	1,1,1-trichloroethane
Chloroform	Tetrachloroethylene
Trichloroethylene	Carbon disulfide
Trichlorofluoromethane	Acetone
Dimethyl disulfide	2-butanone
Methyl isobutyl ketone	Methyl tertiary butyl ether
Limonene	Naphthalene
α -, β -pinene	4-phenyl cyclohexene
Propane	Butane
2-butoxyethanol	Ethanol
Isopropanol	Phenol
Formaldehyde	Siloxanes
Toluene	

Source: Brightman et al. (1996).

Source: ASHRAE Handbook Fundamentals 2013, Chapter 11.14

Inorganic Gases

- Carbon dioxide
- Carbon monoxide
 - incomplete combustion
- Nitrogen oxides
 - high temperature combustion
- Sulfur dioxide
 - combustion of sulfur containing fuels
- Ozone
 - photochemical smog
 - coronal discharges from office equipment
 - air cleaners

Outdoor Air Contaminants

- Common gases
 - EPA critical pollutants
 - primary Ambient Air Quality Standards
 - indoor to outdoor concentration ratios
- Soil Gases
 - radon (primary concern)
 - methane
 - pesticides
 - water vapor

Outdoor Air Contaminants

Table 11 Typical Outdoor Concentrations of Selected Gaseous Air Pollutants

Pollutant	Typical Concentration, $\mu\text{g}/\text{m}^3$	Pollutant	Typical Concentration, $\mu\text{g}/\text{m}^3$
Acetaldehyde	20	Methylene chloride	2.4
Acetone	3	Nitric acid	6
Ammonia	1.2	Nitric oxide	10
Benzene	8	Nitrogen dioxide	51
2-butanone (MEK)	0.3	Ozone	40
Carbon dioxide	612,000	Phenol	20
Carbon monoxide	3000	Propane	18
Carbon disulfide	310	Sulfur dioxide	240
Carbon tetrachloride	2	Sulfuric acid	6
Chloroform	1	Tetrachloroethylene	2.5
Ethylene dichloride	10	Toluene	20
Formaldehyde	20	1,1,1-trichloroethane	4
<i>n</i> -heptane	29	Trichloroethylene	15
Mercury (vapor)	0.005	Vinyl chloride monomer	0.8
Methane	1100		
Methyl chloride	9	Xylene	10

Sources: Braman and Shelley (1980), Casserly and O'Hara (1987), Chan et al. (1990), Cohen et al. (1989), Coy (1987), Fung and Wright (1990), Hakov et al. (1987), Hartwell et al. (1985), Hollowell et al. (1982), Lonnemann et al. (1974), McGrath and Stele (1987), Nelson et al. (1987), Sandalls and Penkett (1977), Shah and Singh (1988), Singh et al. (1981), Wallace et al. (1985), and Weschler and Shields (1989).

Source: ASHRAE Handbook Fundamentals 2009, Chapter 11.15

Outdoor Air Contaminants

Table 12 Primary Ambient Air Quality Standards for the United States

Contaminant	Long-Term			Short-Term		
	Concentration $\mu\text{g}/\text{m}^3$	Concentration ppm	Averaging Period	Concentration $\mu\text{g}/\text{m}^3$	Concentration ppm	Averaging Period, h
Sulfur dioxide	80	0.03	1 year ^b	365	0.14	24 ^a
Carbon monoxide				10,000	9	
				40,000	35	8 ^a
						1 ^a
Nitrogen dioxide	100	0.053	1 year ^b			
Ozone ^c				235	0.08	8
Total particulate (PM ₁₀) ^d				150		24
Total particulate (PM _{2.5}) ^e	15		1 year ^b			
Lead particulate	1.5		3 months			

Source: EPA (2008)

^aNot to be exceeded more than once a year

^bAnnual arithmetic mean

^cStandard is met when three-year average of fourth-highest daily maximum 8-h average ozone concentrations measured at each monitor in an area over each year is less than or equal to 0.08 ppm.

^dPM₁₀ = particulates below 10 μm diameter.

^ePM_{2.5} = particulates below 2.5 μm diameter.

Source: ASHRAE Handbook Fundamentals 2009, Chapter 11.16

Outdoor Air Contaminants

Table 13 Sources, Possible Concentrations, and Indoor-to-Outdoor Concentration Ratios of Some Indoor Contaminants

Pollutant	Sources of Indoor Pollution	Upper Possible Indoor Concentration*	I/O Concentration Ratio for Upper Concentration	Location
Carbon monoxide	Combustion equipment, engines, faulty heating systems	100 mg/m ³	>>1	Indoor ice rinks, homes, cars, vehicle repair shops, parking garages
Respirable particles	Stoves, fireplaces, cigarettes, condensation of volatiles, aerosol sprays, resuspension, cooking	100 to 500 µg/m ³	>>1	Homes, offices, cars, public facilities, bars, restaurants
Organic vapors	Combustion, solvents, resin products, pesticides, aerosol sprays, cleaning products	NA	>1	Homes, restaurants, public facilities, offices, hospitals
Nitrogen dioxide	Combustion, gas stoves, water heaters, gas-fired dryers, cigarettes, engines	200 to 1000 µg/m ³	>>1	Homes, indoor ice rinks
Sulfur dioxide	Heating system	20 µg/m ³	<1	Mechanical/furnace rooms
Total suspended particles (without smoking)	Combustion, resuspension, heating system	100 µg/m ³	1	Homes, offices, transportation, restaurants
Sulfate	Matches, gas stoves	5 µg/m ³	<1	Mechanical/furnace rooms
Formaldehyde	Insulation, product binders, pressed wood products	2 mg/m ³ (2000 µg/m ³)	>>1	Homes, schools, offices
Radon and progeny	Building materials, groundwater, soil	0.1 to 100 nCi/m ³	>>1	Homes, schools
Asbestos	Fireproofing	<10 ⁶ fiber/m ³	1	Homes, schools, offices
Mineral and synthetic fibers	Carpets, clothes, rugs, furnishing materials, wallboard	NA	—	Homes, schools, offices
Carbon dioxide	Combustion appliances, humans, pets	9000 mg/m ³	>>1	Homes, schools, offices, hospitals, public facilities
Viable organisms	Humans, pets, rodents, insects, plants, fungi, humidifiers, air conditioners	NA	>1	Homes, hospitals, schools, offices, public facilities
Ozone	Electric arcing, electronic air cleaners, some copiers, and printers, some UV light sources	400 µg/m ³	<1 >1	Airplanes Offices, homes

Source: NRC (1981).

*Concentrations listed are only those reported indoors. Both higher and lower concentrations have been measured. No averaging times are given. NA indicates that it is not appropriate to list a concentration.

Source: ASHRAE Handbook Fundamentals 2009, Chapter 11.17

Outdoor Air Contaminants

Table 4 Comparison of Indoor Environment Standards and Guidelines

	Canadian ^c	WHO/Europe	NAAQS/EPA ^f	NIOSH REL (TWA) ^h	OSHA (TWA) ^h	ACGIH (TWA) ^h	MAK ^g (TWA) ^h
Acrolein	0.02 ppm ^a			0.1 ppm 0.3 ppm (15 min)	0.1 ppm	C 0.1 ppm, A4	
Acetaldehyde	5.0 ppm			Ca: ALARA ^b	200 ppm	C 25 ppm	50 ppm 100 ppm (5 min)
Formaldehyde	0.1 ppm (1 h) 0.04 ppm (8 h)	0.081 ppm (30 min)		0.016 ppm 0.1 ppm (15 min) Ca	0.75 ppm 2 ppm (15 min) Ca	C 0.3 ppm, A2	0.3 ppm 1.0 ppm (5 min)
Carbon dioxide	3500 ppm			5000 ppm 30,000 ppm (15 min)	5000 ppm	5000 ppm 30,000 ppm (15 min)	5000 ppm 10,000 ppm (60 min)
Carbon monoxide	11 ppm (8 h) 25 ppm (1 h)	8.6 ppm (8 h) 25 ppm (1 h) 51 ppm (30 min) 86 ppm (15 min)	9 ppm (8 h) 35 ppm (1 h)	35 ppm C 200 ppm	50 ppm	25 ppm	30 ppm 60 ppm (30 min)
Nitrogen dioxide	0.05 ppm 0.25 ppm (1 h)	0.02 ppm (1 yr) 0.1 ppm (1 h)	0.053 ppm (1 yr)	1 ppm (15 min)	C 5 ppm	3 ppm 5 ppm (15 min), A4	5 ppm 10 ppm (5 min)
Ozone	0.12 ppm (1 h); Insufficient data for long-term level	0.06 ppm (8 h)	0.12 ppm (1 h) 0.085 ppm (8 h)	C 0.1 ppm	0.1 ppm	0.05 ppm, A4 (for heavy work) 0.2 ppm (2 h) (light, moderate, or heavy work)	
Particles <2.5 MMAD ^d	40 µg/m ³ (8 h) 100 µg/m ³ (1 h)		15 µg/m ³ (1 yr) 35 µg/m ³ (24 h)		5 mg/m ³ (respirable fraction)	3 mg/m ³ (8 h) (no asbestos, <1% crystalline silica, with median cut point of 4.0 µm)	1.5 mg/m ³ (for less than 4 µm)
Sulfur dioxide	0.019 ppm 0.38 ppm (5 min)	0.047 ppm (24 h) 0.019 ppm (1 yr)	0.03 ppm (1 yr) 0.14 ppm (24 h)	2 ppm (8 h) 5 ppm (15 min)	5 ppm	2 ppm 5 ppm (15 min)	0.5 ppm 1.0 ppm (5 min)
Radon	800 Bq/m ^{3e}		4 pCi/l				

() Numbers in parentheses represent averaging periods
C = ceiling limit
Ca = carcinogen
A4 = not classifiable as human carcinogen per ACGIH

^aParts per million (10⁶)
^bAs low as reasonably achievable
^cHealth Canada *Exposure Guidelines for Residential Indoor Air Quality*
^dMass median aerodynamic diameter

^eMean in normal living areas
^fU.S. EPA National Ambient Air Quality Standards
^gGerman Maximale Arbeitsplatz Konzentrationen
^hValue for 8-h TWA, unless otherwise noted
ⁱWHO Air Quality Guidelines for Europe

Source: ASHRAE Handbook
Fundamentals 2013,
Chapter 10.11

Air Processing Equipment

Air Cleaners

- Critical particle sizes
- Types of air cleaners
 - fibrous media filters
 - viscous impingement filters
 - dry air filters
 - renewable media filters
 - electronic air cleaners
 - turbulent air filter
 - cyclonic air filter

Air Filtration

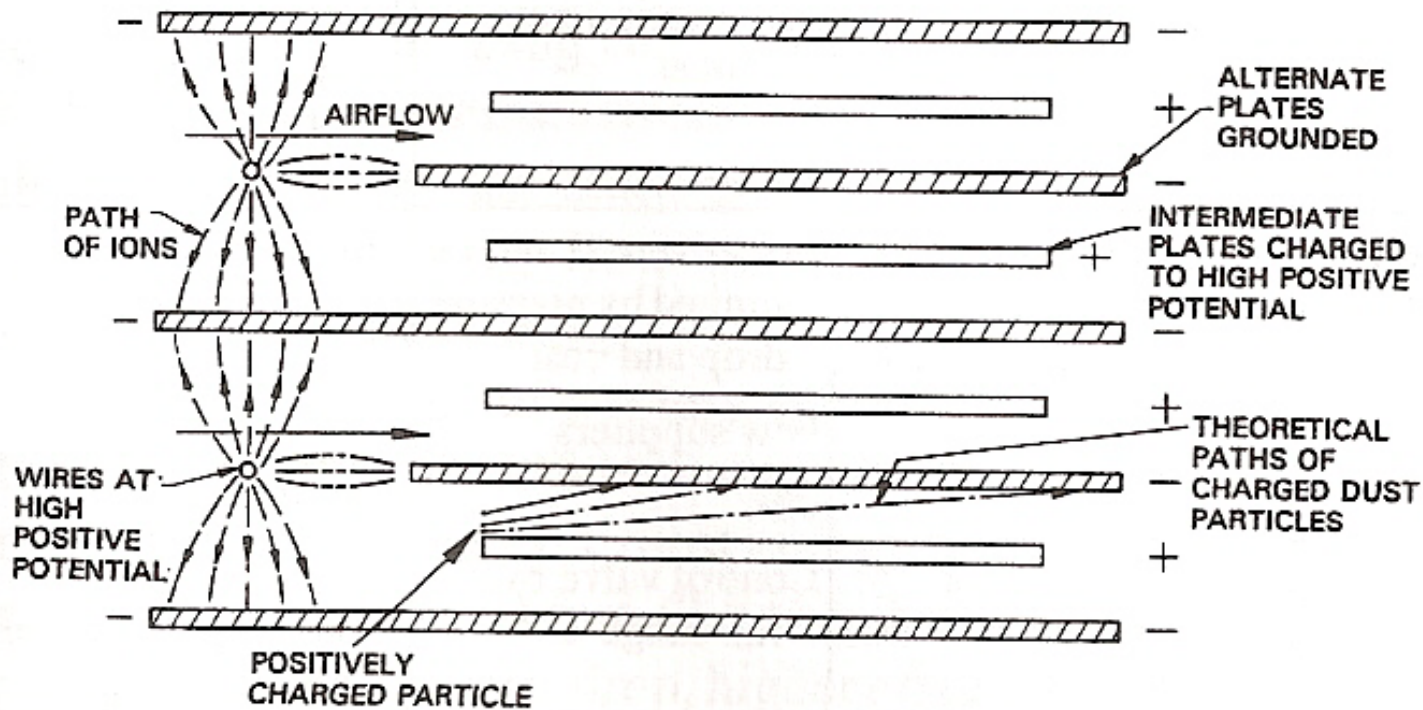
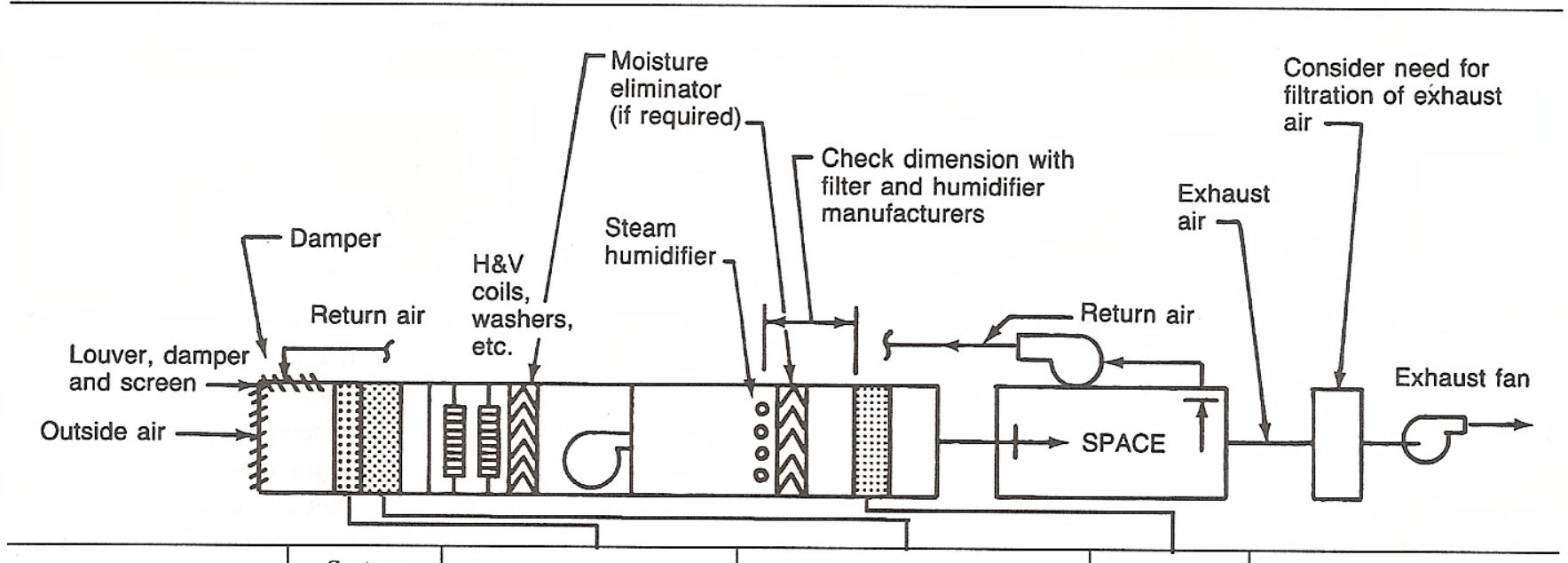


Fig. 17-22 Cross-Section of Ionizing Electronic Air Cleaner

Source: Howell, Sauer & Coad, Principles of Heating, Cooling, and Ventilation 1997, Chapter 17.17

Air Processing Equipment



Source: Howell, Sauer & Coad, Principles of Heating, Cooling, and Ventilation 1997, Chapter 17.15

In Summary

Questions and Discussion

Next Class

- Duct Systems
 - Basics
 - Fans
 - Air-Diffusing Equipment
- Readings
 - HF Chapter 21 (focus on 21.7 to 21.17)
 - RVS Handout Chapter 2 (pages 6 – 12)