#### Indoor Environmental Quality of Sustainable Building Designs and Occupant Health

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a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA

# Sampling strategies: where, when, how to sample

• When

- IAQ complaints
- symptoms suggest allergic responses
- What to look for
  - Potential sources/reservoirs (areas of moisture, RH > 55%, standing water, faecal material)
  - High/low exposure areas
  - Identify occupants expected to receive high/low exposures

- LEED (Leadership in Energy & Environmental Design)
- BOMA BEST (Building Owners and Managers' Association Building Environmental Standards)
- Well Building
- Passivhaus Institut = Passive House

# Intertwined systems of the built environment











**FIGURE 7.1** Basic components of an HVAC system. [Reprinted from EPA (1994). Orientation to Indoor Air Quality. Washington, DC: U.S. Environmental Protection Agency.]









EXHAUST PRESSURE









FIGURE 2.4.1

# Requires substantial energy investment!







# Air movement into & within building: Stack ventilation



# Air movement into & within building: Stack ventilation



### Air movement into & within building: entrainment & turbulent flow













### Occupants and ventilation

#### Record #57 CO2



Time

# Building ventilation is related to infectious PM

$$C = S\left(1 - e^{-\frac{Iqpt}{Q}}\right)$$



*C* = number of new infections predicted

- S = number of susceptible persons in the exposed environment
- I = the number of infections

q = the number of quanta added to air per hour

p=respiration rate per occupant (cfm)

T = exposure time (hours)

# Mechanisms: PM in air

Diameter in µm	Time to fall 3 metres	Pulmonary deposition
100	10 sec	Nose
40	1 min	Upper airways
20	4 min	Upper airways
10	17 min	Thoracic
6	Several hours	Bronchi
0.06 – 6	Many hours	Alveoli

# Need for dilution air exchange







# Volatile Organic Compounds = VOCs



Lipid layer (0.004 – 0.4 µm

Tear fluid (6µm)

Tear fluid enhanced mucin (4 µm)

Epithelium with adsorbed mucin  $(0.02 - 0.4 \ \mu m)$ 

Eye irritation related to breakup of the tear film

# Mechanisms: receptors



# Mechanisms: VOCs



# Mechanisms: VOCs



#### Common sources of VOCs



Smoking puts you and others at risk. It can lead to major health problems such as lung cancer and heart disease. Here's what's in your cigarette and cigarette smoke



Acetaldehyde, benzene, formaldehyde, toluene, xylenes



Acetaldehyde,ethylbenzene,formaldehyde, toluene, xylenes



### Dust (Particulate matter)



Dust mite 50 µm

Antigen 5 -10 µm



Skin flakes 1 – 40 µm





Cat dander 1 – 3 µm Pollen Antigen 10 - 100 µm



Fungal spores 3 – 10 µm

- LEED (Leadership in Energy & Environmental Design)
  - 2 points for consideration of IAQ
  - Points can be obtained prior to occupancy by heating and flushing (14,000 cubic feet air per sq ft. floor area for 2 weeks)
  - Alternately, once occupied, can do air quality testing for particulates, ozone, CO, formaldehyde

https://www.ietbuildinghealth.com/LEED-certification.html

- BOMA BEST (Building Owners and Managers' Association Building Environmental Standards)
  - 1 credit given for including IAQ consideration in plan
  - 1 credit given for ventilation
  - 1 credit for avoiding VOC in product
  - 1 credit for limiting VOC emissions

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• Well Building

- Particulate matter ( $PM_{2.5}$ ) <15 µg/m<sup>3</sup>
- Particulate matter ( $PM_{10}$ ) < 50  $\mu$ g/m<sup>3</sup>
- Ozone < 51 ppb
- CO < 9 ppm
- TVOC < 500 ppm
- Formaldehyde < 27 ppb
- Radon < 0.148 Bq/L

• Passivhaus = Passive House

- Based only on energy demand
- Space Heat Demand max. 15 kWh/m2a OR Heating load max. 10 W/m2
- Pressurization Test Result @ 50 Pa maximum <u>0.6 ACH</u> (both over-pressure and underpressure)
- Total Primary Energy Demand max. 120 kWh/m2a

https://www.passivehousecanada.com/passive-house-building-certification/

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- Ventilation is key to controlling emissions from occupants and materials.
- Local Health and Safety teams should keep IEQ on their proactive agendas.

# Further study:

• Not included in today's notes, but are vital to a full IEQ evaluation are:

Acoustics
Light
Ergonomics
Social capital

# Appendices

# Useful references:

- <u>https://www.canada.ca/en/health-</u> <u>canada/services/air-quality/residential-indoor-air-</u> <u>quality-guidelines.html</u>
- https://www.epa.gov/indoor-air-quality-iaq
- <u>https://www.cagbc.org/CAGBC/Programs/LEED/LEED\_</u> <u>Certification\_Process.aspx</u>
- <a href="https://www.boma.bc.ca/green-buildings/boma-best/">https://www.boma.bc.ca/green-buildings/boma-best/</a>
- <a href="https://www.passivehousecanada.com/">https://www.passivehousecanada.com/</a>
- <u>https://www.cagbctoronto.org/education/well-</u> <u>building-standard</u>
- Spengler, Samet & McCarthy 2001 Indoor Air Quality Handbook. McGraw-Hill
- Healthy Building Manual: Systems, Parameters, Problems & Solutions. Minister of Supply and Services Canada 1989

## Standards? ASTER\*

- Bioaerosols no WCB or ACGIH standards. Indoor < outdoor preferred.
- Carbon dioxide 650 ppm > outdoor.
- Aldehydes weighted average sum
- Carbon monoxide < 11 ppm 8 hr (outdoor 1 – 10 ppm)
- Nitrogen dioxide < 0.25 ppm 1 hr (outdoor 0.01 ppm)
- Ozone < 0.12 ppm 1 hr (outdoor 0.015)
- Humidity 30% 55% (winter)

#### \*Acceptable Short Term Exposure Range

https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html

#### LEED Criteria Pollutants

		Contaminant	Maximum concentration	ASTM and U.S. EPA methods	ISO method
Particulates	PM1	0 (for all buildings)	50 µg/m <sup>3</sup> Healthcare only: 20 µg/m <sup>3</sup>	EPA Compendium	ISO 7708
	FM2 for P	.5 (for buildings in EPA nonattainment areas M2.5, or local equivalent)	15 µg/m³	Method IP-10	
Ozone (for building equivalent)	s in EP	A nonattainment areas for Ozone, or local	0.075 ppm	ASTM D5149 - 02	ISO 13964
Carbon monoxide	(CO)		9 ppm; no more than 2 ppm above outdoor levels	EPA Compendium Method IP-3	ISO 4224
Total volatile orga	nic cor	npounds (TVOCs)	500 µg/m <sup>3</sup> Healthcare only: 200 µg/m <sup>3</sup>	EPA TO-1, TO-17, or EPA Compendium Method IP-1	ISO 16000-6
Formaldehyde			27 ppb Healthcare only: 16.3 ppb	ASTM D5197, EPA TO-11, or	ISO 16000-3
Target volatile organic	1	Acetaldehyde	140 µg/m³	EPA Compendium Method IP-6	
compounds*	2	Benzene	3 µg/m³		
	3	Carbon disulfide	800 µg/m <sup>3</sup>		
	4	Carbon tetrachloride	40 µg/m³		
	5	Chlorobenzene	1000 µg/m <sup>3</sup>		
	6	Chloroform	300 µg/m <sup>3</sup>		
	7	Dichlorobenzene (1,4-)	800µg/m <sup>3</sup>	ASTM D5197	ISO 16000-3
	8	Dichloroethylene (1,1)	70 µg/m³	EPA TO-1, TO-17, or	ISO 16000-6
	9	Dimethylformamide (N,N-)	80 µg/m³	EPA Compendium Method IP-1	
	10	Dioxane (1,4-)	3000 µg/m <sup>3</sup>		
	11	Epichlorohydrin	3 µg/m³		
	12	Ethylbenzene	2000 µg/m <sup>3</sup>		
	13	Ethylene glycol	400 µg/m <sup>3</sup>		
	14	Ethylene glycol monoethyl ether	70 µg/m³		
	15	Ethylene glycol monoethyl ether acetate	300 µg/m <sup>3</sup>		
	16	Ethylene glycol monomethyl ether	60 µg/m <sup>3</sup>		
	17	Ethylene glycol monomethyl ether acetate	90 µg/m³		
	19	Hexane (n-)	7000 µg/m <sup>3</sup>		
	20	Isophorone	2000 µg/m <sup>3</sup>		
	21	Isopropanol	7000 µg/m <sup>3</sup>		
	22	Methyl chloroform	1000 µg/m <sup>3</sup>		
	23	Methylene chloride	400 µg/m <sup>3</sup>		
	24	Methyl t-butyl ether	8000 µg/m <sup>3</sup>		
	25	Naphthalene	9 µg/m³		
	26	Phenol	200 µg/m <sup>3</sup>		
	27	Propylene glycol monomethyl ether	7000 µg/m <sup>3</sup>		
	28	Styrene	900 µg/m <sup>3</sup>		
	29	Tetrachloroethylene (Perchloroethylene)	35 µg/m³		
	30	Toluene	300 µg/m <sup>3</sup>		
	31	Trichloroethylene	600 µg/m <sup>3</sup>		
	32	Vinyl acetate	200 µg/m <sup>3</sup>		
	33- 35	Xylenes, technical mixture (m-, o-, p- xylene combined)	700 µg/m³		

ppb = parts per billion; ppm = parts per million; µg/cm = micrograms per cubic meter

\*The target volatile organic compounds are from CDPH Standard Method v1.1, Table 4-1. The Maximum concentration limits for these target compounds are the full CREL adopted by Cal/EPA OEHHA in effect on June 2014 http://oehha.ca.gov/air/allrels.html.

# **Odorants:**

<b>Odour Character</b>	Chemical class	Typical sources
Rotten eggs	$H_2S$	Refineries, STP, landfills
Barnyard, manure	Sulfides, dimethyl sulfide, dimethyl	Sewage, sludge, composting, landfills
	disulfide	
Rotten cabbage	Methyl mercaptan,	Pulp mills, refineries, petrochemical, gas
Onions, skunk	propyl, n-butyl, t-butyl	odorant leak
natural gas		
Fishy, urine	Amines, Cadaverene, Ammonia,	Pigments, dyes, STP, compost, landfills, dead
Cadaverous	Skatole, indole	animals
ammonia, fecal		
Solvents, Paints	Ketones, Esters, Aromatics	Petrochemical, coatings, plastics
Turpentine, Plastic	Styrene, Acrylates	
Airplane glue		
Rancid, sweaty, body	Organic acids: butyric, valeric, phenyl	Food processing, pharmaceuticals, dirty
odour, cat urine	acetic	clothes, stale tobacco smoke
Musty, mouldy, damp	Quinones, oxygenated compounds in	Insecticides, weed killers, medicinals,
basement	the $C_6$ - $C_{10}$ range, esters	pigments, biologic growth
Phenolic, creosote	Phenols, cresols, xylenes	Resins, smoke, electric motor, tar
Burnt, smoky, wet ash	Aldehydes, guaiacol, juniper oil	Wood smoke, combustion
Sharp, irritating,	Formaldehyde, acetic acid, sulfur	Furniture, plywood, combustion, processes,
pungent	dioxide, carbonyl sulfide, ozone	matches, smoke, electronic devices, carpeting

### Sources of VOCs

Source	Compound	<b>Recognition threshold</b>	Odour character
		ррт	
Air cleaners	Nitrogen dioxide,	0.8	Bleach
	Ozone	0.02	Pungent, thunderstorm
Air conditioners	Benzoquinone	0.4	Musty
	Diacetyl alcohol	1.1	Sweet, musty
	Furfuryl alcohol	8	Ether'ish
Bathrooms	Methyl mercaptan	0.001	Rotten cabbage
Bleach	Sodium hypochlorite		Bleach
Carpeting	Ethyl acrylate	0.004	Plastic, ester
	Methyl acrylate	0.01	Airplane glue, plastic
Cleaners	Acetone	130	Nail polish remover
	Ammonia	17	Pungent, irritating
	Alcohols	9	Musty, sweet
	<i>a</i> -pinine	0.03	Pine
ETS	Acetaldehyde	0.07	Pungent
	Acrolein	2	Pungent
	Adlyl alcohol	2	Mustard
	Cyclohexanone	0.1	Sharp, sweet
Furniture, wood	Formaldehyde	0.6	Waxy, oily
paneling	Octanol	20	
Gasoline	Hexane	150	Gasoline
	Toluene	11	Paint, sour
Insecticides	Methyl parathion	0.01	Pungent, musty
Mothballs	Naphthalene <i>p</i> -dichlorobenzene	0.5	Mothballs
Paints, lacquers,	Toluene	11	Paint, sour
varnishes	Xylene	1	Sweet, paint
	Methyl isobutyl kenone	2	Sharp
	<i>n</i> -butyl acetate	0.02	Banana, sweet

#### **Emission rates of materials**

Source type	Emission factor μg/h/m <sup>2</sup>
Acetaldehyde	
Carpet	5 - 30
Duct liner	< 20 - 25
Paint, water based (2 days)	6000 - 9000
Paint, water-based (1 week)	3000 - 5000
Photocopier, dry process	< 100 - 1200
Wood	10 - 100
n-Decane	
Carpet (1 day)	2000 - 3000
Carpet (1 month)	0.1 - 6
Paint, solvent-based (1 hour)	200,000
Paint, solvent-based (1 day)	2000
Paint, solvent-based (1 week)	0
Photocopier, idle $\rightarrow$ operating	$< 10 \rightarrow 500$
Stain wood (1 hour)	$\sim 500,000$
Stain wood (1 week)	$\sim 200$
Wax on wood flooring (3 days)	10 - 1000
Wax on wood flooring (1 month)	10 - 15
Nonane	
Carpet (1 day)	100 - 1000
Carpet (1 month)	0.1 - 300
Paint, solvent-based (1 hour)	100,000
Paint, solvent-based (1 day)	100
Stain, wood (1 hour)	1000 - 200,000
Stain, wood (1 week)	1 - 50

### Ultrafine particulate matter

Ultrafine particles source	Particles/cm <sup>2</sup>		
	Low end of range	High end of range	
Laser printers	0	100,000	
Fax machine	0	10,000	
Cleaners	0	100,000	
Photocopier	0	100,000	
Auto emissions (fresh air intake)	5,000	20,000	
Boiler/furnace leaks	10,000	500,000	
Humidification	10,000	35,000	
Kitchen/cooking	10,000	75,000	
Vacuum cleaners	0	100,000	
ETS	20,000	200,000	
Laboratory acids	50,000	80,000	
Wood, welding/auto shops	50,000	200,000	
Outdoor air	2,500	50,000	

## Antigenic particulate matter

#### Indoor sources of environmental allergens

#### Dust mites

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Dermatophagoides pteronyssinus Dermatophagoides farinae Euroglyphys maynei Blomia tropicalis Storage mites Lepidoglyphus destructor Tarsonimidae

nsects
Cockroaches
Blattella germanica
Periplaneta americana
Blatta orientalis
Crickets
Flies
Beetles
Fleas
Moths
Midges

Mammals Cats : *Felis domesticus* Dogs : *Canis familiaris* Rabbits : *Leporidae* Rodents Pets : mice, gerbils, guinea pigs, rats Pests: mice, rats

Pollen
Many
- ·
Fungi
Many

Other: Horsehair Kapok Down Spiders