# Analysis of VOCs & Formaldehyde

## Indoor air quality testing in homes, schools & offices

**Tim Robinson – Waverton Analytics Ltd**

Tim_Robinson@wavertonanalytics.com

# Preview

- Factors that define or influence indoor air quality (IAQ)
- Introduction to volatile organic compounds (VOCs) – Exposure limit guidelines & total VOC levels (TVOC) measured
- Measurement of VOCs & Formaldehyde in indoor air, including sample collection & analysis
- Sources of Formaldehyde, exposure limits, materials testing & recent measurements in a UK school
- Overview of other harmful VOCs from building products

# What is indoor air quality (IAQ)?

**Occupant Comfort**
(Temperature, Humidity)

**Particulate-Lifestyle**
(Skin Cells, Dander, Textile & Paper Fibres, Smoke)

**Radon**
(Geology)

***Indoor Air Quality***

**$CO$, $CO_2$, $NO_x$, $SO_x$**
(Combustion / metabolism)

**Allergens**
(Pet Dander, Dust Mites & Pollen)

**Mould**
(Spores, Mycotoxins, Debris, MVOCs)

**Particulate-Building**
(Fibreglass, Corrosion, Rust)

**Lifestyle related** — **Volatile Organic Compounds (VOCs)** — **Building related**

# What are VOCs?

**Very Volatile Organic Compounds (VVOCs)**

- Permanent gases (e.g. methane, Formaldehyde)
- Boiling point range < 50-100ºC (WHO)

**Volatile Organic Compounds (VOCs)**

- Exist in both gas and liquid/solid state
- Boiling point range 50-100 to 240-260ºC (WHO)

**Semi-Volatile Organic Compounds (SVOCs)**

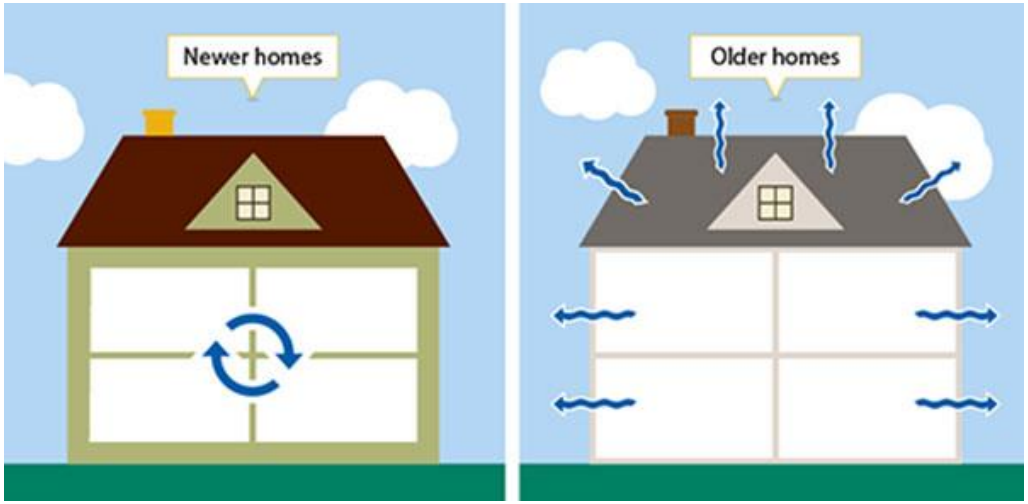
- Exist primarily in semisolid/solid state
- Boiling point range 240-260 to 380-400ºC (WHO)

# Concentration units

- Concentration: normalized amount of chemical substance
  - ng/L nanogramme ($10^{-9}$ g) per litre of room air
  - $\mu g/m^3$ microgramme ($10^{-6}$ g) per cubic meter of room air
  - $mg/m^3$ milligramme ($10^{-3}$ g) per cubic meter of room air
  - ppm parts per million ($10^6$)
  - ppb parts per billion ($10^9$)
- Conversions
  - 1 ng/L = 1 $\mu g/m^3$ = 0.001 $mg/m^3$ or 1 $mg/m^3$ = 1000 $\mu g/m^3$
  - 1 ppm = 1000 ppb or 1 ppb = 0.001 ppm
  - Need molecular weight to convert
    - 1 ng/L of Formaldehyde * 24.04 / 30 = 0.8 ppb Formaldehyde

# Air quality statistics

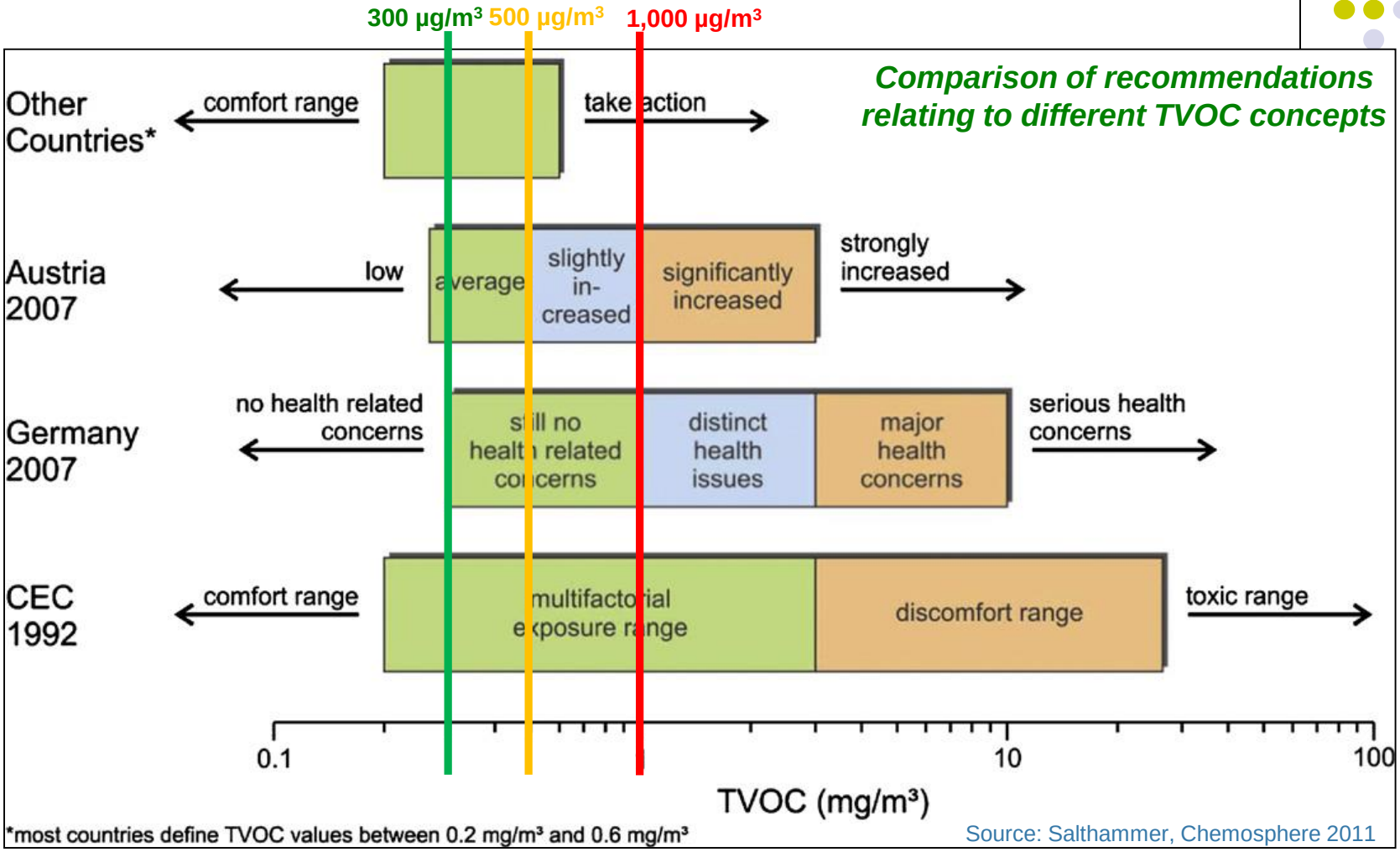
- VOCs in indoor air typically 2-5 times greater than outdoor air (EPA)
- Certain activities may increase VOCs to 1,000 times higher than outdoor air (EPA)
- Indoor VOCs in winter are 3-4 times higher than in summer
- Many older homes are lower in VOCs & formaldehyde compared with newer homes



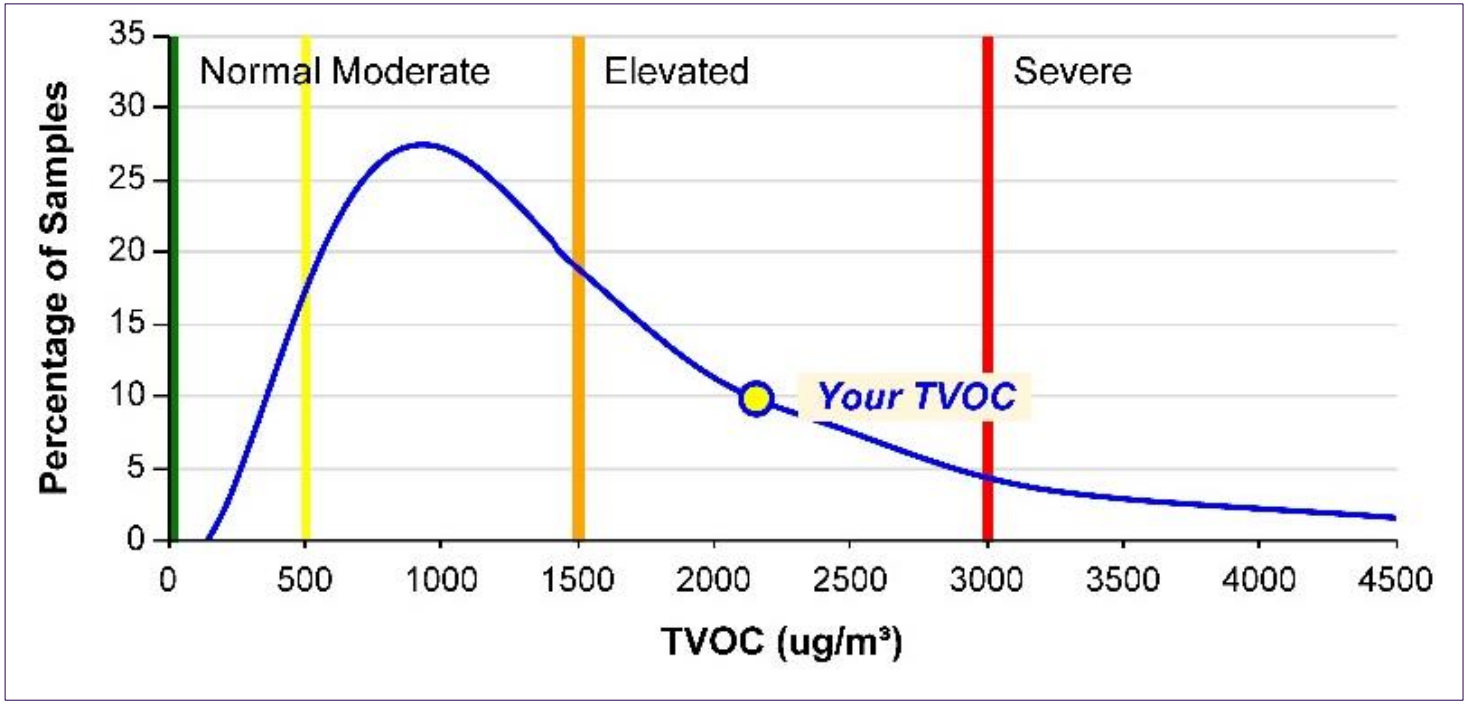
# Environmental conditions

- **Temperature**
  - Higher → more VOCs: higher formaldehyde levels
  - Lower → fewer VOCs
- **Humidity**
  - Higher → more VOCs: higher formaldehyde levels
  - Lower → fewer VOCs
- **Air Flow**
  - Higher → fewer VOCs: lower formaldehyde levels
  - Lower → more VOCs

# TVOC Guidelines



# Total VOCs (TVOC) measured




- Data collected from >8,000 samples
- Mean is 1,900 µg/m$^3$, mode is approx. 1,000 µg/m$^3$

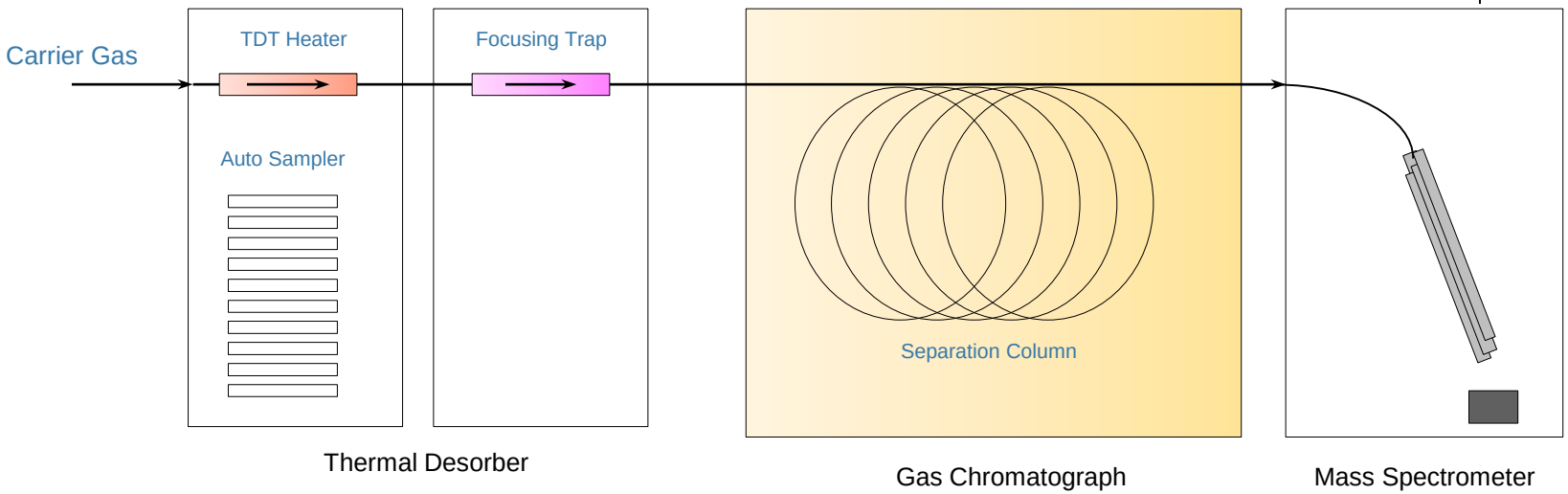
# Sample collection

- Active (pumped) sampling of air through a thermal desorption tube (TDT)
- TDT contains different types of chemical adsorption media
- Different TDTs and sampling requirements for VOCs versus Formaldehyde:
  - **VOCs:** Flow rate 200 ml/min over 2 hours – i.e. 24 litres of air sampled
  - **Formaldehyde**: Flow rate 200 ml/min over 20 mins – i.e. 4 litres of air sampled
- TDTs sent to the lab for analysis


**Sample pump with thermal desorption tube**

**Thermal desorption tubes for Formaldehyde & VOCs**

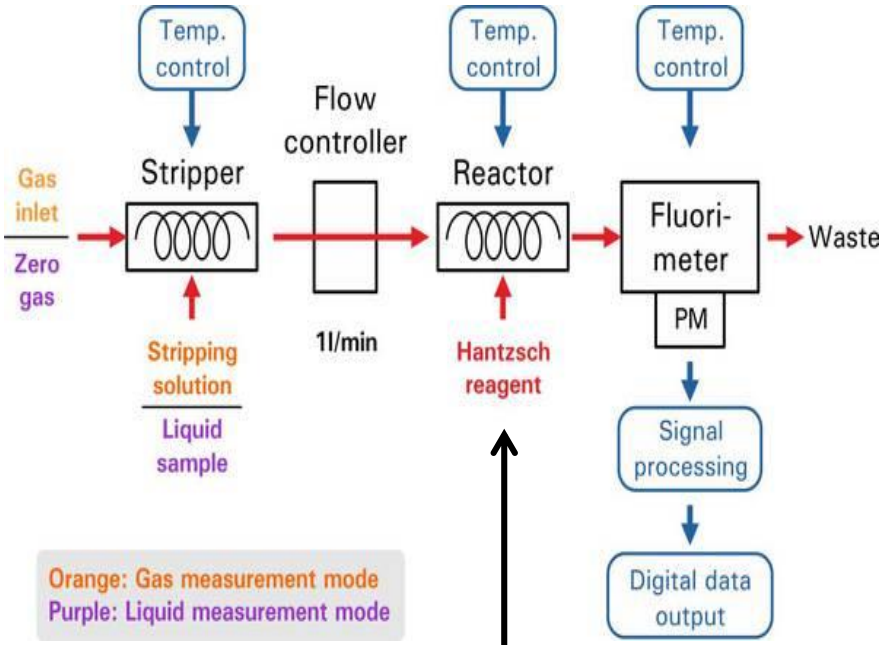
# Analysis of VOCs

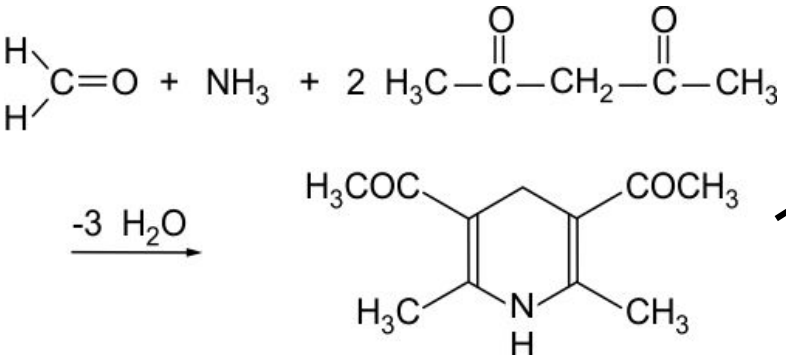



- **Thermal desorption GC-MS**
  - Sample tube heated to drive off captured VOCs
  - GC separates VOCs by volatility and chemical class
  - MS identifies individual VOCs by breaking molecules into characteristic fragments


**GC-MS**

# Formaldehyde analysis



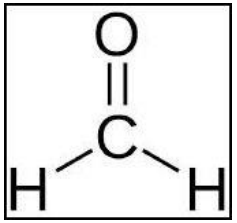

**Hantszch reaction**

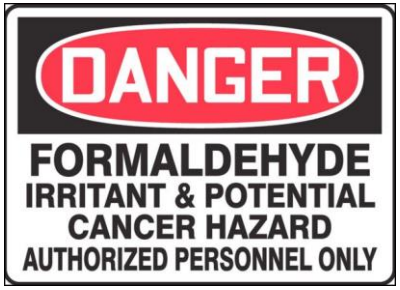

**Aero Laser Fluorimeter**

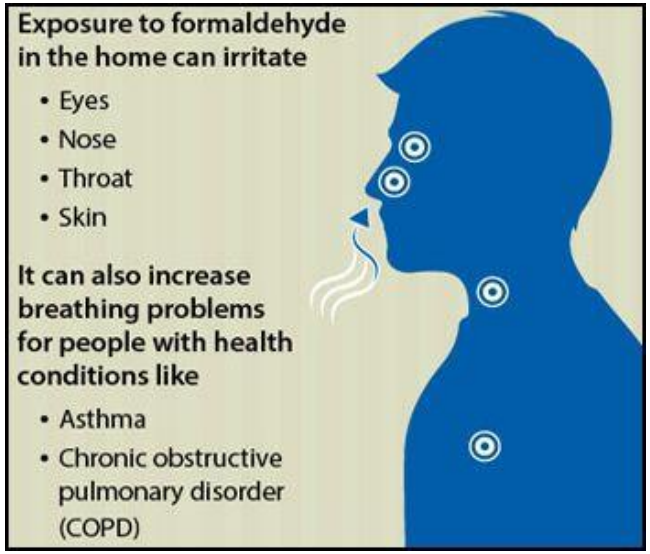
- Formaldehyde reacts with **acetyl-acetone** plus **ammonia** to form **DLL** (3,5-diacetly-1,4-dihydrolutidine)
- **DDL** absorbs light at 410 nm and shows a strong fluorescence at 510 nm
- Highly specific to Formaldehyde and used in European material off-gassing test method **(EN717-1)**

# Formaldehyde

- Naturally occurring VOC
- Gaseous at room temperature (Boiling Point -19ºC)
- Highly reactive with a strong odour
- Used as a precursor in the production of many other products:
  - Very versatile for the formation of resins (urea-formaldehyde, phenol-formaldehyde , melamine)
- Typical levels in air:
  - Outdoor: 1-20 µg/m$^3$
  - Indoor: 20-60 µg/m$^3$
- Symptoms:
  - Irritation of the mucus membranes – eyes, nose & throat
  - Classified as a carcinogen



# Sources of Formaldehyde

- **Outdoor sources**

- Wood/timber (relatively low levels)

- Reaction of ozone with unsaturated hydrocarbons

- Combustion: Vehicle exhaust, fires, tobacco smoke

# Sources of Formaldehyde

- **Indoor sources**
- Present in many construction materials:
  - Engineered hardwood & bamboo laminate flooring
  - Cabinetry:
    - Urea-formaldehyde resins – can off-gas significantly
  - Plywood & OSB:
    - Phenol-formaldehyde resins – tend to off-gas less
  - Insulation (glass & foam)
    - Both urea & phenol formaldehyde types used

**MDF**

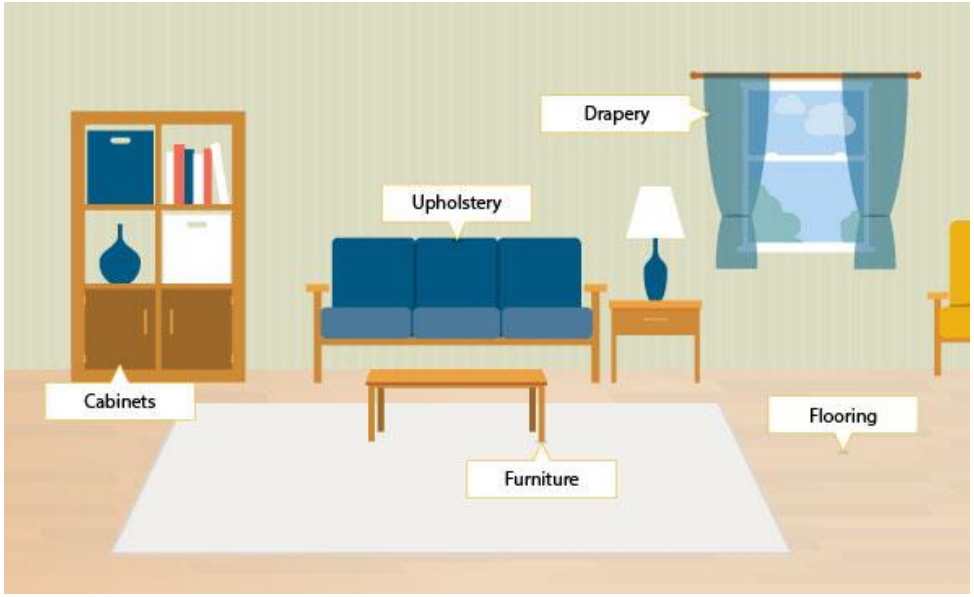
**Oriented Strand Board (OSB)**


**Laminate flooring**

**Plywood**

# Sources – Formaldehyde

- **Indoor sources (cont.)**
  - Lifestyle/personal care products, including treated fabrics
  - Combustion: Appliances, wood burners/fireplaces, tobacco smoke
  - Significant levels often found in new or newly renovated homes



# Exposure limits for Formaldehyde

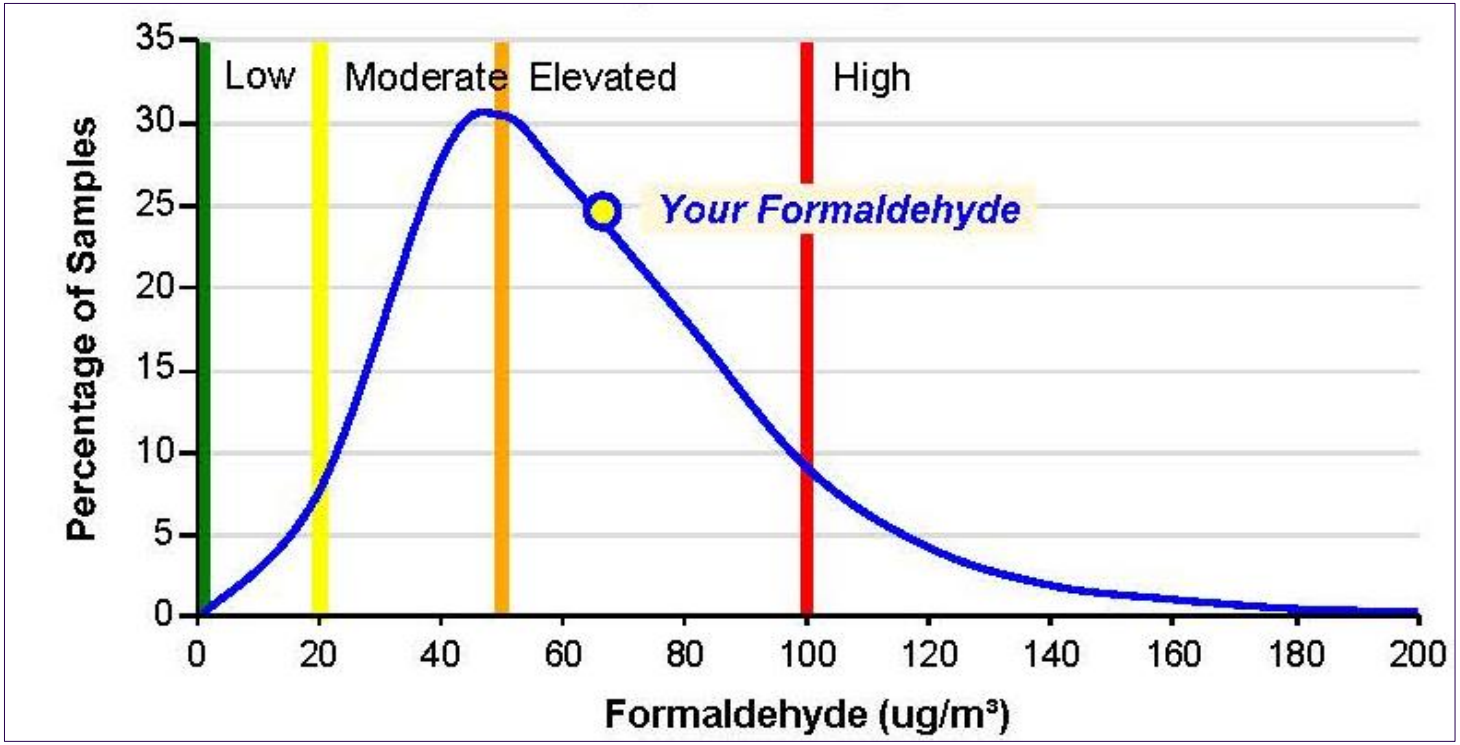
| Organisation | µg/m³ | ppb | Exposure period |
|---|---|---|---|
| World Health Organisation (WHO) | 100 | 80 | Short-term (0.5 hr) |
| Building Research Establishment (BREEAM) | 100 | 80 | Over 30 minutes – pre occupancy |
| National Institute for Occupational Safety & Health (NIOSH) | 20<br>120 | 16<br>100 | REL (8 hr)<br>Ceiling (15 min) |
| Green Building Council – LEED (Leadership in Energy & Environmental Design) | 32 | 27 | 4 hr |
| Germany – Committee for indoor air guide values<br>Germany – AGS & DFG | 124<br>370<br>740 | 100<br>300<br>600 | <br>TWA 8 hr<br>STEL 15 min |
| Japan – JSOH 2015 | 120 | 100 | |
| American Conference of Government Industrial Hygienists (ACGIH) | 370 | 300 | Threshold Limit Value (8 hr) |
| Occupational Health & Safety Administration (OSHA) | 630<br>940<br>2,500 | 500<br>750<br>2,000 | Action level (8 hr)<br>PEL (8 hr)<br>STEL (0.5 hr) |
| Health & Safety Executive EH40 workplace exposure limits | 2,500<br>2,500 | 2,000<br>2,000 | Long-term exposure limit (8 hr)<br>Short-term exposure limit (15 min) |

# Testing – wood-based panels

- **European reference method EN717-1**
- Three different environmental chamber volume options
- Determination of steady state formaldehyde emissions up to 28 days:
  - Temp: 23° C, RH: 45%
  - E1 class requires emissions of ≤0.1ppm (0.12 mg/m$^3$)
- **Other methods derived from EN717-1:**
  - Perforator method EN120
  - Gas analysis method EN717-2
  - Flask method EN-717-3

**Environmental chambers for wood-based panel testing**

# IAQ test results – Formaldehyde




- Data collected from >7,000 samples
- Mean is 67 µg/m$^3$, mode is approx. 45 µg/m$^3$

# Formaldehyde issues in a school

- **Formaldehyde issue in a new school building – Northwest of England**
  - Staff and pupils experiencing irritation of eyes, nose & throat
  - Building had been in active use for 12-months
  - Two tests taken in different locations – Formaldehyde readings of:
    - 1,100 µg/m$^3$
    - 860 µg/m$^3$
    - Factor of 10X greater than WHO recommendations

**Formaldehyde Concentration:** 1100 µg/m³ (890 ppb)

**Your Formaldehyde Level (Highlighted)**

| Low | Moderate | Elevated | High |
|---|---|---|---|
| < 20 µg/m³ < 16 ppb | 20-50 µg/m³ 16-40 ppb | 50-100 µg/m³ 40-80 ppb | > 100 µg/m³ > 80 ppb |

**Recommendation:** There are significant formaldehyde issues. Locate and remove sources. See formaldehyde sources section for more information. Discuss this report with your service provider.

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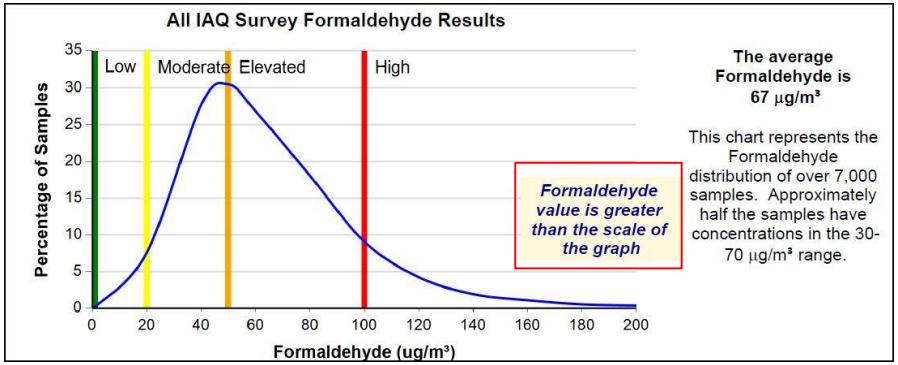

# Harmful VOCs from building products

- **“BTEX” compounds:**
  - Benzene*
  - Toluene
  - Ethylbenzene
  - Xylenes
- **Typical sources:**
  - Adhesives:
    - Flooring
    - Dry wall
    - Construction
    - Cement
    - Caulk

***Benzene heavily regulated and no longer seen in significant quantities***

# Hazardous air pollutants (HAPs)

- Sub-set of EPA list of 187 HAPs which includes “BTEX” compounds & formaldehyde
- Many compounds in the list associated with building materials including adhesives, surface coatings and insulation materials

| Compound | CAS | Estimated VOC Level (µg/m³) | Estimated VOC Level (ppb) | NIOSH Exposure Limit | Description |
|---|---|---|---|---|---|
| Carbonyl sulfide | 463-58-1 | < 1 | < 0.4 | None Listed | Fumigant; contaminated drywall; fuel combustion byproduct; some foods; naturally occurring at low levels |
| Carbon Disulfide | 75-15-0 | < 1 | < 0.3 | 3,000 ng/L (1,000 ppb) | Solvent; fumigant; contaminated drywall; combustion byproduct |
| Methylene Chloride | 75-09-2 | < 1 | < 0.3 | Carcinogen | Automotive products; degreasing solvent; paint stripper; adhesive remover; aerosol propellant; insecticide |
| Hexane (C 6) | 110-54-3 | < 1 | < 0.3 | 180,000 ng/L (50,000 ppb) | Solvent; adhesive; grease; lubricant; paints and coatings; petroleum fuel component |
| 1,1,1-Trichloroethane | 71-55-6 | < 1 | < 0.2 | C; 1,900,000 ng/L (350,000 ppb) | Adhesives, lubricants, cleaners, solvents |
| Benzene | 71-43-2 | < 1 | < 0.3 | 320 ng/L (100 ppb) | Gasoline. Less common sources include some discontinued solvents; printing and lithography; paints and coatings; rubber; dry cleaning; adhesives; detergents |
| 1,2-Dichloroethane | 107-06-2 | < 1 | < 0.2 | Carcinogen; 4,000 ng/L (1,000 ppb) | PVC production; solvent for rubber, insecticides, oils, waxes, gums, resins; rug and upholstery cleaners |
| Trichloroethene | 79-01-6 | < 1 | < 0.2 | Carcinogen | Dry cleaning; degreasers and cleaners for home/automotive; varnish removers; anesthetic |
| Methyl methacrylate | 80-62-6 | < 1 | < 0.3 | 410,000 ng/L (100,000 ppb) | Acrylic Polymers for paints and coatings, adhesives, fillers; solvent; pharmaceuticals; personal care |
| Toluene | 108-88-3 | 3 | 0.7 | 375,000 ng/L (100,000 ppb) | Gasoline; adhesives (building and arts/crafts); contact cement; solvent; heavy duty cleaner |
| Tetrachloroethene | 127-18-4 | < 1 | < 0.1 | Carcinogen | Dry cleaning; adhesives, automotive cleaners, polishes |
| Ethylbenzene | 100-41-4 | < 1 | < 0.2 | 435,000 ng/L (100,000 ppb) | Gasoline; paints and coatings; solvent; pesticide |
| m,p-Xylene | 108-38-3; 106-42-3 | 2 | 0.5 | 435,000 ng/L (100,000 ppb) | Gasoline; paints and coatings; adhesives and cements; solvent; print cartridges |
| o-Xylene | 95-47-6 | < 1 | < 0.2 | 435,000 ng/L (100,000 ppb) | Gasoline; paints and coatings; adhesives and cements; solvent; print cartridges |
| Styrene | 100-42-5 | 2 | 0.4 | 215,000 ng/L (50,000 ppb) | Polystyrene foam; synthetic rubber; flavoring agent |
| 1,4-Dichlorobenzene | 106-46-7 | < 1 | < 0.2 | Carcinogen | Moth balls/crystals; room deodorant |
| Naphthalene | 91-20-3 | 1 | 0.2 | 50,000 ng/L (10,000 ppb) | Gasoline; diesel; Moth balls/crystals; insecticide |

# Summary

- VOCs are an important element in a range of factors that define IAQ
- VOC sampling and analysis follows a well defined, standard procedure
- Formaldehyde is still present in many building materials, particularly engineered wood products & testing has shown that it continues to impact IAQ
- Many other building products, particularly adhesives & surface coatings, contain potentially harmful VOCs

# Thank you!

Tim Robinson
Tim_Robinson@wavertonanalytics.com