Trade-offs between ventilation rates and formaldehyde concentrations in new-build dwellings in the UK

40th AIVC – 8th TightVent & 6th venticool Conference

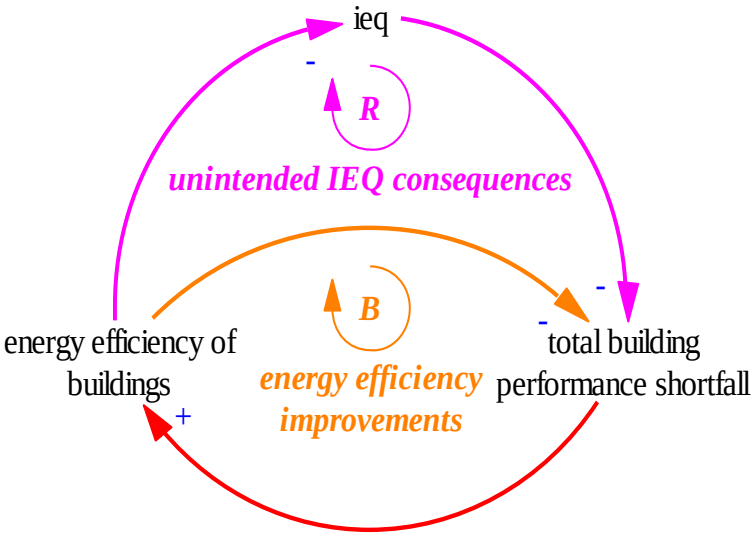
Esfand Burman and Samuel Stamp
UCL Institute for Environmental Design and Engineering

16 October 2019
Ghent University

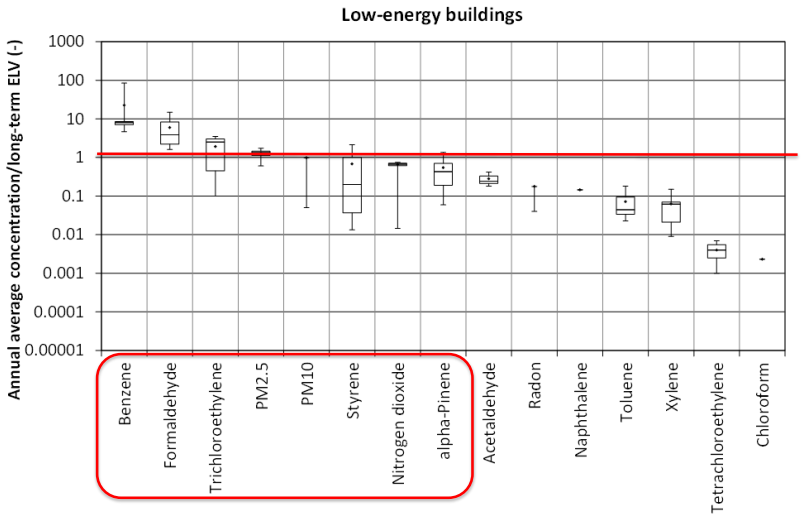
Outline

- Potential conflicts between energy efficiency & IAQ
- Defining the metrics for IAQ in low-energy dwellings (IEA EBC Annex 68)
- A case study from the UK
- Exposure Limit Values (ELVs) for formaldehyde
- Trade-offs between energy efficiency & formaldehyde levels
- Source control measures

Unintended consequences of energy efficiency policies

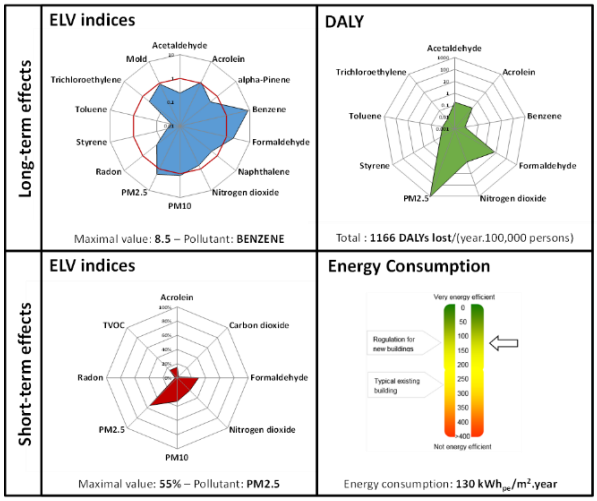


Concentration of pollutants in low-energy building



Source: Abadie et al., 2016. IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings, SUBTASK 1: Defining the metrics

IAQ-Energy Dashboard



Source: Abadie et al., 2016. IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings, SUBTASK 1: Defining the metrics

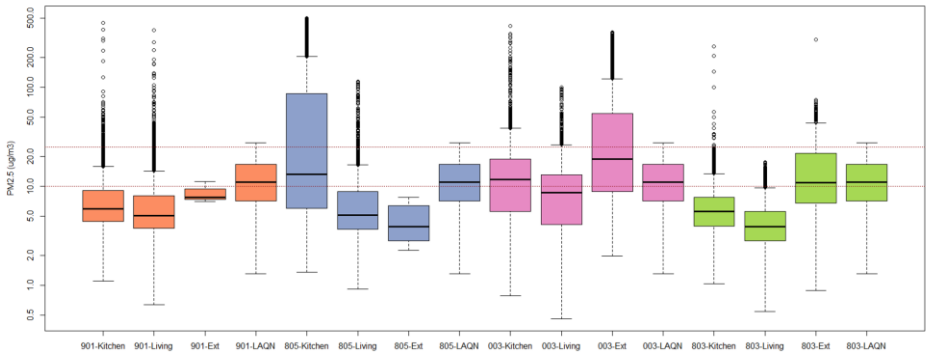
5

Case Study

- New-build apartment blocks in East London (completed in 2015)
- Low air permeability: 2-3 m³/hr/m² at 50 Pa
- Mechanical Ventilation with Heat Recovery (MVHR)
- Low ACH (<1 in heating season): indoor sources become more relevant!

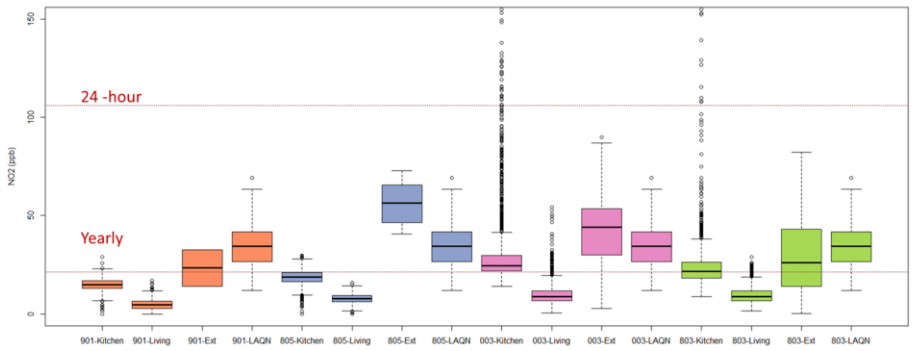
6

PM2.5 Concentrations



Episodes of high concentration on lower apartments close to the main road (Basic G3 filter used in the MVHR units)

NO_2 Concentrations



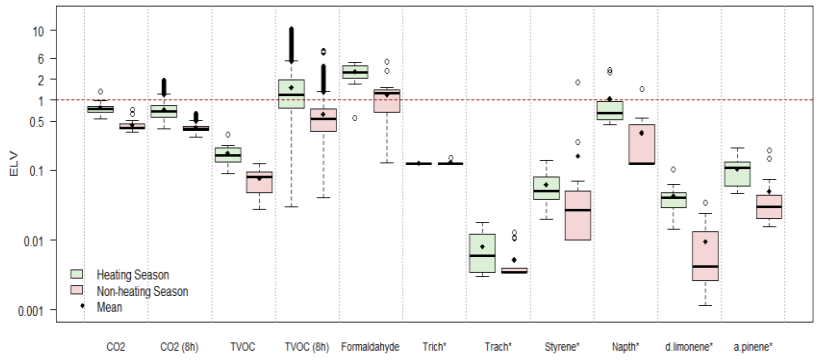
High concentration mainly in the kitchens (background pollutions + indoor events)

VOC concentrations (passive sampling)

VOC	Min	25th pctl.	Median	Average	75th pctl.	Max	Annex 68 ELV
Benzene	**0.55**	**0.55**	**1.20**	**1.14**	**1.48**	**2.8**	0.2
Formaldehyde	1.15	**10.15**	**16.32**	**16.78**	**26.13**	**31.91**	**9**
Trichloroethylene	0.25	0.25	0.25	0.26	0.25	0.3	2
Styrene	0.30	0.63	1.35	1.78	2.00	**53.9**	30
Naphthalene	0.25	0.34	1.00	1.38	1.30	**5.4**	2
Toluene	0.45	1.20	2.15	4.03	3.33	22.8	250
Tetrachloroethylene	0.30	0.35	0.35	0.66	1.09	1.8	100

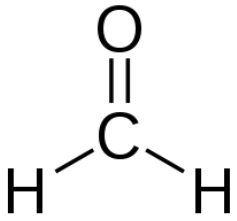
Benzene (primarily driven by outdoor sources) and formaldehyde (driven by indoor sources) consistently show concentrations higher than best practice ELVs.

VOC concentrations (passive sampling)



Internal sources of pollution

- Formaldehyde in all apartments and most zones higher than best practice ELV
- Perceived wisdom of 2-3 years to off-gas is questionable?
- Source control measures
- Boost ventilation mode on MVHR required to be used?



AIR QUALITY STANDARDS

Pollutants generated indoors such as Volatile Organic Compounds (VOCs), combustion byproducts and airborne particles are known to trigger nausea, asthma and allergies. While ambient outdoor air is often better quality, natural ventilation methods, operable windows and doors, and general envelope infiltration can harm indoor air quality if external air quality conditions are poor.

This feature requires that an accredited assessor complete a performance test after occupancy as an independent means of verifying that the building, whether naturally or mechanically ventilated, is meeting critical air quality requirements.

Cardiovascular
Endocrine
Immune
Integumentary
Nervous
Respiratory

PART 1: STANDARDS FOR VOLATILE SUBSTANCES

The following conditions are met:

a.[1] Formaldehyde levels less than 27 ppb. **33.7 µg/m³**

b.[1] Total volatile organic compounds less than 500 µg/m³.

Source: Well Building Standard, 2014

Derivation of ELV for Formaldehyde

Study	Wilhelmsson and Holmstrom, 1992 supported by Edling et al., 1988
Study population	66 human chemical plant workers
Exposure method	Discontinuous occupational exposure
Exposure continuity	8 hr/day, 5 days/week (assumed)
Exposure duration	10 years (average); range 1-36 years
Critical effects	Nasal obstruction and discomfort, lower airway discomfort.
LOAEL	Mean 0.26 mg/m^3 (range 0.05 – 0.6 mg/m3) (described as exposed group)
NOAEL	Mean of 0.09 mg/m^3 (described as control group of office workers)
Benchmark concentration	not derived
Time-adjusted exposure	0.09 mg/m^3 for NOAEL group
Human Equivalent Concentration	not applied
LOAEL uncertainty factor (UF_L)	not applied
Subchronic uncertainty factor (UFs)	not applied
Interspecies uncertainty factor	
Toxicokinetic (UF_{A-k})	1 (default, human study)
Toxicodynamic (UF_{A-d})	1 (default, human study)
Intraspecies uncertainty factor	
Toxicokinetic (UF_{H-k})	1 (no systemic effects)
Toxicodynamic (UF_{H-d})	10 (potential asthma exacerbation in children)
Cumulative uncertainty factor	10
Reference Exposure Level	**9 µg/m^3 (7 ppb)**

Non Observable Adverse Effect Level

Source: California Office of Environmental Health Hazard Assessment, 2014

Reference exposure level for Children

Study	Rumchev et al., 2002
Study population	88 asthmatic children (mean age 25 mo); 104 nonasthmatic controls (mean age 20 mo)
Exposure method	Ambient in home
Exposure continuity	Continuous assumed
Exposure duration	range 0.5-3 years
Critical effects	Parent-reported respiratory symptoms (cough, shortness of breath, wheeze, trouble breathing)
LOAEL	60 µg/m^3
NOAEL	30 µg/m^3 (lower limit of NOAEL range)
Benchmark concentration	not derived
Time-adjusted exposure	not applied
Human Equivalent Concentration	30 µg/m^3
LOAEL uncertainty factor (UF_L)	1
Subchronic uncertainty factor (UFs)	not applied
Interspecies uncertainty factor	
Toxicokinetic (UF_{A-k})	1 (default, human study)
Toxicodynamic (UF_{A-d})	1 (default, human study)
Intraspecies uncertainty factor	
Toxicokinetic (UF_{H-k})	1 (study performed in children)
Toxicodynamic (UF_{H-d})	√10 (inter-individual variation)
Cumulative uncertainty factor	√10
Reference Exposure Level	**10 µg/m^3 (8 ppb)**

Source: California Office of Environmental Health Hazard Assessment, 2014

Table 1. *"Target" VOC List and Reference Levels*

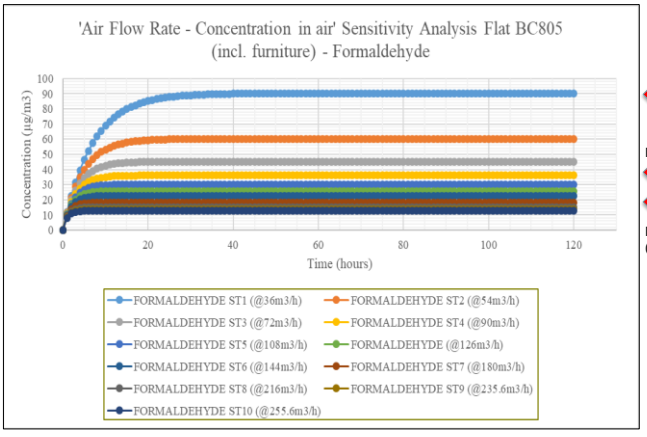
VOC #	Group	CAS #	Chemical Compound	Existing List (see References)											Reference Levels (µg/m³)				
				1	2	3	4	5	6	7	8	9	10	11	Sum	WHO Guidelines [1] (µg/m³)	WHO Guidelines [1] (avg. time)	CREL [2]	OSHA PEL [3]	Odor Detect. Threshold [4]
1	Aldehydes	75-07-0	Acetaldehyde			1		1		1	1	1			5	50	(1 yr)	9	3.6E+05	3.4E+02
2		107-02-8	Acrolein			1			1	1	1	1			5	50	(30 min)	0.06	2.3E+02	4.1E+02
3		100-52-7	Benzaldehyde	1										1	2					1.9E+02
4		123-72-8	Butanal	1											1					2.8E+01
5		112-31-2	Decanal		1										1					5.9E+00
6		50-00-0	Formaldehyde			1		1	1	1	1	1			6	100	(30 min)	3	9.2E+02	1.1E+03
7		98-01-1	Furfural												0				2.0E+04	2.5E+02
8		111-71-7	Heptanal												0					2.3E+01
9		66-25-1	Hexanal	1										1	2					5.8E+01
10		124-19-6	Nonanal	1	1									1	3					1.4E+01
11		124-13-0	Octanal												0					7.2E+00
12		110-62-3	Pentanal	1											1					2.2E+01

Table 3. *Range of Emission Factors of Selected Materials (µg/m²/h) at 24 h*

Group	VOC #	Solid & Engineered Wood Materials							Flooring								Installation Materials				% (Detection)
		OSB		Plywood		Solid wood		MDF	Carpet/ Assembly		Underpad		Laminate/ Assembly		Linoleum/ Vinyl Flooring		Adhesive		Caulking		
		Min	Max	Min	Max	Min	Max		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Aldehydes	1	41.8	265.5					89.9	1.67	20.85			3.68	11.49	2.0	28.5					46
	2																				0
	3	0.1	2.6			0.2	0.2	0.2	0.08	1.41	0.21	1.42	0.01	0.09	0.90	1.55			6057	6057	60
	4	2.7	59.8	2.1	6.0	0.3	1.7	6.0	0.19	0.48	0.21	0.93	2.33	2.33	0.15	0.15			361	361	52
	5	0.6	44.6	3.3	28.4	1.9	10.4	0.9	13.45	13.45	1.08	7.42	0.55	0.55	0.55	0.71			225	757	63
	6	11.1	53.7					441.6	6.17	40.46	6.70	76.57	1.32	37.66	1.2	19.0					54
	7	4.3	4.3			0.3	0.3														5
	8	0.3	6.5	0.9	3.6	0.7	0.7	1.4			0.15	0.15	0.03	1.62	0.9	1.3					46
	9	29.4	1256.7	12.3	33.0	0.4	5.7	135.7			0.25	0.25	12.67	12.67	21.7	26.2					58
	10	1.1	47.3	3.3	24.7	1.6	12.4	2.5	0.60	0.90	3.03	6.37	0.50	0.50	0.3	1.9	89	89	170	742	67
	11	0.6	6.7	1.0	12.8	0.4	3.6	2.6	0.46	2.43	0.60	0.60	0.30	0.30	1.3	1.6					52
	12	12.9	354.1	3.4	12.2	0.4	4.4	29.0					7.70	7.70	15.5	15.5			762	762	49

Source: NRC Canada, 2005.

15



Minimum ACH achievable from installed MVHR (ACH=0.1)

MVHR commissioned flow rate (ACH= 0.5)

Maximum ACH achievable from installed MVHR (ACH= 1.6)

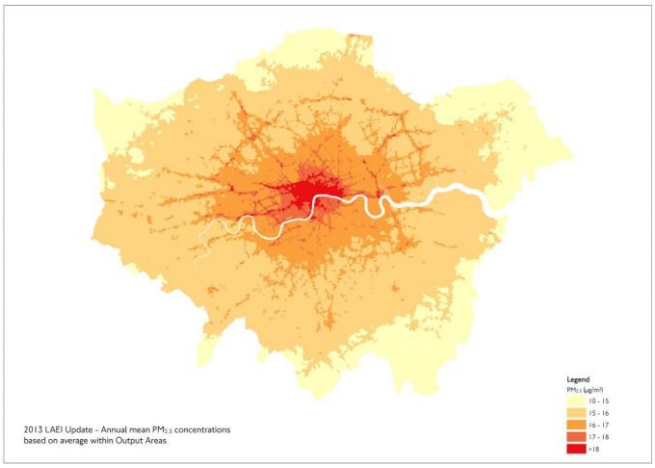
- Given the existing context (material and emission sources) maximum ventilation rate should be around 3 times the commissioning rate to bring formaldehyde concentration down to best practice ELV!
- Increasing the air change rate from 0.5 to 1.6 h-1 with the same MVHR system **will increase the primary energy use of regulated energy end-uses by around 22%**.

16

Further energy improvements

- Increase thermal efficiency of the MVHR system from 85% to 90%,
- Reduce the specific fan power of the MVHR system from 1.0 to 0.6 W/L/s,
- Improving seasonal heating efficiency from 87% to 90%.
- These improvements can reduce the excess in primary energy use for regulated energy and total energy to 9% and 5% respectively.

PM2.5 concentrations in London: higher grade filters are required (higher energy use)!



- EU legal limit (annual mean): 25 µg/m³
- **WHO guideline limit (annual mean): 10 µg/m³**

Conclusions

- Wide range of ELVs proposed for formaldehyde
- Formaldehyde is not currently regulated in the UK Building Regulations (TVOC only).
- Current material used in the construction industry and MDF based products may lead to high concentration levels.
- Source control measures are essential to reduce exposure to formaldehyde (**CARB2 and EPA's new Formaldehyde Standards for Composite Wood Products Act (TSCA Title VI**)
- Enhance ventilation should be used only as a complementary measure (with adequate filtration to protect building users against outdoor pollution).

Contact: esfand.burman@ucl.ac.uk

EPSRC
Pioneering research and skills

Formaldehyde emerges as new risk in China's housing boom

By Kerry Allen
BBC Monitoring

6 September 2018 Share

The recent death of a flat-dweller in Beijing has flagged up concerns about formaldehyde, a carcinogenic substance widely used in construction.