Impact of building material emissions on indoor air quality: simultaneous quantification of VOCs and formaldehyde in indoor air and at the air/material interface

Delphine Bourdin[1,2]
Pierre Mocho[3]
Christophe Cantau[1]
Valérie Desauziers[2]

[1] Nobatek – France
[2] L.G.E.I Mining School of Alès – France
[3] LaTEP University of Pau - France

Siège Social
NOBATEK
67, rue de Mirambeau
64600 ANGLET
Tél. : 05 59 03 61 29
Fax. : 05 59 63 55 41
www.nobatek.com

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Tél. : 05 56 84 63 70
Fax. : 05 56 84 63 71

VOCs and Formaldehyde in indoor air

French Legislation

Indoor air quality

- Decree n°2012-14: measurement of some indoor air pollutants in buildings open to the public (formaldehyde, benzene, CO_2)
- Decree n°2011-1727: guide-values for formaldehyde (10 µg/m^3) and benzene (2 µg/m^3)

Labeling of all building materials according to their VOCs emissions

- Decree n°2011-321: labeling of building products, flooring, wall covering, paints and varnishes on their volatile pollutants emissions (Formaldehyde, acetaldehyde, toluene, tetrachloroethylene, xylene, trimethylbenzene, dichlorobenzene, ethylbenzene, 2-butoxyethanol, styrene, TVOC)

Main source of indoor pollutants: building and decoration materials , furniture [1]

[1] Brown, Indoor Air 12 (2002) 55-63

Efficient tools to study both **indoor air** and **air/material interface** are needed

- Indoor air diagnosis
- Identification of materials responsible for VOC pollution
- Modeling of Indoor air quality

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Analytical strategies

Indoor air

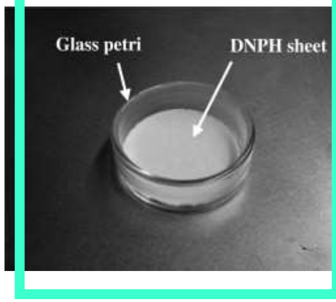
On-site material emissions

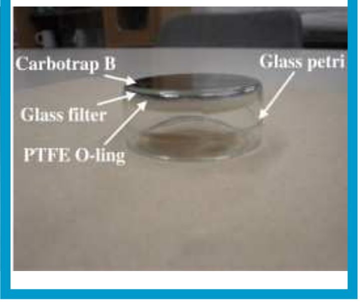
DNPH
Cartridges

Adsorbent tubes

Radiello®

FLEC®
(ISO 16000-10)



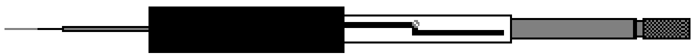


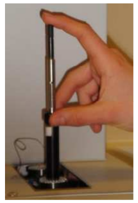
Shinohara et al., 2009
Blondel and Plaisance, 2010

VOCs (GC)

Aldehydes (HPLC)

Solid-Phase Micro Extraction (SPME)





Desorption directly in a GC injector

Development of an analytical method for the simultaneous quantification of VOCs and aldehydes

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Analytical Performances

Indoor air | On-site material emissions

Instantaneous sampling

Desauziers, Auguin, Techniques de l'ingénieur, 2012

✓ Mix of 9 compounds:

- Formaldehyde*
- Acetaldehyde*
- Toluene*
- p-xylene*
- Styrene*
- Alpha-pinene°
- Dichlorobenzene*
- Tetrachloroethylene*
- Hexanal°

* Concerned by material labeling
° Wooden construction

Patent pending…

SPME – emission cell coupling

Non-equilibrium → First Fick's law

$$n_f = U.\,(C_i.t)$$

n_f: extracted amount on the fiber
U: uptake rate
C_i: concentration in air ($\mu g.m^{-3}$)
t: extraction time (min)

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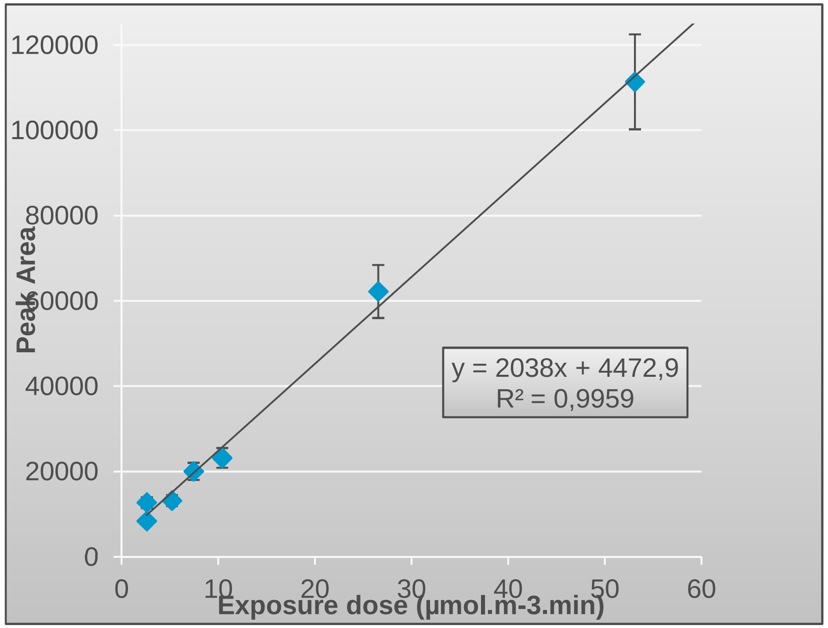
Analytical Performances: calibration curves (FID detection)



Formaldehyde

- ✓ Good linearity for the 9 compounds
- ✓ Should be possible to analyse higher concentrations for other applications…

Compound	R^2	Linearity range for a 5 minute SPME extraction ($\mu g.m^{-3}$)
Acetaldehyde	0.9178	528
Formaldehyde	0.9959	480
Toluene	0.9720	920
Tetrachloroethylene	0.9688	1660
P-xylene	0.9858	1480
Styrene	0.9746	1460
Alpha-pinene	0.9653	1900
hexanal	0.9699	1500
1,2-dichlorobenzene	0.9616	2040
AVERAGE		**1328**

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Analytical Performances: Limits of detection (LOD), limits of quantification (LOQ) and reproducibility

SPME: 20 minute exposure
Concentration of each compound in the standard gas: 2.4 µmol.m^{-3}
Results in µg/m^3

Compounds	GC/FID			GC/MS – SIM mode	
	% RSD (n = 6)	LOD	LOQ	LOD (S/N = 3)	LOQ (S/N = 10)
Toluene	17%	3.6	11.8	0.012	0.042
Tetrachloroethylene	14%	4.7	15.8	0.014	0.048
P-xylene	8%	2.1	6.8	0.027	0.091
Styrene	5%	1.4	4.7	0.013	0.043
Alpha-pinene	11%	3.3	10.9	0.049	0.164
1,2-dichlorobenzene	9%	2.8	9.5	0.011	0.037
Formaldehyde	16%	4.2	14.0	0.005	0.016
Acetaldehyde	22%	11.3	37.8	0.051	0.170
Hexanal	13%	3.7	12.3	0.124	0.414
AVERAGE		**4.1**	**13.7**	**0.034**	**0.113**

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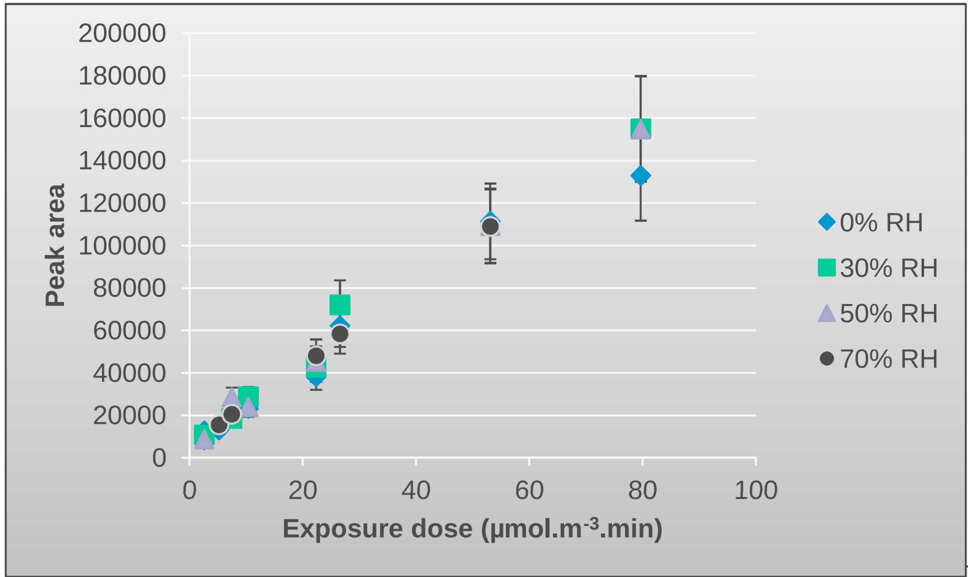
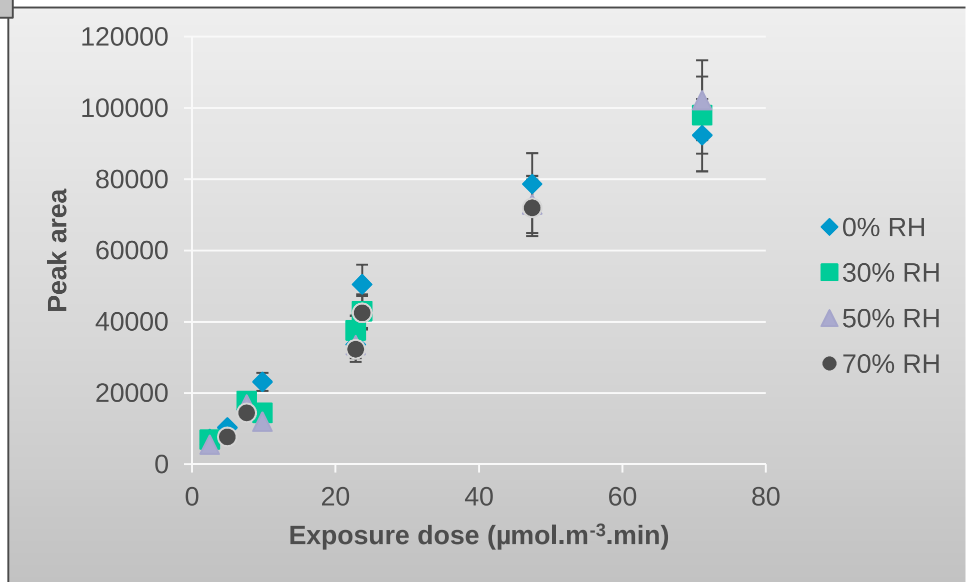
Influence of air relative humidity

Formaldehyde



Alpha-pinene



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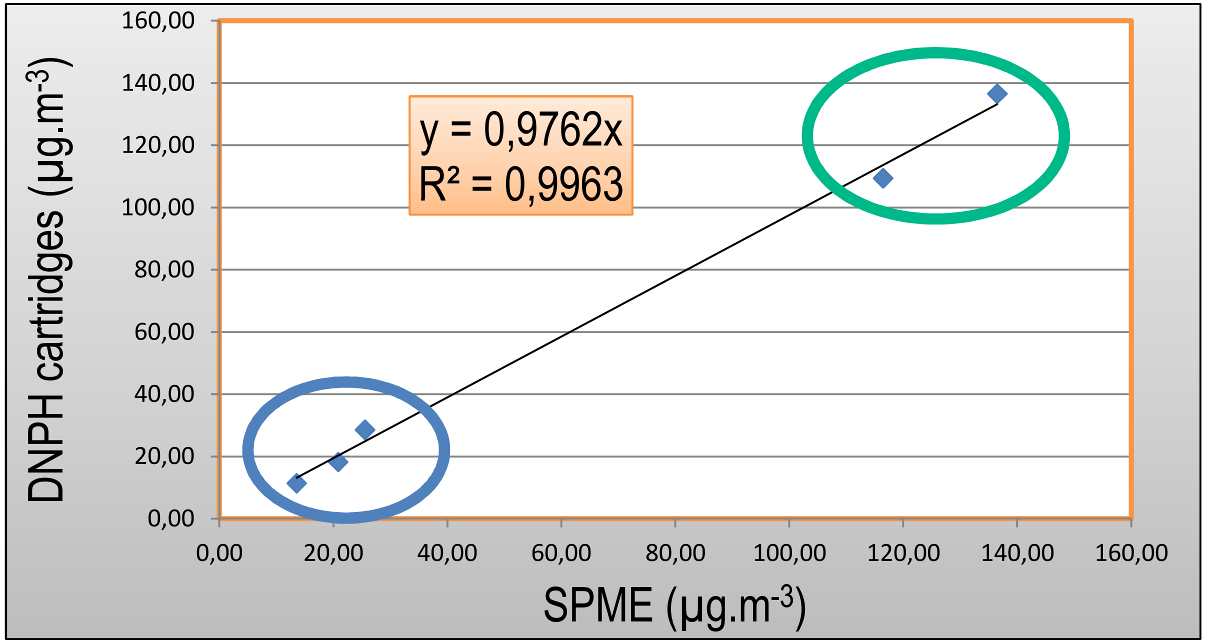
Comparison with the standard method

	NF ISO 16000-3 (2002) DNPH Cartridges	SPME
Sampling	3.5 hours for indoor atmospheres 15 minutes for material emissions	Instantaneous sampling 15 minute SPME extraction
Analyses	HPLC/UV	GC/FID



Material emissions in environmental chamber

Indoor air

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Case Study

Office building located in Mont-de-Marsan (40)
Occupied since one year
Built in a HQE approach

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Lyon, 26 septembre 2012

Case Study

- ✓ Meeting room of 40 m²
- ✓ Study of indoor air by vacuum vial
- ✓ Study of surface's concentration by emission cell
  - ➢ Floor
  - ➢ Tables
  - ➢ Chairs
  - ➢ Doors
  - ➢ Ceiling
  - ➢ Roller blind

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→ Identification of terpenes, aldehydes and alcanes

→ 4 compounds belonging to our model compounds were quantified: alpha-pinene, formaldehyde, acetaldehyde and hexanal

Formaldehyde

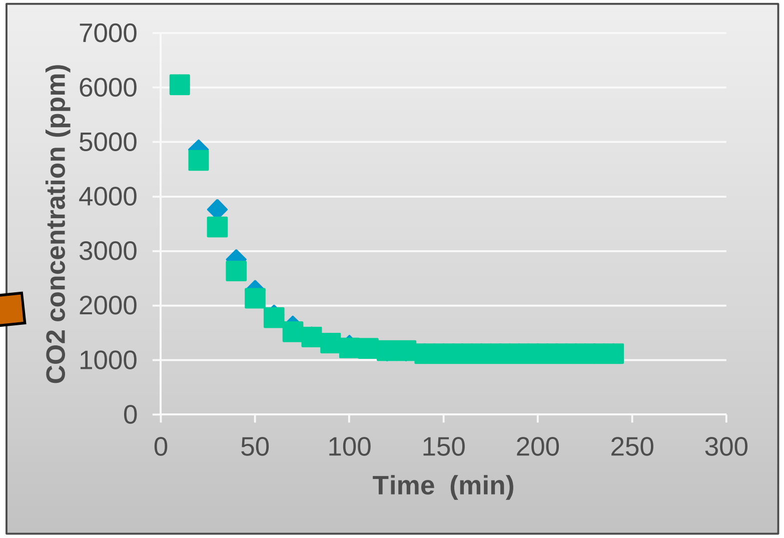
Material emissions

Surface	Air interface concentration ($\mu g.m^{-3}$)
Table	42.8
Floor	15.3
Chair	6.7
Ceiling (painted part)	7.7
Wall (paint)	10.1
Door	16.5
Ceiling (ventilation area)	11.8
Roller blind	10.2

Indoor concentration ($\mu g.m^{-3}$)
7.0

Indoor air quality modeling

Measurement of air exchange rates by CO_2 injection



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Indoor Air Modeling

Mass Balance

$$\underbrace{\frac{dC_i}{dt}}_{\text{Indoor Concentration}} = \underbrace{\sum_{j=1}^{m} Q_{ji}}_{\text{Material Input}} + \underbrace{\lambda_{air} f C_{ext}}_{\text{Outdoor Concentration}} - \underbrace{\lambda_{air} C_i}_{\text{Room Ventilation}} - \underbrace{U_{dep}\left(\frac{A}{V}\right) C_i}_{\text{Sink Effect}}$$

C_i: indoor air concentration (ppb)
t: time (s)
Q_{ij}: emission rate (ppb.s^{-1})
λ_{air}: air exchange rate (s^{-1})
C_{ext}: outdoor concentration (ppb)

U_{dep}: deposit velocity (m.s^{-1})
A: surface (m^2)
V: room volume (m^3)
f: penetration rate (0<f<1)

$$C_i(t) = C_0 e^{-\left(U_{dep}\frac{A}{V}+\lambda_{air}\right)t} + \frac{\sum_{j=1}^{m} Q_{ji} + \lambda_{air} C_{ext}}{U_{dep}\frac{A}{V} + \lambda_{air}}\left(1 - e^{-\left(U_{dep}\frac{A}{V}+\lambda_{air}\right)t}\right)$$

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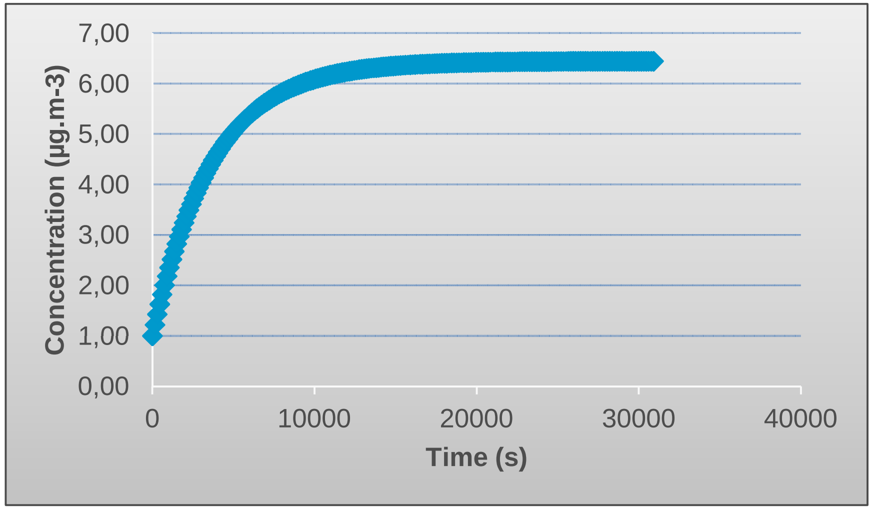
Indoor air modeling: application to formaldehyde

U_{dep} = 0 $m.s^{-1}$
C_{ext} = 1 $\mu g.m^{-3}$
λ_{air} = 0.98 vol/h

Calculated formaldehyde concentration: 6.4 $\mu g.m^{-3}$
Measured formaldehyde concentration: 7.0 ± 1.0 $\mu g.m^{-3}$



=> In accordance with the future French regulation (10 $\mu g.m^{-3}$)

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- Emission rate calculated from the air/material interface concentration
- Modeling considering the air exchange rate and the “real” material contribution
- Possibility to try different scenarii in order to evaluate the impact of various parameters of building management: ventilation, materials….

Conclusion

- ✓ Fast, sensitive, easy to implement analytical method for the evaluation of ***both VOCs and formaldehyde*** was developed. Further comparisons with the standard methods will now be done.

- ✓ On-site determination of material emissions

- ✓ Modeling of indoor air quality:
  - ➢ First experiment in a new building very encouraging
    - ➢ The box model will be adjusted with a 6 month study in a newly built high school
      - ➢ Predictive tool of indoor air quality

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Thank you for your attention

Questions?