Einfluss des Nutzerverhaltens auf die VOC-Konzentrationen (Reinigen, Heimwerken etc.) –

die Komplexität des Innenraums

Dr. Frank Kuebart

WaBoLu - Innenraumtage

Berlin, 17. Mai 2017

Inhalt

- Rückblick
- Innenraum – die unbekannte Größe
- „Luftverbesserer“, Duftkerzen und Räucherwerk
- Reinigungsmittel
- Drucker, Laser und 3D
- Biozide
- Anthropogene, VOC und Partikel
- Körperbewegung
- Freisetzung von VVOC
- PRM, VOC- und Ozon-Reduktion
- Mikrobiom
- Schlussfolgerung

Literatur-Recherche

Folgende Quellen dienten als Informationsgrundlage:

Presentationen	**Kürzel**
Indoor Air 2016	IA 2016
Indoor Air 2011	IA 2011
Healthy Building 2009	HB 2009
Indoor Air 2008	IA 2008
Indoor Air 2002	IA 2002

Journale

Indoor Air 2017 - 2000

und weitere

Insgesamt ca. 4500 Artikel

Ib Andersson 1964 - heute

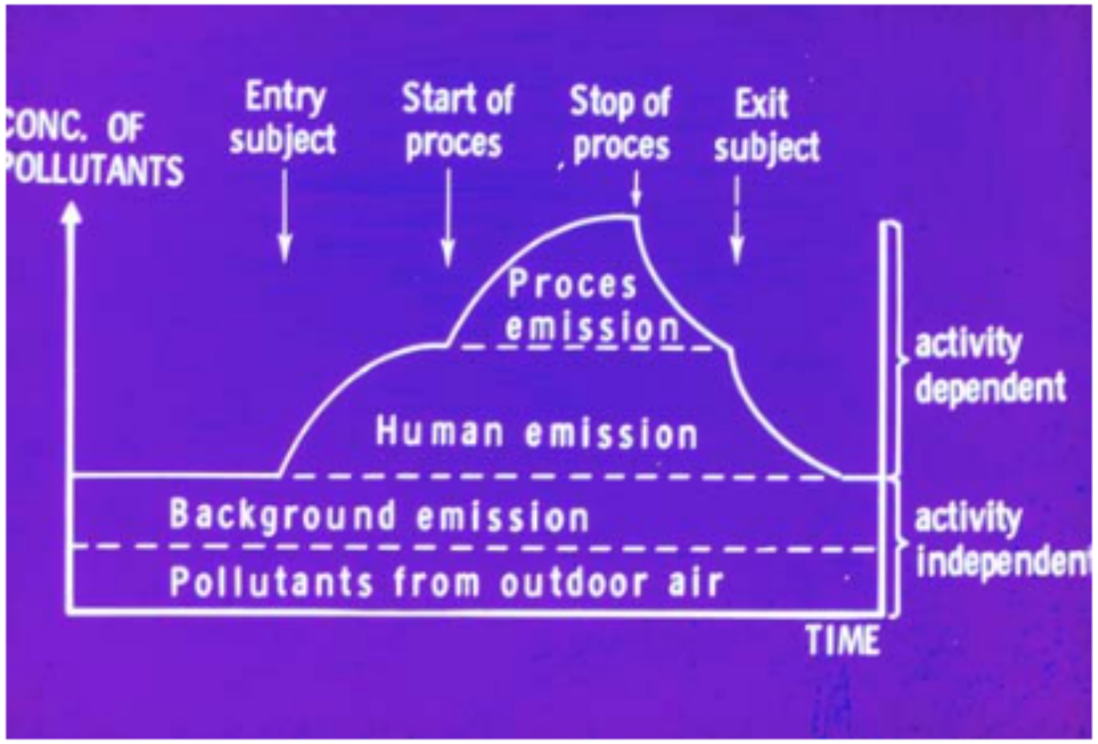
IA 2008, Su17K1\ Ib Andersson

Before the big bang of indoor climate research

We learned that:

– the indoor environment is very complex and each parameter varies during the day and during the year

– future field studies of the indoor climate should measure the multiple exposures and the multiple effects on human subjects simultaneously



Pollutant sources in indoor air - 1964

– future field studies of indoor climate problems should be supplemented by studies under controlled conditions in a climate chamber, where the effects on human subjects of a single exposure parameter can be studied in details

– the results of such studies should be given as evidence based comfort intervals for each indoor climate parameter

Richard L. Corsi - connect or stagnate

Indoor Air 2015; 25: 231–234, Editorial

ECO INSTITUT

Central to the connections found in the indoor air sciences are **building occupants, arguably the most complicated of all subsystems …**

Occupants are connected to almost every aspect of the indoor air sciences:

> ventilate by opening windows,
> activate sources (e.g., gas stoves, candles),
> set thermostats,
> clean indoor surfaces,
> purchase and install HVAC filters,
> operate portable air cleaners,
> purchase and apply cleaning agents and air fresheners,
> activate fans,
> liberate water vapor through cooking and cleaning,
and more…

These actions influence multiple other **subsystems**.

We also disseminate microbes from our skin, hair, nostrils, and gut (e.g., Fox et al., 2008; Hospod- sky et al., 2012), and our skin oils participate in chemical reactions with ozone and other oxidants that generate airborne reaction products (e.g., Wisthaler et al., 2005). And, of course, occupants are affected by other subsystems, with outcomes of interest including acute and chronic health effects, thermal comfort, work performance, and learning experiences.

Given the importance of occupant behavior on the indoor air sciences, it is surprising that the social sciences are not better represented in our field.

Weschler et al.

Indoor Air 2004; 14: 373–375, Guest Editorial

Workshop titled Indoor Chemistry and Health, University of California, Santa Cruz, 2004:

The workshop was a strong reminder that indoor chemistry is much broader than ozone/limonene reactions (the subject of considerable recent study).

- There are other oxidants besides ozone (e.g. hydroxyl and nitrate radicals).
- There are other types of reactions besides oxidation (e.g. hydrolysis and decomposition).
- Pesticide residues can be oxidized to more toxic species (e.g. malathion to maloxone).
- Esters can hydrolyze to more irritating and odorous species (e.g. di-2-ethyl-hexyl phthalate to its acidic monoester and 2-ethyl hexanol).

The workshop was also a strong reminder that we know very little regarding the various ways in which indoor chemistry may impact human health. (!)

SCHER Scientific Committee on Health and Environmental Risks

eco INSTITUT

The SCHER was asked…

to identify potential areas of concern in relation a) to specific chemical compounds, b) **to household–chemicals and other consumer products**, and c) to building dampness/moisture and microbial growth (moulds, bacteria):

→ **Very little is known about true exposure** (in relevant use context) to components of consumer products (e.g. cleaners, furnishings, air fresheners, products for laundering, glues, paints, paint strippers, personal care products) in indoor air, in quantitative terms.

→ **Lack of data on true exposure for emissions in consumer products has hampered evaluation of the associations with possible health effects most of which are also caused by other factors.** The recent data suggest that some of the emitted products may react further in air and on surfaces producing secondary products, including fine and ultrafine particles. The health effects of the reaction products are poorly known.

…most important needs for additional research:

- Emissions of chemicals from consumer products. More data on levels of the emissions in realistic use situations is needed in view of the large part of population handling such products.

…the following key data requirements and gaps in knowledge were identified:

- Effects due to combined exposure to indoor air pollutants and objective methods for their evaluation, i.e., development of validated modeling tools.
- Effects and risks of products which emit indoor air pollutants that can react in indoor air.
- Possible effects and risks of man-made nanoparticles in indoor air.

IA 2008 Keynote Paper Tu9K2 SCHER, Hannu Komulainen
http://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_055.pdf

… Zitate

IA 2008 Keynote Paper WE9K1 **Indoor climate and health: What do we really know?**

Kjell Andersson

The main reason for the difficulties in linking specific pollutants to specific health effects might be that the emissions of chemicals and particles indoors are low, and are mostly several orders of magnitude below occupational threshold limit values (TLV) or health-based indoor guidelines (Nielsen et al., 1998). Based on the difficulties of linking health effects with specific volatile organic compounds (VOCs), the focus has now turned to highly reactive oxidation products and small or ultra-fine particles, sometimes created during the oxidation process with ozone (Weschler et al., 2006; Tamás et al. 2006; Wolkoff et al., 2006). Another obvious reason explaining the difficulties may be the multifactorial indoor environment, including physical, chemical, biological, ergonomic, psychosocial and socioeconomic factors, and the individual vulnerability and anxiety level.

In the future, we need to focus more on i) specific well-defined symptoms and ii) mechanistic research (i.e. pathophysiology, identification of cause-effects relationships, and dose-response relationships) and include methods from medicine and neuropsychology.

IA 2011, a772_2 **Field studies on the impact of domestic activities on indoor air quality**

CSTB

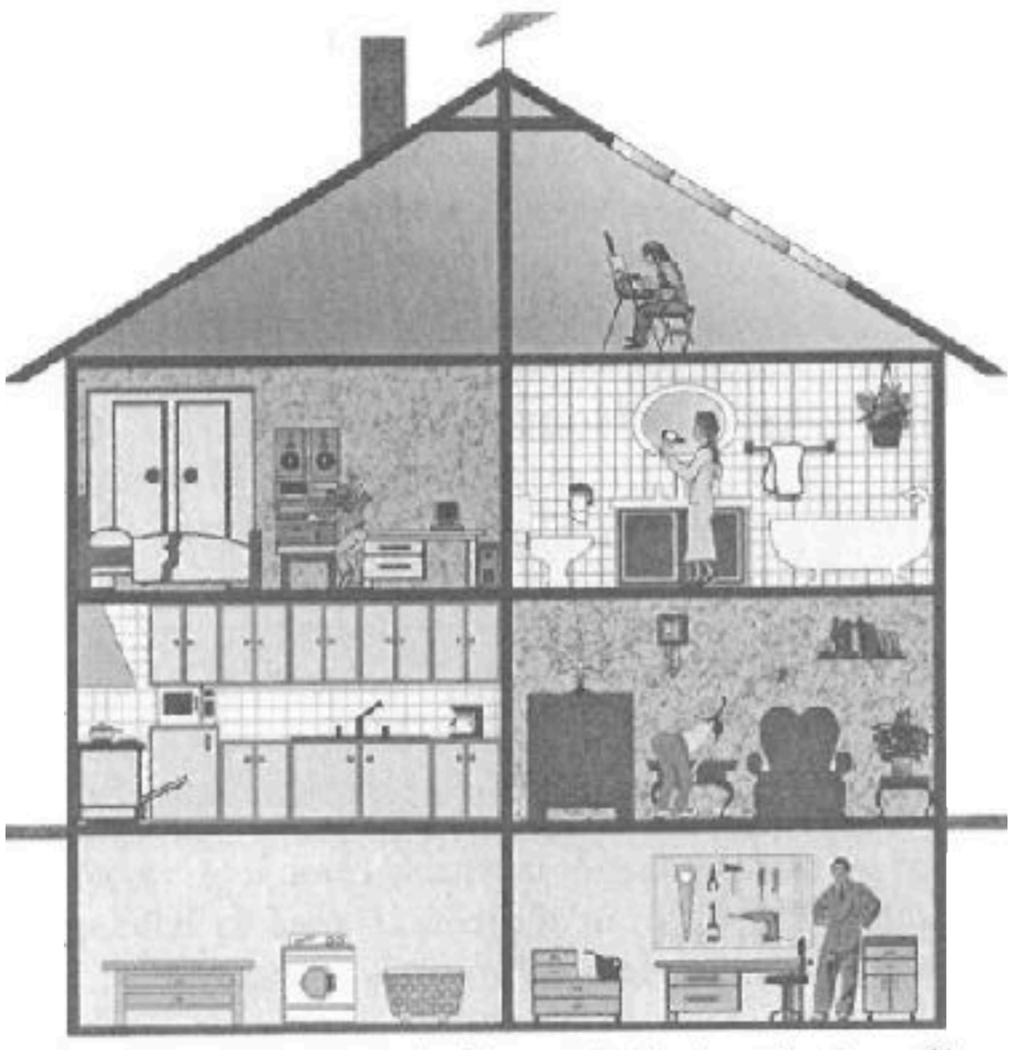
This study shows that household products can be considered as a significant source of VOCs and especially terpenes in real indoor environment. Moreover, ozone-induced chemistry performed in real scale environment provided relevant evaluation of the potential impact on indoor air quality and exposure.

Household products application

electronic equipment
air freshener
furniture polish
wax
insecticide

oven cleaner
floor wax
deodorizer
detergent

textile cleaner
softener
leather polish
shoe polish
detergent



bathroom cleaner
toilet bowl cake
deodorizer
cosmetic

furniture polish, wax
carpet cleaner
insecticide
air freshener
deodorizer

adhesive, glue
adhesive remover
paint, lacquer
paint remover
rust remover

Typical activities in dwellings and related applications of household products

Volatile Organic Ingredients in Household and Consumer Products, Godwin A. Ayoko
aus: Organic Indoor Air Pollutants, T. Salthammer, E. Uhde, 2009, Wiley-VCH

Candles and Incense - References

Gefahrstoffe - Reinhaltung der Luft, 77 (2017) - März, Sampling options for TD-GC-MS monitoring of aroma compounds released from fragranced goods, D.J. Barden, C. Widdowson, M. Dumitraskovic

Candles and Incense

EBENE project, France (414)	Sampling 1 Prod / 32 m³; AER 0,65 /h	Scented candles [µg/m³]	Incense [µg/m³]
Benzol	combustion	1	56
	post combustion (0-1 h)	1	71
Toluol	combustion	3	26
	post combustion (0-1 h)	2	28
Formaldehyd	combustion	2	33
	post combustion (0-1 h)	6	25
Acetaldehyd	combustion	1	39
	post combustion (0-1 h)	2	50
NOx	combustion	56	11
	post combustion (0-1 h)	73	14

VOC from combustion of incense

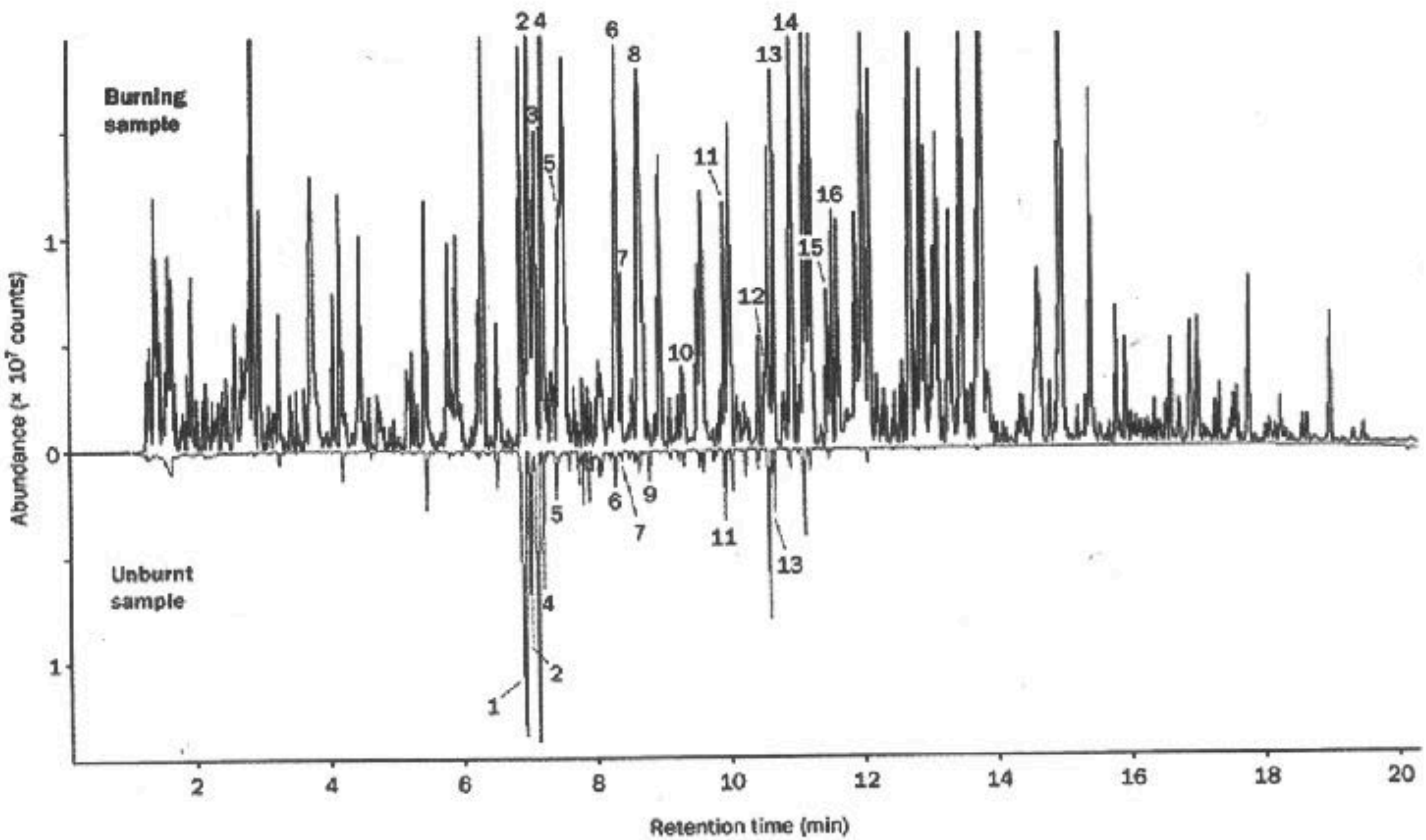


Figure 2. Analysis of the vapour profile from an unburnt incense stick (bottom), and of burning incense sticks (top), sampled onto sorbent tubes using a microchamber device and analysed by TD-GC-MS. Peak identities: 1, Dihydromyrcenol; 2, Phenylethyl methyl ether; 3, Citronellol; 4, Linalool; 5, Phenylethyl alcohol; 6, Terpineol; 7, Decanal; 8, Geraniol; 9, Terpinyl acetate; 10, Eugenol; 11, Nopyl acetate; 12, Coumarin; 13, γ-Methylionone; 14, Lilial; 15, Hedione; 16, Hexyl cinnamaldehyde.

Gefahrstoffe - Reinhaltung der Luft, 77 (2017) - März, Sampling options for TD-GC-MS monitoring of aroma compounds released from fragranced goods, D.J. Barden, C. Widdowson, M. Dumitraskovic

Fragrances

IA 2011, a116_4\ **Fragranced consumer products: Chemicals emitted, ingredients unlisted**
Anne C. Steinemann, Ian C. MacGregor, Sydney M. Gordon, Lisa G. Gallagher, Amy L. Davis, Daniel S. Ribeiro, Lance A. Wallace

…VOCs emitted by common fragranced consumer products. Virtually none of these VOCs were listed on any product label or MSDS.
Overall, "green" product emissions of VOCs classified as toxic or hazardous, or as probable carcinogens, were not significantly different than emissions from the other products.

Collectively, these 25 fragranced products emitted more than 420 VOCs, and 115 of these are classified as toxic or hazardous under federal laws. Of the 133 different VOCs identified across the products, only 1 was listed on any product label, and only 2 were listed on any MSDS. (116)

Most prevalent compounds among 25 products tested

Compound	CAS #	Prevalence (# of products)
limonene	138-86-3	23
alpha-pinene*	80-56-8	20
beta-pinene	127-91-3	20
ethanol*	64-17-5	19
2,4-dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal 1)	68039-49-6	14
benzyl acetate	140-11-4	12
acetone*	67-64-1	12
delta-4-carene, cis-2-carene, trans-2-carene, or delta-3-carene	554-61-0; 5208-49-1; 5208-50-4; 13466-78-9	12
o-, m-, or p-cymene	527-84-4,	10
camphene	79-92-5	9
ethyl butanoate	105-54-4	9
alpha-terpinene	99-86-5	8
acetaldehyde*	75-07-0	8
camphor*	76-22-2	8
3,6-dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal extra)	67801-65-4	7
delta-4-carene, cis-2-carene, trans-2-carene, or delta-3-carene	554-61-0; 5208-49-1; 5208-50-4; 13466-78-9	7
linalool	78-70-6	7
beta-phellandrene	555-10-2	6
gamma-terpinene	99-85-4	6

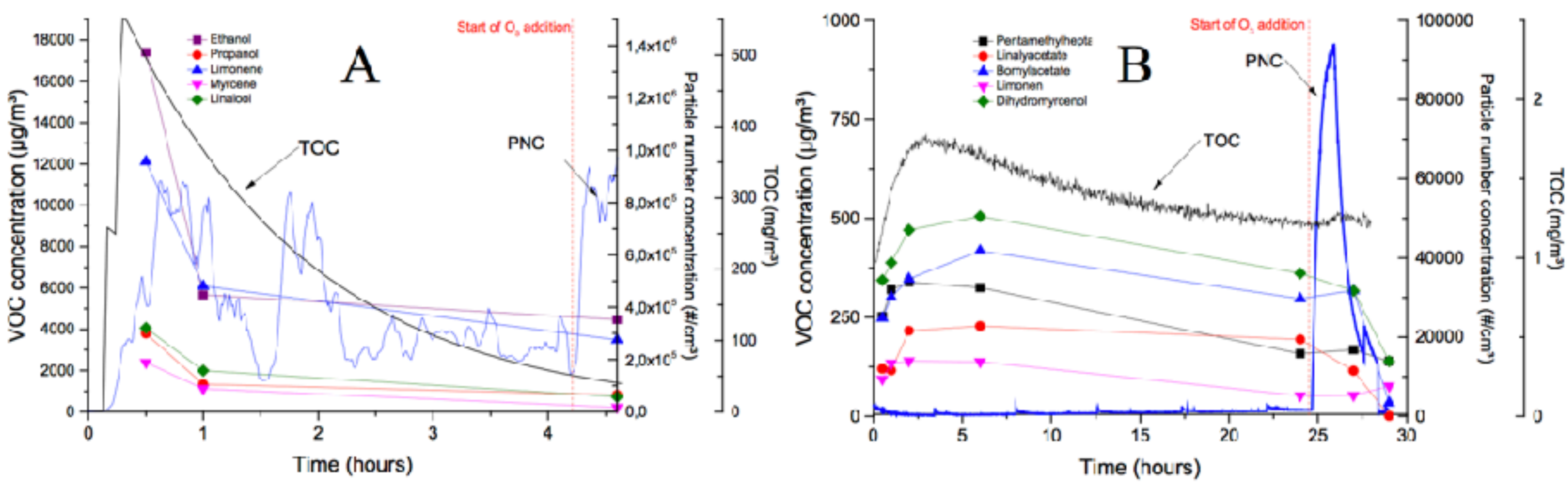
* Classified as toxic or hazardous under federal laws.

Fragrances for classrooms

eco INSTITUT

IA 2016, 1005\ **Room fragrances – sprays and diffusers as sources of indoor pollutants**
Erik Uhde, Nicole Schulz

The test of the **room spray intended for classrooms** started after chamber blank determination with 5 short spray pulses into the chamber (Volume 3 m³). The solvents ethanol and 2-propanol were detected in concentrations up to 17 mg/m³ and 4 mg/m³, respectively, during the following hours. Up to 12 mg/m³ of limonene were reached, linalool, linalyl acetate, and myrcene could be found in concentrations above 2 mg/m3 (Fig. 1-A). After ozone addition the product generated a high aerosol concentration in the chamber (>600000 #/cm³). The passive diffuser (used according to instructions) led to lower chamber concentrations (Fig. 1-B), but due to its lifetime of several weeks, an extended exposure of the users is likely. (1005)



Concentration of VOC and ultrafine particles during the test of a room spray (A) and a passive air freshener (B)

Household cleaners

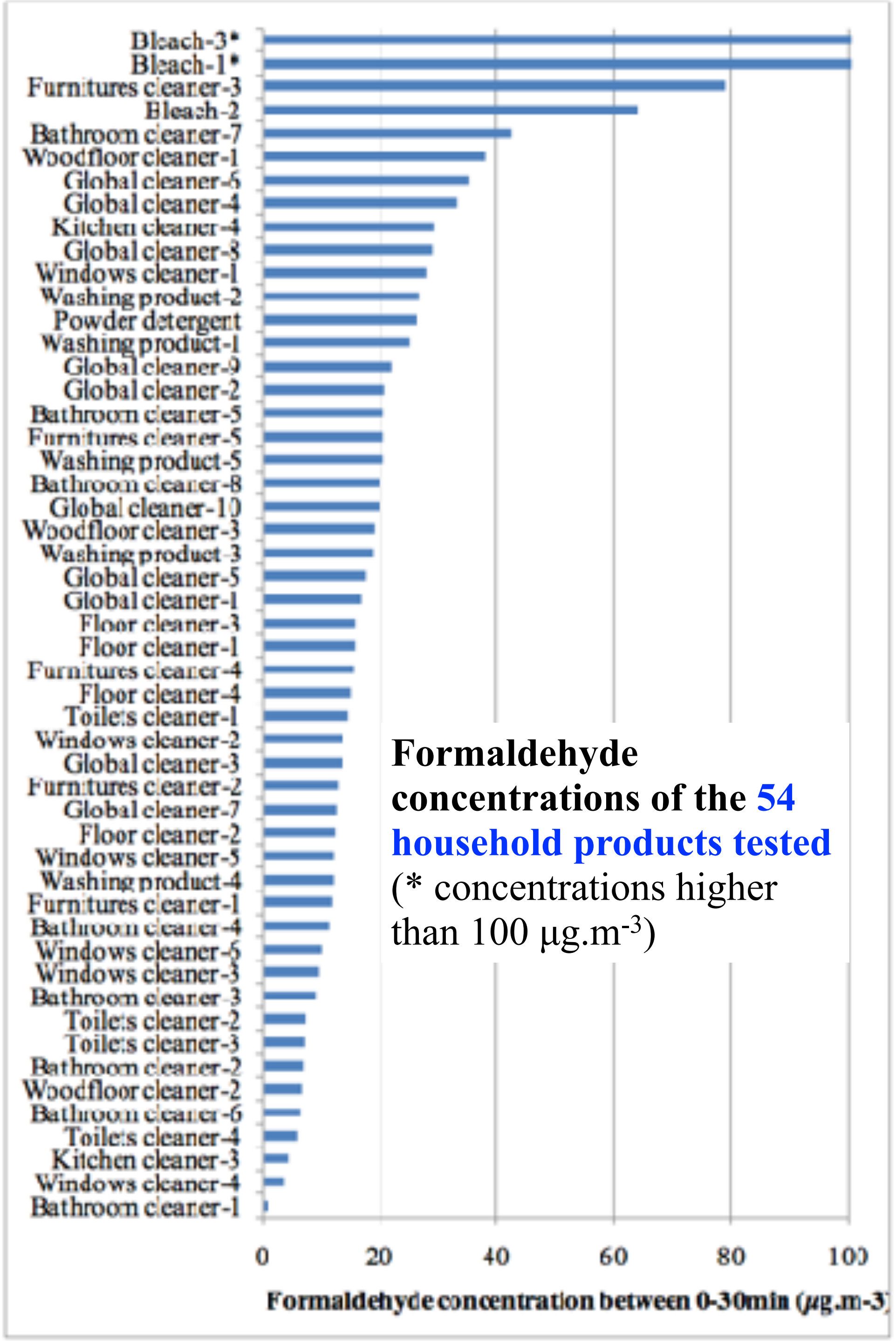
IA 2011, a766_5\ **Characterization of VOCs and Aldehydes emissions from household products,** Melanie Nicolas, Jerome Nicolle, Marianne Fernandez, Laura Chiappini, Barbara d'Anna and François Maupetit

First results have shown **TVOCs** (i.e., total of VOCs between n-hexane and n-hexadecane) concentrations ranging from 65 µg m^{-3} to 385 mg m^{-3} during the first thirty minutes and from 55 µg m^{-3} to 215 mg m^{-3} for the second sampling interval.*) Household products which presented the most important VOCs emission are furniture cleaner.

Major VOCs emissions was obtained for terpenes with highest concentrations for α-pinene, d-limonene and citronellol (70, 552 and 935 µg m^{-3}, respectively).

Moreover, some products emitted important amounts of formaldehyde leading to concentrations up to 470 µg m-3 (0-30 min) and 715 µg m^{-3} (30-60 min). (a766_5)

*) 30-60 min after product application on a glass plate



Cleaning products

Substances with C=C double products bonds contained in the inventoried cleaning

CAS No.	Substance	Content, %	Cleaning use
138-86-3	Limonene	0–2.5	Bed or mattress & toy
5989-27-5	(*R*)-Limonene	0–2.5	Bed or mattress & toy
106-22-9	Citronellol	0–2.5	Bed or mattress & toy
106-24-1	Geraniol	0–2.5	Bed or mattress

CAS No.	Substance	Content, %	Cleaning use
5392-40-5	Citral	0–2.5	Bed or mattress & toy
101-86-0	Hexyl cinnamaldehyde	0–2.5	Furniture
78-70-6	Linalool	0–2.5	Furniture
127-51-5	α-iso-Methylionone	–	Furniture
91-64-5	Coumarin	–	Furniture
8000-41-7	Terpineol	2.5–10	Furniture
97-53-0	Eugenol	0–2.5	Floor

*) **Galaxolide** (trade name; also known as Abbalide, Pearlide, Astrolide, Musk 50, Polarlide; chemical name 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8,-hexamethyl-cyclopenta[*g*]benzopyran or HHCB) is a synthetic fragrance with a clean sweet musky floral woody odor used in fragrances

House cleaning - SOA

IA 2016, 1067\ **Household products and indoor air quality: emission, reactivity and by-products in both gaseous and particulate phases**
A. Même, M. Nicolas L. Chiappini, C. Rio, J. Nicolle, S. Rossignol and B. D'Anna

The present work investigates Secondary Organic Aerosols (SOA) formation in indoor environment from VOCs ozonolysis emitted by housecleaning products.

For each of the **54 housecleaning** products tested physical characterisation of particles has been investigated. Cleaning products, containing high level of terpenes and derivates, have been extensively studied in the occupational house MARIA (Maison Automatisée pour des Recherches Innovantes sur l'Air) allowing simulation of realistic use conditions and exposure.

- The products contributed to high increase of particle number (above 50000p/cm^3), they showed fast growth with diameter going from 10 to 70nm in less than one hour and simultaneous coagulation onto pre-existing particles.
- Major oxygenated products identified are 4-oxopentanal, limonenaldehyde, methylglyoxal, butanal in the gas phase, and levulinic acid, methylglyoxal and nonanal in the particle phase respectively.

These results, obtained under real household product use conditions, are a very useful source of information in order to qualitatively and quantitatively assess the population exposure to both ultrafine particles and oxygenated compounds in indoor environments.

Spray cleaning

IA 2016, 328\ **Cleaning sprays – Aerosol characterization and a human exposure chamber study,**
Christina Isaxon, Karin Lovén, Jörn Nielsen, Gunilla Wieslander, Anders Gudmundsson

Studies have linked the use of cleaning sprays to the development of new-onset asthma and other respiratory conditions. In order to understand how cleaning spray aerosols are deposited in the lungs and why they cause airway symptoms, knowledge of physical characteristics of the particles and their dynamics is needed.

The aerosols were characterized in a 1.3 m^3 stainless steel chamber with controlled temperature, relative humidity (RH) and air exchange rate (AER). In a 22 m^3 stainless steel chamber, a double blind dose-response human exposure study was conducted. The settings of the chamber were set to 22°C, 30% RH and AER 0.5 h^{-1}.

Between 3 and 20 %, depending on product, of the mass sprayed out remained airborne, only between 0.002 and 0.01 % were in the particle phase. Tear film break-up time tended to decrease with increasing spray dose, and self-reported nose symptoms increase. Up to 1/3 of the spray emitted from the bottle never reaches the surface intended to be cleaned, the major part of this airborne spray exposure is in gas phase. Evaporation occurs very fast, and also the residual particle will be part of the worker exposure.

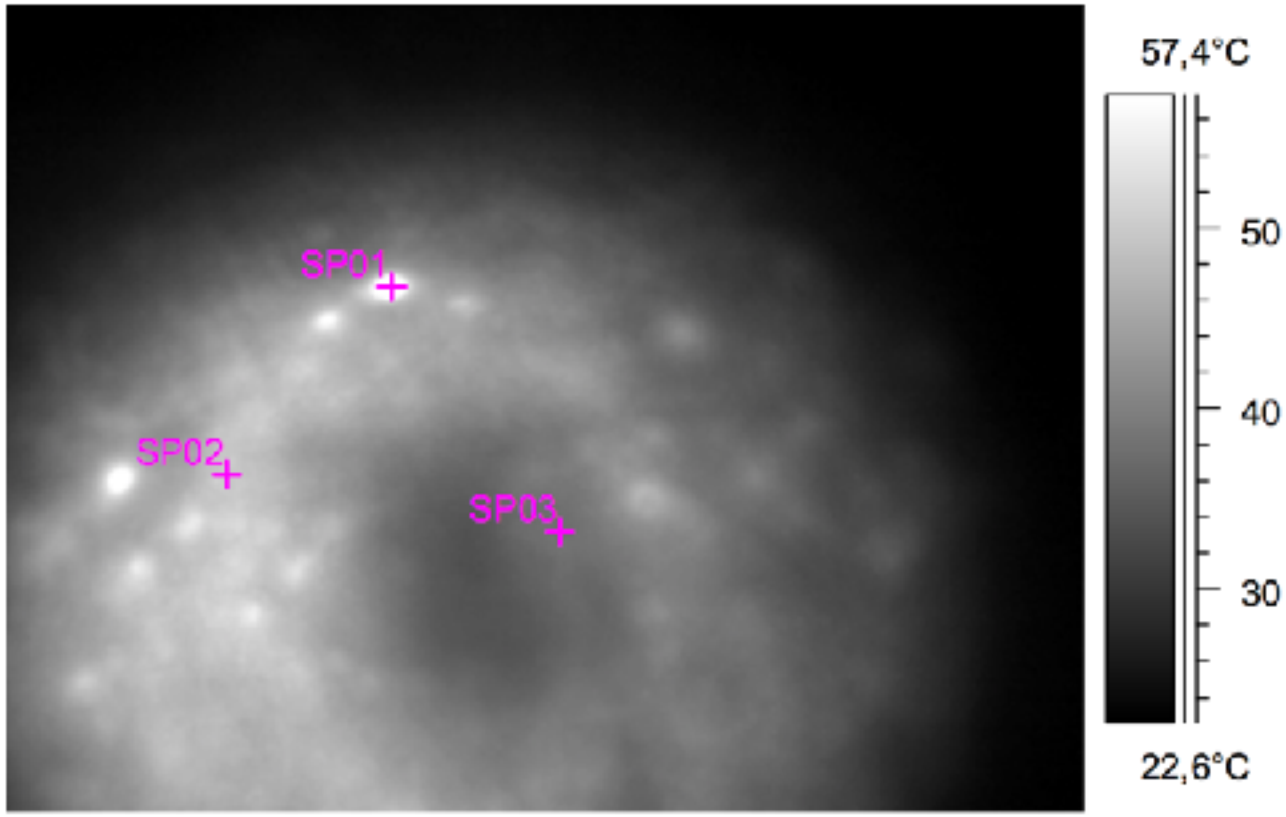
PVC floor cleaning

IA 2002, 3B205\ **Characterization of emission from mechanical polishing of PVC floors**
O Bjørseth, JV Bakke, N Iversen and B Martens

Floor surface temperatures were measured by IR-technique during high-speed polishing of PVC floors, and found in general to be below 40°C at normal operating conditions. Intensive polishing of small areas could produce spot temperatures up to 100°C.

VOC's determined in the exhaust from the high-speed machine:

4-methyl-1-pentene
iso-butanol
propenoic acid, 2-methyl-methyl ester
2-etoxy ethanol
4-methyl-2-pentanol
acetic acid butylester
n-butyl ether
ethyl benzene
propanoic acid, 2 methylpropylester 2-butoxyethanol
styrene
propylbenzene
butanoic acid butylester
1,2-dimetoxypropan 2-(2-ethoxy-ethoxy)ethanol



Surface temperature at intensive polishing (SP01: 70.6 °C, SP02: 50.0 °C, SP03: 38.0 °C)

Particles from laser printer

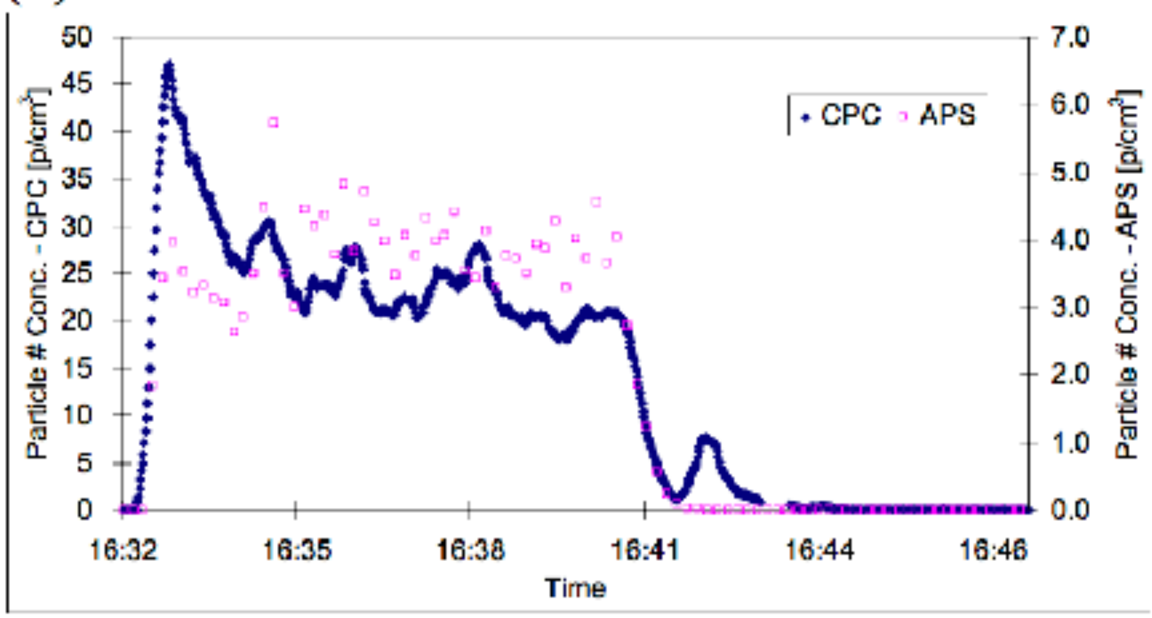
IA 2008, 239\ **Sampling and characterisation of ultra fine particles released from laser printers,**
Olaf Wilke, Stefan Seeger, Harald Bresch, Doris Brödner, Elevtheria Juritsch and Oliver Jann

IA 2008, 1024\ **Particle emission from laser printers,**
Lidia Morawska, Congrong He, Hao Wang, Peter McGarry, Tunga Salthammer, Rohan Jayaratne, Graham Johnson, Thor Bostrom, Robert Modini, Erik Uhde, Goodwin Ayoko and Michael Wensing

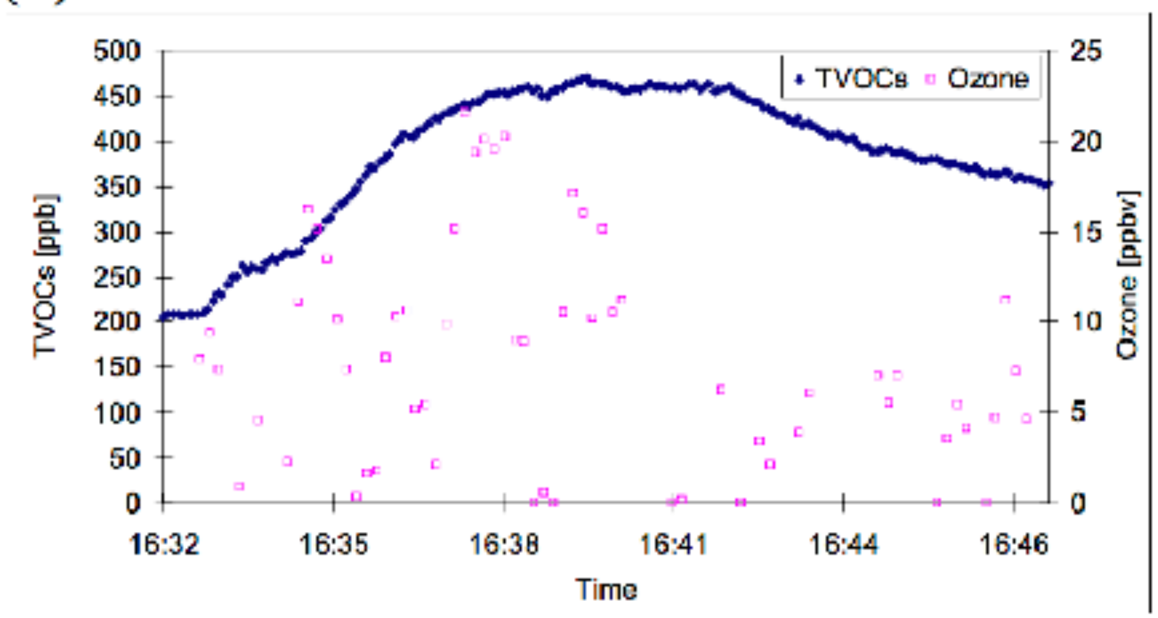
Recent studies have shown that the operation of laser printers can result in the emission of high concentrations of ultrafine particles. However, fundamental gaps in knowledge still remain, for example, it is not clear what makes a

These studies indicated that particles are not the only pollutants emitted by printers, and indicated that printers also emit VOCs and ozone.

(a)



(b)



Characteristics of emissions in the flow tunnel from Printer B during and after printing of 150 pages on Paper 1 at 5% toner. (a) Particle number concentration measured by CPC and APS; and (b) TVOCs and ozone concentration.

Laser printer - health effects

IA 2011, a519_5\ **Investigation into the cytotoxic, genotoxic and proinflammatory effects of laser printer emissions in human epithelial A549 lung cells**,
Volker Mersch-Sundermann, Tao Tang, Richard Gminski, Mathias Könczöl, Rebecca Kuhn, Christoph Modest, Benedikt Armbrust, Carsten Gründemann

Table 1. Release of ozone, VOCs, PM and SMPs during printing in comparison to clean air (mean of two independent experiments)

	Ozone [$\mu g/m^3$]	∑VOC [$\mu g/m^3$]	PM 10 [$\mu g/m^3$]	PM 2.5 [$\mu g/m^3$]	SMPs [#/cm^3]
Clean air	15	60	0.328	0.310	14
Printer A	29	280	0.883	0.809	23
Printer B	19	94	2.379	2.076	13
Printer C	13	180	1.645	1.570	276,132
Printer D	34	191	2.391	1.411	2213
Printer E	17	109	1.594	1.069	20,198

SMP = sub micrometer particles

3D printer

eco INSTITUT

IA 2016, 266\ **Evaluating and controlling human exposure to ultrafine particle and VOC emissions from desktop 3D printers**, Parham Azimi, Dan Zhao, Neil Crain, Brent Stephens

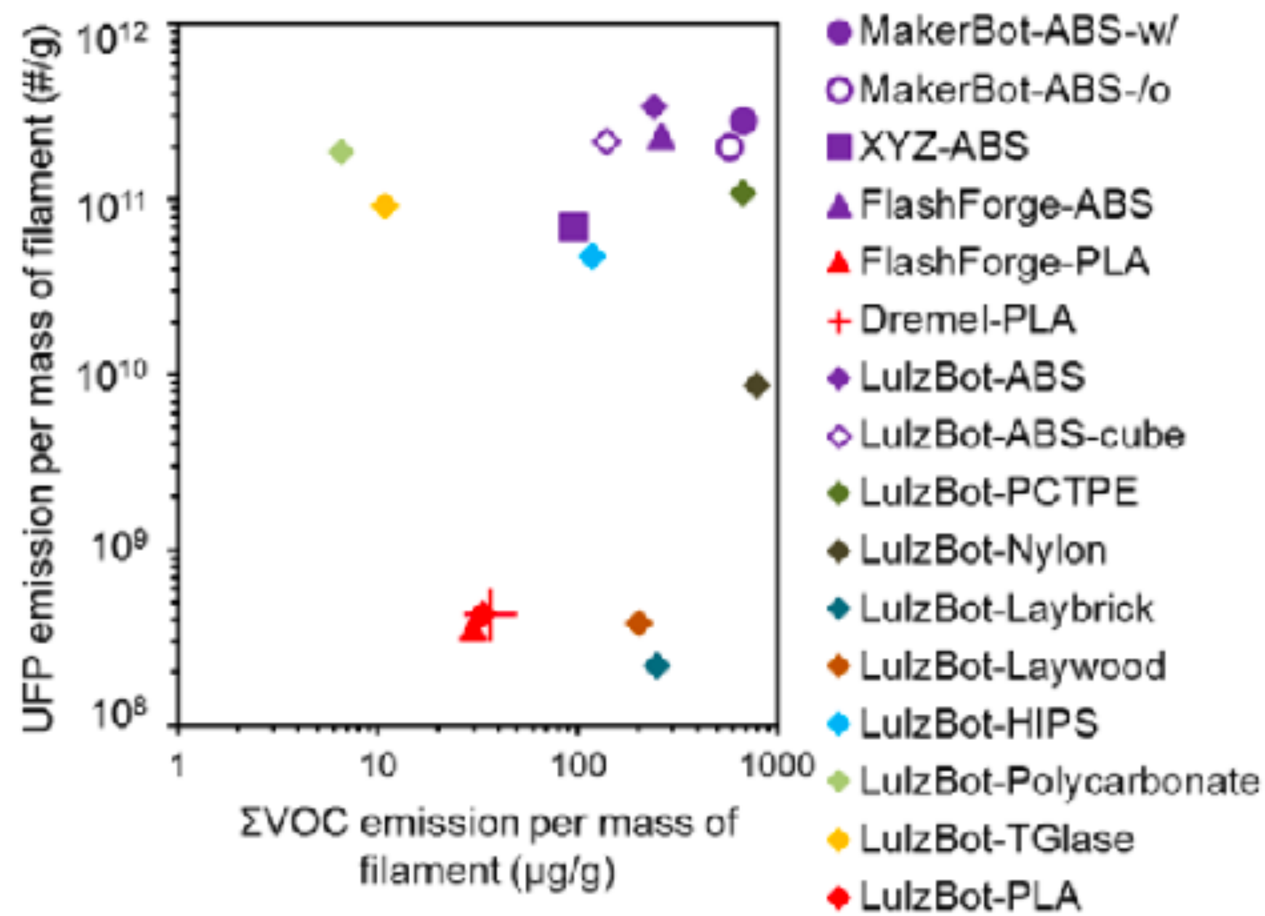
IA 2016, 899\ **VOC and particle emissions from home and hobby 3D printers,** Samuel Hartikainen Markus Johansson, Marko Hyttinen, Pertti Pasanen

The primary individual VOC emitted from ABS filament and high-impact polystyrene (HIPS) filament was
Styrene, ranging from ~12 µg/min to ~113 µg/min.

Caprolactam emission rates were as high as ~180 µg/min for nylon-based filaments.

ABS, PCTPE, and HIPS filaments had high mass-normalized emission rates of both UFPs and ΣVOCs, while PLA filaments had lower mass-normalized UFP and ΣVOC emission rates.

Comparison of total UFP and TVOC emissions per mass of filament



ABS	Acrylnitril-Butadien-Styrol Copolymer
PCTPE	"Plasticized Copolyamide TPE" or a chemical co-polymer of highly flexible nylon and TPE (thermoplastic elastomer)
HIPS	High Impact Polystyrene
PLA	Polylactid (Polyester)

Biocides indoors

IA 2011, a57_1\ **Persistence of pesticides in residential indoor air and chair seat foam,** David E. Camann, Michelle Zuniga, Alice Yau Lynne Heilbrun,Tatjana Walker and Claudia Miller

Semivolatile organic pesticides redistribute among the gas phase, airborne particles, settled dust, and other surfaces in indoor environments as a function of vapor pressure (Weschler and Nazaroff, 2008). Mattresses, pillows, sofa cushions and toys with PUF foam interiors will also collect the pesticide and other SVOC residues from the air during decompression after being compressed, and may thus serve as passive samplers of past residential SVOC exposure.

…rapid organophosphate biological degradation makes retrospective exposure studies difficult. This study documents that chlorpyrifos and diazinon persist in indoor air and shows that foam cores with a documented history can be used to assess past organophosphate exposure.

A longitudinal series of indoor air samples, foam samples from a chair, and house dust was collected from two homes with known minimal usage of pesticides over a six-year period to investigate the effective dissipation rate of organophosphate pesticides in indoor air and the retention of pesticides measured in the chair foam. Despite the active measures taken to reduce the organophosphate pesticide levels, **the indoor air concentrations of chlorpyrifos and diazinon have persisted for years in both monitored homes, with estimated dissipation half-lives of 4.5 –6 years for chlorpyrifos and about 2.3 years for diazinon. Concentration gradients into seat cushion foam with a known usage history can provide insight into the past exposure of residents to the detected pesticides.**

Sampled chair in House:1989

Biocides indoors II

IA 2011, a113_1\ **Evaluation of the biocide concentration levels during and post-application of electric vaporizers using a Proton-Transfer-Reaction Mass Spectrometer device**,
Aude Vesin, Etienne Quivet, Brice Temime-Roussel, Henri Wortham

Experiments were carried out under controlled conditions (air exchange rate, temperature and relative humidity) in a full-scale environmental chamber, located in the "Mechanized house for Advanced Research on Indoor Air"(MARIA) experimental house, at the Scientific and Technical Center of Building (CSTB) research centre in Marne la Vallée, France.

The volume of the chamber is 32.3 m^3 (2.50 × 2.53 × 5.15 m) without furniture.

A Proton-Transfer-Reaction Mass Spectrometer (PTR-MS) originally designed for Volatile Organic Compounds (VOC) monitoring (Lindinger et al., 1998; Blake et al., 2009) and providing on-line and high time-resolved measurements, is used for pesticides monitoring in indoor environments during pesticide use. The PTR-MS technique applies chemical ionization through H_3O^+ transfer reactions, combined with subsequent mass spectrometric ion detection.

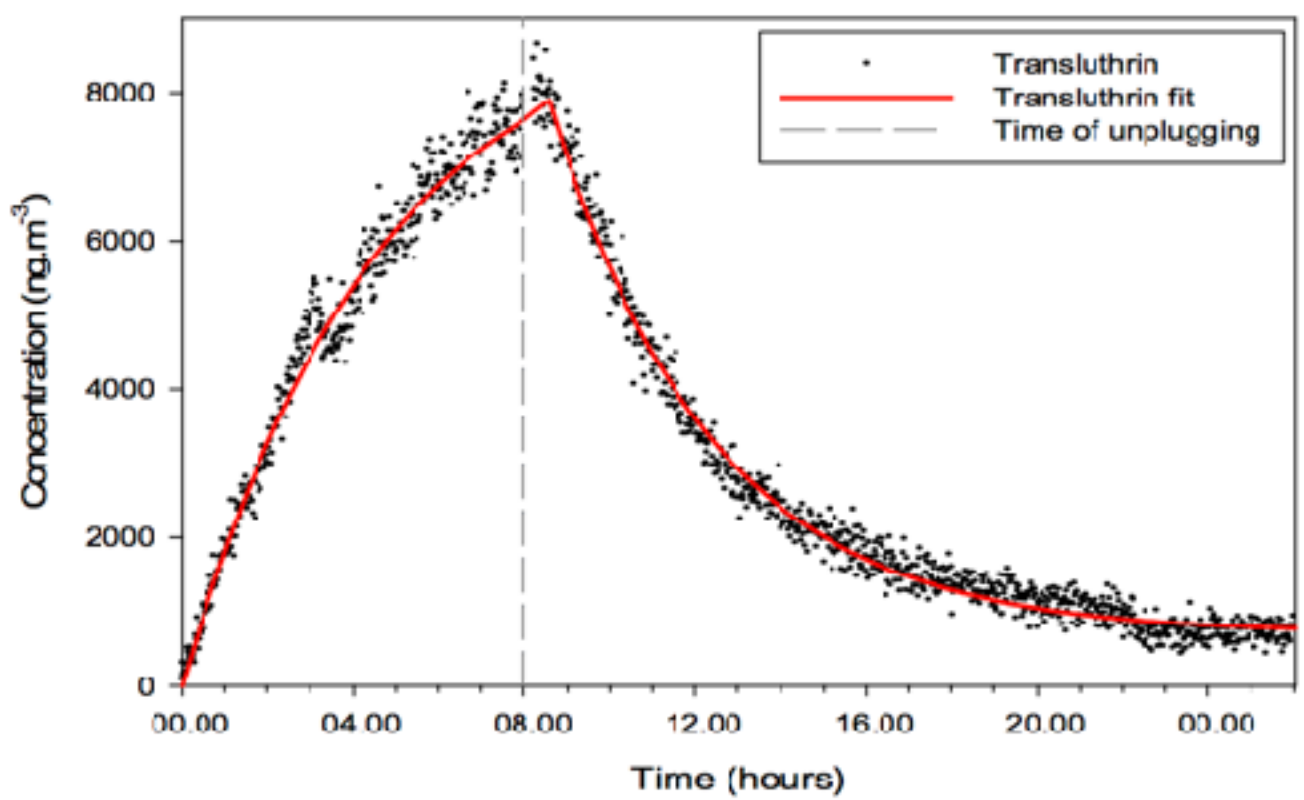
…Biocides indoors II

IA 2011, a113_1\ **Evaluation of the biocide concentration levels during and post-application of electric vaporizers using a Proton-Transfer-Reaction Mass Spectrometer device**, Aude Vesin, Etienne Quivet, Brice Temime-Roussel, Henri Wortham

…five electric vaporizers were placed on a support located at a distance of about 2 m from the sampling line and at a height of about 1 m.

A simplified exposure modeling realized with ConsExpo (RIVM, the Netherlands) provides the exposure doses inhaled by a resting adult weighting 70kg during 24 hours exposure, assuming a constant rate release of the insecticide during 8 hours. The doses range from 2 to 4 µg kg^{-1} bw for the three experiments realized with **transfluthrin**, compared to an Acceptable Exposure Level (AEL) of 3 µg kg^{-1} bw (Directive 98/8/EC), **meaning that the doses may be beyond the acceptable limit.**

The use of the high time-resolved PTR-MS results to study the exposure level thus gives a more accurate output on the **exposure doses and duration that turn out to be crucial especially for the fragile populations such as children and pregnant women.**



Concentration profile of transfluthrin during and after vaporizer application.

Anthropogenic VOC

HB 2009, 645\ **Identification of anthropogenic volatile organic compounds correlating with bad indoor air quality**
Andrea Burdack-Freitag, Rainer Rampf, Florian Mayer, Klaus Breuer

In human breath nearly 4000 VOCs of various compound classes have been found:
e.g. acetic acid, nonanal, benzene, dimethyl sulfide, isoprene, commonly acetone, alcohols, a huge number of n-alkanes and methyl branched alkenes as well as isoprene derivatives.

Bad air quality does not necessarily correlate with high CO_2 concentrations but also not with a high TVOC content.

CO_2 concentration change is too slow to contribute directly to air quality perception. This is rather influenced by other compounds – VOCs.

The presence of eight anthropogenic emissions in ambient air, namely acetone, isoprene, ethanol, limonene, nonanal, decanal, eucalyptol and α-pinene indicates human presence and **the combined occurrence of acetone, isoprene and limonene, at elevated concentrations, also bad air quality**.

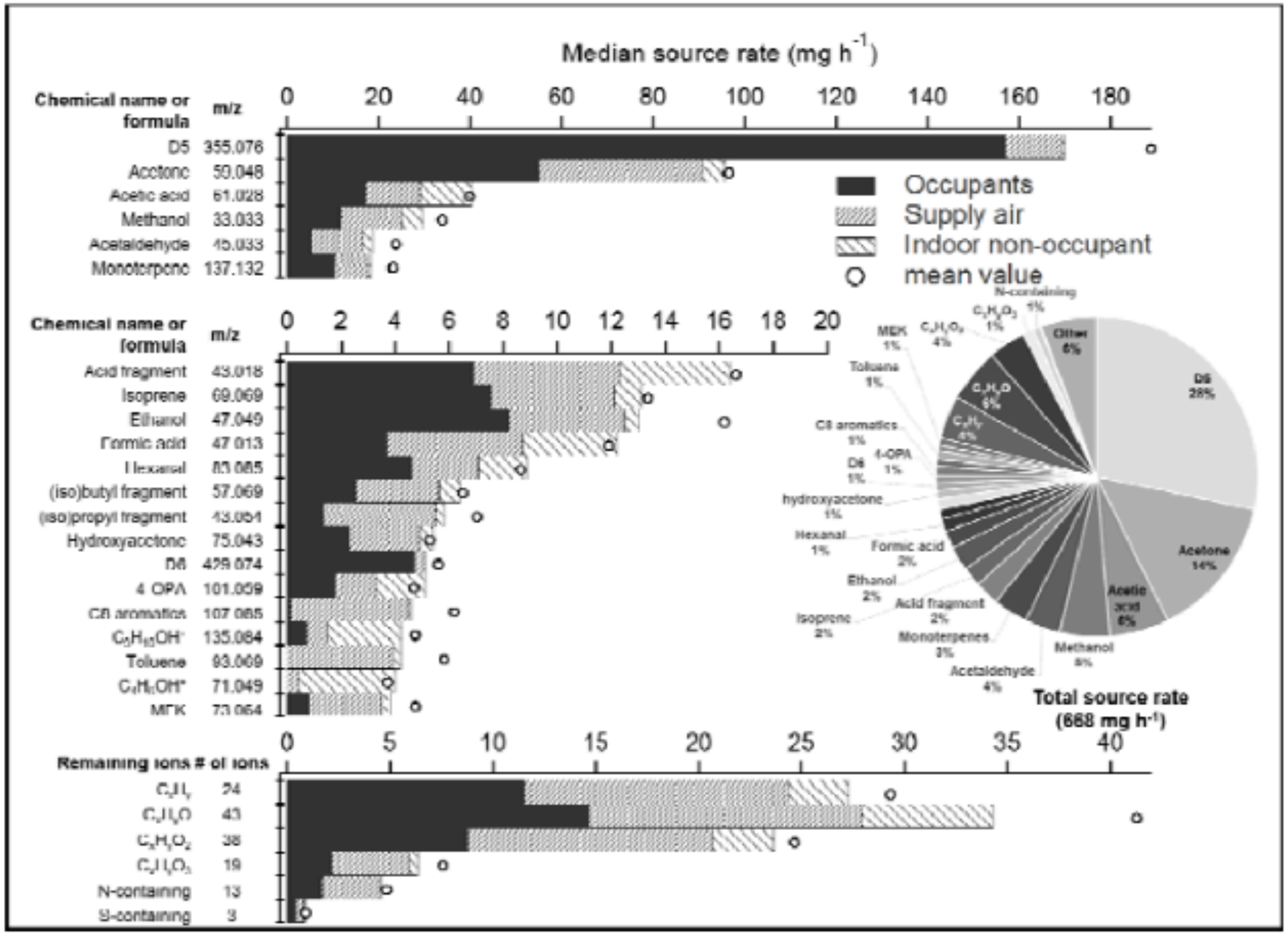
VOC in der ausgeatmeten Luft	[ppb]
Aceton	1,2 - 1880
Isopren	12 - 580
Ethanol	13 - 1000
Methanol	160 - 2000

Human as indoor emission source

IA 2016, 653\ **Contributions of Human Emissions to Indoor Air Composition**
Allen H. Goldstein, Xiaochen Tang, Pawel K. Misztal, William W Nazaroff

The contributions of human occupants as indoor emission sources have rarely been studied.

We determined that humans were the dominant indoor volatile organic compound (VOC) source in a university classroom. By mass, human-emitted VOCs were the dominant source in a well-ventilated classroom (58%), outdoor air was the second most important source (~33%), and indoor non-occupant emissions were the least important source (~9%).



Human activities, personal clouds

IA 2016, 276\ **Personal activities as sources of human personal clouds**
Dusan Licina, Yilin Tian, William W Nazaroff

IA 2016, 288\ **Measurements of Dermal and Oral Emissions from Humans**
Sayana Tsushima, Gabriel Bekö, Rossana Bossi, Shin-ichi Tanabe and Pawel Wargocki

IA 2016, 656\ **Size-resolved total particle and fluorescent biological aerosol particle emissions from clothing**, Yilin Tian, Dusan Licina, Nicole Savage, J. Alex Huffman and William W Nazaroff

Humans emit large number of volatile organic compounds (VOCs) called bioeffluents. They are mainly emitted via the skin and the breath. They depend mainly on diet and the medical condition of an individual, as well as on hygiene and the use of cosmetics.

Human bioeffluents, especially skin oils, can undergo reactions with ozone, which create yet another subset of compounds related to the presence of humans (Wisthaler and Weschler, 2010).

Studies have been conducted to determine major components of bioeffluents both emitted by the skin and through the exhaled breath (e.g. Marples, 1970; Fenske and Paulson, 1999), but no studies can be identified that separate the effects of emissions from the various body parts on perceived air quality (PAQ).

Human walking

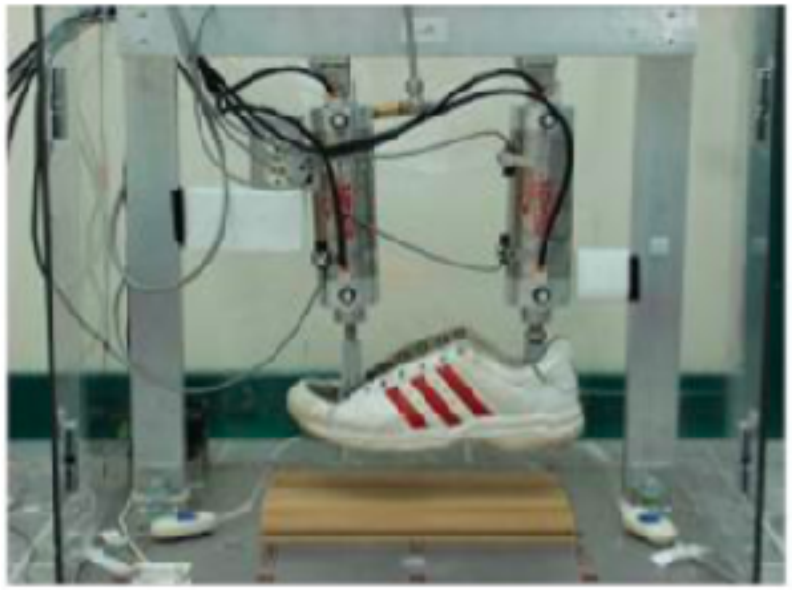
IA 2011, A420_3\ **Numerical and Experimental Investigation of Particle Resuspension due to Human Walking,**
Kyung Sul, Behrang Sajadi, Yilin Tian, Iman Goldasteh, Goodarz Ahmadi and Andrea R. Ferro

IA 2011, a587_3\ **Using human activity patterns to estimate the impact of flooring types on exposures to PM2.5 resuspended during walking,**
Lisa Bramwell, Steven Foti, Sumona Mondal and Andrea R. Ferro

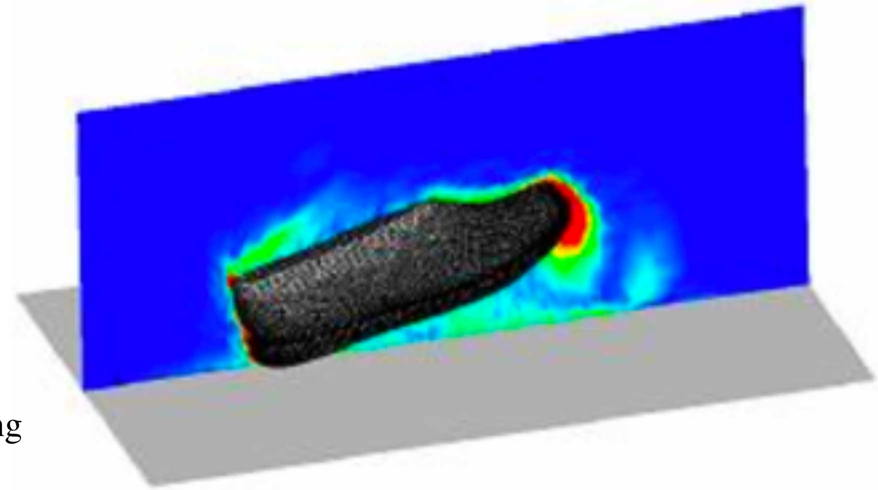
IA 2011, a678_2\ **The effect of human movement on the resuspension of airborne particles,**
Mohammed Alshitawi, Hazim Awbi

Human walking is known to be a significant source of particulate matter in the indoor air via particle resuspension.

The experimental results show that the resuspension rate of particles is highly dependent on the particle size and flooring type which is supported by the numerical data.



Mechanical foot device developed by Lawrence Berkeley National Laboratory.



A sample of vorticity contours during stepping motion of the shoe

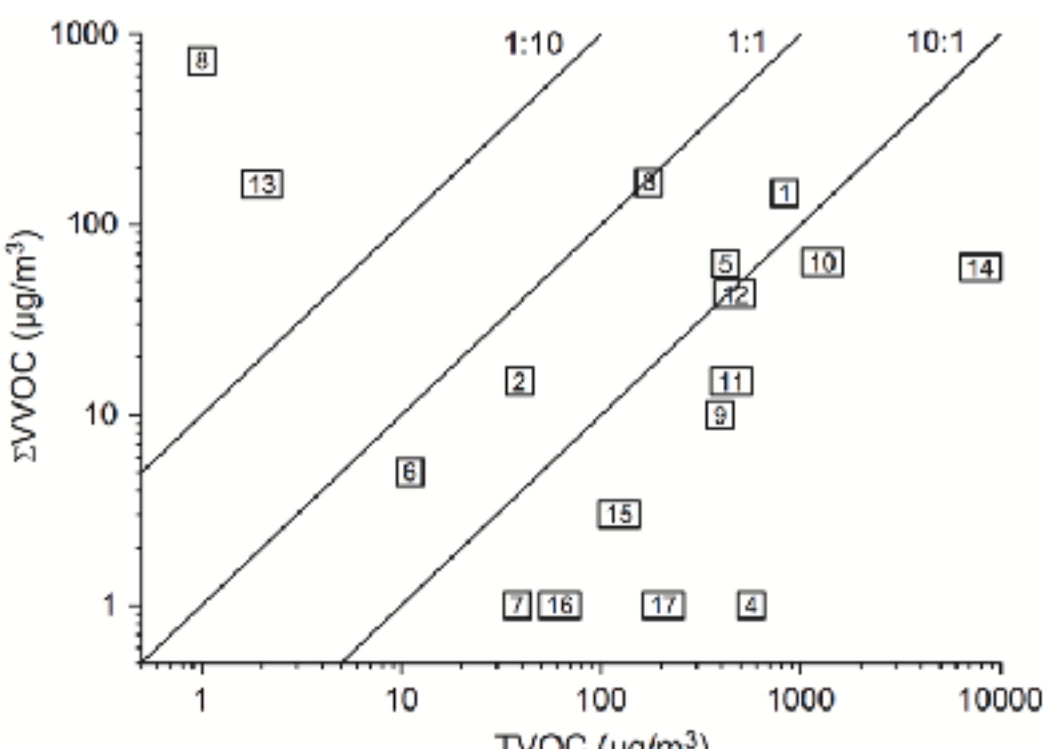
VVOC

IA 2016, ina12173\ Keynote: **Very volatile organic compounds: an understudied class of indoor air pollutants**, T. Salthammer *)

A significant source for VVOCs is human activities in the household, especially the use of cleaning products and cooking, frying, and baking.

During test chamber investigations on the fire behavior of incense sticks, Lee and Wang (2004) were able to prove the presence of the VVOCs formaldehyde, acetaldehyde, acetone, acrolein, propanal, methacrolein, butanal, methyl chloride, dimethyl chloride, 1,2-dichloroethene, and chloroform.

Acrolein	Heating of glycerine containing food	**2,3-Butanedione (Diacetyl)**	Popcorn in microwave
Furan	heating food	**Saturated / unsaturated aldehydes**	Thermal decomposition of linoleic acid



VOC vs. VVOC concentrations for 17 building products after 28 days in a test chamber at T = 23 °C, rH = 50%, q = 1.25 m³/(m2 h), analysis acc. to ISO 16000-6, 1, 2 (flooring material); 3 (concrete); 4 (parquet coating on glass); 5 (pine board); 6 (melamine resin foam); 7 (flooring adhesive on glass); 8 (insulation material); 9 (laminate); 10 (paint on oak); 11 (oak parquet).
q = 0.5 m³/(m2/h): 12 (plywood); 13 (insulation material); 14 (MDF board); 15 (fiber board); 16 (wall paint on glass); 17 (wall covering)

*) Approx. 80 VVOC are listed in this presentation

HONO

IA 2016, 131\ **Towards the next generation of indoor air chemistry models,**
Nicola Carslaw and Magdalena Kruza

IA 2016, 133\ **Indoor oxidation: which process dominates chemical processing indoors?**
Nicola Carslaw

Indoor air chemistry is entering a new and exciting phase:

Recent measurements have shown that HONO chemistry may be more important as a radical source indoors than was traditionally considered (Alvarez et al., 2013). Another interesting area of research is the impact that human occupancy can have on indoor chemistry: humans can act as a surface for deposition of some indoor species (such as ozone), and as a source of others through reactions on the surface of skin (Wisthaler and Weschler, 2010). However, these processes (and many others) are at a preliminary stage of understanding and owing to their complexity, are somewhat poorly defined. The absence of a complete understanding of such processes makes parameterising them in models for indoor air chemistry a major challenge.

Reducing uncertainties in indoor air chemistry models is important if we wish to gain further insight into the new measurements that are becoming available indoors. It is possible to do so, but requires a concerted effort by the indoor air community to target future experimental and field measurements accordingly **and to engage the outdoor air community in the process**.

In order to reduce these uncertainties, a number of experimental and field measurements are required. Many of these could be carried out as part of an intensive measurement campaign (as held outdoors for many years) within a test-house facility.

Surface reaction

IA 2016, 564\ **Exploring the nature of indoor oxidative heterogeneous chemistry,**
Shouming Zhou, Ramina Alwarda, Matthew W. Forbes, Jonathan Abbatt

When assessing the composition of material on indoor surfaces, it is important to recognize that the species present may have been modified via heterogeneous oxidation with the overlying atmosphere. This is true not only for inanimate surfaces, such as walls or windows, but also for human subjects which have particularly reactive constituents in their skin oil.

The rates of these indoor multiphase processes may be dependent upon the environmental conditions, such as relative humidity. The effects of light, temperature and the underlying building materials have still to be examined.

It is noteworthy that a number of species that will be deposited on indoor surfaces are reactive with ozone. These include many constituents of skin oil and components of combustion aerosol. Some reaction products are highly oxidized which increases their polarity, indicating that they will likely remain in the condensed phase.

Thus, surfaces indoors will consist of not only the reactive precursors but also a large suite of oxygenated products.

PRM - Ozone reduction

HB 2009, 141\ **Removal of Indoor Ozone with Reactive Materials: Preliminary Results and Implications,** Clement Cros, Elliott Gall, Jeffrey Siegel, Glenn Morrison, Richard L. Corsi

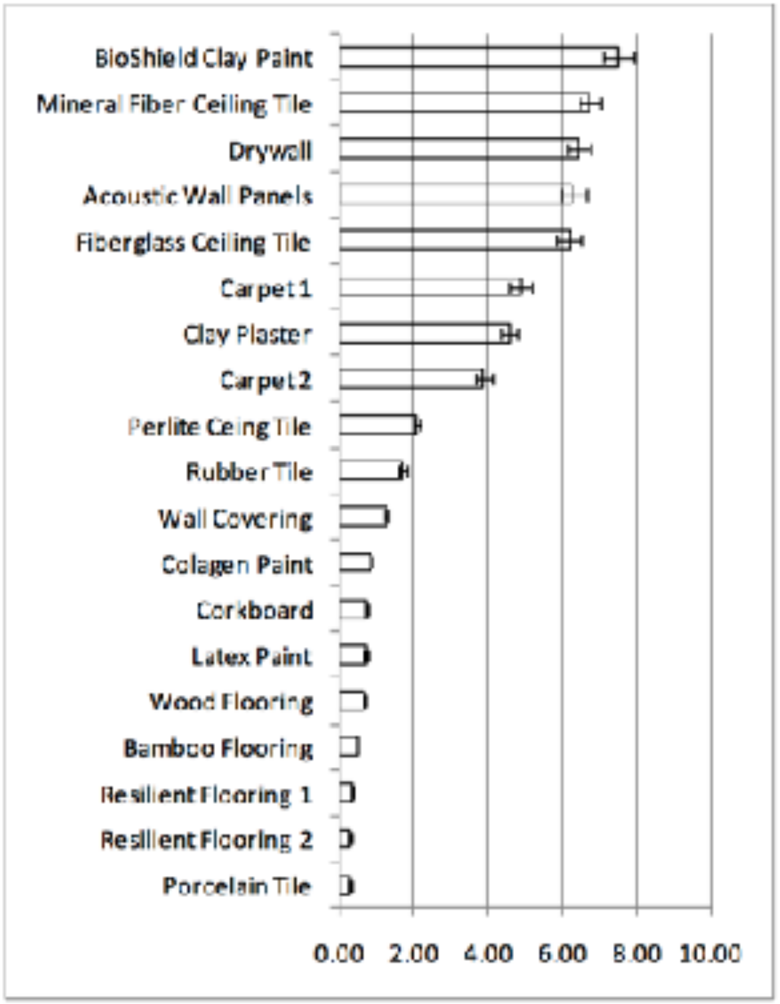
HB 2009, 336\ **Time-Scale Analysis for Reactive Deposition of Ozone via Passive Reactive Materials,** Elliott Gall, Clement Cros, Richard Corsi, and Jeffrey Siegel

IA 2011, a103_2\ **Removal of Indoor Ozone by Green Building Materials**
Clement Cros, Glenn C. Morrison, Jeffrey A. Siegel and Richard L. Corsi

IA 2011, a103_2\ **Passive Air Cleaning With Green Building Materials: Ozone deposition velocities,** Seth Lamble, Glenn Morrison and Richard Corsi

Passive Reactive Materials (PRM), which are materials that react with ozone without creating by-products, have been previously studied during short-term experiments at the University of Texas at Austin (UT). Virgin gypsum wallboard and activated carbon mats proved to be efficient PRMs. 12% of wall surfaces covered with **activated carbon mat** will reduce indoor ozone concentration by 50% (Kunkel et al., 2008).

This analysis showed that PRM reaction time scales competed with existing indoor surfaces, and were one to two orders of magnitude faster than indoor homogenous chemistry. Building designers and air quality engineers could significantly improve indoor air quality and reduce ozone exposure by controlling concentrations of ozone in indoor environments. Passive reactive materials present a novel means for accomplishing this goal with little or no additional energy expenditure.



Deposition velocities for materials (m h^{-1})

PRM - VOC reduction

ECO INSTITUT

HB 2009, 652\ **Sorptive interactions between selected VOCs and building materials**
Neil Crain, Richard Corsi, Anna Iwasinska, Chi Chi Lin, and Beverly Coleman

Migration of the VOCs through gypsum wallboard and plywood was monitored.

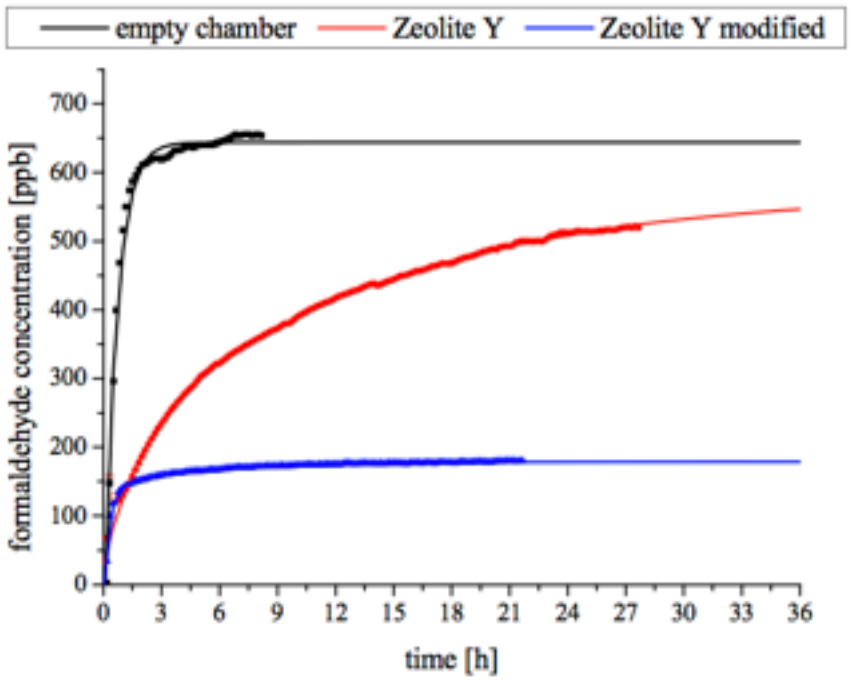
HB 2009, 652\ **Gypsum wallboard as a sink for formaldehyde**
Xiaoyu Liu, Mark Mason, Zhishi Guo, Ken Krebs, Nancy Roache

The large ka/kd ratios (>10) imply that gypsum board can be a significant sink for formaldehyde.

IA 2011, a437_1\ **Application of Zeolites for the Removal of Indoor Air Pollutants**
Jan Gunschera, Tunga Salthammer, Doreen Markewitz, Volker Thole, Katrin Bokel- mann, Annett Halbhuber and Gerhard Sextl

After incorporation into fibreboards, formalde-hyde emission from such boards was up to 40% lower compared to reference samples.

Until now, experiments with zeolites, zeolite containing fibreboards and plasters have been performed only at laboratory and semi-technical scales. Therefore it is uncertain to what extent the reduction of formaldehyde and VOC con-centrations are achievable in real indoor envi-ronments.



Reduction of the formaldehyde concentration in a chamber with zeolites.

Microbiome - prebiotic buildings

IA 2016, 982\ **The Microbiome of the Built Environment and Mental Health**
Maj Andrew J. Hoisington, Lisa A. Brenner, Teodor T. Postolache, Christopher A. Lowry, Kerry A. Kinney

Extensive research is underway to identify potential links between the human microbiome and mental health conditions. At least fifteen bacterial species have been shown to act in beneficial ways on mental health conditions and reduce fear/anxiety in mouse, rat, and human models.

IA 2011, 968\ **Prebiotic Buildings: A note of caution**, Jeffrey Siegel

Although indoor microbiome research is still in its infancy, there are already attempts to move from investigation to manipulation of the indoor microbiome. This general approach often involves adding microorganisms to buildings and/or changing building characteristics to encourage the development of particular indoor microbial communities.

The indoor microbiome has been the focus of increasing attention over the past decade. There have also been preliminary attempts to alter the indoor microbiome. The broad concept is often termed "**prebiotic**" and is defined here to mean a change in an environment that promotes the growth of beneficial organisms. Prebiotic approaches, also called **bioinformed design** encompass several facets including the increasing of indoor microbial diversity, the addition of specific microorganisms to buildings, and the creation of conditions that lead to favorable indoor microbial communities.

The idea of prebiotic buildings is compelling but we are at the very beginning of any understanding of the practicalities of actually achieving microbially healthy indoor environments.

We should consider ourselves to be less at the cusp of an architectural revolution, and more at the beginning of a process of engagement in the building design, construction, and operation process.

Conclusion

eco INSTITUT

HB 2009, 39\ **Performance indicators for healthy and comfortable buildings: a way forward**
Philomena M. Bluyssen and Nadia Boschi

HB 2009, 34\ **The European project HealthyAir: first results and recommendations**
Philomena M. Bluyssen, Sabine de Richemont, Derrick Crump, Francois Maupetit, Thomas Witterseh, Petr Gajdos

The indoor air comprises a complex mixture of compounds for which the source and effects are poorly understood. Establishing threshold levels in air and checking compliance for all seems unrealistic considering the numerous compounds of concern. A clear knowledge gap exists about health and comfort impacts of contaminants and differences in the response of individuals. Further gaps relate to the mechanisms of interactions between pollutants in the air and also at the surfaces of indoor materials.

Many ways, tools and concepts have been developed to determine performance indicators and criteria for healthy and comfortable buildings. Perhaps the most important observation in these tools and concepts is the fact that because dose-response relations are not fully defined most indicators do not seem to be useful.

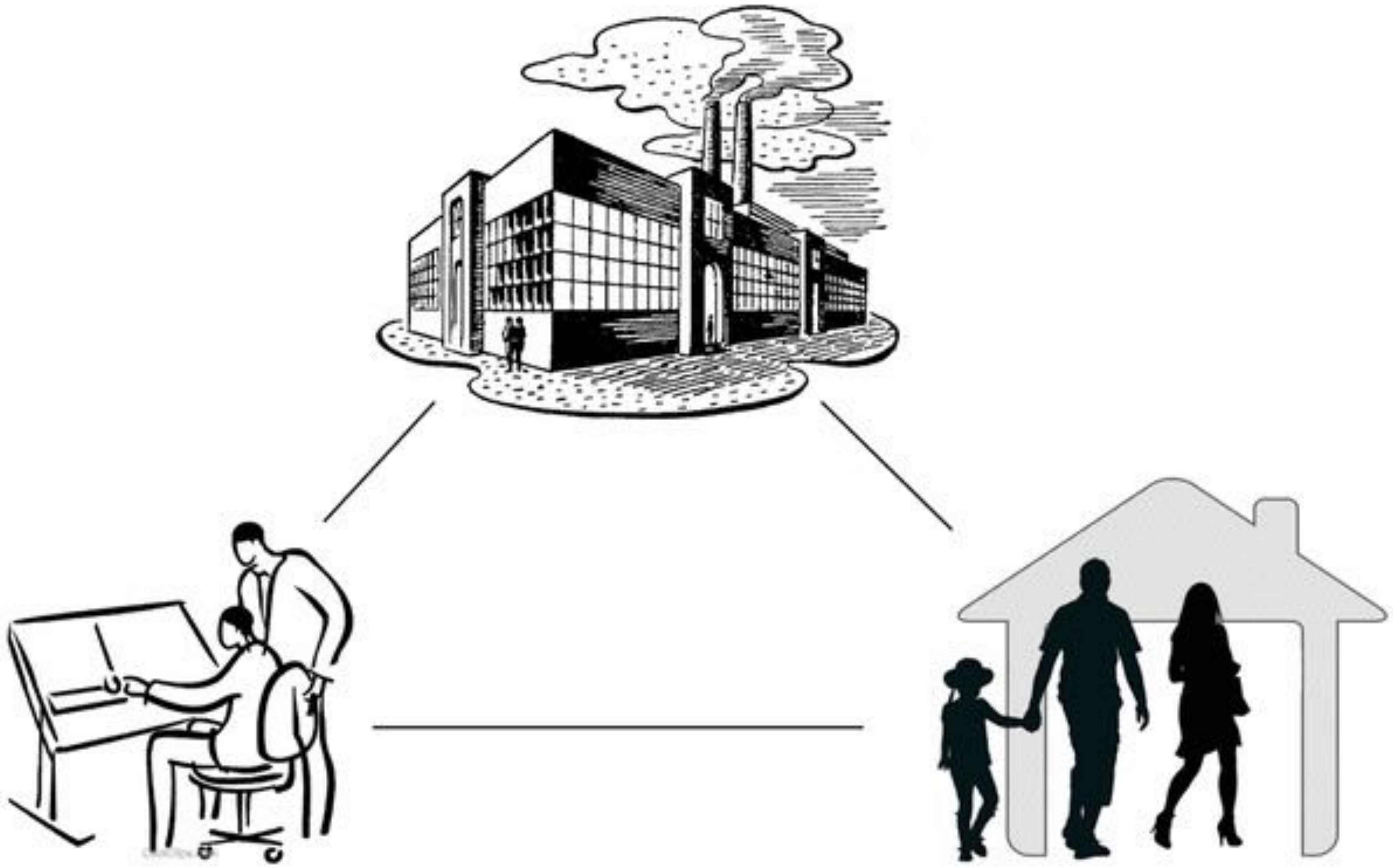
A second observation is the fact that interactions occurring at different levels (at human level, parameters of the indoor environment and at building level) are not taken into account.

Moreover, the timeframe taken, is often static (a certain point in time) and not dynamic. Comparing static performance indicators with a dynamic process (being exposed in a building) will therefore most likely result in a non valid outcome.

There is a need for a different or at least an adapted approach towards evaluation of health and comfort of occupants in the indoor environment.

Vernetzung

oder – was ich mir wünschen würde



Zeitschriften mit Fokus auf Innenraumklima
(unvollständige Liste)

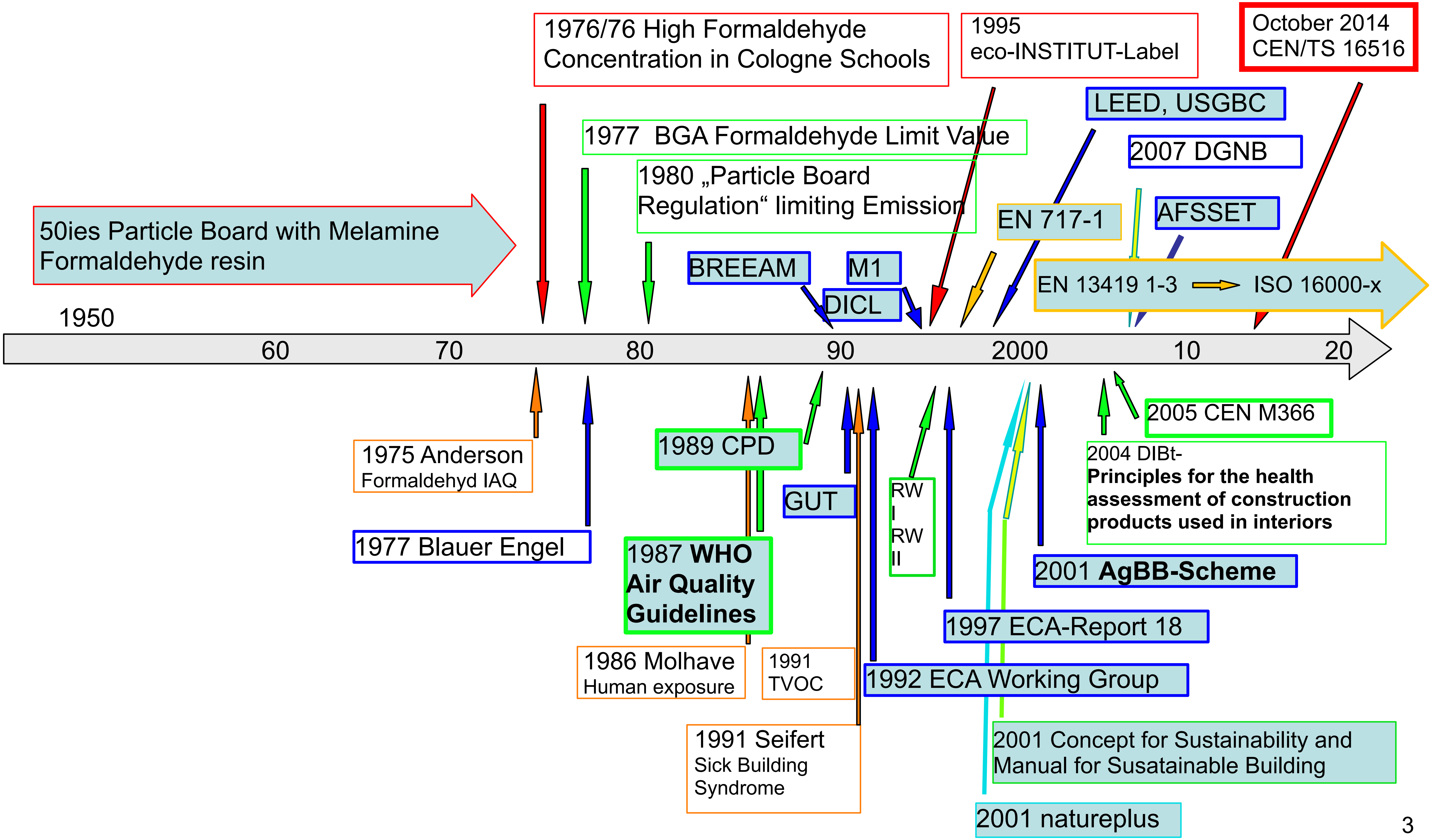
Aerosol Science and Technology
American Journal of Industrial Medicine
Analytical Chemistry
Atmospheric Chemistry and Physics
Atmospheric Environment
Biochemical and Biophysical Research Communications
Building and Environment
Chemie in unserer Zeit
Circulation
Clinical Chemistry
Cosmetics & Toiletries
Environment International
Environmental Health Perspectives
Environmental Science & Technology
European Respiratory Journal
Experimental Brain Research - Atmospheres
Flavour and Fragrances Journal
Forensic Science Communications
Free Radical Biology and Medicine
Gefahrstoffe, Reinhaltung der Luft
Indoor Air
Indoor and Built Environment
International Journal of Chemical Kinetics
International Journal of Hygiene and Environmental Health (Formerly: Zentralblatt fur Hygiene und Umweltmedizin)
Journal of Air PollutionControl Association
Journal of American Industrial Hygiene Society Association
Journal of Chemical Ecology
Journal of chromatographic science
Journal of Chromatography A and B
Journal of Cosmetic Science
Journal of Environmental Engineering
Journal of Environmental Science and Health, Part A, and B
Journal of Exposure and Analysis and Epidemiology
Journal of Geophysical Research
Journal of the Air and Waste Management Association
Proceedings of the National Academy of Sciences
Respiratory Medicine
Science of the Total Environment
The Journal of Investigative Dermatology
Toxicological Sciences
Toxicology Letters

Vielen Dank

für

Ihren Forschergeist …

History


1976/76 High Formaldehyde Concentration in Cologne Schools
1995 eco-INSTITUT-Label
October 2014 CEN/TS 16516
LEED, USGBC
1977 BGA Formaldehyde Limit Value
2007 DGNB
1980 „Particle Board Regulation“ limiting Emission
EN 717-1
AFSSET
50ies Particle Board with Melamine Formaldehyde resin
BREEAM
M1
DICL
EN 13419 1-3
ISO 16000-x
1950
60
70
80
90
2000
10
20
1975 Anderson Formaldehyd IAQ
1977 Blauer Engel
1989 CPD
GUT
1987 WHO Air Quality Guidelines
1986 Molhave Human exposure
1991 TVOC
1991 Seifert Sick Building Syndrome
RW I RW II
2005 CEN M366
2004 DIBt- Principles for the health assessment of construction products used in interiors
2001 AgBB-Scheme
1997 ECA-Report 18
1992 ECA Working Group
2001 Concept for Sustainability and Manual for Susatainable Building
2001 natureplus