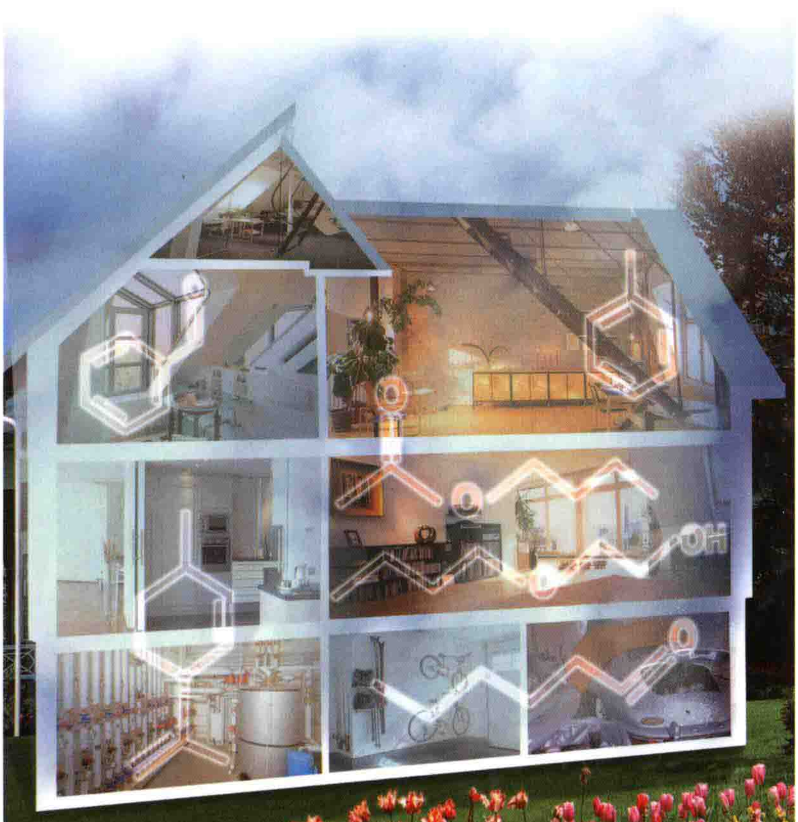
Edited by Tunga Salthammer
and Erik Uhde

WILEY-VCH

Organic Indoor Air Pollutants

Occurrence, Measurement, Evaluation



Second,
Completely
Revised Edition

Organic Indoor Air Pollutants

Occurrence, Measurement, Evaluation

Edited by
Tunga Salthammer and Erik Uhde

Second, Completely Revised Edition

WILEY-VCH

WILEY-VCH Verlag GmbH & Co. KGaA

The Editors

Prof. Dr. Tunga Salthammer
Fraunhofer
Wilhelm-Klauditz-Institut (WKI)
Material Analysis and Indoor Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Dr. Erik Uhde
Fraunhofer
Wilhelm-Klauditz-Institut (WKI)
Material Analysis and Indoor Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
Die Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Composition SNP Best-set Typesetter Ltd., Hong Kong
Printing betz-druck GmbH, Darmstadt
Bookbinding Litges & Dopf GmbH, Heppenheim
Cover Design Adam Design, Weinheim

Printed in the Federal Republic of Germany
Printed on acid-free paper

ISBN: 978-3-527-31267-2

Organic Indoor Air Pollutants

Edited by
Tunga Salthammer
and Erik Uhde

Related Titles

Parlar, H., Greim, H. (eds.)

The MAK-Collection for Occupational Health and Safety

Part III: Air Monitoring Methods, Volume 11

Series: The MAK-Collection for Occupational Health and Safety. Part III: Air Monitoring Methods (DFG) (Volume 11)

2009

ISBN: 978-3-527-31959-6

Parlar, H., Greim, H. (eds.)

The MAK-Collection for Occupational Health and Safety

Part III: Air Monitoring Methods, Volume 10

Series: The MAK-Collection for Occupational Health and Safety. Part III: Air Monitoring Methods (DFG) (Volume 10)

2007

ISBN: 978-3-527-31601-4

Bester, K.

Personal Care Compounds in the Environment

2007

ISBN: 978-3-527-31567-3

Foreword

During my lectures on 'indoor air quality' with architectural students, I often ask them how much, in their opinion, air weighs. The most common answer I get is that $1\,m^3$ of air must weigh just 1 g or less. They believe that air is very light. However, the weight of $1\,m^3$ of air is 1.2 kg. Our daily breathing rate is $15{\sim}20\,m^3$ of air – approximately $0.3\,m^3$ per 1 kg of body weight. Thus, we inhale and exhale approximately 20 kg of substances every day. The mass of inhaled air is much more than that of drinking water and food.

Materials made from organic compounds contribute to improvement of the quality of life; on the other hand, organic chemical pollutants emitted from materials and appliances can adversely affect human health. People in developed countries spend more than 90% of their time indoors. In the light of this fact, the cleanliness of occupied spaces such as buildings, houses, and transportation systems becomes very important. In contemporary society it can be assumed that the quality of building products, houses and equipment is relatively poor. Moreover, people often suffer from pollutants caused by activities like cooking, cleaning and heating.

The conservation of energy is strongly recommended from the viewpoint of saving the global environment. An air-conditioning system is often installed to obtain thermal comfort indoors; as a result, there is a marked increase in energy consumption for cooling, heating, and ventilation. With regard to buildings and their environments, the increase in life-cycle CO_2 emissions has often been discussed in recent years. Approximately 40% of CO_2 is emitted from the building sector, including housing. Therefore, reducing the emission of CO_2 from the building sector is imperative to prevent global warming.

Air-tightness and insulation are effective measures for energy conservation. Reduction in ventilation in air-conditioned spaces is often considered to be one of the most effective methods to conserve energy. However, as a result of lower air exchange rates, the indoor air concentrations of pollutants, such as volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) emitted from building materials and other sources, increase. This often leads to building-related symptoms if the dwell time in a polluted indoor environment is high.

During the 1980s in Europe and North America and the 1990s in Japan, indoor air pollution by formaldehyde was identified and suitable countermeasures were

Organic Indoor Air Pollutants. 2nd Edition. Edited by Tunga Salthammer and Erik Uhde

ISBN: 978-3-527-31267-2

taken. Formaldehyde is a single chemical compound, and since we are already aware of the sources of emission, it is comparatively easy to control it. However, since VOCs and SVOCs consist of many substances, it is difficult to control their emissions effectively. VOCs and SVOCs are also emitted from natural materials. Moreover, a proper health risk assessment of VOC mixtures has not yet been established.

Indoor air quality is an important determinant of health and well-being. To maintain better indoor air quality, we have to understand the mechanism of indoor air pollution. For this purpose, the measurement of indoor air concentration and use of chemical analysis methods are essential. To estimate indoor air concentration, we have to know the emission and ventilation rates. Emission takes place not only from building products but also from automobile parts, electric appliances, office equipment such as printers, household consumer products, and even printed materials like newspapers. This book serves as a useful guide for chemists, architects, mechanical engineers, constructors, and manufacturers of electronic products. It emphasizes a holistic and multidisciplinary approach toward the indoor environment.

This book reminds us that a healthy indoor environment is essential, and provides scientific evidence and countermeasures for the future.

Department of Architecture,
Waseda University, Tokyo, Japan

Shin-ichi Tanabe, Prof., Ph.D.

Preface to the Second Edition

The first edition of this book went to print in 1999, the year that the 8th Conference on Indoor Air Quality and Climate was held in Edinburgh, Scotland. The papers read at this last major indoor air conference of the final years of the 20th century dealt once again with the central concerns of indoor air research in the 1990s, most of which are also found in the various chapters of the first edition. As regards determination of volatile organic compounds (VOCs), the definition of the sum parameter TVOC by an European Union work group and the standardization of emissions test chambers and cells by a CEN committee may be regarded as milestones. With the introduction of the TVOC value, GC/MS thermal desorption also finally established itself as a standard method of analysis. Furthermore, during this period important fundamentals were laid down for the derivation of indoor air guide values and for product labeling.

Over the last ten years, indoor air research has experienced a significant transformation and this has made substantial revisions necessary for the 2nd edition of this book. A number of chapters dealing with the topics of solid sorbents, passive sampling, automobile interiors and household products could, after updating, also be included. However, many sampling techniques and analytical methods today form part of the tools routinely used in indoor air research and are for this reason no longer treated in such detail in this new edition. On the other hand, real-time methods, sensory testing and SVOC analysis have gained in importance and have now been given their own chapters. At the present moment probably the highest level of research activity is to be found in the field of indoor chemistry. Although chemical reactions in indoor air were recognized more than 15 years ago as the source of air-polluting substances, systematic investigations have not been possible until relatively recently when the necessary measuring technology became available. A new chapter provides an overview of the state of development in this field. Two contributions are concerned with the effects on health of VOCs and SVOCs as regards exposure and the identification of guide values. Other chapters are devoted to further topics of current interest in the field of indoor air research such as ventilation concepts, museums and archives and also emissions from electronic devices.

Organic Indoor Air Pollutants. 2nd Edition. Edited by Tunga Salthammer and Erik Uhde

ISBN: 978-3-527-31267-2

Despite all of these changes the book still has the same demand: to provide the reader with a clear introduction to an important area of indoor air research. We should like to express our thanks to all colleagues and friends who as authors submitted state-of-the-art contributions despite their daily workloads and other commitments. We also thank Mrs Lesley Belfit of the WILEY-VCH Verlag for her support and patience and Frau Susanne Beerstecher for organizational work.

Braunschweig, May 2009

Tunga Salthammer
Erik Uhde

List of Contributors

Godwin A. Ayoko
Queensland University of Technology
School of Physical and Chemical Sciences
International Laboratory for Air Quality and Health
GPO Box 2434
Brisbane 4001, QLD
Australia

Klaus Breuer
Fraunhofer Institute for Building Physics (IBP)
Fraunhoferstr. 10
83626 Valley
Germany

Stephen K. Brown
CSIRO Sustainable Ecosystems
PO Box 56
Highett
Victoria 3190
Australia

Werner Butte
Universität Oldenburg
Fakultät V, Institut für reine und angewandte Chemie
Carl-von-Ossietzky-Str. 9-11
26129 Oldenburg
Germany

Per Axel Clausen
National Research Centre for the Working Environment
Lersø Parkallé 105
2100 København Ø
Denmark

Derrick Crump
Cranfield University
Institute of Environment and Health
Cranfield Health
Cranfield
Beds, MK43 0AL
UK

Birger Heinzow
Landesamt für soziale Dienste
Dezernat Umweltbezogener Gesundheitsschutz
Brunswikerstr. 4
24105 Kiel
Germany

University of Notre Dame
School of Medicine
Sydney Campus
Australia

Vivi Kofoed-Sørensen
National Research Centre for the Working Environment
Lersø Parkallé 105
2100 København Ø
Denmark

Organic Indoor Air Pollutants. 2nd Edition. Edited by Tunga Salthammer and Erik Uhde

ISBN: 978-3-527-31267-2

Florian Mayer
Fraunhofer Institute for Building Physics (IBP)
Fraunhoferstr. 10
83626 Valley
Germany

Jinhan Mo
Tsinghua University
College of Architecture
Department of Building Science & Technology
Beijing 100084
China

Lars Mølhave
Aarhus University
Department of Environmental and Occupational Medicine
Bartholins Allé 2
BLd 1260
8000 Aaarhus
Denmark

Glenn C. Morrison
Missouri University of Science & Technology
Civil, Architectural and Environmental Engineering
221 Butler-Carlton Hall
1401 N. Pine St.
Rolla, MO 65409
USA

Helmut Sagunski
Behörde für Soziales, Familie, Gesundheit und Verbraucherschutz
Billstraße 80
20539 Hamburg
Germany

Tunga Salthammer
Fraunhofer Wilhelm-Klauditz-Institute (WKI)
Material Analysis and Indoor Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Alexandra Schieweck
Fraunhofer Wilhelm-Klauditz-Institute (WKI)
Material Analysis and Indoor Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Tobias Schripp
Fraunhofer Wilhelm-Klauditz-Institute (WKI)
Material Analysis and Indoor Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Klaus Sedlbauer
Fraunhofer Institute for Building Physics (IBP)
Fraunhofer Straße 10
83626 Valley
Germany

Chandra Sekhar
National University of Singapore
School of Design and Environment
Department of Building
4 Architecture Drive
Singapore 117566
Singapore

Kwok Wai Tham
National University of Singapore
School of Design and
Environment
Department of Building
4 Architecture Drive
Singapore 117566
Singapore

Erik Uhde
Fraunhofer Wilhelm-Klauditz-
Institute (WKI)
Material Analysis and Indoor
Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Simon F. Watts
Victoria University Wellington
Department of Geographical,
Earth and Environmental
Sciences
2 Kelburn Parade
Kelburn
Wellington 6012
New Zealand

Michael Wensing
Fraunhofer Wilhelm-Klauditz-Institute
(WKI)
Material Analysis and Indoor
Chemistry
Bienroder Weg 54 E
38108 Braunschweig
Germany

Elizabeth Woolfenden
Markes International Ltd.
Gwaun Elai Campus
Llantrisant
RCT
CF72 8XL
UK

Yinping Zhang
Tsinghua University
College of Architecture
Department of Building Science &
Technology
Beijing 100084
China

Mohamed Sultan Zuraimi
National University of Singapore
School of Design and Environment
Department of Building
4 Architecture Drive
Singapore 117566
Singapore

List of Symbols and Abbreviations

A	sample surface
ACH	air exchange
ADI	acceptable daily intake
AM	arithmetic mean
APM	airborne particulate matter
APS	aerodynamic particle sizer
AQG	air quality guidelines
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BaP	benzo[a]pyrene
BHT	2,6-di-tert-butyl-4-methyl-phenol
BREC	building related environmental complaints
BRI	building related illness
BRS	building related symptoms
BTV	breakthrough volume
C or C(t)	concentration
C_0	initial concentration
C_S	vapor pressure [mg/m^3]
CAPs	concentrated air particles
CEN	European Committee for Standardization
CFU	colony forming unit
CIB	National Council for Building Research, Studies and Documentation
CMD	count median diameter
CPC	condensation particle counter
d	distance
δ	boundary layer thickness
D	molecular diffusity (diffusion coefficient)
D_p	particle diameter
DBP	di-*n*-butylphthalate
DEHP	di-(2-ethylhexyl)phthalate
DIBP	di-isobutylphthalate

Organic Indoor Air Pollutants. 2nd Edition. Edited by Tunga Salthammer and Erik Uhde

ISBN: 978-3-527-31267-2

DINP	di-isononylphthalate
DMA	differential mobility analyzer
DMPS	differential mobility particle sizer
DNPH	dinitrophenylhydrazine
DOP	di-octylphthalate
EC	electrostatic classifier
ECA	European Collaborative Action
ECD	electron capture detector
EDS	energy dispersive spectrometer
EDXRF	energy dispersed X-ray fluorescence
ELISA	enzyme linked immunosorbent assay
ELPI	electrical low pressure impactor
EM	electron microscopy
EPA	Environmental Protection Agency
EPXMA	electron probe X-ray microanalysis
ETS	environmental tobacco smoke
FAAS	flame atomic absorption spectrometry
FID	flame ionization detector
FLEC	field and laboratory emission cell
FT-IR	Fourier transform infrared spectroscopy
GC	gas chromatography
GFAAS	graphite furnace atomic absorption spectrometry
GM	geometric mean
GSD	geometric standard deviation
h	height
HDM	house dust mite
HPLC	high performance liquid chromatography
HVAC	heating ventilating air conditioning system
IAP	indoor air pollution
IAQ	indoor air quality
IC	ion chromatography
ICP-AES	inductively coupled plasma – atomic emission spectrometry
ICP-MS	inductively coupled plasma – mass spectrometry
INAA	instrumental neutron activation analysis
ISIAQ	International Society of Indoor Air Quality and Climate
ISO	International Organization for Standardization
I/O	indoor/outdoor
k_1	source strength
i_2	air exchange (modeling)
k_i ($i > 2$)	rate constant
L	loading factor [m^2/m^3]
LOAEL	lowest observed adverse effect level
LOEL	lowest observed effect level
LOI	loss on ignition
LR	leak rate (test chamber) [h^{-1}]

m	mass
M	mass in source
M_0	initial mass in source
MCS	multiple chemical sensitivity
MD	median
MS	mass spectrometry
MVOC	microbiological originated volatile organic compounds
N (or n)	air exchange rate [h^{-1}]
N_p	particle concentration
NDIR	non-dispersive infrared
NOAEL	no observed adverse effect level
NOEL	no observed effect level
OEL	occupational exposure limit
OPC	optical particle counter
OSHA	Occupational Safety and Health Administration
OT	odor threshold [mg/m^3]
P	percentile
PAD	photo-acoustic detector
PAH	polycyclic aromatic hydrocarbon
PAN	peroxyacetyl nitrate
PAS	photoelectric aerosol sensor (or photoacoustic spectroscopy)
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
PCR	polymerase chain reaction
PID	photo-ionization detector
PIXE	particle induced X-ray emission
PM	particulate matter
$PM_{2.5}$	suspended particulate matter (<2.5 μm)
PM_{10}	suspended particulate matter (<10 μm)
POM	particulate organic matter
PPN	peroxypropionyl nitrate
PUF	polyurethane foam
q	area specific flow rate (N/L)
Q	air flow rate [ml/min, l/h]
QSAR	quantitative structure-activity relationship
r	correlation coefficient
RH	relative humidity
RI	retention index
RPM	respirable particulate mass
RSD	relative standard deviation
RSP	respirable suspended particulate
RT	retention time
SBS	sick building syndrome

SD	standard deviation or solvent desorption
SEM	scanning electron microscopy
SER_A or $SER_A(t)$	area specific emission rate
SER_u or $SER_u(t)$	unit specific emission rate
SER_V or $SER_V(t)$	volume specific emission rate
SER_l or $SER_l(t)$	length specific emission rate
SIM	single ion modus
SMPS	scanning mobility particle sizer
SOA	secondary organic aerosol
ΣVOC	sum of volatile organic compounds
SVOC	semi-volatile organic compound
t	time
T	temperature
TD	thermal desorption
TE	thermal extraction
TEM	transmission electron microscopy
TEOM	tapered element oscillating microbalance
TIC	total ion chromatogram
TLV	threshold limit value
TNFα	tumour necrosis factor α
TSP	total suspended particles
TVOC	total volatile organic compounds (use only as defined by ECA report no 19 !)
μm	micrometer
μg	microgram
v	air velocity
V	volume
VDI	Verein Deutscher Ingenieure
VOC	volatile organic compound
VVOC	very volatile organic compound
WAGM	weighted average geometric mean
WDXRF	wavelength dispersed X-ray fluorescence
WHO	World Health Organisation
XRF	X-ray fluorescence

Contents

Organic Indoor Air Pollutants. 2nd Edition. Edited by Tunga Salthammer and Erik Uhde

ISBN: 978-3-527-31267-2