

HealthyAir



State-of-the-art DRAFT

November 2007

DRAFT

STATE OF THE ART REPORT

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Preface

HealthyAir is a project sponsored by the European Commission DG Sanco, programme of community action in the field of public health (2003-2008). The project focuses on defining, initiating and developing activities that improve indoor air quality and reduce exposure to indoor air pollution sources, in particular of construction products. In the underlying draft state of the art a first attempt is made to inventory the current available information with respect to emissions of construction products and effects of those emissions on people.

This draft version of the state of the art will be used as a basis for discussion at the first workshop of HealthyAir held in Rotterdam, the Netherlands, on November 21st, 2007.

Delft, November 2007

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1 Introduction

Objective: To provide a state of the art on the effects of construction products on indoor air quality, the effect of indoor air pollution (quality) on occupants and the sources of pollution responsible for that, including methods for emission testing, but also including methods of assessment from the occupant's health point of view. Collaboration with the BUMA¹ project will be undertaken as part of achieving this objective.

For most of the 20th century, appropriate ventilation was considered to be the only means to create an acceptable indoor air quality. Recommendations for a good indoor air quality were therefore always directly related to the ventilation rate. Ventilation to prevent spread of disease (such as cholera, yellow fever,..) and to provide adequate comfort (no noxious odours) was the key objective. The discussions on how much ventilation is sufficient remain current and are informed by on-going research.

Now in the 21st century it is acknowledged that by controlling the indoor sources of emission through lowering these emissions or even eliminating them, the indoor air quality can be improved. In this state of the art an overview is given of the indoor sources and their emissions encountered, the ways of measuring or evaluating their contribution to the indoor air pollution and possibilities of reducing the effect of this pollution on people. For each of the different stakeholders of the indoor environment, it is studied how and what type of action could lead to a reduced exposure to indoor air pollutants originating from those indoor sources with a special emphasis on construction products.

Of the remedial actions, vs. dilution by ventilation, reduction by air cleaning, and prevention of emissions by product amelioration, the latter should always be given preference. Source control reflects the general philosophy of environmental protection: preventing rather than curing. It also offers the potential for greater energy efficiency of the built environment by minimising the amount of ventilation required for health and well being and thereby reducing the associated energy used particularly for space heating.

This state of the art is mainly concerned with the emission from construction products to the indoor environment, e.g building materials and furnishing (excluding ventilation system components).

2 Sources of pollution

2.1 Introduction

The pollution sources, from which substances are emitted or transported to the indoor air, can be divided into the following categories:

- Outdoor sources: traffic, industry
- Occupant related activities and products: cooking, tobacco smoke, equipment (laser printers and other office equipment), consumer products (cleaning, hygienic, personal care products), open flames (candles, gas stoves, wood heaters)
- Building materials and furnishings: insulation, plywood, paint, furniture (particle board), floor/wall covering, etc.
- Ventilation systems.

In the European Audit project (European Audit Project to Optimise Indoor Quality and Energy Consumption in fifty-six office buildings), nine European countries were audited during the heating season of 1993-1994 (Bluyssen et al., 1996). In this audit, besides the normal measurements such as questionnaire, physical/chemical analysis of air etc., panels of persons, trained to evaluate the perceived air quality, were used to measure the air quality in pre-selected spaces of those office buildings as well as the outdoor and supply air.

¹ BUMA: Prioritization of building materials as indoor pollution sources

Table 2.1 Possible sources of most prevalent VOCs found in the audited buildings as found in a literature survey (Lagoudi et al., 1995).

Sources							Sources								
No	Compound	O ¹	T ²	Materials				No	Compound	O	T	Materials			
				E ³	B ⁴	F ⁵	C ⁶					E	B	F	C
1	(CF ₂) _n					x		31	benzene	x	x		x	x	
2	1,1,1-trichloroethane					x	x	32	C ₃ -alkylbenzenes	x	x		x	x	x
3	C ₂ Cl ₃ F ₃						x	33	m-xylene	x	x		x	x	x
4	tetrachloroethylene						x	34	o-xylene	x	x		x	x	x
5	dichloromethane				x		x	35	p-xylene	x	x		x	x	x
6	dichlorobenzene						x	36	toluene	x	x		x	x	x
7	butane	x						37	naphthalene						x
8	n-hexane	x	x		x	x		38	phthalate comp.					x	
9	aliphatic C ₇ H ₁₆	x					x	39	1-butanol				x	x	x
10	n-heptane	x					x	40	1-ethoxy-2-propanol				x		
11	octane	x	x					41	2-butoxy-ethanol				x		x
12	aliph. C ₉ H ₂₀				x	x	x	42	2-phenoxy-ethanol				x		x
13	nonane				x	x	x	43	C ₅ -alcohol				x		x
14	decane C ₁₀ H ₂₂				x	x	x	44	ethanol					x	x
14	undecane				x	x	x	45	ethoxy-ethoxy-ethanol				x		x
16	dodecane						x	46	4-methyl-2-pentanone		x			x	
17	tetradecane						x	47	acetone					x	
18	pentadecane						x	48	cyclohexanone						x
19	2-methylbutane	x						49	benzaldehyde			x		x	x
20	2-methylpentane	x						50	nonanal			x	x		x
21	3-methylpentane	x						51	decanal			x		x	x
22	2,4-dimethylhexane	x				x		52	acetic acid butyl ester					x	
23	2-methylhexane	x				x		53	acetic acid ethyl ester					x	
24	nonane/o-xylene					x		54	butoxy-ethoxy-ethylacetate					x	
25	nonane/styrene					x		55	acetic acid				x	x	
26	dimethylcyclopentane					x	x	56	benzoic acid						x
27	methylcyclopentane					x	x	57	dodecanoic acid					x	x
28	methylcyclohexane	x				x	x	58	a-pinene					x	x
29	cyclohexane					x	x	59	l-limolene						x
30	2-methyl-1,3-butadiene					x		60	terpene comp.						x

¹Outdoor air (O) ²Tobacco smoke (T) ³Office Equipment (E) ⁴Building materials (B) ⁵Furnishings (F) ⁶Consumer products (C)

From this investigation it was concluded that the main pollution sources were the materials, furnishing and activities in the offices and the ventilation system in the buildings. In Table 2.1 the possible sources for the most important chemical compounds identified in the European Audit project, is presented (Lagoudi et al., 1995). The most important source of was materials, especially furnishings. The dominant volatile organic compounds, VOCs, detected in the majority of the buildings were solvents used in floor or wall coverings and pressed wood products (carpets, PVC flooring, floor adhesives, wallpaper, particle board, etc.).

2.2 Construction products and their emissions

This report is primarily concerned with the emission from construction products. There are a number of general reviews of the type and amounts of chemicals released into air from these products. Wolkoff (1995) summarised available literature on sources of VOCs and their impact on indoor air quality, IAQ. Examples of building material sources (Table 2.2) and those related to human activity are provided and typical VOCs emitted are listed. Approaches to the testing of source emissions are discussed and classed as follows;

- extraction analysis (provides information on total content of VOCs that are present in the material),
- static emission testing (headspace analysis),

- dynamic chamber emission testing,
- dynamic large chambers,
- test house studies,
- field studies with a portable emission cell.

Table 2.2 Examples of building material related sources of VOCs (Wolkoff 1995).

Source	Typical VOCs emitted / measured
Adhesive	C ₉ -C ₁₁ alkanes, toluene, styrene
Building elevator	C ₁₃ -C ₁₈ alkanes
Carpets	C ₃ -C ₆ -alkyl aromatics, styrenes, 4-phenylcyclohexene, vinylcyclohexene, 2-ethylhexanol, siloxanes, amines
Cork	1,2-propandiol
Linoleum	C ₅ -C ₁₁ aldehydes, aliphatic acids, benzaldehyde
Parquet (wood)	C ₅ -C ₆ aldehydes, terpenes
Rubber	Acetophenone, alkyl-aromatics, styrenes
Vinyl (PVC)	Alkanes, aromatics, 2-ethyl-1-hexanol, glycol esters, TXIB
Gypsum board	Diacid esters
Particleboard	Alkanes, aldehydes, butanol, formaldehyde, ketones
Sealant/caulk	Ketones, esters, glycols, polychlorinated biphenyls, siloxanes
Lacquer	Alkanes, aldehydes
Paint	Alkanes, glycols, glycol esters, Texanol
Varnish	Alkanes, aromatics
Thermal insulation	Aldehydes, ketones, aromatics
Textile/drapery	Acetone, ethyl acetate, methylfuran, thiophene, dimethyl sulphide
Vapour barrier	Naphthalenes
Ventilation system	Broad VOC spectrum
Wallpaper	Hexanal, terpenes

Brown (1999) considers VOCs from occupants, from microbial sources, automobile exhausts and new construction or renovation. New buildings, arbitrarily classified exhibit higher concentrations than established buildings and the period for which the emissions remain elevated is an important factor determining exposure of occupants. Case studies have shown decay of emissions takes place over periods of several months to years. The indoor air quality survey of England found correlation between some house characteristics and VOC concentrations that indicate that some building and furnishing products are important sources; TVOCs and time since painting, age of house and formaldehyde and TVOC concentrations (higher in newer homes), presence of chipboard floors and formaldehyde concentrations (Raw et al. 2004).

Yu and Crump (1998) reviewed the emission of VOCs from polymeric materials used in buildings. Two main groups of materials were identified i) solid and cured materials and ii) liquid / wet materials. The emission of VOCs can be a diffusion or evaporation process or a combination of the two processes. The diffusion of VOCs through a material is governed by Fick's law; it is a function of the diffusion coefficient of the compound in the material and therefore the physical and chemical properties of the material and the temperature. Initial rapid emission from wet products is evaporation controlled whereas longer term and lower rates are controlled by the rate of diffusion of VOCs to the surface. The emission process can be limited by a barrier layer of high concentration of VOCs in the air over the material surface, the effect of which will depend on the air speed and surface structure of the material. Rates of emission of the total VOC for a range of solid and liquid products were summarised. These show wide ranging values depending upon the type of product and its age. Also provided are extensive lists of compounds reported in the literature as being emitted from particular product types.

Saarela (1999) provides an overview of emissions from flooring materials using data collated in a database of emission tests in Finland. Rates of emission of individual VOCs are presented after 3 and 28 days of testing using chambers or emission cells. Results for timber boards, parquet, (varnish, oil

and wax finishes), linoleum, PVC coated cork tile, PVC cushion vinyls and calendared PVC flooring are presented. The time dependence of the emissions is discussed as well as the effects of moisture, temperature, oxidation process and sorption on the emission and consequent indoor concentration. Lundgren et al. (1999) summarise a further database of emissions determined using an emission cell for 50 PVC flooring products. Rates of TVOC emission were measured after 4 and 26 weeks exposure and ranged from $4,000 \mu\text{g m}^{-2} \text{h}^{-1}$ to less than $10 \mu\text{g m}^{-2} \text{h}^{-1}$. Emission rates declined on average by 60% from 4 to 26 weeks though some compounds such as cyclohexanone, TXIB and undecane declined only slowly.

Salthammer (1999) shows that wood and wood-based furniture are sources of a variety of organic compounds depending upon the substrate, the type of coating and the quality of the manufacturing process. Lacquers and varnishes contain solvents and additives and 17 types of coating system are identified including solvent and water based types and those with conventional, acid and uv curing. Volatile ingredients are listed for a range of different coating types and examples provided of rates of emission given by chamber testing of products. Also specifically discussed are emissions of aldehydes formed by oxidation of unsaturated fatty acids, terpenes from untreated pine and lacquers containing turpentine balsam, compounds such as benzaldehyde formed by fragmentation of photoinitiators, as well as monomers and diisocyanates. Jann and Wilke (1999) describe tests of the emission of biocides including dichlofluanid, tebuconazole and permethrin from timber treated with preservative.

Salthammer (2004) reviewed methods of testing emissions and some studies reporting emission data. He refers to a summary by Tucker (2001) of the major factors that influence the emission of vapour phase organics from materials;

- the total amount and volatility of constituents in the material,
- distribution of these constituents between the surface and the interior of the material,
- time (i.e. age of material),
- surface area of the material per volume of the space it is in ('loading'),
- environmental factors such as temperature, air exchange rate and relative humidity,
- chemical reactions in the source (e.g. conversion in some varnishes and some adhesives).

An extensive list of about 170 VOCs is presented as examples of compounds detected in indoor air and from building products in test chambers. These are classed into a number of chemical groups; aromatic compounds, aliphatic hydrocarbons, cyclic hydrocarbons, terpenes, alcohols, glycols/glycol ethers, aldehydes, ketones, halogenic compounds, acids, esters, phthalates, phosphor-organic compounds and miscellaneous e.g. isocyanates.

Godish (1989) reviewed methods to control emission of VOCs and formaldehyde from materials and presented data on emissions of formaldehyde from products where surface treatments, barriers and overlay materials had been investigated to determine their effect on reducing emissions. Examples are provided of a variety of physical barriers and coatings to particleboard products. Some products such as plastic laminate and vinyl flooring are shown to be effective barriers but others such as a carpet are not effective. The possible time dependence of the barrier action is noted. Also discussed is air contamination by spray application of pesticides in homes. Brown (1999) reported experimental studies using small and room sized chambers to determine VOC and formaldehyde emissions from particleboard, medium density fibreboard (MDF) and office furniture. VOC emissions were low for the MDF product, higher for particleboard and highest for laminated office furniture and decreased quicker than the emission of formaldehyde. Large inter-sheet variations were found in the amount of VOC emissions from particleboard. Jang et al. (2006) report small chamber tests of the emission of VOCs and formaldehyde from 200 building materials in Korea including wallpaper, flooring, paint, and adhesives. The mean rate of emission for TVOC and formaldehyde ranged $0.4\text{-}3.2 \text{ mg m}^{-2} \text{ h}^{-1}$ and $0.01\text{-}0.18 \text{ mg m}^{-2} \text{ h}^{-1}$ respectively.

Wirtanen (2005) reviewed existing studies and undertook further investigations of the effects of substrate and humidity on the emission of VOCs from surfaces. The effect of substrate was strong and the drying process of both the substrate and the surface layer was influential. High humidity prolongs

the drying process of wet products resulting in differences in the timing of emissions of different compounds.

Bluyssen et al. (2000) describe a database of sources of indoor air pollutants including building materials and furnishings. The emission data is from test chamber studies and toxicological data is included as well as a tool for predicting indoor concentrations in a room. BAM² (2007) summarise emission tests of 50 different liquid, paste and solid building products and the evaluation of the emission data according to the requirements of the AgBB³ scheme in Germany. 36 of the products met the requirements for VOC emissions in the scheme. The VOC emissions that did not meet the requirements are summarised as mixtures of n- and iso- alkanes, benzene, dipropylene alcohol, mixture of different esters, acetic acid, ethane diol, methyl isothiazolinone, propane diol and siloxane. These were from types of synthetic resin premixed plaster, sealing products, chipboard, and floor varnish. There is discussion of the composition of the main types of products investigated and examples given of the chemical emission and results of an assessment of odour. It was found that products from different manufacturers showed different emission results even if they were the same type of product. Therefore it is recommended that each product of distinct composition should be considered and tested as an individual case.

It should be noted that while most emission data has been obtained by exposure of materials in test chambers and rooms under controlled conditions, the actual emission in a building will be influenced by the substrate and its surroundings as well as the material combinations found in real structures. Also secondary emissions can occur such as reactions with ozone and hydrolysis reactions in floor structures producing ethyl hexanol. Jarnstorm et al. (2007) summarise some of these studies and report experimental work involving use of emission cells to measure emission rates in-situ in buildings. Highest VOC emissions in the new buildings were from the ceiling structure and from some PVC floorings. Hodgson et al. (2000) calculated whole house emission rates by measuring indoor concentrations of VOCs and the ventilation rate in four new manufactured houses and seven new site built houses. Predominant compounds were α -pinene, formaldehyde, hexanal, and acetic acid. Major identified sources included plywood flooring, latex paint and sheet vinyl flooring. Compounds such as formaldehyde and hexanal that were of interest because of their irritant properties did not decline in concentration over the 7.5 month study period.

Crump et al. (1997) measured concentrations of VOCs and formaldehyde in test houses and measured emissions of VOCs from a range of materials used in their construction. Yu and Crump (1999) undertook a similar study during the construction and occupation of a newly constructed office building. These studies showed the important impact of construction and furnishing products on the VOCs in the indoor air.

2.3 Emission mechanisms

A product can emit substances (particles and/or gases) to the indoor air that originate from the product itself, that are caused by coming into contact with other products or arise during the in use phase of the product itself. Examples are:

Emissions that originate from the product itself (primary emission):

- Organic compounds; very volatile VOCs (VVOCs), VOCs, and semi-volatile VOCs (SVOCs) e.g. phthalates in PVC products, pentachlorophenol (PCP) in impregnated floor coverings, formaldehyde in wood based boards (a long term continuous emission from a dry material), VOC in non-water carrying paints (a short term high emission from a wet material), and polycyclic aromatic hydrocarbons (PAHs) in coatings and bituminous materials.
- Airborne particles and fibres from products containing e.g. asbestos or man made fibres.

² BAM: German Federal Institute for Materials Research and Testing

³ AgBB: Health-related Evaluation for Volatile Organic Compound Emissions from Building Products

Emissions caused as a result of the product environment: emissions resulting from the interaction of products (or primary emission compounds) with environmental factors such as ozone or water (Figure 2.1).

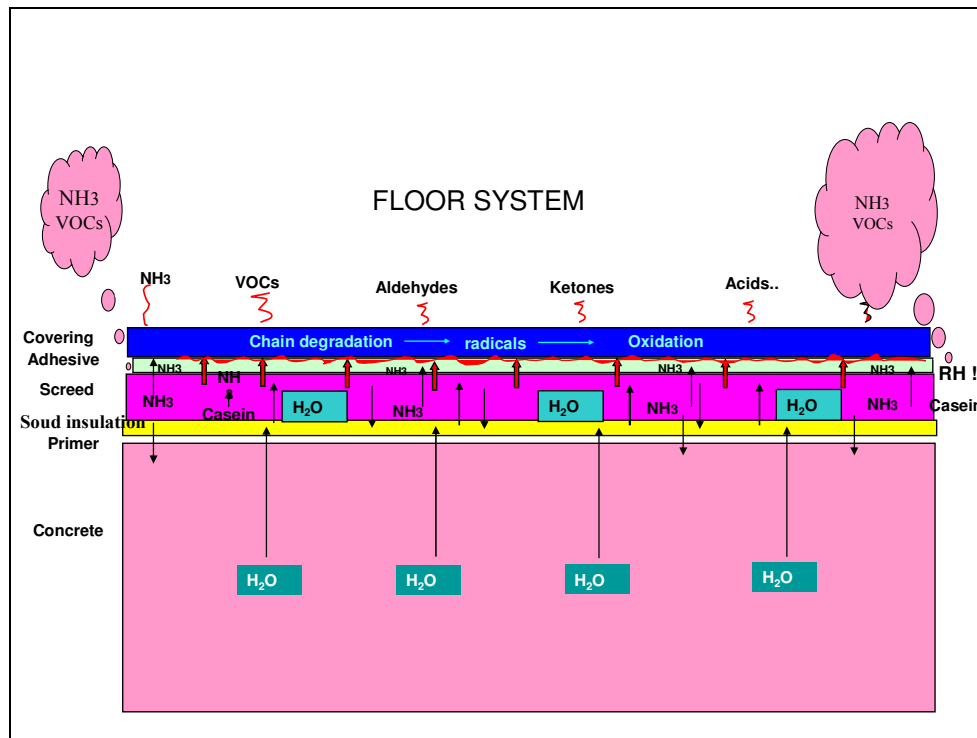


Figure 2.1 Possibilities for secondary emissions form a complex picture (from Kristina Saarela). This example illustrates possible chemical reactions in a flooring system, an actual case that has been identified in the Nordic countries.

Emissions that arise during the in use phase of the product itself (secondary emission) External substances may be adsorbed to the surface of the product and desorbed at a later time, e.g. certain cleaning compounds. Microbial growth in or on the surface of the product can result in emission of spores, mycotoxins, synergizers and VOCs. The material constituents and moisture retention characteristics of a product determine the risk for microbial growth, and therefore sensitivity to microbiological growth is a material characteristic just as adsorption and desorption ability is.

Emissions from HVAC-systems: For HVAC system components that are not in the occupied space and any emissions are moved by air passing through to the occupied space, the following major emission sources have been indicated (Bluyssen, 2004):

- Air filters: Both, new and used filters pollute the air. New filters because of the material itself emits VOCs.
- Air ducts: Oil residuals are the dominating source of pollution in new ducts. Depending on the machinery used in the manufacturing process, new spiral wound ducts, flexible ducts and other components of the ductwork might contain small amounts of processing oil residuals. The oil layer is very thin and invisible. Growth of microorganisms, dust/debris accumulated in the ducts during the construction at the work site (mostly inorganic substances) and organic dust accumulated during the operation period in the ducts can be sources of pollution as well. Condensation in ducts passing through cold zones favours mould growth.
- Air humidifiers: Micro-organisms are the main source of air pollution if the air humidifier is not used in the manufacturer-recommended way and/or if they are not properly maintained. Desalination and demineralization devices/agents can also contribute to pollution of the passing air.
- Rotating heat exchangers (RHEs): In general, rotating heat changers are not pollutant sources in themselves, except when the wheels are dirty. RHEs may transport contaminants from the supply

to the exhaust in three ways: through air caught by the wheel, by leakage between wheel and gasket, and by adsorption-desorption on the surface area of the wheel.

- Cooling and heating coils: Heating and cooling coils without condensed or stagnating water in the pans are components that make a small contribution to the overall perceived air pollution. On the other hand, cooling coils with condensed water in the pans are microbiological reservoirs and amplification sites that may be a major source of pollution in the inlet air.

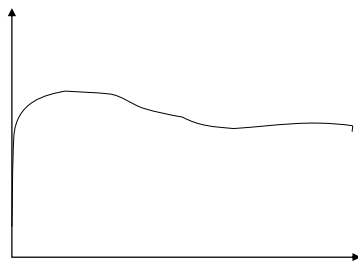
A sink is defined as a source that shows adsorption and after a while emits those adsorbed pollutants again. The emission of pollutants from materials or products, specifically volatile organic compounds, is determined by three fundamental mechanisms (Bluyssen, 1994):

- Diffusion in the product
- Desorption of adsorbed or absorbed pollutants
- Evaporation of the pollutants from the surface area of the product to the air above the product.

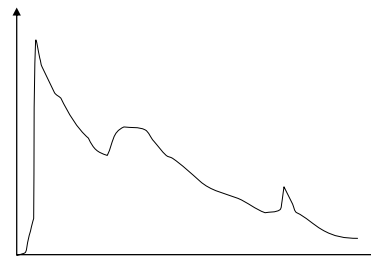
Additionally, two other processes can take place which might result in emissions of products:

- Chemical reactions, followed by emission (diffusion and evaporation)
- Microbiological growth, followed by emission of products from microorganism

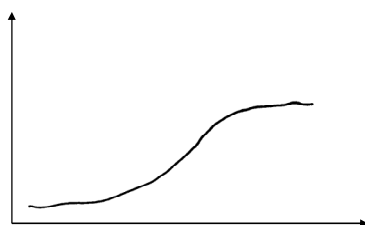
Depending on the substance emitted, a different pattern of emission over time can occur. In general you can encounter the following emission patterns (also occurring together):



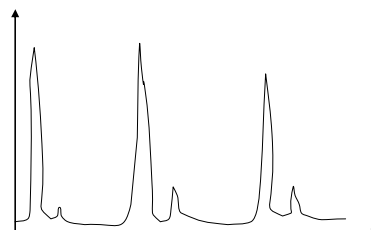
Curve 1: in general for VOCs



Curve 2: in general for VVOCs



Curve 3: in general for SVOCs



Curve 4: intermittent release

SVOC (the more involatile compounds) might have the opposite curve as VVOC and start their emission much later in time (for example some sealants). Or some VOCs show an intermittent release due to the conditions in the indoor space (temperature and humidity variations) influencing the emission.

3 Exposure and health effects

3.1 Introduction

The exposure to indoor air pollutants, emitted (primarily or secondary) by construction and HVAC products, is influenced by the indoor environmental parameters such as ventilation rate, air velocity, temperature, relative humidity, the activities taking place in that indoor environment resulting in introduction or removal of the same or other pollutants, and the time (age of product) and duration of the exposure.

Small variations in the indoor environmental parameters, activities or just the introduction of another source, make the prediction of emissions of products complicated. Emissions or production of a pollutant (substance) are expressed in $\mu\text{g/h}$ or $\mu\text{g/h}$ per m^2 surface area of source and concentrations in the air can be expressed in ppm or ppb (parts per million or billion) or $\mu\text{g}/\text{m}^3$. Figure 3.2 shows the relationship between the emission of pollutants and the processes of removal by ventilation and sorption to surfaces. The concentration (C_i) in air in the room and therefore the exposure of occupants depends on these processes and the concentration of pollutant in the air entering from outside (C_o). This is therefore a dynamic situation as the rates of emission and the other parameters vary over time. It should be noted that the actual indoor air quality does not depend on a single product, but is a function of input from many sources and ventilation.

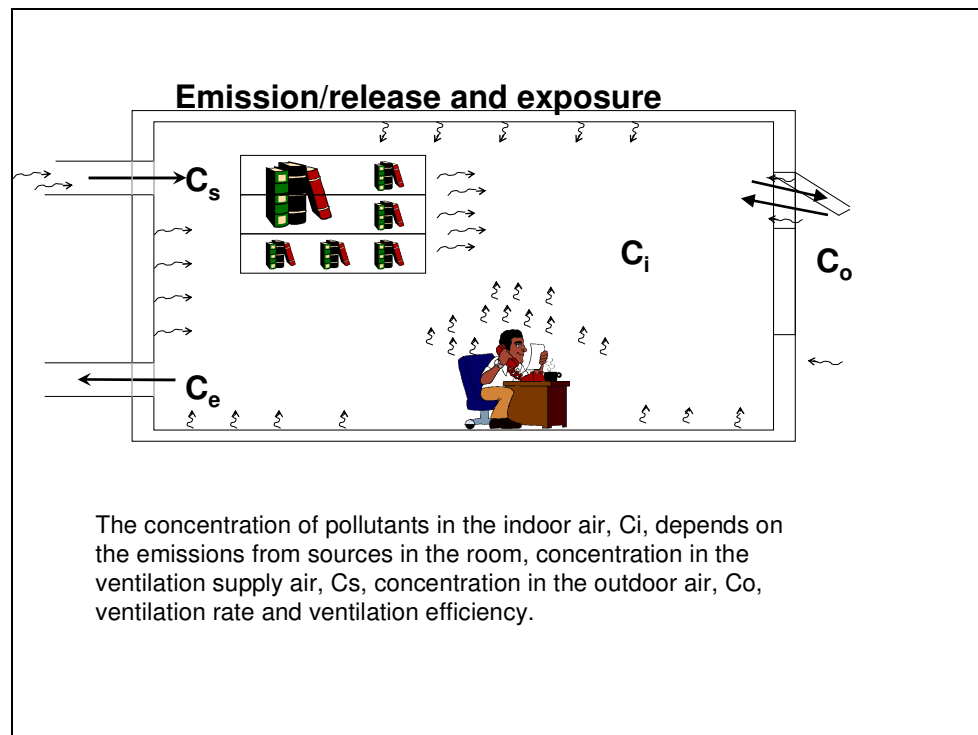


Figure 3.2 Factors determining the indoor concentration of an air pollutant

The concentration of indoor air pollutants may vary widely as a function of both time and space. The sampling strategy used to determine the concentration level has a marked influence on the result.

Short term peak concentrations of inorganic components and suspended particulate matter may exceed the average concentration by a factor 5 to 10 or even more. This is of importance in case where a potential health effect is associated with a short term exposure at elevated concentration rather than with a long term exposure at average concentration.

3.2 Emissions and health effects

The health effects of the substances found in the indoor air are in most cases not clearly identifiable. Some substances may have adverse effects on their own while others, seemingly harmless, become harmful when they interact with each other. Also, different humans will react differently to the same exposure.

There are few examples where a direct correlation between a specific substance and health effects have been shown, one being formaldehyde which is associated with allergies, hypersensitivity and cancer. However, in general it is recognized that certain groups of substances can or might cause health effects such as BRI (Building Related Illness), SBS (Sick Building Syndrome) and multiple chemical sensitivity, MCS, (Spengler, 2001).

It is assumed after decades of research that certain combinations of VOCs, VVOCs, SVOCs can cause SBS symptoms, although a clear statistical relationship between concentrations and effect(s) has never been found. For sensory irritation of the mucous membranes in eyes, which is probably one of the most important symptoms in the SBS, no strong and reproducible association between exposures and responses have been found in the field studies. However, in laboratory environments it has been shown that several VOCs in combination will cause chemosensory irritation of eyes and nasal passages, even when each individual compound is substantially below its threshold.

The respiratory tract can suffer from many diseases and disorders, most of them caused by an infection (bacterial, viral or fungal), inflammation (allergic reaction), damage or tumours. In most cases they are caused by an external pollutant that is breathed into the lungs, causing an immediate or long term effect.

Symptoms can be cough, shortness of breath, dyspnoea or chest pain. Coughing with sputum is the most important manifestation of disease in major airways, for example bronchitis. An irritative cough without sputum may be caused by extension of malignant disease to the bronchi from nearby organs. The presence of blood in the sputum is an important sign and can result from an infection but can also indicate the presence of inflammation, capillary damage or tumour. Shortness in breath may vary in severity, as a result of something harmless such as walking on the stairs, but can also indicate something more serious when it is continuously present, such as emphysema. It can also occur acutely when a foreign body is inhaled into the trachea or with the onset of a severe attack of asthma. Dyspnea is also an early symptom of congestion of the lung as a result of impaired function of the left ventricle of the heart. Chest pain may be an early symptom, but is mostly related to pneumonia, due to an inflammation of the pleura. Severe chest pain may be caused by the spread of a malignant disease or a tumour, such as mesothelioma, arising from the pleura itself. Other symptoms are

- wheezing caused by airway obstruction (as in asthma),
- swelling of the fingertips and sometimes toes (a feature of bronchiectasis (chronic inflammation and dilation of the major airways), diffuse fibrosis of the lung, and lung cancer),
- swelling of the lymph nodes that drain the affected area, particularly the small nodes above the collarbone in the neck, should always lead to suspicion of intrathoracic disease.
- General feeling of malaise, unusual fatigue or minor symptoms as first indication of disease

Whether the cause is an infection or an allergic reaction is not always so clear, because the symptoms might be similar. *Asthma* and *Bronchitis* are examples of this.

With asthma a contraction of the smooth muscle of the airways occurs and in severe attacks, obstruction from mucus that has been accumulated in the bronchial tree occurs. Two forms of asthma can be distinguished: the extrinsic asthma, caused by an identifiable antigen and intrinsic asthma, occurring without a identifiable antigen or specific antibody. Extrinsic asthma is caused by being in contact with the any of the proteins to which sensitization has occurred, such as pollens, mould spores, animal proteins of different kinds and proteins from a variety of insects (e.g. cockroaches and mites). Intrinsic asthma may develop at any age, while extrinsic asthma commonly manifests during childhood. Intrinsic asthma may be triggered by infections, which are assumed to be viral in many

cases. In people with asthma, symptoms may occur at much lower concentrations of histamine or acetylcholine (both normally occurring smooth muscle constrictors). Airways in affected persons may also develop obstruction when inhaling cold air or during exercise.

Acute bronchitis is mostly caused by a viral infection, but may also be by an acute exposure to irritant gases, such as ammonia, chlorine, or sulphur dioxide. The bronchial tree is reddened and congested and minor blood streaking of the sputum may occur. Bronchiolitis refers to inflammation of the small airways. It normally clears spontaneously.

Then the disease can be induced by several pollutants or agents, for example *Hypersensitivity pneumonitis*. This is a disease in which the lung is sensitized by contact of a variety of agents and in which the response consists of an acute pneumonitis, with inflammation of the smaller bronchioles, alveolar wall edema and a greater or lesser degree of airflow obstruction due to smooth muscle contraction. For example the Farmer's Lung, caused by spores from mouldy hay (thermophilic *Actinomyces*), and the Bird Fancier's lung, allergic responses to proteins from birds (particularly in the excreta of pigeons and parakeets). Humidifier fever, an influenza like illness caused by exposure to moulds growing in the humidifier system, is another example (the agent is not known).

There are a number of pollutants of which the health effect has been given a specific name, such as:

- *Legionnaires' disease* named after the outbreak of pneumonia among US veterans attending a convention in Philadelphia in 1976, is caused by *Legionella pneumophila*. This bacterium may grow in air-conditioning systems or in hot water systems.
- *Silicosis*: inhalation of silica dust leads to development of masses of fibrous tissue and nodules of dense fibrosis, which, by contracting, distort and damage the lung.
- *Black lung*: coal dust causes a distinctive pattern of change in the lung known as coal worker's pneumoconiosis. The dust causes a fibrotic reaction in the terminal bronchioles.
- *Byssinosis or Brown lung*: caused by dust produced in the processing of raw cotton, causing chronic obstructive lung disease.
- *Hay fever*: allergy to grasses and pollen causing conjunctival infection and edema of the nasal mucosa leading to attacks of sneezing.
- *Asbestosis*: The microscopical fibers of asbestos may cause significant health damage when inhaled. Fibrous materials are not metabolised after entering the body, but there is leaching of chemical constituents which varies with fiber type and size. Some fibers become coated with an iron-protein matrix and form an "asbestos body" when asbestos is the core material. Some structural and compositional changes occur after fibers are taken up in tissue, particularly in the lungs. The mechanism by which asbestos and other fibrous materials produce fibrosis appears to be different from that of silica, which acts by causing secondary lysosomal release of enzymes of macrophages that lead to a fibrotic tissue reaction. Fibrotic process of either the lung parenchyma or the visceral pleura develops only after considerable time (> 20 years), when earlier exposure has been intense. The latency period for asbestosis, mesothelioma or lung cancer, is 20 to 30 years (WHO, 2006).

And then there are specific pollutants that depending on the exposure time and exposure concentration can cause different diseases and disorders when inhaled, such as:

- *Radon* and its progeny attach to an aerosol and reach the lungs by inhalation and can eventually lead to lung cancer in the upper bronchial epithelium. The knowledge about health effects of radon and radon daughters is merely based on the experience of underground uranium-miners in the US and former Czechoslovakia and of non-uranium miners in Sweden, Canada and UK, there is no doubt that radon and its progeny in sufficient doses can produce lung cancer in man. Smokers seem to be at a higher risk of lung cancer than non-smokers (NRC, 1981).
- *Formaldehyde* causes upper airway irritation, comprising of dry throat irritation, tingling sensation of the nose and sore throat, lower airway and pulmonary effects (cough, chest tightness) and pulmonary edema, inflammation, pneumonia; and may be fatal with very high and long exposures.
- *Inorganic gases* (SO_x , NO_x) can cause severe airway symptoms.

- *Micro-organisms*, such as bacteria, viruses and fungi, can produce health effects like infection, disease and allergic reactions, the most famous example being the legionnaire's disease.
- *Particulate matter*, PM, can cause a wide range of health effects. While PM from different sources have different effects on the human body, DNA damage refers to all, i.e. these particles may cause cancer.
- *Lead*: Inhaled or ingested, lead can have toxicological effects in particular on the nervous system, for example causing damage to the developing brain of young children (WHO, 2006).

In the INDEX project an Exposure Limit (EL) was derived for each chemicals selected after the identification of key-studies (critical-study) describing the appropriate toxicological endpoints (among those selected by health organizations for the derivation of health based reference concentrations) (Kotzias et al., 2005). Basically for each chemical or pollutant, a no-observed-adverse-effect-level (NOAEL) was derived. For the threshold levels of the pollutants given by the WHO (200X), the NOAEL is used for pollutants without carcinogenic effects or for pollutants for which data on carcinogenicity are lacking or insufficient. Where no NOAEL observation was documented, a lowest-observed-adverse-effect level (LOAEL) was taken into consideration and an additional assessment factor of 10 used for effect level derivation. For one compound only (benzene) the characterization has been based on population cancer risk estimation rather than on an effect level.

Guidelines based on carcinogenic effects are indicated in terms of incremental unit risks in respect of those carcinogens that are considered to be genotoxic. To allow risk managers to judge the acceptability of risks, guidelines provide concentrations of carcinogenic air pollutants associated with an excess lifetime cancer risk of 1 per 10,000, 1 per 100,000 and 1 per 1,000,000. For example for tobacco smoke, the unit risk of cancer associated with lifetime ETS exposure in a home where one person smokes is approximately 1×10^{-3} , at levels of 1–10 $\mu\text{g}/\text{m}^3$ nicotine (WHO, 2000).

Some effects and exposure limit values are presented in Table 3.1.

Table 3.1 Health effects and exposure limits for air pollutants

Pollutant	Possible sensitivity/effect	Recommended exposure limit
Organic gases		
Formaldehyde (CH ₂ O)*	Short-term: irritation of the eyes, nose and throat, together with concentration-dependent discomfort, lachrymation, sneezing, coughing, nausea, dyspnoea and finally death Long-term: upper and lower airway irritation and eye irritation in humans; degenerative, inflammatory and hyperplastic changes of the nasal mucosa nasopharyngeal cancer	The non-carcinogenic no-effect level is 30 $\mu\text{g}/\text{m}^3$. Pending on IARC revision of formaldehyde carcinogenicity, a guideline should be as low as reasonably achievable
Benzene (C ₆ H ₆)*	aplastic anemia and acute myelogenous leukemia	Benzene is a carcinogen, its indoor air concentration should be kept as low as reasonably achievable, and not exceed outdoor concentrations.
Naphthalene (C ₁₀ H ₈)*	sensitivity of certain subpopulations to naphthalene toxicity, including infants and neonates hemolytic anemia caused by deficiency in glucose-6-phosphate dehydrogenase (G6PD),	long term guideline value is 10 $\mu\text{g}/\text{m}^3$.
Acetaldehyde (C ₂ H ₄ O)*	Short-term: irritation of the eyes and respiratory tract and altered respiratory function Long-term: eye and upper respiratory tract irritation with the possibility of	200 $\mu\text{g}/\text{m}^3$

	chronic tissue damage and inflammation in the respiratory tract considered a probable human carcinogen: upper respiratory tract cancer (smoking)	
Toluene (C ₇ H ₈)*	Short-term: Dysfunction of the central nervous system and narcosis; irritation of the skin, eye, and respiratory tract; Inhalational abuse of toluene with high Long-term: progressive and irreversible changes in brain structure and function	300 µg/m ³ Acute 15,000 µg/m ³
Xylenes (C ₈ H ₁₀) meta (m-), para (p-) and ortho (o-)*	short-term inhalation: irritation of the eyes, nose, and throat, gastrointestinal effects, eye irritation, and neurological effects. Chronic (long-term) inhalation: central nervous system (CNS) effects, such as headache, dizziness, fatigue, tremors, and incoordination; respiratory, cardiovascular, and kidney effects have also been reported.	200 µg/m ³ Short-term 20 µg/m ³
Styrene (C ₈ H ₈)*	Short-term: irritate the eyes and mucous membranes and may be toxic to the central nervous system Long-term: central nervous system (CNS) and peripheral nervous system effects, Possible carcinogenic	long-term 250 µg/m ³
Limonene (C ₁₀ H ₁₆)*	low acute toxicity	450 µg/m ³
α-pinene (C ₁₀ H ₁₆)*	irritative effects to the eyes, nose and throat	450 µg/m ³
TVOC	Irritation, intoxication, cancer, allergy	TVOC < 0.2 mg/m ³ Allergic people: with much lower concentrations effects possible
Inorganic gases		
O ₃ **	decrements in lung function, airway inflammatory changes, exacerbations of respiratory symptoms and symptomatic and functional exacerbations of asthma in exercising susceptible people.	120 µg/m ³ (8 hour)
Ammonia (NH ₃)*	Short-term: site-of-contact lesions primarily of the eyes and the respiratory tract; eye, nose, and throat irritation, coughing, and narrowing of the bronchi. Long-term: respiratory distress	Short 70 µg/m ³ Long term 100 µg/m ³ ,
Radon	Radon is a known human carcinogen (classified by IARC as Group 1 with genotoxic action.)	A lifetime lung cancer risk below about 1 × 10 ⁻⁴ cannot be expected to be achievable because natural concentration of radon in ambient outdoor air is about 10 Bq/m ³ . No guideline value for radon concentration is available.
Particulate matter		
PM 10** PM2.5**	Short term: Eye irritation, conjunctivitis, reduced lung function	These effects have been observed at annual average concentration levels below 20 µg/m ³ (as PM2.5) or 30

	Long-term exposure to particulate matter is associated with reduced survival, and a reduction of life expectancy in the order of 1–2 years. Prevalence of bronchitis symptoms in children, and of reduced lung function in children and adults.	$\mu\text{g}/\text{m}^3$ (as PM10). No guidelines can be given.
Man-made vitreous fibres (MMVF)**	MMVF of diameters greater than 3 μm can cause transient irritation and inflammation of the skin, eyes and upper airways; IARC classified rock wool, slag wool, glass wool and ceramic fibres in Group 2B (possibly carcinogenic to humans) while glass filaments were not considered classifiable as to their carcinogenicity to humans (group 3)	The corresponding concentrations of refractory ceramic fibres producing excess lifetime risks of 1/10 000, 1/100 000 and 1/1 000 000 are 100, 10 and 1 fibre/l, respectively. For most other MMVF, available data are considered inadequate to establish air quality guidelines.
Biaerosols		
Moulds (10 – 30 μm), mycotoxines	Intoxication, allergy	-

* INDEX report (Kotzias et al., 2005);** WHO guidelines (WHO,2000) *** ECA, 1991

3.3 Indoor air chemistry

Indoor and surface chemistry

This section refers to reactions between pollutants in the air and on a surface affect the indoor air quality people are exposed to (Weschler, 2004). Emissions of products/materials can be significantly changed by surface chemistry, and the products of such reactions might dominate materials long-term emissions. Indoor air chemistry influences indoor air quality. The mix of pollutants in indoor environments can be transformed due to chemical reactions, and is the reason for short lived, highly reactive compounds indoors.

According to Weschler, reactions between ozone (in ventilation air) and terpenes (such as limonene, α -pinene, styrene) present in indoor environments frequently dominate indoor chemistry. Hydroxyl radicals ($\text{OH}\cdot$) are formed in these reactions, which in their turn react with other products and form oxidized products. The indoor conditions such as relative humidity and VOC concentration, influence these reactions in an unpredictable way. Ozone reactions, hydroxyl radical reactions, but also other radical reactions (for example nitrate radical $\text{NO}_3\cdot$) occur in the indoor environment. Secondary products formed comprise of formaldehyde, aldehydes and NO_2 . The concentrations of free radicals are not well known and are needed to advance indoor chemistry modelling.

Surface reactions may have a greater influence on the chemical composition of indoor air compared with outdoor air, because for a give volume of air, there a far more surfaces indoors. It seems that reactions on the surfaces can increase the concentration of products in the room air. However, the ventilation rate influences the surface and the gas phase processes: with very high ventilation rates surface processes are favoured over gas phase processes (reactions in the air).

From the above, it is reasonable to speculate that the products of ozone initiated indoor chemistry may contribute to comfort and health complaints, although the magnitude of these effects still needs to be elucidated (Weschler, 2004).

Bornehag et al. (2004, 2005) studied the relation between IAQ and asthma/allergy in a Scandinavian investigation comprising 11000 children and detailed chemical, physical, biological and medical measurements have been performed in 200 homes with asthmatic children and 200 homes with healthy children. These homes were situated in areas with good outdoor air quality. The results showed a relation between the concentration of phthalates and the risk of asthma. Decreasing the concentration of phthalates by a factor of seven, decreased the risk of asthma to one third.

While Mendell (2007) found in a review of 21 studies associations between risk factors such as particleboard (formaldehyde), plastic materials (phthalates) and recent painting, and health or allergy in infants or children, Nielsen et al (2007) did hardly find evidence that indoor chemical exposures possess allergy-promoting effects. In the later literature study, formaldehyde was excluded because of the volume of literature. Dust was found to be associated with allergy-promoting effects in humans and animals. Several exposures such as dampness and combustion products may promote development of asthma or asthmatic symptoms. A recent and attractive hypothesis is that dampness promotes survival of vira that may be the causative agents of the dampness-related symptoms (Hersoug, 2005).

On the other hand, a series of independent studies document that the quality of indoor air has a significant and positive influence on the productivity of office workers (Seppänen and Fisk, 2005). And it has been expected that poor indoor air quality in the classroom can have a negative impact on children's learning. Wargocki et al. (2005) studied parallel classes of 10-year old children and measured a performance increase of 15% when increasing the ventilation rate from 5 to 10 l/s.

Microbiological growth interference

Microbiological growth can be a problem in the indoor environment. Substances given off may be irritating or allergenic, and health effects include respiratory problems as well as general malaise and headaches. Micro organisms may even cause constructional problems (e.g. *Serpula lacrymans*).

It is known that moulds grow on practically any organic material provided there is enough water. Some yeasts, or yeast-like fungi, arise primarily from tap water, humidifiers and outdoor air. With rare exceptions, these require liquid water for growth.

Fungi can produce spores, mycotoxins (toxic to humans), synergizers (increase potency of most obvious toxins) and volatile organic compounds (the dominant VOC of moulds is ethanol, which itself is a potent synergizer of many toxins). Mycotoxins are chemicals manufactured by fungi, some of which are extremely toxic to humans and animals (Schmidt-Etkin, 1994). When moulds make them, they also make synergizers, substances that can enhance the potency of other toxins in the environment. Some of these compounds may not be toxic in themselves but become toxic when combined with other substances. Fungi also emit volatile organic compounds, which are responsible for their odour. More than 500 VOCs have been identified from different fungi.

Next to other factors, the amount of water available to a fungus determines foremost whether it will grow. Availability of water does not necessarily mean presence of liquid water. Water activity (A_w) describes the effective concentration of moisture in a substrate in equilibrium with relative air humidity. The A_w that will support the growth of a given mould is affected by temperature and available nutrients.

The availability of water in the indoor environment and on or in construction products is influenced by several factors: thermal performance of a building envelope, ventilation and *material characteristics*. The latter is the primary reason for microbial growth (IUMS, 2005; Adan, 1994). *The material constituents and moisture retention characteristics of a product determine the risk for microbial growth:*

- Constituents: If a product comprises of organic materials, the risk for growth is higher than for completely inert materials. The trend towards eco-friendlier products has thus increased the potential growth risks (for example the use of water-based paints instead of oil-based). Organic dirt on inert material can also increase the risk, making the cleanability a product characteristic of importance.
- Moisture retention: In general, in bathrooms and kitchens in a short period of time a lot of water vapour is produced. This water vapour condenses at the surface areas and is retained on or in the surface layer of the material. Surface moistening and storage cannot be avoided with high ventilation rates, so the material will have in general enough moisture for growth until the next shower and the process starts again. On average the relative humidity of the air in the bathroom is low, but the moisture retained by the surface areas can be high and thus the conditions for growth can be favourable all the time.

In a meta-analysis of associations of respiratory health effect with dampness and mould in homes performed by Fisk et al. (2007), it was found that building dampness and mould are associated with

increases of 30-50% in a variety of respiratory and asthma-related health outcomes. The risk factors included in the study were visible dampness and/or mould, or mould odour.

4 Emission testing

4.1 Introduction

The testing of emissions of certain sources can in principle be approached in three ways:

- *The source*: identify the contents of the source (product characteristics) and predict what might be emitted or subject the source to an extraction process that is indicative of emission under intended use conditions.
- *The air nearby the source*: identify the substances emitted under intended use conditions in a standard test chamber and predict the indoor air concentration for the intended use situation by modelling.
- *Analysis of the air in the space with several sources*: identify the substances and try to deduct from which source it came (source identification).

The first approach requires a detailed knowledge of the composition of the product. A substance could be present in the product even though it has not intentionally been added, perhaps by being a trace component in feedstock material. Also validation of extraction methods is required to show correlation with emissions under intended use conditions. This can be problematic when dealing with emissions consisting of many substances that may behave differently from each other, but can be applicable for specific substances and products.

Therefore, up to now the second and the third approach have been the preferred methodologies. For the second approach the translation to practice (the in-use situation) with modelling is complex, but by using assumptions to simplify the exposure scenario provides information to compare construction products based on their emission patterns for specified groups of substances. The third approach is technically difficult as in practice it is often not easy to apportion all the measured substances in the air to a single or even a few sources and, as discussed previously, concentrations vary with time because of the dynamic nature of the determining factors.

4.2 Chemical emissions

The measurement procedure requires in general two steps: the sampling of the air to be tested on or in a medium and the analysis (detection and characterisation) of the pollutants in or on that medium. The substances emitted from materials/products have different characteristics and therefore require also different methods of sampling and of analysis.

Particles

The applied sampling method depends on whether the concentration is expressed gravimetric (mg/m^3 , ug/m^3) or numerical (e.g. fibers/ m^3), which part of the particle spectrum has to be measured, and the required average sampling time. To determine the gravimetric concentration of dust a specific air quantity is led through a filter. The amount of dust that remains on the filter is determined by weighing the filter on a micro-balance before and after the sampling. The difference in weight divided by the total amount of air that has passed the filter, results in the dust-concentration. Filters which are used the most are glassfiber filters, polystyrene-fiber filters, membrane filters and nucleopore filters. The air flow through the filter, the amount of air, the shape of the suction-opening, the orientation of the opening and the air velocity and flow direction of the air in the sampled space, are all parameters which can influence the determined dust concentration.

When the respirable fraction of dust has to be sampled a separator is used to remove 50% of the particles larger than or equal to 5 μm and all particles larger than or equal to 7 μm . A small change in the air flow rate will however change the penetration effect of the separator. Another separator is used when the particulate matter, PM10, has to be sampled. The numerical concentration of for example

asbestos fibers can be determined with the use of a membrane filter. After the sampling the filter is made transparent and the particles are counted using a microscope.

The continuous monitoring dust meters which are used most widely are the aerosolphotometer or tyndallmeter (based on lightscattering by particles; light pulses are transformed into an electrical signal, depending on particle size and other characteristics of the particles), the betaparticlemonitor (which measures the attenuation of beta radiation by a filter before and after sampling with that filter; the difference in radiation is directly related with the mass of the collected particles), and the piezo-balance, which contains a quartz crystal brought into resonance with an oscillator (the frequency adjustment required to bring the crystal into resonance is directly related to the amount of dust collected on the crystal). The last monitor is also available as a portable version.

Recommended conditions for sampling asbestos fibers and suspended particulate matter are given by Seifert et al. (1989).

Radon

Radon is a gaseous element which originates from the radioactive decay of uranium. Radon can be measured by integrating methods, like solid nuclear track detectors in a filtered cup, charcoal with/without TL-dosemeters and passive radon monitors; by continuous monitoring of radon daughters on a filter, measured by a semiconductor; and by equipment for instantaneous measurement of radon daughters (Swedjemark et al., 1989). Recommendations on the conditions for sampling radon in indoor air are given by Seifert et al. (1989).

Mycotoxins

One can sample either the fungi or the individual toxins concerned. The first approach has a number of problems. Sampling and culturing do not detect dead fungi. This may give misleading results since mycotoxins can persist long after the fungal organisms perish. Culturing of toxin-producing fungi can also be difficult. The second approach requires high-volume air samples and is only appropriate if the investigators are reasonably certain of the nature and concentration of the suspected toxin. Studies have indicated that polycarbonate filters with a pore-size of 0.2 μm at a 10-20 litres per minute are well-suited for collecting samples of airborne mycotoxins. After the collection the filters are subjected to toxicity analysis, using chemical methods. (source: Schmidt-Etkin, 1994)

Bioaerosols

Bioaerosols are usually sampled on a solid medium (morphological determination). During the incubation the living microorganisms can grow into countable colonies. Different organisms require different incubation conditions, so several methods are available. Non-colony forming bioaerosols require other biochemical methods (Meer, 1990). Mout Extract Agar (MEA) is a common used medium in aerobiological studies (Burge, 1987), but depending on the expected pollution other media can be used.

Suction devices with different kinds of filter materials are frequently used for the sampling of airborne allergens. The sampled particle size depends on the cut-off (separator) for the filter material. Some suction devices combine the principle of adhesion to a sticky surface and suction (especially used in sampling of pollens and spores). The air sampling devices which are used most widely are the Andersen N-6 sampler and the Reuter Centrifugal air Sampler (RCS) (Smid, 1987).

Another method for sampling of indoor allergens is vacuum cleaning and extraction of the dust samples. This method gives an indirect description of the possible aeroallergens in the environment, and has been widely used in the detection of house dust mites and allergens of animal origin.

In general three basic techniques are used to describe the sampled material (Johnson, 1989). Recognition by light microscopy of complete particles (e.g. whole house dust mites, whole pollens and whole mould spores), immunochemical analysis of sampled materials by radioimmunoassays or enzymeimmunoassays (an exposed person provides some grams of vacuum cleaner dust for the laboratory, where the allergenic molecules are extracted and identified), and the measurement of the enzymatic activity of the sampled materials itself (f.e. guanin or protease activity in house dust mite samples).

Gases

Many gases are present in the indoor air, some of them organic, others inorganic. Depending on the sampling objective these gases are monitored following different procedures.

The available methods or instruments to measure indoor air compounds can be divided into two groups (Bluyssen, 1996b):

- those that require an extraction step before making a physical or chemical analysis (f.e. chromatography)
- those that make a direct physical measurement of some property of the sample (f.e. non-dispersive infrared spectrometry).

Some methods of detection for the different groups of gases:

Very volatile compounds (VVOC):

- Formaldehyde and other carbonyl compounds (f.e. acetaldehyde): collection on cartridges; analysis by high performance liquid chromatography (HPLC); and detection by ultraviolet absorption
- Other VVOC (f.e. acetone, dichloromethane, tetrahydrofuran): adsorption on charcoal, SpheroCareb and other materials for sampling with later analysis by thermal desorption, or use of portable gas chromatograph

Volatile organic compounds (VOC): for example solvents and terpenes

- test method: sampling on Tenax in sampling tubes, thermal desorption from sampling tubes, separation VOCs with gas chromatograph; not fully appropriate for VVOC and SVOC; Tenax and activated carbon are not suitable as sorbents for SVOC.
- detection with Flame ionization detection (quantification) and mass spectrometric detection (MS) (identification + quantification)

Semi volatile organic compounds (SVOC):

- for example pesticides (e.g. chlorpyrifos, lindane, pentachlorophenol (which is a biocide)) and plasticizers (e.g. phthalates) (biocides can originate from treated wood, impregnated textiles, etc.)
- test method: specially manufactured polyurethane foam (PUF) which has good absorption characteristics can be applied as adsorbents or other adsorbents.

4.3 Sensory emission testing

Sensory evaluation of air quality comprises of the use of human subjects as measuring instruments. The attributes that can be measured in this way are the same as for all other sensory modalities:

- Detection (the limit value for absolute detection)
- Intensity (odour intensity, sensory irritation intensity)
- Quality (value judgement such as hedonic tone or acceptability).

In a discrimination evaluation a subject is asked mainly to compare an air sample with another and express this comparison in 'greater, smaller or equal than', depending on the attribute evaluated (pleasantness, strength, etc.). For this type of evaluation several techniques are available (Bluyssen, 2004).

Detection

The classical threshold theory assumes the existence of a momentary absolute sensory threshold. However, in real life, there is no fixed odour or irritation threshold of absolute detection for a particular individual or a particular pollutant but rather a gradual transition from total absence to definitely confirmed sensory detection (Garriga-Trillo, 1985). Therefore, in the theory of signal detectability (Engen, 1972), the same repeated signal is assumed to have a defined distribution, and thus each sensory evaluation by a subject is executed on a probability basis. Berglund and Lindvall (1979) have used this signal detection approach to test a few single compounds and a few building investigations.

In the classical methods the threshold level is defined as the level at which 50% of a given population will detect the odour. One of these methods is the threshold method which is standardised in many countries for the evaluation of outdoor air (CEN, 1994). In this threshold method an air sample is diluted stepwise (for each step, by a factor of 2) with clean (odour-free) air to determine the dilution at

which 50% of a panel of 8 persons can no longer distinguish the diluted air from odour-free air. This number of dilutions, expressed in odour units per m³ air of 20°C (o.u./m³), is the numerical value for the odour concentration of the original air sample.

Some measurements using the classical threshold level method, have been made on indoor air, ventilation systems and building materials (Bluyssen and Walpot, 1993; Bergund and Lindvall, 1979). The absolute detection threshold varies widely with chemical substances, as is shown by the large spread in literature reported odour thresholds for single compounds (Devos et al, 1990). This is caused among others by the procedure used, purity of chemical substance, equipment applied and sample of subjects.

Recognition threshold values (concentration at which a certain chemical is recognised) are usually measured in the same way as detection levels. Both use either the method of limits or the method of constant stimuli (ECA, 1999).

In the method of limits, the chemical substance is presented in alternating ascending and descending series, starting at different points to avoid having the subject fall into a routine. The subject is asked to report whether the sample can be detected or not.

The method of constant stimulus is based on the assumption that the momentary individual threshold value varies from time to time and that this variation has a normal distribution. The chemical substance is usually presented in a random selection of concentrations.

For both methods, no training is required, although subjects may be selected on their sensitivity to the chemical substances tested.

Intensity

The intensity of odours or irritants can be obtained by several methods: equal-intensity matching, magnitude estimation or direct scaling methods (ECA, 1999). The latter is the most common in indoor air quality studies and uses for example visual, semantic scales (for example: no odour, weak odour, moderate odour, strong odour, very strong odour, over-powering odour). With equal intensity matching the subject matches the intensity of for example two different odorants.

Magnitude estimation techniques generate magnitude estimates of intensity resulting from direct numerical estimations by subjects. The perceived intensity of an odour is established by rating the intensity of that odour on a magnitude scale, using reference odours or not. The ASTM technique (ASTM, 1981) uses for example samples of 1-butanol vapour presented at varying concentrations and the Master Scale unit method (Berglund and Lindvall, 1979) uses five concentrations of pyridine which are jointly measured with indoor air samples.

The assessment of decipol levels using trained panels of the air in office buildings (European Audit project (Bluyssen et al, 1995) is an example of magnitude estimation with memory references. The same method but instead having the references (with numerical values) nearby to compare, is an example of magnitude estimation with several references. This method that was applied in several European projects (European Audit project (Bluyssen et al, 1995), Database (Oliveira Fernandes and Clausen, 1997), MATHIS (Oliveira Fernandes, 2001), AIRLESS (Bluyssen et al, 2001) and is presented in Annex A).

Quality

A value judgement of indoor air quality can be given in several ways. One can make a classification (for example yes/no), such as the ASHRAE 62-1989 (ASHRAE, 1996) is using (is the air acceptable or not), resulting in a percentage of dissatisfied, or one can use a list of descriptors to describe a chemical substance. The latter is mainly used in the food and perfume industry from which many classification systems of odours have been developed.

For the evaluation of the acceptability of an air sample (percentage of dissatisfied persons), several methods have been applied. Besides the yes/no classification ('acceptable' or 'not acceptable'), the continuous acceptability scale (Gunnarsen and Fanger, 1992) is used. The middle of the scale is indicated as the transition between just acceptable and just not acceptable. With both methods, however, large panels (depending on the statistical relevance required) of untrained persons are required

Two units, olf and decipol, were introduced to quantify sensory source emissions and perceived air quality (Fanger, 1988). With these units the so-called decipol method was developed. The decipol

method comprises a panel of 10 or more persons who are trained to evaluate the perceived air quality in decipol or an untrained panel of at least 50 persons (Gunnarsen and Bluysen, 1994). A method to train a panel to evaluate perceived air quality in decipol has been developed (Bluysen, 1990; Bluysen, 1991). The latest research indicates, however, that this method is not evaluating the acceptability but the intensity of the air sample.

4.4 Secondary emissions

As presented, construction products can also emit secondary emissions caused by microbiological growth, chemical reactions, adsorption and desorption effects. The possibility for having secondary emissions under certain conditions is not easy to predict. For sensitivity to microbiological growth as a material characteristic, a procedure has been developed as for sensitivity to adsorption.

Sensitivity to microbial growth

For furnishing materials (coatings, paints, etc.) a method has been developed to assess the resistance of materials against fungal growth (Adan et al. 2003). The test encloses both steady state and transient conditions, addressing microbial problems on a heat bridge, or in transient climates. The test proved to be applicable for a wide range of materials: silicon caulk, coating types, including waterborne interior paints, specialties like high-absorbing claddings and ceramic coatings, gypsum based products, wall papers including glues and cement-based panels. And the test has shown in the past 15 years high reproducibility of results that reflect actual performance characteristics in practice.

The experimental arrangement consists of a closed re-circulating system, resulting in a defined relative humidity level or intermittent patterns of condensation and drying. Single fungal species are used, being predominant indicator organisms in W-European domestic environments. Analysis of growth is based on the entire growth pattern as a function of time, including all stages of growth.

Most products exhibit divergent behaviour as a function of the moisture load. Fungal resistance is a product based feature and not a generic characteristic of a type of material. A labelling system for the fungal resistance of a building product should take into account the overall characteristics of the indoor humidity load. The test introduces a three level classification system, based on estimators originating from the moisture regime.

Adsorption/desorption

This part is under construction, references to the MATHIS project are expected.

5 Strategies for reducing impact of construction products on IAQ

5.1 Introduction

In order to reduce exposure to emissions of construction products (including also HVAC components), several types of measures can be taken in principle:

- Measures to reduce the primary emissions of construction products: by the products producers themselves and by the architect/end-user through selection of products
- Measures to reduce secondary emissions of construction products: by certain control strategies indoors such as ventilation, but also by selecting the right product for the location (environmental conditions) and activities it is meant to be exposed to.
- Measures to prevent the emissions of construction products to reach the occupant: by the occupant themselves through ventilation options, use of certain selected cleaning methods and/or.....

From this overview it is clear that to be able to reduce emissions from products indoors it is important to know what type of emissions and amounts emitted. Furthermore, it is important to know how the product will behave (emit) in the in-use situation when exposed to different environmental conditions and indoor activities such as smoking or cleaning.

Actions are taken at different levels:

- European level (CE marking, CEN TC 351) and national regulations (e.g.: AgBB)
- National Environmental and Health Action Plans (NEHAPs)
- Voluntary labelling schemes in the EU
- Building design

5.2 European level

Construction Products Directive, CPD

DG Enterprise in cooperation with CEN, is closely working with national standardization bodies (e.g. NEN in the Netherlands) to implement mandates for the CPD and the EPBD (Energy Performance Building Directive).

The second generation of harmonized product standards under the CPD requires harmonized test methods for release or emission of dangerous substances to at least partly satisfy the requirements of Essential requirement 3 of the CPD, Hygiene, health and the environment. The European Commission has issued Mandate M/366 to CEN. This mandate Work package 5 'horizontal standards: emission scenarios in indoor air', states that four horizontal standards will be developed:

1. Horizontal standard on the methods for generation of emission of dangerous substances from construction products into indoor air in standardized testing facilities
2. Horizontal standard on the measurement of regulated dangerous substances in indoor air samples as generated from construction products in the standardized testing facilities
3. Horizontal standard on the measurement of radiation and radioactive emissions from construction products
4. Horizontal standard on assessment for potential growth of relevant micro-organisms on construction products in the indoor environment.

These standards will most likely not include the evaluation of how a product will behave when exposed to indoor activities such as smoking or cleaning, neither will they consider the effects of growth of micro-organisms, or the effects of other substances introduced into the indoor environment (such as ozone) that can be adsorbed and desorbed or react with other substances and form new substances.

ISO 16000 series of standards

The most widely applied standard series for testing construction products at the moment is the ISO-16000 series (CEN, ISO). The DIBt regulation on floor coverings (DIBT, 200X), which makes use of the AgBB scheme, and a number of voluntary labelling schemes in Europe use these series as a base, although some differences are identified (see 5.4).

The standards series comprises of standards for sampling of product, for simulating emissions in either a small scale emission test cell or a larger emission test chamber, and several different ways of sampling and analyzing the emitted substances.

Although the analyzing parts (EN ISO 16000-3 and 6) are mainly for aldehydes and VOCs (TVOC), the potential and intent is there to widen it with other analyzing methods for other groups of substances. The sampling and chamber methods (EN ISO 16000-9, 10 and 11) were originally developed for construction and furnishing products in direct contact with indoor air. However, for construction and finishing products not in direct contact with indoor air it is assumed that they are, so the worst case situation is assumed (all emission enters the indoor air).

For the measurement of aldehydes of wood-based panels, a slightly different standard has been developed: the EN 717-1, 2 and 3, better described as a thermal extraction test than an emission test. The main difference being that the emissions are simulated at a different test climate making comparisons of results achieved by EN 717 and EN ISO 16000 respectively not possible.

AgBB evaluation scheme

The AgBB evaluation scheme (AgBB, 2005) comprises of a health-related evaluation of VOC emissions from building products used for application indoors. Within this scheme, volatile organic compounds include compounds within the retention range of C_6 to C_{16} , which are considered to be both as individual substances and in calculating a sum parameter following the TVOC concept and semi-volatile organic compounds within the retention range from C_{16} up to C_{22} .

For health evaluation, a product has to undergo a series of tests as shown in the flow chart in Fig. 5.1. The procedure starts from a product wrapped in an airtight cover. The start of the experiment (t_0) is defined as the time at which the product to be tested is unwrapped and placed into the test chamber or cell. The product remains in the test chamber or cell over the entire period of the test. For certain product groups it is necessary to define special test conditions. These specific requirements are defined separately. They may also include the definition of criteria for anticipated termination of the emission measurement. In principle, anticipated termination of the test is permitted at the earliest 7 days after placing the test specimen into the chamber and under the condition that the values determined are less than half the requirements for the 28-day values and no significant increase in the concentration of individual substances is observed in comparison to the measurement on day 3. The fulfilment of these criteria has to be sufficiently demonstrated by the testing body.

In accordance with ISO 16000 /6 the following definitions apply for the emission to be determined in the test chamber:

VOC: all individual substances within the retention range $C_6 - C_{16}$

TVOC: sum of the concentration of all individual substances with concentrations equal to or greater than 5 $\mu\text{g}/\text{m}^3$ within the retention range $C_6 - C_{16}$

SVOC: all individual substances within the retention range $> C_{16} - C_{22}$

SVOC: sum of the concentration of all individual substances with concentrations equal to or greater than 5 $\mu\text{g}/\text{m}^3$ within the retention range $> C_{16} - C_{22}$

The assignment of the individual substances to the retention ranges $C_6 - C_{16}$ and $C_{16} - C_{22}$ is based on the separation on a non-polar column. Individual substances comprise identified and non-identified compounds.

In the AgBB scheme, the identification of all individual substances is based on a presumed uniform detection limit of 1 $\mu\text{g}/\text{m}^3$ in order to cover the emission spectrum as fully as possible in a qualitative way.

All individual substances have to be quantified as required (Identified substances with LCI values as well as carcinogens have to be quantified using their individual calibration factors while identified substances without LCI values and non-identified ("unknown") substances are quantified on the basis of toluene equivalents) and need to be considered individually and in the summation if their concentration is equal to or greater than 5 $\mu\text{g}/\text{m}^3$. Exceptions apply to particularly critical substances; these have to be included in the calculation of R values if their concentration in substance-specific quantification is equal to or greater than 1 $\mu\text{g}/\text{m}^3$.

VOC and SVOC shall be measured using Tenax sampling and subsequent thermodesorption and analysis by GC/MSD according to DIN ISO 16000-6. Aldehydes, in particular low-chained aldehydes listed in Group 7 of the list of LCI values, shall be determined using the DNPH method according to DIN ISO 16000-3.

The following explanations are given to the flow chart in Figure 5.1:

Measurement and testing after 3 days:

TVOC₃: A product satisfies the criteria, if the TVOC value after 3 days (TVOC₃) is $\leq 10 \text{ mg/m}^3$.

Carcinogenic substances: Every building product has to meet the general requirement of not emitting any carcinogenic, mutagenic or reprotoxic substances. Emission of carcinogenic substances belonging to categories 1 and 2 according EU Directive 67/548/EEC is first tested at this stage of the flow chart. Substances with mutagenic or reprotoxic properties and those with potential carcinogenic effects (EU category 3) are checked within the LCI concept and assigned higher safety factors if necessary. Carcinogens have to be quantified in a substance-specific manner. The sum of all EU categories 1 and 2 carcinogens [EU Directive 67/548/EEC] detected after 3 days shall not exceed 0.01 mg/m^3 .

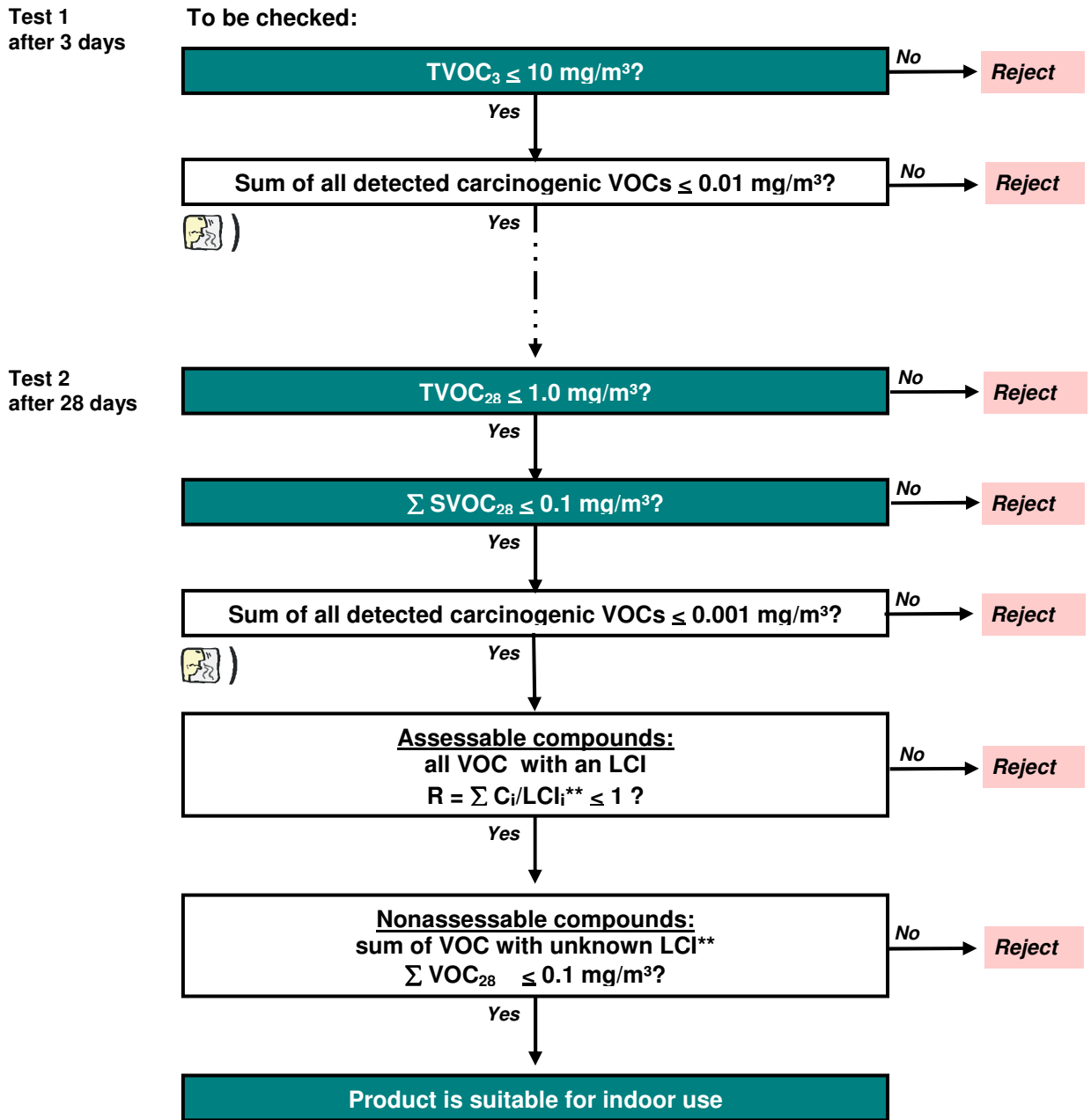
First sensory testing: For determining the equally important sensory properties it will be necessary to agree upon more precise details before an initial sensory test can be performed at this stage of the flow chart. Until an adequate test method is available, there is only a reference in the flow chart to the necessity of a sensory test.

Measurement and testing after 28 days

- *TVOC₂₈*: In order to assess the long-term behaviour of the VOC emissions from a building product, the TVOC value is determined again after 28 days. This is done in the same way as described for TVOC₃. When calculating the TVOC₂₈ value, in addition to the instructions given in DIN ISO 16000/6, it is important to be as complete as possible in the identification of compounds to permit the evaluation of individual substances. A product satisfies the criteria, if the TVOC₂₈ value is $\leq 1.0 \text{ mg/m}^3$. Products with a TVOC value higher than that are rejected.
 - *Semivolatile organic compounds (SVOC)*: Products that satisfy the criteria for VOC emissions but instead exhibit increased emission of SVOC should not be given advantages. To prevent this from happening the SVOC concentration in the chamber air shall also be determined. Emission of semivolatile organic compounds with a retention time $>C_{16}$ (hexadecane) can be quantitatively determined by chamber or cell measurements over 28 days using today's modern analysis apparatus up to a volatility comparable to that of docosane (C₂₂ alkane, boiling point 369 °C). According to current knowledge, the analysis semivolatile organic compounds with an even lower volatility will encounter increasing difficulty if the method of Tenax sampling and thermodesorption is used in chamber tests.
- A product satisfies the criteria if the sum of the SVOC concentrations in the chamber air does not exceed 0.1 mg/m^3 . This corresponds to an additional content of 10 % of the maximum allowable TVOC₂₈ concentration of 1.0 mg/m^3 . Higher concentrations result in rejection.
- *Carcinogenic substances*: The emission of carcinogenic substances of EU categories 1 and 2 [EU Directive 67/548/EEC] is tested again, with an emphasis on the long-term behaviour from the user's point of view. The sum of all carcinogens detected shall not exceed the value of 0.001 mg/m^3 . Higher concentrations result in rejection.
 - *Second sensory testing*: Until the test procedure has been agreed upon finally, the requirement for a second sensory test after 28 days is indicated. The reason for a second test is that chemical reactions may only occur within the product which may lead to odour or other sensory perception.
 - *Evaluation of individual substances*: In addition to evaluating the emissions of a product via the TVOC value, the evaluation of individual VOC is also necessary. For this purpose all compounds whose concentration in the chamber air equals or exceeds $1 \text{ } \mu\text{g/m}^3$ are first identified, listed with their CAS number, and quantified according to the following:
 - a) VOC assessable via LCI: For a large number of VOC found in indoor air a list of so-called LCI values (Lowest Concentration of Interest) is contained. The details of how these LCI values have been derived are documented in the introduction to the list. Listed substances with a concentration exceeding $5 \text{ } \mu\text{g/m}^3$ are evaluated based on LCI. They are quantified in a substance-specific manner. Particularly critical substances with LCI values $\leq 10 \text{ } \mu\text{g/m}^3$ shall be included in the evaluation if their concentration equals or exceeds $1 \text{ } \mu\text{g/m}^3$.
For the evaluation of each compound i the ratio R_i is established as defined in equation (2).
$$R_i = C_i / \text{LCI}_i \quad (2)$$
where C_i is the chamber concentration of compound i . For $R_i < 1$, it is assumed that there will be no effects. If several compounds with a concentration $> 5 \text{ } \mu\text{g/m}^3$ are detected, additivity of effects is assumed and it is required that R , the sum of all R_i , shall not exceed the value 1.
$$R = \text{sum of all } R_i = \text{sum of all ratios } (C_i / \text{LCI}_i) \leq 1 \quad (3)$$
Products which do not fulfil this condition are rejected.
 - b) VOC not assessable via LCI In order to avoid the risk of a positive evaluation of a product which emits larger quantities of non-assessable VOC, a limit is set for those VOC which cannot be identified or do not have an LCI value. This limit equals 10 % of the permitted TVOC value, for the sum of such substances. A product meets the criteria when the sum of such VOC determined at concentrations $\geq 0.005 \text{ mg/m}^3$ does not exceed 0.1 mg/m^3 . Higher concentrations result in rejection.



Fig. 5.1: FLOW CHART FOR THE EVALUATION OF VOC* AND VOC* EMISSIONS FROM BUILDING PRODUCTS



 VOC, TVOC: Retention range C₆ – C₁₆, SVOC: Retention range C₁₆ – C₂₂
LCI: Lowest Concentration of Interest (German: NIK)

Substances under ban, such as asbestos, PCB, certain metals and flame retardants, shall not be put in new products at all. However, it is becoming more and more common to recycle old materials and mix virgin materials with recycled in the process of making new products. This may cause unintentional contamination of new products by substances now under ban, and an unspecified dilution of dangerous substances throughout. The solution could be a) to verify the material to be recycled is “clean” when it comes to banned substances or b) to verify that the performance of the finished product is below any limit values.

For asbestos, regulations are based on two parallel approaches: The ban of asbestos and the control and management of the material containing asbestos that have been used before the ban (WHO, 2006). The last change of the Directive 76/769/EED adopted the 26th July 1999 added together the different partial bans of asbestos taken from 1976 and made the ban compulsory, at the latest on the 1st January 2005, for all types of asbestos and all type of products with temporary exception for very particular products and for existing products.

For other fibres, some standards are available. These are mainly concerned with analytical procedures for fibres in air, not with the emission of fibres from products. Since it is not very likely that fibres suddenly come of products into the indoor air, if no mechanical motions are involved, fibres from products are considered not relevant for an emission test of products in the in-use scenarios of construction and finishing products.

EN ISO 16000

The international standard EN ISO 16000 consists of several parts. Some have been elaborated by CEN/TC264 and some by ISO/TC146 and have been mutually accepted under the Vienna agreement. In practise, the tester starts with sample handling (Part 11), then selects a test chamber (part 9 or 10) and finally performs the analysis of sampled air from test chamber (part 6 for VOC and TVOC and part 3 for Aldehydes). The full procedure is illustrated by the slide series below, for a flooring material.

- Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method
- Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID
- Part 9: Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber (earlier: EN 13419-1)
- Part 10: Determination of the emission of volatile organic compounds from building products and furnishing – Emission test cell method (earlier: EN 13419-2)
- Part 11: Determination of the emission of volatile organic compounds from building products and furnishing – Sampling, storage of samples and preparation of test specimens (earlier: EN 13419-3)

In December 2005, a proposal for regulation was made in the European Parliament and the Council of Europe, on REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), establishing a European Chemical Agency and amending Directive 1999/45/EC. It provides provisions for substances and preparations that do not adversely affect human health or the environment.

The programme of work within CEN/TC 350 will provide with a standardised voluntary approach for the delivery of environmental information on construction products, and to assess the environmental performance of buildings. The objective is to cover all kinds of building products and all kinds of buildings, new and existing buildings, and possibly other construction works, if appropriate.

5.3 National environmental health action plans, NEHAPs

We are not sure whether to include this in the report. Thoughts on this?

5.4 How to inform and involve stakeholders

There are various stakeholders who may benefit from having information about how to achieve and maintain indoor air quality. These can be classified into three groups;

1. producers of products used in buildings
2. specifiers of products to be used in buildings
3. people who use buildings.

Producers include manufacturers of construction materials, furnishings and consumer products. All of these products have the potential to release pollutants into the indoor environment and have an adverse effect on indoor air quality. Specifiers include all those responsible for the design and furnishing of a building where an awareness of the need for source control and adequate ventilation to maintain occupant health and well being is required. In particular selection of products to minimise any adverse impact on indoor air quality requires appropriate knowledge and supporting information. Occupants and persons responsible for maintaining buildings need to know how their activities can influence the IAQ and the measures they can undertake to avoid or address problems.

To be effective, information should be available at an appropriate technical level and presented in a language and manner that can be clearly understood by the intended recipient. Therefore information for a householder should be of a different detail than that required by a professional specifier such as an architect.

The main routes of currently providing this information are written booklets and web site presentations. For the most interested reader books and scientific and professional journals may also be appropriate. However to raise awareness of IAQ issues there is a need to educate with some relatively simple messages and the purpose of this section of the report is to summarise some of the information available in order to consider any further needs. As an example it gives some detailed information about sources of information particular to the UK and highlights some further information available in other countries and institutes.

Inventory of current and previous activities in UK concerning IAQ

BRE is the pre-eminent centre for research in the built environment within the United Kingdom. It is the UK's leading centre for research and consultancy on:

- construction quality, process and productivity
- environmental impact of construction, sustainability and whole-life performance
- energy efficiency of buildings
- renewable energy in buildings
- certification and listing (www.RedBookLive.com)
- aircraft cabin environments
- building performance - structures, materials and systems
- prevention and control of fire
- risk science
- crime and security

BRE has issued a number of information papers and guides concerning IAQ. These are generally aimed at the informed reader. This could be the material producer or specifier and some are appropriate for the users of buildings. They would be for people with a strong interest in the subject and provide considerable detail. Information on BRE and the publications can be found through the web page www.bre.co.uk.

5.5 Voluntary labelling systems in the EU

For many years, chemical substances in indoor air have been under discussion with regards to their possible health effects. It has been recognised some of these chemical substances are emitted from building products. In spite of several projects involving European and international experts, it is still considered not possible to determine exactly which substances, or which mix of substances (and concentrations of these) have these adverse health effects. Some exemptions to this have resulted in legislation considering for example asbestos, flame retardants, and formaldehyde. In the light of lack of legislation and limit values, many countries and/or markets have decided upon using voluntary schemes for reducing possible health effects due to (among other sources) emissions from building products.

Most of the voluntary schemes used today in the Member States, apply the newly developed EN or ISO standards (EN-13419 parts 1-4 and the CEN ISO 16000 parts 3, 6, 9, 10, 11) or very similar methods for emission testing and analysis. Most schemes, or labels, apply a short-term test for initial emissions after 1 or 3 days, and all labels apply a test for characterising long-term emissions after 28 days – or even earlier (after 10 or even 3 days) if the initial emissions of all covered products will decrease very fast.

In report 24 of the European Collaborative action “Urban air, Indoor environment and human exposure – Environment and Quality of life” (Kephelopoulos, S., et.al, 2005), the following labelling systems and concepts have inventoried, compared and discussed:

- ECA report no. 18. (A concept for a global scheme for the evaluation of VOC emissions from building materials, established by a European working group),
- AgBB scheme (Germany, see 5.2),
- AFSSET (previously named CESAT – Evaluation of environmental and health-based properties of building products) (France)
- M1- Emission classification of Building Materials (Finland),
- Danish Indoor Climate Label (DICL-Denmark),
- LQAI scheme (Portugal),
- Natureplus (Germany and Europe),
- The Blue Angel (Germany),
- Ecolabel scheme (Austria),
- GUT for carpets (Germany and Europe),
- Emicode system by GEV for adhesives and related material (Germany and Europe), and
- The schemes applied in Belgium and UK and The Scandinavian Trade standards.

The intention of the 1997 report no.18 of the European Collaborative Action “Indoor Air Quality and its Impact on Man” (“Evaluation of VOC Emissions from Building Products”) was to serve as a guideline and has in fact laid good grounds for harmonising systems.

Only some labels are applying an odour test, the M1 and the Danish ICL, and documentation on reliability and reproducibility of such tests is still lacking. A large variety of odour testing methods are applied. These tests are mainly based on either desiccator tests, or on dynamic chamber tests as described in the European database project Bluysen et al, 2000), Nordtest Standard (Nordtest, 1998) and ECA report no. 20 on sensory evaluation (ECA, 1999). A number of labels do not include any odour testing at all. Some of the schemes include control of labelled products in certain intervals or frequency. Most labels require involved testing laboratories to apply for approval. Only some labels organised round-robin tests for checking the quality of the testing labs.

The Danish Indoor Climate Labelling scheme (DICL) was in 1995 one of the first emission classification schemes with respect to the indoor air quality. The emissions from the products are measured in climate chambers and converted into standard room concentrations. These are evaluated in relation to sensory irritation (eye and upper airways) by chemical analysis and sensory evaluation (acceptability and odour intensity).

The scheme has requirements for the standard room concentration of individual VOCs believed to result in sensory irritation. The parameter used as a criterion of acceptance is the time required for the emission of the VOCs to decay to the point where their room concentrations are below 50% of the sensory irritation estimate for each individual VOC cited in VOCBASE (Jensen and Wolkoff, 1996). The use of 50% of the threshold value is a pragmatic safety factor that accounts for the possibility of contributions of the same VOC from other pollution sources. The time required for the model room concentrations to fall below the threshold is the so-called indoor-relevant time-value. Carcinogenic compounds belonging to Category 1 of the IARC Monographs (IARC, 2004) (except formaldehyde) must not be detected in the emission.

In addition to the chemical emission testing, ceiling systems are tested for the release of particles and fibres.

The M1 labelling system is also one of the oldest systems, established in 1995, and is regarded as one of the voluntary schemes with most experience today. The system uses the emission scenario as defined in the CEN ISO 16000 series (based on more than 20 years of research). The M1 was developed before the CEN ISO 16000 series was available and is based on testing protocols developed in the European projects “EDBIAPS”, “MATHIS” and “AIRLESS”.

- EBDIAPS (1994-1997): focussed on building and furnishing materials (Joule II program)
- AIRLESS (1998-2000): concerned with HVAC systems and components (coordinator TNO – P.M. Bluysen under the Joule III program)
- MATHIS (1998-2001): created a database SOPHIE (Sources of Pollution for a Healthy indoor Environment) (Joule III program)
- VOCEM (1996-1998): developed a measurement protocol for VOC from construction products (together with Mathis this formed the basis for the ISO 16000 series developed in WG7 of CEN TC 264)
- CEN TC 264 WG7: developed a measurement protocol VOC resulting in the ISO 16000 series (secretary Sara Giselsson)
- ISO TC 146 SC6 development of analytical procedures to the CEN ISO 16000 series (convenor Kristina Saarela)
- European Collaborative action Indoor Air Quality & its impact on man, Environment and Quality of life, report no. 18: Evaluation of emission of flooring materials (this reports forms the base for most evaluation schemes used today)

The M1 system measures the emission of TVOC (all VOC between C6-C16 in toluene equivalent) according to 16000-6. $200 \mu\text{g}/\text{m}^3$ is the limit, at 28 days. In practice this does the job with regards to reducing possible health effects from chemical emissions from building products, according to the Finnish experience. More than one thousand products have been given the M1 label and it has been shown that the indoor air environment has improved (lower TVOC concentrations: 1/5 of before) in the indoor air scenario (see figure 5.2).

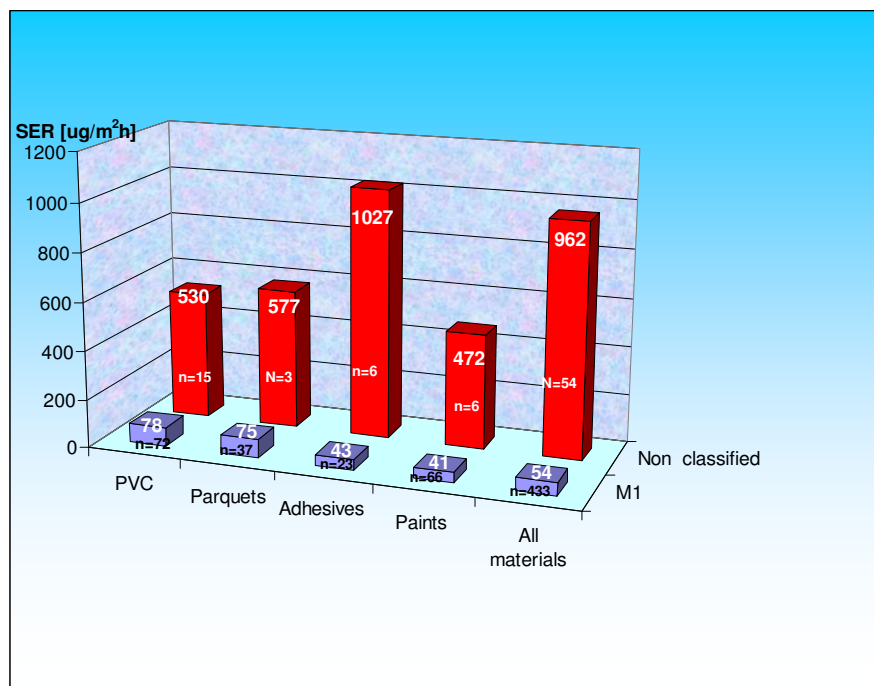


Figure 5.2 TVOC emission rate from classified and non-classified products tested by M1 system (from Kristina Saarela)

Most testing protocols are quite similar, here illustrated by the M1 testing protocol:

1. *Sampling of the material or product*
2. *Transport of sample*
3. *Storage of the sample before testing*
4. *Test specimen preparation*
5. *Testing age and conditioning of the test specimen*
6. *Chamber technique*
7. *Air sample collection from the test chamber*
8. *Analyses*
9. *Reporting documents for application for the classification*

The Swedish building product declarations system was not referred to in the ECA report. Can we still write about it? It is a voluntary scheme developed by the Ecocycle council which is an association of 30-something organizations within the Swedish building sector and real estate sector. The first prototype of the scheme was presented in 1997 and the third version was presented in October 2007. As of November 4th the *Building product declarations – Ecocycle Council Guidelines* are also available in English on their website, www.kretsloppsradet.com. The scheme was presented at the European expert meeting on national lists in June 1998.

The basic idea of the system is to provide an extensive declaration of the product, regarding several environmental issues. This includes chemical content and release. The declarations are wider than what is necessary to comply with regulations because we might need the information in the future. When knowledge develops in the future we can easily go back and see which products are of concern – and where they have supposedly been used.

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Annex: Work shop program 21 November 2007

Which way forward for healthy air in buildings?

HealthyAir Workshop – November 21, 2007

Chair: Prof. Eduardo de Oliveira Fernandes (Univ. Porto)

Programme

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- 9.30 Registration and coffee
- 10.00 Opening and presentation of the HealthyAir project Philo Bluysen (TNO) / Chair
- 10.15 Goals of the workshop François Maupetit (CSTB)
- 10.30 The impact of building materials on indoor air quality Derrick Crump (BRE)
- 11.00 Coffe break
- 11.10 What can we expect from CE marking of building products? Jeroen Bartels (CEN TC351)
- 11.30 Overview of existing labelling schemes in the EU Stelios Kephelopoulos (JRC Ispra)
- 11.50 Are labelling schemes effective? Kristina Saarela (VTT)
- 12.20 Introduction to the afternoon session François Maupetit (CSTB)
- 12.30 Lunch
- 13.30 Discussions on healthy air in buildings:
- Emission labelling schemes: are they an effective way to achieve good indoor air quality in buildings; are there other ways?
 - What factors should be controlled to achieve good indoor air quality in buildings? Is TVOC and formaldehyde enough?
 - What are the information needs of producers, specifiers and end-users of buildings?
- 14.30 Presentation of the discussions
- 15.00 Coffee break
- 15.30 Conclusions of the workshop Thomas Witterseh (DTI)
- 15.45 What next? Eduardo de Oliveira Fernandes (UP)
- 16.00 End of the workshop: get together drink

Healthy Air

Location: Engels (www.engels.nl), Rotterdam, Netherlands

Organization: francois.maupetit@cstb.fr