Project no. SSPE-CT-2004-502671

EnVIE

Co-ordination Action on Indoor Air Quality and Health Effects

Instrument: Co-ordination Action

Thematic Priority: Policy-oriented research (SSP)

Deliverable 3.1
WP3 Technical Report
Characterisation of spaces and sources

Due date of deliverable: 15 December 2008
Actual submission date: 15 December 2008

Start date of project: 01/04/2004 Duration: 55 months

Organisation name of lead contractor for this deliverable: IDMEC

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

ENVIE
Co-ordination Action on Indoor Air Quality and Health Effects



WP3 Final Report

Characterisation of spaces and sources

by

Eduardo de Oliveira Fernandes (WP3 leader), IDMEC, Instituto de Engenharia Mecânica, Portugal

with

Hans Gustafsson, SP, Technical Research Institute, Sweden

Olli Seppänen, HUT, Helsinki University of Technology, Finland

Derrick Crump, BRE. Building Research Establishment, United Kingdom

Gabriela Ventura Silva, IDMEC, Instituto de Engenharia Mecânica, Portugal

and

Joana Madureira, IDMEC, Instituto de Engenharia Mecânica, Portugal

Anabela Martins, IDMEC, Instituto de Engenharia Mecânica, Portugal

TABLE OF CONTENTS

Executive Summary 7
1. Introduction 9
2. Sources 10
2.1. Emissions from building construction 10
2.1.1. Building materials 11
2.1.1.1. Synthetic materials 11
2.1.1.2. Materials based on natural raw materials 12
2.1.1.3. Interior paints and varnishes 13
2.1.1.4. Products based on coal tar 13
2.1.2. Interactions in building materials 14
2.1.2.1. Moisture induced degradation of materials 14
2.1.2.2. Chemical degradation of flooring materials on damp alkaline concrete 15
2.1.2.3. Indoor surface chemistry 15
2.1.2.4. Release and sorption of semi-volatile organic substances 17
2.1.3. Decay of emissions in building materials 18
2.2. Emissions from HVAC systems 19
2.2.1. Outdoor and other pollution sources related to ventilation 19
2.2.2. Pollutants in air handling equipment and systems 19
2.2.3. Ventilation and spread of contaminants 21
2.3. Consumer products 23
2.4. Occupant behaviour and maintenance 25
2.4.1. Combustion sources 26
2.4.2. Other 28
3. Existing policies on IAQ or IAQ related in EU 29
4. Recommendations 37
References 41

Executive Summary

Human exposure to environmental pollutants occurs via various pathways. For many pollutants, especially the volatile ones, air exposure is the dominant pathway. Exposure via air occurs both outdoors and indoors, with diverse types of indoor spaces playing a role, e.g., home, workplace, and passenger cabins of means of transportation.

In average people spend over 90% of their time indoors, that percentage being particularly high for some specific groups as new-born, elderly, disabled or sick people. The global exposure to air contaminants is therefore drastically determined by indoor conditions.

It is now well established that indoor air pollution contributes significantly to the global burden of disease of the population. For a majority of indoor air contaminants, particularly in the presence of common indoor sources, however, indoor concentrations usually exceed outdoor concentrations, for some pollutants even with an indoor/outdoor ratio of 10 or 20.

Emissions are identified, accordingly to the EnVIE approach and grouped into four categories: building materials and related sources, including dampness and moulds; ventilation, natural and mechanical, including, or not, heating, cooling and humidification/ dehumidification; consumer products, furnishing, cleaning and household products; and occupant activities.

Emission of chemical substances from construction materials and products in buildings to the indoor air have been reported and reviewed for a wide range of substances, including those formed during secondary reactions, causing complaints of irritation and odour. During the last two decades there has been increasing advances in construction technology that have caused a much greater use of synthetic building materials. Whilst these improvements have led to more comfortable buildings, they also provide indoor environments with contaminants in higher concentrations than are found outside. Wood and cork are now frequently used as a building product for floor coverings, because the material is often regarded as “natural” and “healthy”. However, industrial products, even based on natural raw materials, may contain a number of artificial ingredients and the chemical emissions will strongly depend on the type of additives and the manufacturing process. Modern interior paints are usually based on a polymeric binder. In order to fulfil requirements on e.g., durability, paint contains various functional chemicals. Water-borne paints usually also contains small amounts of approved biocides. Polymeric binders with a very low content of residual monomers have been developed for paint. Besides the release of substances to the indoor air due to primary emission, damp building materials may give rise to volatile substances formed during secondary reactions. Semi-volatile organic compounds (SVOCs) are now receiving much more attention than heretofore.

The HVAC (Heating, Ventilation and Air Conditioning) systems as providers, among others, of services of cleaning and dilution of pollutants in the indoor air are also recognized as potential pollution sources. Several studies have shown that the prevalence of SBS symptoms is often higher in air conditioned buildings than in buildings with natural ventilation.

The outdoor air introduced indoors through either ventilation systems or natural means is also an important and not always controllable source for the intake of some outdoor pollutants. Outdoor air used for ventilation may also be source of pollution containing particulate matter, particulates of biological origin (microorganisms, pollen, etc.) and various gases like NOx and O_3. Ventilation together with stack effect and wind effects create pressure differences over the building structures which is a driving force for the airflows which will transport to indoors water vapour and gaseous or particulate contaminants.

Volatile organic compounds are emitted from a wide variety of household and consumer products with emission rates that are strongly dependent on the type of application and are distributed over several orders of magnitude. A number of product classes are identified and information on ingredients and available data on emissions from individual products are presented. Human activities and the associated use of products encompass a wide range of indoor sources involving release of inorganic gases, particles and organic compounds as a consequence of the activity. For some releases such as with air fresheners the release is a necessary part of the activity to achieve the intended effect whereas for others, such as the release of combustion fumes from a gas appliance, the purpose of the action (in this case generation of heat) is different from the emission. Combustion processes are an important source of a range of air pollutants as carbon monoxide, nitrogen dioxide, sulphur dioxide, particulates and associated inorganic and organic chemicals, organic vapours e.g. formaldehyde, acetaldehyde, and benzene. Sources of these are present in both ambient and indoor environments. The concentrations present in the ambient air provide a baseline for the level of pollutant found indoors as this air enters indoors by processes of infiltration and ventilation. However, the concentration indoors will be modified by processes of sorption to surfaces and chemical reaction depending on the chemical and physical properties of the pollutant and internal surfaces.

People themselves are a source of emissions of chemicals and gases, notably CO_2, but also a range of organic compounds that are referred to as body odours. The removal of such body odours is a prime objective of ventilation in order to achieve a satisfactory indoor environment.

WP3 aims at to characterize spaces and sources in order to understand where and how to act to guarantee good IAQ. From the two strategies for good IAQ, source control and ventilation, the precautionary principle suggests that first priority shall be given to source control, avoiding, mitigating or simply managing sources of emissions.

An overview of all policies on IAQ or related to IAQ, existing or in preparation, directly related to indoor air sources, but also covering outdoor air and industrial emissions, which could affect indirectly IAQ is made. Considering the presented it could be concluded that IAQ is yet poorly regulated at EU level, and in view of that some recommendations are made.

The recommendations on policies have taken into account the existing related to IAQ policies such as new EU policies on chemicals (REACH; 2006/121/EC), consumer products (GPSD; 2001/95/EC), construction products (CPD; 89/106/EC) and energy performance of buildings (EPBD; 2002/91/EC) all refer to IAQ issues - suggesting that they could, and probably should, contribute to IAQ policy development and advocate an integrative and comprehensive policy approach centred on IAQ.

1. Introduction

Human exposure to environmental pollutants occurs via various pathways such as air, drinking water, food, and dermal contact. For many pollutants, especially the volatile ones, air exposure is the dominant pathway. Exposure via air occurs both outdoors and indoors, with diverse types of indoor spaces playing a role, e.g., home, workplace, and passenger cabins of means of transportation.

In average people spend over 90% of their time indoors, that percentage being particularly high for some specific groups as new-born, elderly, disabled or sick people. The global exposure to air contaminants is therefore drastically determined by indoor conditions. Throughout a single day we spend our time in a series of multiple micro environments much different from one to another (e.g.: home, outdoor, transportation, workplace, sport hall, theatre, etc.).

It is now well established that indoor air pollution contributes significantly to the global burden of disease of the population. For a majority of indoor air contaminants, particularly in the presence of common indoor sources, however, indoor concentrations usually exceed outdoor concentrations, for some pollutants even with an I/O ratio of 10 or 20.

Air pollutants in buildings are linked to building indoor factors (structure, fabrics, coating, furnishing, ventilation system, etc.), the specific activities of the occupants, or to other sources found outdoors. Major sources of indoor air contaminants are:

- Ambient air pollution (due to traffic, urban and industrial activities) comes into the building through the ventilation system or by infiltration (building envelop permeability);
- Building materials and furnishings (wall and floor coverings, paints, insulation materials, ...);
- Processes that occur within buildings (combustion, heating, ventilation and air conditioning systems, etc.);
- Occupants themselves and their activities (tobacco smoking, use of cleaning products, plant and pet drugs, cooking, paper processing such photocopying, ...);
- Water and soil (air pollutants coming through water supply, radon and contaminated soils).

This report collates the respective information distributed in scientific journals, conferences, project reports. The 2nd workshop from EnVIE was a unique opportunity to collect the most updated information, identified in the context of the EU R&D projects, on the causes and related preventive measures for the impact of indoor air quality on health.

2. Sources

To act in order to improve Indoor Air Quality (IAQ) in any space it is necessary to understand the sources and dynamic of spaces. One of the main factors is without doubt the sources which can be categorized in building materials and furnishings, the HVAC systems and the occupants themselves and their activities. Ventilation and air changes between inter-spaces are other important aspects in the indoor air composition. We will try to show the contribution to indoor environmental dysfunctions of the identified sources, presenting some study cases with interesting aspects.

2.1. Emissions from building construction

Emission of chemical substances from construction materials and products in buildings to the indoor air have been reported and reviewed (Gustafsson, 1992) for a wide range of substances including those formed during secondary reactions causing complaints of irritation and odour.

Since materials in building structures, and especially those applied to indoor surfaces in large quantities, are permanently exposed to indoor air, it is crucial to have an understanding to what extent they contribute to indoor air pollution. Numerous laboratory investigations have been reported concerning release of chemical substances from interior building materials. However, several of these substances are seldom associated with complaints or building related illness. Usually these substances are released due to migration from the interior of the material, and partly by air currents in the boundary layer in contact with the surface of the material. Molecular migration within the material is influenced not only by the size and the structure of the migrating molecule, but also by the micro structure of the material, the temperature, the moisture content, the pH and other factors. Theoretical models for the process of release of substances from materials have been formulated in various contexts (Dunn, 1987; Kohlhammer *et al*., 1995). In order to be able to compare emission rates from different materials it is essential to measure them under controlled conditions in climate chambers (ISO 16009:2006 - part 9, 10 and 11).

In most of the case studies complaints had been made of the indoor climate and the substances concerned have been released over periods of several years. Various materials have been reported as long-term emission sources on-site in buildings, e.g. paints, products based on coal tar and different polymeric materials. In some cases, the emissions have been caused by moisture-induced degradation of materials (Gustafsson, 1992). Products intended for outdoor use have sometimes been used indoors causing complaints of odour from sealant (Wolkoff, 1987, Wolkoff, 1990) and paint (Wolkoff and Nielsen, 1985).

In the frame of a European project, EDBIAPS - European Data Base on Indoor Air Pollution Sources (1995-1997), a database was created and a set of protocols for testing materials has been prepared (Clausen and Oliveira Fernandes, 1997). These documents were the basis for the existent standards ISO 16000. The work was continued within MATHIS - Materials for Healthy Indoor Spaces and More Energy Efficient Buildings (1998-2000) an European project of the JOULE programme of European Commission Directorate General XII with the

objective of enhance and consolidate the database (Oliveira Fernandes, 2001). In this database renamed SOPHIE over two hundred materials are listed. The database SOPHIE can be characterised as having three main features: identification of a few hundred indoor air pollution sources both through the chemical substances emitted and their sensory impact; qualification of those substances in toxic terms; and a model to establish the link between emissions, including adsorption/desorption effects, and ventilation rates. The sources included in the database (SOPHIE) are both the materials and the HVAC components and systems.

More recently, BUMA - Prioritizitation of BUilding MAterials as sources of indoor pollution (2006-2009), a project supported from European Commission Health & Consumers DG (DG SANCO) has the objective of the formation of a comprehensive database containing up-to-date quantified emitted compounds by construction products and other building materials and the classification and prioritization of building materials from the developed database with respect to hazardous compounds emission factors and the relevant exposure levels. A number of 260 different materials have been added to the database (Bartzis et al., 2008) (http://www.buma-project.eu).

During the last years practical examples of the development of various low-emitting materials have been demonstrated (Gustafsson and Jonsson, 1999).

There are a high number of different building materials and it is difficult to group them in classes, but in this report they will be grouped by function/type materials.

2.1.1. Building materials

Many building materials release gaseous, vapour phase or particulate contaminants into indoor air. Both natural and man-made materials exhibit such releases. Examples include terpenes and formaldehyde from fresh wood and monomers and phthalate plasticisers from man-made polymers. Some releases are caused by inherent decay of the material, such as formaldehyde from chemically unstable urea-formaldehyde resins and vapour phase irritants from the slow oxidation of aging linoleum, while some result from moisture induced reactions, such as ammonia release from the degradation of wetted casein containing fillers. Releases are not necessarily inherent for a certain material, such as PVC tiles or latex paints; rather it is the quality of the specific product brand and batch - e.g. its monomer residue level or physical durability - that may critically determine the exposure of the occupants. The emissions from a material may not be due to the material itself, but instead to chemicals used to treat it, for example to reduce fire hazard (e.g. PBDE in furniture, carpets and appliances) or to prevent mould growth - i.e. for purposeful beneficial purposes in their own right. Releases from some building materials may decay in days or weeks, such as the smell of fresh wood or new carpet, while others may persist as long as the material is present. There are materials which exhibit inherently low emissions, such as stone, glass and stainless steel in the extreme, but these cannot be used for everything.

Some releases may be toxic, allergenic, and odorous or irritating, others are - so far as is known at present - harmless and innocuous at the levels to which we are presently exposed.

The huge qualitative and quantitative differences in the releases and their health effects (if any) set remarkable challenges for the regulators and industry concerning how to measure, test and report the releases, how to judge the data, and how to select and best use the materials considering both long and short term risk and benefits.

2.1.1.1. Synthetic materials

During the last two decades there has been increasing advances in construction technology that have caused a much greater use of synthetic building materials. Whilst these improvements have led to more comfortable buildings, they also provide indoor environments with contaminants in higher concentrations than are found outside.

Polymeric materials are usually products based on petroleum hydrocarbons. The polymer itself is not volatile, due to its high molecular weight. Polymeric materials may emit various process solvents and residual monomers remaining from the raw materials for polymerisation (Gustafsson, 2007).

Long-term emission of volatile residual monomers have been reported from paint (ethylhexylacrylate), carpet (styrene), glass-fibre-reinforced polyester fabric (styrene) (Wolkoff and Nielsen, 1985) and rubber floor covering (styrene) (Wolkoff, 1990). Plasticized products such as PVC is used as floor and wall covering materials and is recognized as sources of phthalate esters indoor (Afshari et al., 2004). There is some epidemiological evidence for associations between phthalates and/or allergic symptoms in the airways (e.g. asthma), nose and skin (Sundell et al., 2007). Various process solvents (dodecene, dodecylbenzene, TXIB® - 2,2,4-trimethyl-1,3-pentanediol diisobutyrate) have been reported to give rise to emission from vinyl floor coverings.

2.1.1.2. Materials based on natural raw materials

Wood and cork are now frequently used as a building product for floor coverings, because the material is often regarded as “natural” and “healthy”. However, industrial products even based on natural raw materials may contain a number of artificial ingredients and the chemical emissions will strongly depend on the type of additives and the manufacturing process.

Horn *et al*. (1998) have reported high emissions of furfural and acetic acid from composite cork products. From chamber experiments it was concluded that furfural is not present in natural cork. Both substances are produced under thermal stress from degradation of hemicelluloses. Acetic acid results from elimination of acetyl-groups, while furfural is formed from pentoses and hexoses under elimination of water. The high concentrations of acetic acid and furfural result from the manufacturing conditions. But the emissions of furfural and acetic acid are not exclusively limited to cork products, being also measured in considerable amounts (1000 $\mu g/(m^2h)$) during chamber studies on particleboard (Salthammer and Fuhrmann, 2000). This effect is attributed to increased temperatures during the manufacturing process.

Adhesives like urea-formaldehyde (UF) and phenol-formaldehyde resin binders are widely used as a major component in the production of building and furniture materials, such as medium density fiberboard (MDF), particleboard (PB) and plywood. However, decreasing the emission levels of formaldehyde fumes from PB manufactured using UF resins has now become one of the major concerns of the timber and wood adhesives industry, particularly in the case of adhesively bonded wood products (Kim et al., 2007).

2.1.1.3. Interior paints and varnishes

Modern interior paints are usually based on a polymeric binder. In order to fulfil requirements on e.g. durability, paints contain various functional chemicals. Water-borne paints usually also contain small amounts of approved (98/8/EEC) biocides. Polymeric binders with a very low content of residual monomers have been developed for paint (Gustafsson and Jonsson, 1999).

Some water-borne paints and varnishes have been giving rise to long terms emissions even after the drying-phase. Examples on substances emitted during several months after the application of the paint are Texanol® (2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate) (Wolkoff *et al*., 1990; Lin and Corsi, 2007), butyl acetate (Schriever and Marutzky, 1990) and dibutylpthalate (Risholm-Sundman, 1981).

Alkyd paint has been reported (Seifert and Ullrich, 1987; Ullrich *et al*., 1982) to emit hexanal and other aldehydes during the oxidative hardening process of the alkyd binder. The study conducted by Chang and Guo (1998) shows that the alkyd paint itself contained no aldehydes and indicated that the aldehydes emitted (mainly hexanal, propanal and pentanal) should be produced after the paint was applied to a substrate, formed as by-products from spontaneous autoxidation reactions of unsaturated fatty acids (in the applied paint) with atmospheric oxygen. In a similar way linseed oil also hardens by the formation of cross-bonds between high-molecular acids. Paint with linseed oil as a binder, and also linoleum, form volatile aldehydes during the oxidative hardening. Another indoor source for aldehydes is wood-based materials in furnishing (Wolkoff *et al*., 1990).

2.1.1.4. Products based on coal tar

Coal tar is a viscous liquid resulting from the carbonization of coal. Many commercially important substances are derived from coal tar. Coal tars are complex and variable mixtures of phenols, polycyclic aromatic hydrocarbons (PAHs) and heterocyclic compounds. In construction coal tar products has previously been used as damp-proof membrane applied to concrete floors, roofing, road paving and as solvent for impregnating wood materials. Creosote is obtained by dry distillation of coal tar and is mainly composed of PAHs, but also contains phenols and cresols. For more than a century, creosote has been a common preservative for construction timber. It is nowadays forbidden (2001/90/EC) to use creosote-impregnated timber for residential buildings. Construction timber impregnated with creosote has also been an indoor source for naphthalenes.

Damp-proof membranes containing coal tar have been reported to give rise to emission of naphthalenes in residential buildings (Brown *et al.*, 1990). Mothballs can also be an indoor source for naphthalenes (Edwards *et al.*, 2005). Coal tar has been used as solvent in preparations with chlorinated substances intended for impregnating and eliminating fungi in wood constructions and wood-derived materials in e. g. fibre boards. Several volatile substances such as naphthalene and chloronaphthalene have been prevalent in the indoor air in various premises where this kind of preparations ("Xylamit") has been used (Deptula *et al.*, 2007).

2.1.2. Interactions in building materials

2.1.2.1. Moisture induced degradation of materials

Besides the release of substances to the indoor air due to primary emission, damp building materials may give rise to volatile substances formed during secondary reactions.

Damp mineral wool in exterior walls and roofs can release aldehydes to the indoor air (van der Wal *et al*., 1987). The aldehydes, ranging from pentanal to decanal, are probably formed by microbial growth. Linoleum can release aldehydes and odorous carboxylic acids, especially if incorrectly wet-washed by the use of excessively strong detergent, which damages the surface layer of the floor covering (Wolkoff *et al.*, 1995).

Self-levelling flooring compounds based on Portland cement and containing casein as a levelling agent may give rise to odorous substances when laid on a damp sub floor. Casein breaks down and form volatile amines such as cadaverine (Karlsson *et al.*, 1989). A breakdown substance of casein, ortho-aminoacetophenone, has a very unpleasant odour that can be recognised at concentrations as low as of the order of nanogram/m^3. Ortho-aminoacetophenone is formed as a result of breakdown of the amino acid tryptophane in the casein.

Portland cement based casein-containing self-levelling compound may also release ammonia, which is capable of discolouring oak parquet laid on top of it (Gustafsson, 1996). Another example for the release of volatile products from rather non-volatile precursors is the release of halogenated compounds from phosphorous-organic flame retardants. 1-chloro-2-propanol, 2-chloro-1-propanol and 1,3-dichloro-2-propanol can appear in indoor air samples from hydrolysis of the common flame retardants tri(chloropropyl)phosphate (TCPP) and tris(dichloropropyl)phosphate (TDCPP), respectively (Salthammer et al., 2003, Uhde and Salthammer, 2007). The later requires increased attention since 1,3-dichloro-2-propanol has been acknowledged as a carcinogenic substance.

A completely different indoor contamination source is glue based on urea-formaldehyde (UF). The stability of these UF polymers against water is low. Therefore, the presence of the unavoidable amounts of water leads to a hydrolysis of the N–O bond and, as a consequence, to the release of formaldehyde. Since UF glues are commonly used in the manufacture of both building materials and furniture the loading factor of such products can be quite high in housings and offices. Especially the application of water-based flooring adhesives on UF-bonded particleboard may cause high and long term emissions of formaldehyde (Uhde and Salthammer, 2007).

The increase of the humidity can also be an indirect factor on the emission of new compounds as they may cause an increase in biological agents as house dust mites, fungi and bacteria. It is known that some examples of building materials, when attacked by fungi, emit odorous VOCs, the so-called MVOC (Microbiologic Volatile Organic Compounds) that result from their metabolism (Norback, 1995; Smedje *et al*., 1996; Thogersen *et al*., 1993; Rocha *et al*., 1996; Clausen and Oliveira Fernandes, 1997). In a more recent paper, the formation of metabolites from biological materials has been reported in detail by Fiedler *et al*. (2001) that have identified about 150 MVOCs from 12 types of mould.

2.1.2.2. Chemical degradation of flooring materials on damp alkaline concrete

Moisture induced chemical degradation of vinyl flooring and floor adhesive may give rise to the formation of odorous alcohols (mainly C_{10-12}) if laid on damp alkaline concrete. The phthalate plasticizer content in resilient vinyl floor coverings can amount to 30% of the weight of the material. The chemical degradation of the plasticizer is strongly accelerated by the presence of alkali. Until the last years the most common phthalate plasticizer in floor coverings has been diethylhexyl phthalate (DEHP) giving rise to emission of 2-ethylhexanol.

In addition, phthalate plasticizers can contain small traces of alcohol components even when supplied to the makers of the floor coverings, in the form of residual quantities from manufacture, in which alcohol is one of the starting chemicals. Octanol is also used as constituent of metal organic stabilizers in PVC. This can be one of the reasons why even unused vinyl floor covering (in which the plasticizer has not been exposed to alkaline hydrolysis) can release octanols. However, the quantity of free octanol, and of octanol that can be released from stabilizers, is negligible in comparison with the quantity released as a result of hydrolysis of the plasticizer.

The types of adhesives most commonly used for laying floor coverings are dispersion-based. This type of adhesive is often based on acrylate copolymers of ethylhexacrylate. 2-ethylhexanol is a feedstock material (an estering alcohol) for the manufacture of ethylhexylacrylate. In the same way as plasticizers, ethylhexylacrylate can be hydrolysed by damp alkaline concrete, thus reforming the odorous alcohol.

Vinyl floor coverings containing phosphorus plasticizer are used in premises with particularly stringent fire safety requirements. The hydrolysis of this type of plasticizer specifically gives rise to the formation of phenol and cresol (Gustafsson, 1992).

Damp concrete is strongly alkaline with pH values of up to 14 in the pore water (Page and Vennesland, 1983). It can take years before a building element, such as a concrete floor slab cast directly on the ground, reaches equilibrium in terms of moisture conditions. Therefore, the odorous substances concerned can be released over a period of several years (Gustafsson, 1992).

2.1.2.3. Indoor surface chemistry

Weschler and Shields (1997) resumed the indoor chemistry: ‘‘From a chemical perspective, the indoor environment is a reaction vessel with chemicals continually entering and exiting. Some of these chemicals can react with one another (or themselves) creating reaction products that might otherwise be absent from the indoor setting. Many of the resulting products are more reactive and/or irritating than their precursors’’.

Indoor air contains many highly reactive molecules and radicals such as ozone (O_3), nitrogen oxides (NO_x), hydroxyl radicals (OH) and sulfur dioxide (SO_2), that are either introduced from the outside air or generated directly indoors by human activities (photocopiers, laser printers, gas cookers, UV lighting, etc.).

There have been several investigations of the interaction between O_3 and surfaces. The experimental investigations on the topic of indoor chemistry became known at the beginning of the 1990s by the work of Weschler *et al*. (1992) on aldehyde emission from carpet in the

presence of ozone. They observed a significant decrease of compounds containing double bonds like styrene and 4-phenylcyclohexene, but also an increase of oxidation products like aldehydes. Morrison et al. determined that carpet exposed to a mean indoor concentration of 2.7 ppb O_3 could result in long-term (years) emissions of aldehyde and ketone species (Morrison and Nazaroff, 2000, 2002a,b). Secondary organic aerosols were measured as a product from ozone-initiated reactions with emissions from wood-based materials and a ‘‘green’’ paint (Toftum *et al*., 2008).

Another problem might become dominant when components of different materials can react with each other. Many building materials, furnishings and household products demonstrate emission of volatile organic compounds (VOCs) during usage (Uhde and Salthammer, 2007). Typical reaction products are aliphatic aldehydes, 2-ethyl-hexanol, MIBK and photoinitiator fragments, while acrylic monomers, reactive solvents, terpenes and diisocyanate monomers are reactive species. Especially such substances may affect humans due to low odour thresholds or low TLV-levels (Salthammer *et al*., 1999).

Another identified problem become from the use of cure- UV during manufacture of some building materials and the role of light in increase of secondary emissions (Uhde and Salthammer, 2007). In many countries, legal requirements regarding the consumption and release of volatile solvents have encouraged manufacturers of coating systems to introduce more and more UV-curable formulations. The technique reduces the amount of solvents required for the coating of metal, wood or other materials significantly and can even be used for powder-based systems. Photoinitiators start the curing process and are essential ingredients of UV-curable coating systems. However, photoinitiators are usually overdosed to avoid undercuring of the lacquer film and a certain amount of residual photoinitiator is left in the finished product after curing.

A resume of test chamber studies on primary and secondary emissions from building products can be found in Table 1 (Uhde and Salthammer, 2007).

Table 1. Test chamber studies on primary and secondary emissions from building products

Building product	Parameters	Reference
Carpet	Ozone	Weschler et al. (1992)
Carpet		Sollinger et al. (1993; 1994)
Linoleum		Jensen et al. (1995a; b)
Latex paint	Ozone	Reiss et al. (1995b)
Wallcovering, latex paint, carpet, plaster, plywood	Ozone	Moriske et al. (1998)
PVC, parquet, carpet, sealant, paint	Air velocity, humidity, temperature, air	Wolkoff (1998)
Cork products		Horn et al. (1998)
PVC, parquet, carpet, sealant, paint	Air velocity	Knudsen et al. (1999)
Wood-based furniture coatings		Salthammer et al. (1999)
Carpet, PVC flooring, sealant, floor varnish, wall paint	Temperature, humidity	Fang et al. (1999)
PVC, adhesive	Complete floor structures	Sjöberg (2000)
Particle board, MDF		Baumann et al. (1999, 2000)
UV-cured lacquer	Light	Salthammer et al. (2002)
Wood	Heat-treatment	Manninen et al. (2002)
Carpet	Ozone	Morrison and Nazaroff (2002)
Polyurethane		Salthammer et al. (2003b)
Plasterboard, paint, carpet, linoleum, pinewood, melamine	Ozone	Knudsen et al. (2003)
Wood-based products, laminate, cork, adhesive, lacquer	Complete floor structures	Salthammer et al. (2004)
Adhesives, PVC, linoleum, rubber, polyolefine	Complete floor structures	Wilke et al. (2004)
UV-coating	Light	Salthammer et al. (2002)

Some examples of reactants and products, as well as, possible sources are summarized in Table 2 (Uhde and Salthammer, 2007).

Table 2. Possible reaction products in indoor air with potential emission sources and reactants

Reactants	Products	Possible source
α-pinene	Pinene oxide, pinonaldehyde	Wood, wood-based products
Limonene	Limonene oxide, carvone, formaldehyde	Wood, coating systems
Oleic acid	Heptanal, octanal, nonanal, decanal, 2-decenal	Linoleum, eco-lacquers, nitrocellulose-lacquers, alkyd resins
Linolenic acid	2-pentenal, 2-hexenal, 3-hexenal, 2-heptenal, 2,4-heptedienal, 1-penten-3-one	
Linoleic acid	Hexanal, heptanal, 2-heptenal, octanal, 2-octenal, 2-nonenal, 2-decenal, 2,4-nonadienal, 2,4-decadienal	
Hemicelluloses	Furfural, acetic acid	Cork
PHMP	Benzaldehyde, acetone, benzil	UV-cured coatings
HCPK	Benzaldehyde, cyclohexanone, benzil	UV-cured coatings
2-ethyl-hexyl acetate	Acetic acid, 2-ethyl-1-hexanol	Solvent
Zn-2-ethylhexanoate	2-ethyl-1-hexanoic acid	Stabilizers
n-butylacrylate	*n*-butanol	Acrylate coatings
DEHP	2-ethyl-1-hexanol	Plasticiser
DBP	*n*-butanol	Plasticiser
DIBP	2-butanol	Plasticiser
TCPP	1-chloro-2-propanol, 2-chloro-1-propanol	Flame retardant
TDCPP	1,2-dichloropropane, 1,2-dichloropropanol	Flame retardant
TCEP	2-chloro-ethanol	Flame retardant
TBPP	1-bromo-2-propanol, 2-bromo-1-propanol	Flame retardant
TDBPP	2,3-dibromo-1-propanol	Flame retardant
Styrene + cis-1,3-butadiene	4-phenyl-cyclohexene (4-PCH)	SBR
Cis-1,3-butadiene + trans-1,3-butadiene	4-vinyl-cyclohexene (4-VCH)	SBR
2-chloro-1,3-butadiene	1-chloro-4-(1-chlorovinyl)-cyclohexene 1-chloro-5-(1-chlorovinyl)-cyclohexene	Rubber
Zn-diethyldithiocarbamate	CS_2, diethylamine	Vulcanization accelerator
Azodicarbonamide	Semicarbazide	Foaming agent
Adipinic acid + 1,4-butanediol	1,6-dioxa-cyclododecane-7,12-dione	Adhesive
Dimethylaminoethanol + formic acid	Dimethylformamide	"Green" paint
l-tryptophane	*o*-aminoacetophenone	Casein products
2,3,4,6-tetrachlorophenol	2,3,4,6-tetrachloroanisole	Application of PCP
T4MDD	MIBK, 3,5-dimethyl-1-hexyne-3-ol	Water-based paint
AIBN	Tetramethyl succinonitrile	Flexible PU foam

Recently, new photocatalytic paints have been launched on the market, which are claimed to have air-purifying effects. A study carried out by Auvinen and Wirtanen (2008) shows that photocatalytically active paints were able to decompose only more reactive VOCs (1-hexanol and nonanal), but at the same time they also generated, for instance, formaldehyde, acetaldehyde, and acetone that may cause adverse health effects in people.

2.1.2.4. Release and sorption of semi-volatile organic substances

Semi-volatile organic compounds (SVOCs) are now receiving much more attention than heretofore. Their major sources are in the outdoor air (containing contaminants such as pesticides) that may also infiltrate the building giving high level of concentration in the indoor environment. The trend nowadays, with the new building materials becoming cleaner, is that the VOC levels tend to decrease and the SVOC levels tend to increase, reflecting a substitution of VOC with SVOC to decrease exposure concentrations. The use of additives to increase the performance of building materials, as biocides and flame retardants, contribute also to the increase of SVOC emissions. However, the toxicity of the new compounds is unclear and health related criteria for the substitution is lacking (ECA Report 25, 2006).

Release of low-volatility chemical substances from construction materials and products in buildings have been reported, e.g. dibutylpthalate from wall paint (Risholm-Sundman, 1981), TXIB from vinyl floor covering (Rosell, 1990), PCB from paint on ceiling tiles (Todd, 1987) and various hydrocarbons from sealant and rubber floor covering (Wolkoff, 1990). These

SVOCs seem to be largely adsorbed on airborne particles. SVOCs can condense on electronic equipment and cause it to malfunction. Extensive measurements have therefore been made in telephone exchanges and other installations (Weschler and Shields, 1987).

Deposition of SVOCs on dust may lead to significant exposure through inhalation of indoor air. Additive phosphor containing flame retardants (PFR) are ubiquitous substances that appear to be present in all types of indoor environments and identified sources include floor coverings and acoustic ceilings (Hartmann *et al.*, 2004, Marklund *et al.*, 2005). The increasing strictness in regulating the use of additive brominated flame retardants will probably cause a further increase of the use of PFR (WHO, 1997).When dust in residential buildings is heated, e.g. on radiators, refrigerator compressors and incandescent lamps, phthalates and other substances can be released to the air (Vedel and Nielsen, 1984).

2.1.3. Decay of emissions in building materials

When emission has been caused by a chemical reaction in or between the materials, it has often been difficult to document precisely when the elevated rate of emission occurred. The progress of the chemical reactions naturally depends on the materials involved and, in many cases, also on if and when the structure was exposed to moisture (Gustafsson, 1996).

However, when the emission has not been caused by chemical reactions but can be regarded as straightforward evaporation, it means that it will be highest for new materials. Well-known examples are solvent-borne paint and varnish, from which the volatile substances has largely evaporated after a few hours. Water-borne paints take longer to dry out, and glycol ethers have been found in indoor air six months after the application of paint (Wolkoff, 1990).

Various substances have been reported to be released over periods of several years (Gustafsson, 1992). This is the case, for example, for TXIB, dodecane, styrene, naphthalene, ethylhexylacrylate, cresol, dibutylphthalate, butyl acetate (Schriever and Marutzky, 1990) and chlorinated aromatics (Deptula *et al.*, 2007).

As far as the time of reduction of emission from building materials in general is concerned, measurements made in low-energy houses in Denmark can give some guidance (Mølhave, 1985). The measurements were made in six low-energy houses built with various materials and by different methods. The houses were unoccupied and unfurnished, but the ventilation systems were in operation. A conclusion is that, in the majority of the houses investigated, the indicative sum of volatile substances have halved over periods of 2-6 months.

Investigation of the air quality in a newly-built child day-care centre has shown that the concentrations of substances typical found in indoor air fell by about two-thirds during the first six months after taking the building into use (Berglund *et al.*, 1982a). Other investigations have shown, too, that a large proportion of the volatile substances originating from building materials have been emitted within a period of six months (Wallace *et al.*, 1987).

In another investigation, it has been noted that the concentration level fell to the original level about four months after completion of renovation (Shields and Weschler, 1990). The same length of time was noted in connection with the use of an entirely solvent-based adhesive (Seifert and Ullrich, 1987). The concentrations of air pollutants in buildings in response to

different ventilation rates have been investigated by Berglund *et al*. (1982b), Hodgson and Girman (1989), Turiel *et al*. (1983) and in other works.

2.2. Emissions from HVAC systems

The HVAC (Heating, Ventilation and Air Conditioning) systems as providers of services of cleaning and dilution of pollutants in the indoor air but also as recognized potential pollution sources. The outdoor air as an important and controllable source from some indoor pollutants will be also taken in account in the characterisation of IAQ.

2.2.1. Outdoor and other pollution sources related to ventilation

Outdoor air used for ventilation may also be source of pollution containing particulate matter, particulates of biological origin (microorganisms, pollen, etc.) and various gases like NOx and O_3. Some O_3 is removed by the contact with building surfaces. In the naturally ventilated buildings all pollutants in the outdoor air enter to the inside. In mechanically ventilated building it is possible to reduce concentrations of certain pollutants in outdoor air for ventilation air before it enters indoors, but usually not NOx and O_3.

Daily inhalation intakes of indoor O_3 (μg/day) are estimated to be between 25 and 60% of total daily O_3 intake. This is especially noteworthy in light of recent work indicating little, if any, threshold for ozone's impact on mortality. Lack of air conditioning is suggested to be associated to higher morbidity and mortality in cities with older housing where less air conditioning is prevalent (Weschler, 2006).

The outdoor air intakes should be placed so that the air taken into the building is as clean as possible and in summer time as cool as possible and not polluted by the sources close to the building.

Potential outdoor sources are such as:

- garbage collection point;
- evaporative cooling systems and cooling towers (risk of *Legionella*);
- busy streets;
- loading decks;
- exhaust air openings;
- biomass burning stoves and boilers.

The arrangement of air intakes and discharge openings should also minimize the possibility of external recirculation between polluted exhaust air and clean air for ventilation.

2.2.2. Pollutants in air handling equipment and systems

Several studies have shown that the prevalence of SBS symptoms is often higher in air conditioned buildings than in buildings with natural ventilation (Mendell and Smith 1990; Seppänen and Fisk, 2002). One explanation for the association of SBS symptoms and mechanical HVAC systems is VOCs and other chemical pollutants which are emitted by HVAC components and ductworks. It has been shown that chemical and sensory emissions of building materials, ventilation systems and HVAC components are significant and play a

major role in the perceived IAQ of a space (Fanger, 1988). The emissions may originate from any component in the HVAC system.

The measurements of chemical emission from typical materials used in HVAC system are sparse. Measurements indicate (Morrison and Hodgson 1996, Morrison *et al*., 1998) that emission rates of VOCs emitted by the materials vary considerably. High emitting materials according to their measurements were used duct liner, neoprene gasket, duct connector and duct sealant. The high surface area materials such as sheet metal had lower emission rates. The emission of VOCs may increase when the components and surfaces get dirty due to inferior maintenance. This hypothesis is supported by several field studies which have reported the association between the indoor air problems and dirtiness of HVAC system (Sieber *et al*., 1996; Mendell *et al*., 2003). Crandall *et al*. (1996) and Sieber *et al*. (1996) reported that poor HVAC cleanliness was significantly related to elevated multiple respiratory symptoms with risk ratio of RR= 1.8, dirty filter with RR= 1.9, debris inside air intake with RR= 3.1, and dirty duct work with RR= 2.1. These all are indicators of sources of chemical pollutants in the HVAC-system. Studies have shown that a major source of pollution can be also a used air filter loaded with dust. The dust further may react with other chemicals in the outdoor air and new chemicals are generated into the ventilation air passing through the filter (e.g. Wargocki *et al*., 2004).

Poor condition and maintenance of HVAC systems has been identified as a risk factor (Mendell *et al*., 2003, 2006). Current findings (Mendell *et al*., 2007) support earlier findings (Mendell *et al*., 2006) that moisture-related HVAC components such as cooling coils and humidification systems, when poorly maintained, may be sources of contaminants that cause adverse health effects in occupants, even if we cannot yet identify or measure the causal exposures.

The European Audit project on IAQ (Bluyssen *et al*., 1996), the European Data Base Project on Air Pollution Sources and the European Airless project (Bluyssen *et al*., 2001) have shown that the perceived quality of supply air is not always the best possible, and is often even worse than the perceived quality of outdoor air quality. The perceived air quality of the air supplied to the rooms, however, was usually not as bad as it was immediately after passing through a filter. This may be due to absorption in duct systems or chemical reactions in the air. A recent study (Wargocki *et al*., 2000) has shown a slightly lower but still significant pollution load from building sources including the air handling systems (0.04 - 0.27 olf /m^2).

One of the most important reasons for duct cleaning is preventive maintenance. Duct cleaning minimizes the possibilities of microbial growth that would be likely in dirty ducts should water leaks or high humidity conditions occur (Luoma *et al*. 1993; Batterman and Burge 1995; Fransson 1996). Another reason is the reduction of odorous compounds in the indoor air. Björkroth *et al*. (1998) showed in a laboratory setting using a trained sensory panel that an old dirty duct and a new uncleaned duct emitted odour to the supply air whereas a new clean duct absorbed odour from the supply air. Odour generation of dirty ducts increased with air velocity, which also increased the sink effect of the new cleaned duct. Additionally, Björkroth and Asikainen (2000) found a strong correlation between perceived air pollution and the cumulative mass of oil residuals in old ventilation ducts.

Ventilation systems have several other components beside ducts which may act as a source of odours, and their effects on perceived air quality have been investigated in several studies (e.g. Pejtersen *et al*., 1989; Finke and Fitzner, 1993; Tuomainen *et al*., 2000; Alm 2001; Bitter

and Fitzner, 2002). The main potential components increasing the sensory load are filters, humidifiers, heating and cooling coils and rotating heat exchangers (Bluyssen *et al*., 2003).

The evidence from the epidemiological studies and laboratory measurements support the hypothesis that contaminated HVAC system may be source of pollutants, and increases the exposure to pollutants which increase prevalence of sick building symptoms in office buildings. There is also substantial amount of evidence that suggests neglected maintenance being a major reason to these problems (Lam *et al*., 2006). Evidence also suggests that inferior maintenance is a common problem both in North America and Europe.

Severe problems are created also with condensation if the components are not properly maintained, drained and cleaned. Improperly maintained condensing cooling coils may be a major source of microbial pollution in buildings. Several studies and guidelines (e.g. ISIAQ, 1996) have pointed out the importance of the cleanliness of cooling coils. For example a study in Southern California discovered that one third of the cooling coils in the large air handling units and two thirds in the small ones were contaminated in the United States (Byrd, 1996).

2.2.3. Ventilation and spread of contaminants

Ventilation together with stack effect and wind affects also the pressure differences over the building structures. Pressure difference is a driving force for the airflows which will transport water vapour and gaseous or particulate contaminants.

One of the most important issues in respect of healthy buildings is to keep building structures dry and prevent the condensation of water in and on structures. Air and moisture convection through the building envelope may cause severe moisture loads for the structures. In cold climates the water content of the air is usually higher indoors than outdoors. If the pressure is higher indoors the air with high moisture content may flow into the cold structure and water vapour may condense. The opposite is also true in hot climates. Thus, exfiltration in cold climates and infiltration in hot climates may cause moisture accumulation or condensation, leading to microbial growth on materials, reduction of the thermal insulation properties and changes of the other material properties or even leads to structural deterioration. The relative humidity at the connection of floors and external walls in multi-storey platform timber-frame houses can be rather high, causing the risk of mould growth and rot fungi when there is positive air pressure inside the building (Kilpeläinen *et al*., 2000). The simulation results of Janssens and Hens (2003) have shown that, even when a roof design complies with condensation control standards, a lightweight system remains sensitive to condensation problems because of air leakage through the discontinuities, joints and perforations, common to most existing construction methods.

The effect of the pressure differences is utilized in certain spaces which are designed for overpressure in relation to outdoors or adjacent spaces. Clean rooms, rooms for sensitive electronic/data processing equipment and operating theatres in hospitals are examples for such spaces. In situations with no special requirements or emissions, ventilation systems are normally designed for neutral pressure conditions in the building. Pressure conditions should also be continuously monitored in spaces where heavy emission of impurities occurs. The air pressures in stairways, corridors and other passages should be designed so that they will not cause airflows from one room or apartment to another.

It has been suspected that the air flows through the mouldy structure may carry harmful pollutants inside. Residential buildings often have mechanical exhaust ventilation, where intake air comes through inlets and cracks. In cold climates, inlets will cause draught in winter and they are often closed, resulting in a high negative pressure indoors and forced airflow through cracks. Typically, mechanical exhaust ventilation creates a negative pressure of 5-10 Pa in the apartments (Säteri *et al*., 1999) if the inlets are open. A field study (Kurnitski, 2000) showed high infiltration airflow rates through leaks in the base floor to the apartment at a pressure difference of around 6 or 15 Pa which depended on the speed of the exhaust fan. Pessi *et al*. (2002) have found that fungal spores can penetrate sandwich element external wall structures when mechanical exhaust ventilation is used. Field measurements (Mattson, 2002) have shown that the mould spores can be carried inside through a base floor in a house with mould growth in the crawl space. The transport was highly dependent on exhaust ventilation, as outdoor concentration and indoor concentrations with non-operating ventilation were between 200-500 cfu/m^3, but when exhaust ventilation was switched on, indoor concentration of about 5000 cfu/m^3 was measured. In the field measurements of ten residential buildings (Airaksinen *et al*., 2004) the extent of the correlation between the fungal spores in the crawl space and indoors depended on the microbial species. The concentration of the most abundant species, *Penicillium*, did not correlate between crawl spaces and indoors. The concentration of *Acremonium*, which do not have a natural source indoors correlated to the indoor concentration, indicating air leakage and fungal spore transport from crawl space air to indoors.

The relative pressures of the building, different spaces and the ventilation system should be designed so that spreading of odours and impurities in harmful amounts or concentrations is prevented. No significant changes to the pressure conditions are allowed due to changes in weather conditions. The air tightness of the building envelope, floors and partition walls, which affect the pressure conditions, should be studied and defined in the design stage, taking account of both temperature and wind conditions. The pressure relationships should be confirmed in the commissioning of the building and periodically re-commissioned to ensure that deterioration of building components or shifting due to thermal, wind or seismic forces has not denigrated the envelope tightness or other pressure-critical components.

Low ventilation may lead to high indoor humidity and moisture accumulation into building structures or materials. That may lead to increased dust mites, and particularly high humidity can increase the risk of microbial growth, and subsequently to microbial contamination and other emissions in buildings. In epidemiological studies, moisture damage and microbial growth in buildings have been associated with a number of health effects including respiratory symptoms and diseases and other symptoms (Bornehag *et al*., 2001; Nevalainen, 2002); although, the evidence of a direct link between higher air humidity levels and adverse health is quite limited. The health effects associated with moisture damage and microbial growth seem to be consistent in different climates and geographical regions (ISIAQ, 1996).

In many cases ventilation reduces the moisture contents indoors. The effect of ventilation is twofold. Ventilation can remove indoor generated moisture directly, and dilute the water content of the air to a lower level. However, when it is hot outdoors, the moisture content in the outdoor air is often higher than the indoor moisture content, because air conditioning and/or dehumidification systems are used to reduce indoor moisture levels. In these situations, ventilation is ineffective for indoor humidity control – in fact ventilation becomes a source of moisture and mechanical systems are needed to remove moisture from the incoming outdoor

air or from recirculated air. In climatic conditions (summer in some coastal areas) the outdoor moisture contents may be high. In those conditions the ventilation is not effective.

2.3. Consumer products

Salthammer (1999) reviewed the scientific literature on volatile ingredients of household and consumer products and emission into the indoor air. The paper shows that VOCs are emitted from a wide variety of household and consumer products with emission rates that are strongly dependent on the type of application and are distributed over several orders of magnitude. A number of product classes are identified and information on ingredients and available data on emissions from individual products are presented. The product classes identified are;

- Newspaper and journals;
- Electronic devices;
- Insecticides;
- Air fresheners / deodorisers;
- Household cleaners;
- Adhesives;
- Polishes;
- Personal hygiene and cosmetics;
- Toys.

Nazaroff *et al*. (2004) discuss the nature and air pollutant exposures resulting from the use of cleaning products and air fresheners in homes and non-industrial workplaces. They consider both the chemical exposures resulting from primary emissions from the products themselves and the formation of secondary pollutants caused by interaction with other reactive species such as ozone. It is reported that in the United States, adults spend on average about 20 to 30 minutes per day on house cleaning and in a study from 1992, 31% of adults surveyed were near or used scented room fresheners. The following mechanisms by which cleaning products can influence inhalation exposure are identified;

- Volatilisation of ingredients e.g. formaldehyde from wood floor cleaning spray;
- Production of airborne droplets e.g. through aerosol or pump-spray delivery;
- Suspension of powders; e.g. sodium tripolylphosphate from carpet cleaner;
- Suspension of wear products e.g. surfactants, disinfectants;
- Inappropriate mixing e.g. chloramines from mixing bleach and ammonia based cleaners;
- Chemical transformations e.g. terpene reaction with O_3 to form radicals;
- Altered surfaces e.g. enhanced VOC emissions from wet linoleum.

Jensen and Knudsen (2006) undertook a health assessment of chemicals in the indoor environment released from various consumer products. The assessment was based on 60 reports published by the Danish Environmental Protection Agency on the study of chemicals in various consumer products, although not all considered release to the indoor air. Potential indoor concentrations of eight selected VOCs (phenol, formaldehyde, acetaldehyde, benzene, toluene, xylenes, styrene and limonene) were estimated in three model rooms: a hall/utility room, a kitchen/family room and a children's room. The products shown to release the prioritised products are listed, for example for xylenes; computers, monitors, chargers, playing consoles, household ovens, decorative lamps, hair dryers, mobile phones, TV apparatus, recharged batteries, printed matter, incense, tents for children, beads, Christmas spray.

It was concluded that highest concentrations in a home are likely to occur in the children's room as this room is normally smaller than most others and it contains many products which may release chemicals into the air. It is noted that products differ from each other by having different emission patterns. Use of incense and spray products indoors were the most polluting of the studied products/activities and emitted considerable amounts of hazardous chemicals.

Spruyt *et al*. (2006) investigated chemicals released from 20 air fresheners of different types; candles (white and scented), gel and spray in an environmental chamber and investigated six products in real rooms. According to Wang and Morawska (2008) the consumables used for printing like paper and toner are possible sources of ultra fine particles, but aerosols might also be formed by VOC which are emitted during the printing process from the consumables or from printer materials. Other study (He et al., 2007) found ultrafine particles pollution in an office which could be related to the use of hardcopy devices. They also classified some printers due to their emission strength in "low", "medium" and "high" emitters. Jann *et al*. (2005) reported results of chamber tests of nearly 60 hardcopy devices (printers, copiers and multifunctional devices) to determine rates of emission of VOCs, O_3 and dust. Ozone emission rates were mostly near zero, but nine products gave between 2 and 9 mg/h. Dust emission was below 4 mg/h. A wide range of VOCs were emitted and 59 individual compounds were identified. Nonaka *et al*. (2005) investigated the performance of a test chamber method to determine the chemical emissions from a laser printer, including formaldehyde and VOCs.

There is an increasing concern about the use of consumer products in indoor environments, because of their content of terpenes that potential react with O_3 to produce harmful oxidation products, both gaseous and ultrafine particles. For example, use of consumer products has been associated with airway problems among preschool children and cleaning personnel (Wolkoff et al., 2008).

As well as the direct impact of emissions from indoor sources on IAQ consideration should be given to that resulting from exposure to the products of chemical reactions in the indoor air. Weschler (2003) reviewed the role of indoor chemistry in the formation of particles in indoor air. Reactions of O_3 and hydroxyl radicals with terpenes were once considered only an issue of outdoor air with photochemistry playing an important role, but occurrence of such reactions indoors is well recognised. As well as entering buildings from outdoors, O_3 can be released indoors from photocopiers, laser printers, electrostatic precipitators and ozone generators marketed as 'air purifiers'. Terpenes can be emitted during use of solvents, cleaners, degreasers, odorants in various products, air fresheners and from unsealed wood products. The ozone/terpene reaction products have a broad range of volatilities and those of low volatility sorb to existing particles or they may nucleate to form new particles. About half of the initial mass increase resulting from indoor terpene/ozone reactions is in the ultra-fine mode and this fraction has high deposition in the human respiratory tract. Indoor chemistry can contribute to indoor particulate exposures, but in a complex way since the contribution will vary with time of day, from day to day and with season. Noting that outdoor particles are correlated with outdoor ozone concentrations, the generation of particles by indoor chemistry is likely to correlate with outdoor levels, in the absence of strong internal sources of O_3. Therefore indoor chemistry should be considered in the evaluation of epidemiological studies of associations between changes in outdoor sub-micron particle concentrations and increases in rates of morbidity and mortality.

Results presented by Singer *et al*. (2006) provide information about emissions and concentrations of primary pollutants and the secondary pollutants of cleaning products and air fresheners. They conclude that the use of such products in the presence of elevated indoor ozone is of concern because of the formation of secondary air pollutants that pose health risks. Limonene and other ozone-reactive terpenoids present in cleaning products can reach milligram per cubic meter levels in air and persist at levels of tens to hundreds of micrograms per cubic meter for many hours after cleaning. Air fresheners can produce steady-state levels of tens to hundreds of micrograms per cubic meter of ozone-reactive terpenoids. Some household cleaning agents contain formaldehyde solution as disinfectant.

As well as contaminants in the air, consumer products are a source of some non-volatile and semi-volatile contaminants found in house dust. Chemicals in the dust can be ingested directly, particularly through hand to mouth contact by children and through contamination of foodstuffs. They can also be inhaled when re-suspended which can occur during human activities such as cleaning. Sources of chemicals in dust include material tracked in from outdoors, compounds deposited after entry of contaminated outdoor air and indoor sources. Contaminants from consumer products include nicotine from ETS and pesticides from products used in the home (Butte 1999, 2003).

2.4. Occupant behaviour and maintenance

This chapter concerns the release of pollutants resulting from human activities and the associated use of products. This encompasses a wide range of indoor sources involving release of inorganic gases, particles and organic compounds as a consequence of the activity. For some releases such as with air fresheners the release is a necessary part of the activity to achieve the intended effect whereas for others, such as the release of combustion fumes from a gas appliance, the purpose of the action (in this case generation of heat) is different from the emission.

While not discussed further here, it should be noted that humans and their associated activities, such as washing and cleaning as well as combustion of fuel, release water vapour into the indoor environment. Ventilation and heating in cold climates is needed to prevent condensation and dampness occurring. Damp conditions encourage the growth of fungal moulds and sensitisation to spores produced by such moulds is a well recognised exacerbating agent of asthma. Particles (spores) and volatile compounds (fungal metabolites) can also be released from such growths. The release of water can to some extent be mitigated by occupant behaviour, such as by not drying clothes indoors where alternative methods are available and by opening windows for high ventilation after a bath or shower.

It is difficult to generalise about the relative importance of human activities as sources of indoor pollutants compared with other sources such as contaminants in outdoor air, emissions from building and furnishing materials, and ingress of soil gas. The relative importance will depend on the particular pollutant and the characteristics of the building and the occupants. It can be expected that the concentration will have a time dependency that relates to the use of the product that is the indoor source. This is clearly the case for elevation of levels of nitrogen dioxide and carbon monoxide during the use of a gas cooker for example. However there may be other sources of the same pollutant that could be in outdoor air or released from indoor

materials, and this can make it quite difficult to distinguish the contribution of different sources to the observed concentration of a particular pollutant in an occupied building.

2.4.1. Combustion sources

Combustion processes are an important source of a range of air pollutants as follows:

- Carbon monoxide (CO);
- Nitrogen dioxide (NO_2);
- Sulphur dioxide (SO_2);
- Particulates and associated inorganic and organic chemicals;
- Organic vapours e.g. formaldehyde, acetaldehyde, benzene.

Sources of these are present in both ambient and indoor environments. The concentrations present in the ambient air provide a baseline for the level of pollutant found indoors as this air enters indoors by processes of infiltration and ventilation. However, the concentration indoors will be modified by processes of sorption to surfaces and chemical reaction depending on the chemical and physical properties of the pollutant and internal surfaces. Also sources of these pollutants indoors will result in direct emissions to the indoor environment and resulting concentrations will depend upon rates of emission, dilution by internal space and removal by air exchange with the outside.

The most common cause of high exposure to CO is the smoking of tobacco. Faulty domestic cooking and heating appliances inadequately vented to outside air can cause high concentrations. Gas stoves, unflued gas stoves, unflued gas room heaters and exhaust from vehicles in attached garages are important sources. The type of fuel used is an important factor on CO emissions as illustrated in Table 3 (Kotzias et al., 2005).

Burning of fuels for heating and cooking as well as candles and incense are sources of organic compounds such as formaldehyde, acetaldehyde and benzene. Cooking fumes from heating of cooking oils contain potentially harmful chemicals such as aldehydes, ketones, hydrocarbons, fatty acids, alcohols, aromatic compounds and heterocyclic compounds. The surveys of indoor pollutants that look at associations between pollutant concentrations and possible sources can provide information about the relative importance of sources including combustion products. For example the IAQ survey of England found a significant correlation between the presence of a gas cooker with indoor NO_2 concentrations and integral garages with benzene concentrations.

Table 3. Estimated indoor CO concentrations resulting from burning 1 h of fuel in stove without flues using assumptions relevant in developing countries i.e. fuel consumption equal to the energy used for burning 1,7 kg of fuel wood, ventilation rate oh $15h^{-1}$ and room volume of 40 m^3.

Fuel	CO concentration (mg/m^3)	
	Avgerage during burning	maximum
Charbiquette	562	603
Charcoal	528	566
Brush wood	511	548
Coal	178	191
Fuel wood	150	161
Kerosene	9.4	10
LPG	4.5	4.8
Biogas	1.6	1.7
Natural gas	0.083	0.089

Jantunen (2007) notes that domestic combustion devices used to heat, cook and entertain (fireplaces, incense, candles) use heterogeneous fuels, are operated by untrained persons and are hardly ever equipped with any feedback control or flue gas cleaning. The combustion process generates particulate matter, certain VOCs and carbon monoxide as well as water and carbon dioxide. By far the highest exposures to combustion particles (also gases and vapours) occur in indoor air and originate from indoor sources.

Some incense was revealed as important source of CO and benzene (see Figure 1).

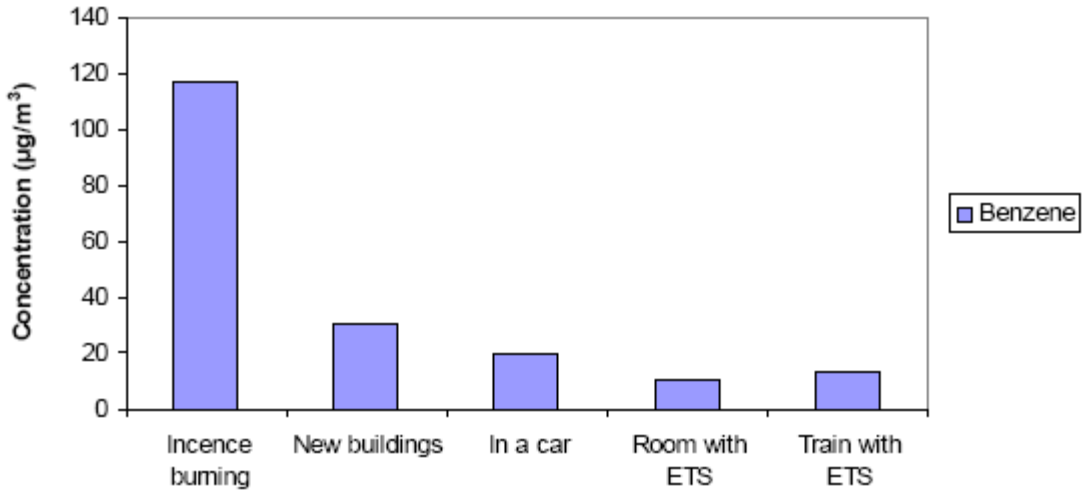


Figure 1. Short time benzene concentrations related to specific microenvironments or emission sources (from Kotzias et *al.*, 2005)

Jetter *et al.* (2002) reported emission rates of 23 different types of incense such as incense rope, cones, sticks, rocks, powder etc. that are typically used indoors. The measured emission rates of CO ranged 144-531 mg/h. The authors estimated a peak concentration of 9.6 mg/m^3 caused by incense burning. Lee and Wang (2004) reported similar results when studying emissions of incense burning in chamber (18 m^3) tests. They measured maximum carbon monoxide concentrations up to 44 mg/m^3 during burning and concluded that incense burning is an important indoor air pollution source in addition to CO also to fine particles and VOCs.

Nazaroff and Klepeis (2003) reviewed the contribution of environmental tobacco smoke (ETS) to indoor air concentrations and human exposures to particles. ETS is a mixture of gases and particles generated by combustion of tobacco products including cigarettes, cigars and pipes. Once released the particles and gases are subject to processes that alter their concentration, physical form and chemical composition. The particles are small liquid products mostly in the size range 0.02-2 µm. Studies have demonstrated that ETS is an important source of fine particles indoors and that when present it typically increases average fine particle indoor concentrations in the range of 10 to 45 µg/m^3. The chemical composition of the gases and particles is complex with more than 4,000 components identified in mainstream smoke (Guerin *et al.*, 1992). As well as the release of a wide range of VOCs and SVOCs during tobacco combustion, CO and oxides of nitrogen are important contaminants released with regard to risks to human health. In the Expolis study in Helsinki it was noted that the only significant indoor source of benzene was tobacco smoke.

2.4.2. Other

People themselves are a source of emissions of chemicals and gases, notably CO_2, but also a range of organic compounds that are referred to as body odours. The removal of such body odours is a prime objective of ventilation in order to achieve a satisfactory indoor environment.

There is also other behaviour that could be a cause of problems, like lack of maintenance activities in a building. With the age a building deteriorates and needs little repairs to avoid problems like leaks and consequent infiltrations in the structure. Mould and fungi problems could be avoided with a good maintenance by the owners of the buildings, for example.

Hubbard *et al*. (2005) refer to the many air purifiers including those marketed as electrostatic precipitators, negative ion generators that produce O_3. Because of known effects of O_3 on health, several government agencies in the United States have warned against their use. This group undertook experiments to determine the effect of an air cleaner on indoor air O_3 levels and investigated the formation of particles in the air resulting from chemical reactions involving O_3 and terpenes.

3. Existing policies on IAQ or IAQ related in EU

The purpose of EnVIE is to be able to propose policies to face the indoor air quality issue. Basically there are two strategies: source control where, by using the precautionary principle, the nature or strength of the sources, or even their existence indoors is removed, replaced or moderated; and exposure control, essentially through ventilation, as the ultimate solution for a given existing space.

As the scope of this WP3 is the sources, the policies addressed here are those related with the origin of emissions of designated pollutants. Nevertheless once ventilation is always necessary and that means introducing outside air indoors, ventilation may appear associated to indoor sources by two different ways: ventilation is making outdoor air an indoor air source; and ventilation, when assured through mechanical equipments, may, itself, be a source of its own pollutants.

In such a context, and following the EnVIE structure for sources we could organize them the following way:

- building materials and products, including supervening effects (dampness and mould);
- HVAC systems, related to the service of ventilation (besides, eventual, heating, cooling and hu & dehumidification) and other equipments in the building;
- consumer products;
- occupants and their activities.

The European situation with regard to outdoor air pollutants has improved in recent decades, particularly in relation to concentrations of SO_2, total suspended dust and CO, but NO_2 and soot concentrations are also showing a downward trend. This is due to reduced emissions in the industrial, transport and energy sectors. The quality of outdoor air is a good start point for a good IAQ as air exchange between indoor and outdoor is crucial. If air quality outdoor is poor, the outdoor air supply will inevitably increase the concentration of pollutants in the room air and thus decrease the IAQ.

Concerning indoor air pollutants the situation is more difficult, due to the complexity of indoor spaces being by the different functions and sources that can occur, being by the high number of compounds that can exist and the reactions that could occur in simultaneous. In addition people spend approximately 90 percent of their time indoors. To aggravate the situation, there is a big difference in terms of scales between exposure concentration in industrial work and in indoor spaces. The occupational exposure limits (OEL, TLV, MAK, etc.) are not directly applicable to indoor environments because they have been developed for healthy adult populations and more or less controlled 40 h exposure in a 168 h week. In addition, people who may be exposed to indoor air pollutants for the longest periods of time are often those most susceptible to the effects of indoor air pollution: the children, the elderly, and the chronically ill, especially those suffering from respiratory or cardiovascular disease.

For many chemicals present in indoor environments, the risk to human health and comfort is unknown and difficult to predict, in particular, the risk associated with chronic low dose

exposures to these compounds because of a quite limited toxicological data and information on dose-response characteristics in human or animal models. Due to missing risk assessment of these chemicals, however, it has been difficult to regulate the presence of these substances in indoor air. In 2002, a European Project called INDEX was started with the aim to identify these priorities and to assess the need for a Community strategy and action plan in the area of indoor air pollution. The INDEX report (Kotzias *et al*., 2005) provides a list of priority substances to be regulated in indoor environments on the basis of health impact criteria and provides suggestions and recommendations on potential exposure limits for these substances.

From the policy perspective indoor air quality is a rather complex issue as there are not one or a few indoor air environments but, for instance, for EU there are millions of, let us say, indoor microenvironments.

While the quality of outdoor air is a public responsibility many of those indoor microenvironments are basically dependent from occupant behaviours and can be seen as a consumer matter.

As most of the relevant sources are related to the nature and management of buildings, including HVAC systems and other equipment, i.e., to buildings materials and products and to consumer products and occupants, it becomes clear that solutions to reach better IAQ for people require a broad approach as upstream as possible to the place and time where the emissions take place.

That suggests a holistic approach of the policies already in place or in preparation related to outdoor air, construction products and materials, building energy and ventilation performance, and consumer products, together with some typical behaviours indoors, such as tobacco smoking.

Therefore an exercise was made of identifying the potential causes for sources and to scrutinize the legislation, basically at EU level that may be related to the IAQ impact of those sources (Figure 2).

Four major groups must be called upon to play a specific role on IAQ management:

Building Materials: From the global scheme (Figure 2) we can observe that only one EC Directive refers specifically to the regulation of building materials emissions:

- Construction Products Directive (1989/106/EEC).

The second generation of harmonised product standards under the Construction Products Directive (CPD) require harmonised test methods for release or emission of dangerous substances to satisfy the requirements of Essential Requirement 3 (ER3) of the CPD. The European Commission has issued a mandate (M/366) to CEN in which there is a request for horizontal standards on emission scenarios in indoor air, planned to be developed by CEN/TC 351.

However, many countries and/or markets are already using voluntary schemes to control emissions from building materials. Most of the voluntary schemes used in the Member states apply the newly developed EN or ISO standards (EN 13419 parts 1-4 and ISO 16000 parts 3, 6, 9, 10, 11). Report 24 “Harmonisation of Indoor Material Emissions Labelling Systems in the EU”, Inventory of existing schemes (2005) from European Collaborative Action present

with detail, comparing and discussing, the different labelling schemes: ECA report 18; AgBB (Germany); CESAT (France); M1 (Finland); ICL (Denmark); LQAI (Portugal); Natureplus (Germany and Europe); Blue Angel (Germany); Ecolabel (Austria); GUT (Germany and Europe); Emicode (Germany and Europe); and schemes applied in Belgium and UK and the Scandinavian trade standards.

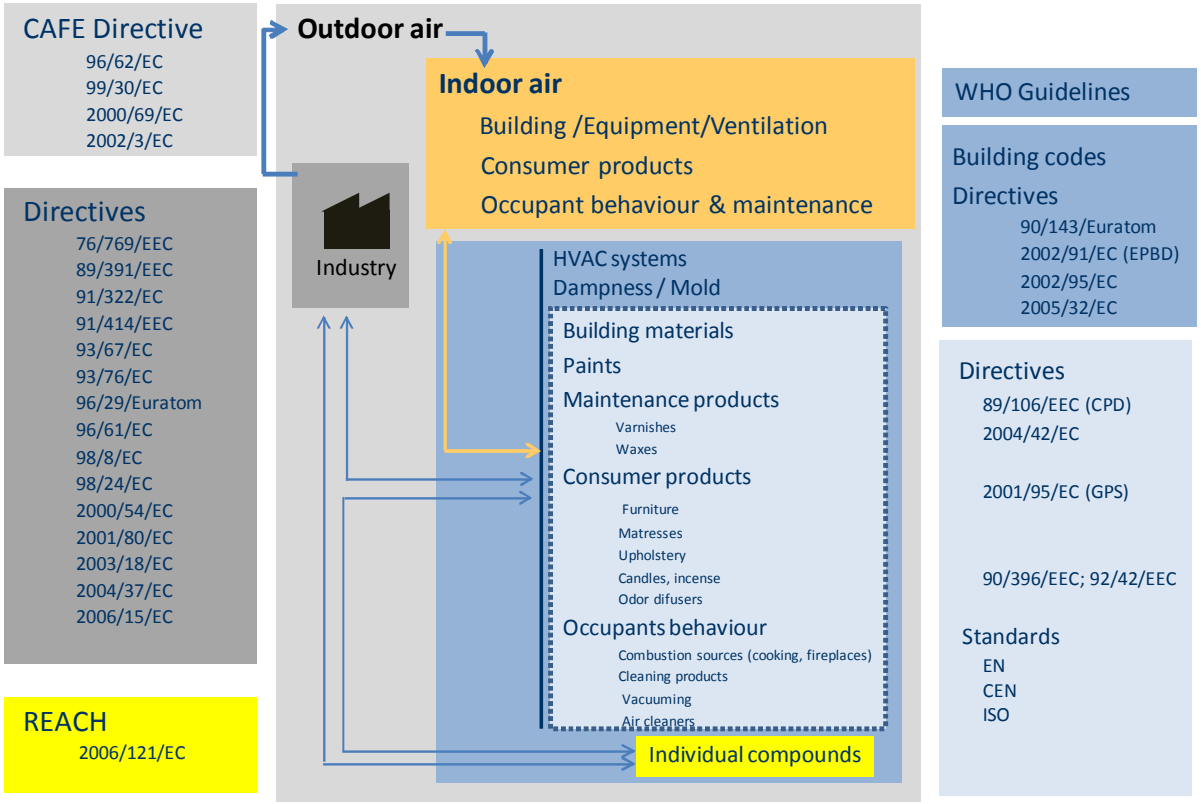


Figure 2. Some relations between the policies for each group.

Paints and varnishes: the paints and varnishes are considered chemical products, and in consequence, the object of control is the VOC content (in can) and not the emissions to indoor air.

- Limitation of emissions of VOCs Directive (2004/42/EC).

One controversy aspect in paints versus construction products is that the definition of VOCs is not the same for both groups, which increase the difficulty of comparison. In addition, under United States government legislation, the term VOC is restricted solely to those compounds that are photo chemically active in the atmosphere, being any other compound defined as an exempt compound that not contributes to VOC content.

Building (including Equipment and Ventilation): From the scheme (Figure 2) we can observe that only some EC Directives and Recommendations regulate building, including equipment and ventilation:

- Energy Performance of Buildings Directive - EPBD (2002/91/EC);
- Recommendation on the protection of the public against indoor exposure to radon (90/143/Euratom);
- Directive on the Hazardous Substances in Electrical and Electronic Equipment (2002/95/EC);

- Ecodesign Requirements for Energy-Using Products Directive (2005/32/EC);
- Ventilation for buildings - Design criteria for the indoor environment (CEN 1752, 1996).

The REACH, is a new European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the Registration, Evaluation, Authorisation and Restriction of Chemicals substances and came into force on 1 June 2007 with the aim of streamlining and improving the former legislative framework for chemicals in the EU. The controls outlined above are superseded by REACH during 2008/09 except for the Biocidal, Cosmetic and General Product Safety Directives which remain in effect. The REACH regulation obliges manufacturers and importers of substances to provide a defined set of information concerning the hazards and whether they could pose risks when being used in the form of a 'registration dossier'. Manufacturers and importers of certain dangerous substances need to assess the exact nature and extent of these risks in a 'chemical safety assessment'. Certain substances of very high concern will require authorisation before they can be used and restrictions may be placed on the use of certain other substances.

The regulation defines downstream users as someone who uses a substance, either on its own or in a preparation in the course of industrial or professional activities. A downstream user must not place on the market or use any substances which are not registered in accordance with REACH. They will receive information on dangerous substances and preparations in safety data sheets and some will include an annex called an exposure scenario on how to use the substance or preparation safely and to ensure protection of the environment. For any use not covered, the downstream user should work with the supplier to develop an exposure scenario or, if necessary, develop their own chemical safety report. The various requirements under REACH are being phased in over the period 2008 to 2013 (ECHA, 2008).

This regulation therefore could result in the phasing out of some chemicals currently contained in products used indoors and the substitution of some substances with others that are less hazardous to health. It should also result in greater evaluation of exposure scenarios, including the possible exposure of humans through use of consumer products. ECHA (2008) outlines a number of exposure scenarios including use of a domestic cleaning product where the assessment includes consideration of inhalation and dermal exposure arising from use of the product. Further detailed guidance on consumer exposure assessment is to be contained in a Technical Guidance Document supporting the REACH regulations. This evaluation could result in changes to product formulation and the instructions for use of products in order to prevent exposure to hazardous concentrations.

However REACH will take some years to produce results. In addition some "less positive" aspects exists: lless stringent safety requirements for carcinogens and chemicals which can cause birth defects and reproductive illnesses; substances imported in low volumes (below ten tonnes per year) for which "no meaningful safety data" will be required, and; provisions relative to 'high-concern' chemicals that will still be allowed onto the market if producers can prove that they can be "adequately controlled" when a "safe threshold" can be defined where their detection is considered as posing no threat to human health.

Directive 2006/121/EC contains technical adaptations of Directive 67/548/EEC that are necessary in the light of the new REACH Regulation (Directive 67/548 concerns the classification, packaging and labelling of dangerous substances and applies in parallel with REACH).

Consumer products, occupant behaviour and maintenance: On occupant behaviour and maintenance (including household and consumer products) and related equipment, the main controls are those concerned with provision of adequate ventilation in buildings to prevent the build up of hazardous concentrations of pollutants, requirements for installation of gas appliances, restrictions on the content of products, particularly compounds classed as carcinogens, mutagens, or substances toxic to reproduction (CMRs), and advice on the proper and safe use of products.

From the scheme we can observe that only some EC Directives explicitly or indirectly regulate IAQ and for consumer products and human activities those are:

- Gas Appliances Directive (1990/396/EEC);
- Heating Appliances Directive (1992/42/EEC);
- General Product Safety (GPS) Directive (2001/95/EC).

The UK Royal Commission on Environmental Pollution reviewed the regulations governing chemicals in products in 2003 and highlighted shortcomings with the legislation and discussed the then proposals for the new provisions under the REACH regulations (RCEP 2003). They note that national legislation on chemicals management in the EU member states is derived almost entirely from EU instruments, the three main being:

1. Classification, Packaging and Labelling of Dangerous Substances and Preparations that classified chemicals according to their hazards, prescribed packaging and labelling regimes and the notification and assessment of 'new' chemicals. Preparations are mixtures or solutions composed of two or more substances and about 90-95% of all chemicals on the European market appear as preparations.
2. New Substances notification that required a manufacturer of a new chemical to submit a dossier to a competent authority giving information about the hazardous properties of the substance before it can be placed on the market.
3. Existing Substances Regulation which provided a procedure for the risk assessment of existing substances.

Other Directives relevant to control of chemicals and protection to human health described are:

- The Marketing and Use Directive (76/769/EEC) that provides a framework for restriction of some chemicals and in particular substances classed as CMRs.
- The Biocidal Products Directive (98/8/EC) whereby substances can be prevented from being marketed if there is an alternative that presents lower risk.
- The Cosmetics Directive (76/768/EEC) that lists banned cosmetic substances and lists ingredients permitted for specific uses. There are no pre-market controls and the system relies on testing by producers and importers and a market surveillance and liability scheme.
- The General Product Safety Directive (2001/95/EC) which regulates the safety of consumer products and places obligations on producers to place only safe products on the market and to provide consumers with relevant information to assess the risks associated with the product.

Some consumer products are subject to voluntary labelling schemes based on their environmental performance and this can include requirements for maximum permissible emissions of gases, vapours and dust to the indoor air. For example, the Nordic Swan labelling of copying machines, fax machines and multifunctional devices (Nordic

ecolabelling, 2007) has requirements for emissions rates of pollutants in monochromatic printing and in ready mode as shown in Table 4. Emission rates should be measured in accordance with the German Blue Angel scheme: RAL-UZ 62, RAL-UZ 85 and RAL-UZ 114.

Table 4. Maximum permissible values of emission rates for copiers, printers, fax machines and multifunctional devices.

Substance	Emission rate mg/h		
	Printing phase	Ready mode (tabletop units)	Ready mode (floor mounted units)
TVOC	10	1	3
Benzene	0.05	-	-
Styrene	1.0	-	-
Ozone	2.0	-	-
Dust	4.0	-	-

The Nordic ecolabel also applies to cosmetic products for which there are no requirements for emissions to indoor air, but there are restrictions on chemical ingredients that could thereby have an indirect effect on release to air. Similarly requirements for shampoo, conditioners and soap, cleaning products and cleaning services, car and boat care products are based on constituents and could have an indirect effect on release of chemicals indoors.

The German Blue Angel scheme is a voluntary labelling scheme with award criteria covering 83 product groups that began some 30 years ago. In 2007, around 10,000 products had the Blue Angel label. Consumer products in the scheme include personal computers (RAL-UZ 78 and 93) and televisions (RAL-UZ 91). These may provide benefits by minimising emissions to indoor air by control of constituents as for RAL-UL 78 where neither chloro-organic nor bromo-organic compounds nor carcinogenic, mutagenic or reprotoxic substances may be added to the plastics used in casings. The award criteria for some products involves measurement of emissions to indoor air as in RAZ-UZ 122 for office equipment with a printing function (similar to Table 4 above) and RAL-UZ 119 for mattresses which have limits based on the concentration of some substances resulting from release from the mattress placed in a test chamber. The test chamber method is defined by a European standard method. Table 5 gives the emission values in RAL-UZ 119. Further information about the scheme is available from their web site (www.blauer-engel.de).

Table 5. Emission requirements for mattresses based on concentration produced in a test chamber.

substance	Requirement $\mu g/m^3$ (less than or equal to value)		
	Day 3	Day 7	Day 28
Formaldehyde	-	60	60
Other aldehydes (total)	-	60	60
TVOC (C6-C16)	-	500	200
Total SVOC (>C16-C22)	-	100	40
Carcinogenic substances	10 total	1 (per substance)	1
Total VOC without LCI value	-	100	40
R value	-	1	1

LCI = lowest concentration of interest.
R = sum of concentrations normalised to individual LCI values.

Others (Industry): IAQ can also benefit from legislation introduced in Industry, in indirect mode. This is the case for example of Directive 1976/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations - Short Chain Chlorinated Paraffins -that could apply to consumer products and human activities, or 2004/42/EC on the limitation of emissions of VOCs due to the use of organic solvents in certain activities and installations, that could affect positively varnishes and paints.

4. Recommendations

Considering the presented above, it can be concluded that IAQ is yet poorly regulated at EU level. Ambient air has been the object of directives in the last years by the limitation of industrial emissions, and by imposition of limit values for certain pollutants in ambient air.

Nowadays there is already sufficient information that demonstrates the relation cause-effect between poor indoor air and health problems. EnVIE reports on Health effects and Exposure show that the main weakness is the definition of "poor indoor air". The principal actors want to know who the pollutant responsible is, and this is impossible to answer. The invocation of the precautionary principle did not convince those involved, because of the magnitude of costs necessary to produce some changes. Manufacturers of building materials, for example, want to know exactly which compounds need to be substituted or reduced, and their safe levels. They don't accept easily to reduce the VOCs emissions in general. But, indoor air is a complex mixture of chemical, biological and physical parameters, and some specific combination off all or partial can provoke health problems. This is the challenge for the next years, to discover the algorithm of the indicator of a good IAQ.

Another point of discussion is the behaviour in terms of IAQ of the material after to be in use, and to decide who is responsible for this, the manufacturer or the consumer. The manufacturer can claim that the guilty is from the bad conditions of use. But, for example, a material with a low fungal growth resistance is more susceptible to incubate fungi during its life cycle, with recognized bad consequences to health. The same can be said in respect to adsorption of other pollutants or chemical reactivity. So, there are some aspects that should be clarified and defined as characteristics of the material or environmental conditions (Bluyssen and Adan, 2006).

Meanwhile is necessary to act. The CPD is running, but will take some years to produce the results and is restrictive face to the high number of building materials not covered. A more global initiative will be perhaps well accepted, like a **new IAQ directive**. It will be necessary to define limit values for indoor air pollutants. This will put the responsibility in the building constructor and building managers to choose better materials. And the market will regulate and will impose the quality. It will be necessary to inform the building constructors, managers and end-users about the factors that affect IAQ, in order they have the necessary tools to do a right choice. By this way, the manufacturers worried with IAQ will be rewarded.

To perform **a link between IAQ and energy efficient buildings directive** will be also a way to introduce some rules in the building sector, as occurred in Portugal (Jesus L. *et al*., 2006).

The **review and update of the building codes** will be necessary in some member states, in order to cover specific aspects like:

- Requirements for safe installation and servicing of fuel burning appliances;
- Use of flued appliances to vent fumes to outdoors;
- Extractor fans and hoods for venting cooking fumes;
- Requirements for fuel quality;

- Provision of means for adequate ventilation such as opening windows and trickle ventilators;
- Smoking bans in workplaces and enclosed public places;
- Advice to the public about threat to health caused by tobacco smoking;
- Restrict the construction of attached garages, and to isolate the garages from living and working quarters (closing the doorways, sealing the structures, and ensuring proper air pressure difference between the garage and other indoor spaces).

Recommendations specific to the individual high priority chemicals, as defined in Index project, were as follows:

Formaldehyde

- Restrict emissions of formaldehyde from building products, furnishings and household/ office chemicals,
- Discourage the use of formaldehyde containing products.

Nitrogen dioxide

- Apply the indoor air concentration guideline in the building design process,
- Develop building codes, ventilation standards, and equipment/appliance standards (design, maintenance and use) so that all indoor combustion equipment will exhaust to chimneys/hoods/vents leading outdoors.

Carbon monoxide

- Apply the indoor air concentration guideline in the building design process,
- Develop building codes, ventilation standards, and equipment/appliance standards (design, maintenance and use) so that all indoor combustion equipment will exhaust to chimneys/hoods/vents leading outdoors,
- Require regular mandatory inspections of indoor combustion equipment,
- Recommend alarm systems responding to abnormally high concentrations.

Benzene

- Sources emitting benzene (tobacco smoking, etc.) should not be allowed in the indoor environment,
- Lower the permissible benzene content in any building material and consumer product.

Naphthalene

- Restrict the use of naphthalene containing household products, particularly mothballs.

It will be necessary also to:

- Develop **criteria for healthy homes** including the limit values for indoor pollutants,
- Develop a strategy for the identification of priorities in testing, risk assessment and regulations in Europe,
- Regulate ambient perfumes (incense, odours diffusers, etc.),
- Control harmful emissions from consumer products; guidelines and procedures to measure emissions from consumer products should be developed including criteria for low emitting products and a labelling system to control emissions from consumer products. Define standard methods for testing emissions from consumer products similar to those developed for building materials and furnishings within the European standards organisation (CEN) to provide comparable data on the release of chemicals and gases during the use of consumer products,

- Keep consumers informed,
- Include consideration of pollution released by human activities as part of a broad campaign to inform the public, medical and building professionals and product manufacturers about the importance of IAQ for health and well being,
- Review of VOC definition - must exist an harmonization.

New studies, more research will be necessary especially in consumer products emissions. Jensen and Knudsen (2006) in their report on assessment of chemicals released from various consumer products recommend further studies and some actions:

- Measurements of indicator substances released from consumer products in a large number of randomly selected dwellings;
- Measurements in a dwelling furnished in a realistic worst case scenario;
- Use of dangerous substances in consumer products, substances which may be released indoors and expose children to risk, should be terminated by voluntary agreements or bans;
- Building materials and consumer products containing phthalate plasticisers should not be used in or to furnish a children's room;
- Use of incense indoors should be avoided, because this activity is the most polluting of all studied activities and it is likely to be a direct health hazard;
- Use of spray products indoors is also an extreme source which should be avoided or at least limited as much as possible;
- Children's exposure to dangerous substances indoors should be reduced as much as possible by frequent and sufficient cleaning and ventilation.

SCHER (2006) reviewed a study of the chemical substances present in indoor air following the use of air fresheners undertaken by The European Consumers Organisation (BEUC). They recommended further studies to quantify emissions based on use patterns and data on volumes of products sold in Member states. New studies particularly of combustion/pyrolysis processes (candles and incense), including dioxins are required. In addition fine and ultra fine particles should be measured. Spruyt *et al*. (2006) suggest that further research on emissions from air fresheners is required and that adding warnings on incense packing to prevent excessive use and to ventilate the dwelling after use should be considered.

References

Afshari, A., Gunnarsen, L., Clausen, P. A., Hansen, V., 2004. Emission of phthalates from PVC and other materials**.** *Indoor Air*, 14, 2, 120-128.

Airaksinen M., Pasanen P., Kurnitski J., Seppänen O., 2004. Microbial contamination of indoor air due to leakages from crawl space: a field study. *Indoor Air*, 14, 55-64.

Alm, O., 2001. Ventilation filters and their impact on human comfort, health and productivity. Ph.D. Thesis. International Centre for Indoor Environment and Energy, Department of Mechanical Engineering, Technical University of Denmark, July 2001.

Auvinen, J., Wirtanen, L., 2008. The influence of photocatalytic interior paints on indoor air quality. *Atmospheric Environment*, 42, 4101–4112.

Bartzis, J.G., Michaelidou, S., Kotzias, D., Missia, D., Michael, C., Barrero-Moreno, J., Tolis, E., Demetriou-Georgiou, E., Michael, N., Dimitroulopoulou, C., McLaughlin, J.,Carrer, P., Ketrup, A., Wolkoff, P., Sfetsos, A., Petaloti, C., Andronopoulos, S. and Ganatsiou, K. 2008. The Buma (Prioritization of building materials as indoor pollution sources) Project: An Overview, In Proceedings of Indoor Air 2008, Copenhagen, Denmark, paper ID: 116.

Batterman, S. and Burge, H., 1995. HVAC systems as emission sources affecting indoor air quality: a critical review. *HVAC&R Research*, Vol. 1, No.1, 1995.

Berglund, B. et al., 1982a. A longitudinal study of air contaminants in a newly built preschool, *Environ. Int.*, 8, 111-115.

Berglund, B. et al., 1982b. The influence of ventilation on indoor/outdoor air contaminants in an office building, *Envir. Int.*, Vol 8, 395-399.

Bitter, F. and Fitzner, K. 2002. Odour emissions from an HVAC-system. *Energy and Buildings*, 34, 809–816.

Björkroth, M. and Asikainen, V., 2000. The effect of ventilation duct material and dust accumulation on perceived supply air quality. In Proceedings of Healthy Buildings 2000, Vol. 2, 157–162.

Björkroth, M., Seppänen, O. & Torkki, A. 1998. Chemical and Sensory Emissions from HVAC Components and Ducts. In: Design, Construction, and Operation of Healthy Buildings. Ed: Moschandreas, D. J. American Society of heating, Refrigerating and Air-Conditioning Engineers, Inc., 47–55.

Bluyssen, P. and Adan, O.C.G., 2006. Marketing the Indoor Environment: Standardization or Performance on Demand? In Proceedings of HB2006, vol. 5, 275-280, Lisboa, Portugal.

Bluyssen, P., Cox, C., Seppänen, O., de Oliveira Fernandes, E., Clausen, G., Müller, B., & Roulet, C.-A. 2003. Why, when and how do HVAC-systems pollute the indoor environment and what to do about it? The European AIRLESS project. *Building and Environment* 38, 209–225.

Bluyssen, P., de Oliveira Fernandes, E., Groes, L., Clausen, G., Fanger, P.O., Valbjørn, O., Bernhard, C., Roulet, C., 1996. European indoor air quality audit project in 56 office buildings. *International Journal of Indoor Air Quality and Climate*. Vol 6, 4.

Bluyssen, P., Seppänen, O., Fernandes, E., Clausen, G., Müller, B., Molina, J., Roulet, C.A., 2001. AIRLESS: A European project to optimise Indoor Air Quality and Energy consumption of HVAC-systems. In Proceedings of CLIMA 2000, Naples.

Bornehag, C-G., Blomquist, G., Gyntelberg, F. et al., 2001. Dampness in buildings and health. *Indoor Air*; 11:72-86.

Brown, V.M. et al., 1990. Investigations of the volatile organic compound content of indoor air in homes with an odorous damp proof membrane, In Proc. 5th Int. Conf. on Indoor Air Quality and Climate Vol. 3, 575-580, Toronto.

Butte W. 1999. Occurrence of biocides in the indoor environment. In: Organic Air Pollutants: Occurrence, Measurement, Evaluation. pp 233-249. Wiley- VCH.

Butte, W., 2003. Reference values of environmental pollutants in house dust. In: Indoor Environment; Airborne Particles and settled Dust. Morawska L and Salthammer T (Ed.). pp 407-435. Wiley-VCH, Weinheim.

Byrd, R., 1996. Prevalence of microbial growth in cooling coils of commercial air-conditioning systems. In Proceedings of Indoor Air ’96, 3: pp. 203-207, Seec Ishibashi, Inc., Japan.

Chang, J.C.S. and Guo, Z. 1998. Emissions of odorous aldehydes from alkyd paint. Atmospheric Environment Vol. 32, No. 20, pp. 3581-3586.

Clausen, G. and Oliveira Fernandes, E., 1997. Final Report, European Data Base on Indoor Air Pollution Sources in Buildings. European Commission (DGXII), Brussels.

Crandall, M., Sieber, W. and Malkin, R., 1996. HVAC and building environment findings and health symptoms associations in 80 office buildings, In Proceedings of IAQ 1996, pp 103-108.

Deptuła, H., Niesłochowski, A. and Prejzner, H., 2007. Wood Preservative Xylamit as a Source of Indoor Air Pollution, Wood preservative Xylamit as a source of indoor air pollution, In Conf. Proceedings "Indoor Air Quality and Health for EU Policy", pp 219-227, Helsinki 2007.

Dunn, J., 1987. Models and statistical methods for gaseous emission testing of finite sources in well-mixed chambers, *Atm. Envir*. 21, 2, 425-531.

ECA-IAQ (European Collaborative Action, Urban Air, Indoor Environment and Human Exposure), 2005. Harmonisation of indoor material emissions labelling systems in the EU: Inventory of existing schemes, Report No 24. EUR 21891 EN. Luxembourg: Office for Official Publications of the European Communities.

ECA-IAQ (European Collaborative Action, Urban Air, Indoor Environment and Human Exposure), 2006. Strategies to determine and control the contributions of indoor air pollution to total inhalation exposure (STRATEX), Report No 25. EUR 22503 EN. Luxembourg: Office for Official Publications of the European Communities.

ECHA, 2008. Guidance for downstream users; guidance for implementation of REACH. European Chemicals Agency, January 2008.

Edwards, R.D., Schweizer, C., Jantunen, M.J., Lai, H.K., Bayer-Oglesby, L., Katsouyanni, K., Nieuwenhuijsen, M.J., Saarela, K., Srám, R. and Künzli, N., 2005. Personal exposures to VOC in the upper end of the distribution - relationships to indoor, outdoor and workplace concentrations. *Atmos. Environ.* 39, 2299-2307.

Fanger, P.O., 1988. Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings.* 12, 1-6.

Fiedler, K., Schütz, E., Geh, S., 2001. Detection of microbial volatile organic compounds (MVOCs) produced by moulds on various materials. *Int. J. Hyg. Environ. Health* 204, 111-121.

Finke, U. and Fitzner, K. 1993. Ventilation and air-conditioning systems – investigations to the odour and possibilities of cleaning. In Proceedings of Indoor Air ’93, Vol. 6, 279–284.

Fransson, J., 1996. Particle deposition in ventilation air supply ducts. In Proceedings of Indoor Air ’96, 2, 717–722.

Guerin, M., Jenkins, R. and Tomkins, B., 1992. The chemistry of environmental tobacco smoke: composition and measurement. Lewis publishers, Michigan USA.

Gustafsson, H., 1992. Building Materials Identified as Major Emission Sources for Indoor Air Pollutants - a critical review of case studies, D10, Swedish Council for Building Research.

Gustafsson, H., 1996. Einwirkung von feuchten Betonuntergründen auf Kleber und Fuβbodenbeläge-Übersicht und Kommentare zur Laboruntersuchungen über chemische Abbauprozeβe und Emissionen flüchtiger chemischer Verbindungen, SP Bericht 25.

Gustafsson, H., 2007. Essential requirements on construction products and current European standardization of emission test methods, In Conf. Proceedings "Indoor Air Quality and Health for EU Policy", pp 72-80, Helsinki.

Gustafsson, H. and Jonsson, B., 1999. Development of Low-emitting Building Materials, In Conf. Proceedings "Indoor Air -99", 4, pp 678-683.

Hartmann, P.C., Burgi, D., Giger, W., 2004. Organophosphate flame retardants and plasticizers in indoor air. *Chemosphere*, 57, pp 781-787.

He, C., Morawska, L. and Taplin, L. 2007. Particle Emission Characteristics of Office Printers. Environ. *Sci. Technol*. 41, 6039-6045.

Hodgson, A.T. and Girman, J.R. 1989. Application of a multisorbent sampling technique for Investigations of Volatile Organic Compounds in Buildings, Design and Protocol for Monitoring Indoor Air Quality. ASTM STP 1002, 244-256.

Horn, W., Ullrich D. and Seifert B., 1998. VOC Emissions from Cork Products for Indoor Use. *Indoor Air*; 8: 39–46.

Hubbard, H., Coleman, B., Sarwar, G. and Corsi, R., 2005. Effects of an ozone-generating air purifier on indoor secondary particles in three residential dwellings. *Indoor Air* 15, 432-444.

ISIAQ 1996. Flannigan B and Morey P. Control of moisture problems affecting biological indoor air quality. ISIAQ guideline. Task Force I. International Society of Indoor Air and Climate. Ottawa. Canada.

ISIAQ 2003. Indoor Air Quality in Hospitals and Other Health Care Facilities.

ISO 16000-9:2006 Indoor air - Part 9: Determination of the emission of volatile organic compounds from building products and furnishing - Emission test chamber method.

ISO 16000-10:2006 Indoor air - Part 10: Determination of the emission of volatile organic compounds from building products and furnishing - Emission test cell method.

ISO 16000-11:2006 Indoor air - Part 11: Determination of the emission of volatile organic compounds from building products and furnishing - Sampling, storage of samples and preparation of test specimens.

Jann, O., Rochstroh, J., Wilke, 2005. Influence of emissions from hard copy devices on indoor air quality. In Proceedings of Indoor Air 2005, 2123-2128, Beijing.

Janssens, A., Hens, H. 2003. Interstitial condensation due to air leakage: a sensitivity analysis. *Journal of Thermal Envelope and Building Science*; 27(1):15–29.

Jantunen, M. and Carrer, P., 2007. Introduction to the EnVIE concept and overview of EnVIE programme. In Proceedings of the first EnVIE conference on indoor air quality and health for EU policy, 41-52. Helsinki

Jensen, A. and Knudsen, H., 2006. Total health assessment of chemicals in indoor climate from various consumer products. Survey of chemical substances in consumer products nº. 75, Danish Ministry of the Environment.

Jesus, L., Almeida, M. and Pereira, E., 2006. Indoor Air Quality (IAQ) guideline: Contribution for Portuguese Measures. In Proceedings of HB2006, vol. 5, 317-322, Lisboa, Portugal.

Jetter, J., Guo, Z., Jenia, McBrian, J.A., Flynn, M.R., 2002. Characterization of emissions from burning incense. *The Science of the Total Environment* 295:51-67.

Karlsson, S. et al., 1989. Gas chromatographic detection of volatile amines found in indoor air due to putrefactive degradation of casein-containing building materials, *Materials and Structures*, 22, 163-169.

Kilpeläinen, M., Luukkonen, I., Vinha, J., Käkelä, P. 2000. Heat and moisture distribution at the connection of floor and external wall in multi-storey timber frame houses. World Conference on Timber Engineering Whistler Resort, British Columbia, Canada July 31 -August 3, 2000.

Kim, S., Kim, J.A., An, J.Y., Kim, H.J., Kim, S.D., Park, J.C., 2007. TVOC and formaldehyde emission behaviours from flooring materials bonded with environmental-friendly MF/PVAc hybrid resins. *Indoor Air*, 17, 5, 404-415.

Kohlhammer, K., Krell, M. and Zeh, H., 1995. Berechnung der Innnenraumluftbelastung durch Beschichtungsstoffe während der Applikation; Emissionen aus Beschichtungsstoffen, S. 135-150, Band 478, Expert Verlag.

Kotzias, D., Koistinen, K., Kephalopoulos, S., Schlitt, C., Carrer, P., Maroni, M., Jantunen, M., Cochet, C., Kirchner, S., Lindvall, T., McLaughlin, J., Mølhave, L., Fernandes, E.O., Seifert, B., 2005. The INDEX project: Critical appraisal of the setting and implimentation of indoor exposure limits in the EU. Final report. EUR21590 Ed. European Commission, Joint Research Center, Ispra, Italy.

Kurnitski, J., 2000. Crawl space air change, heat and moisture behaviour, *Energy and Buildings*, 32, 1, 19-39.

Lam, K.S., Chan, F.S., Fung, W.Y., Lui, B.S.S., Lau, L.W.L., 2006. Achieving ‘excellent’ indoor air quality in commercial offices equipped with air-handling unit – respirable suspended particulate. *Indoor Air*, 16: 86–97.

Lee, S.C., Wang, B., 2004. Characteristics of emissions of air pollutants from burning of incense in a large environmental chamber. *Atmospheric Environment* 38:941-951.

Lin, C-C. and Corsi, R.L. 2007. Texanols ester alcohol emissions from latex paints: Temporal variations and multi-component recoveries. *Atmospheric Environment* 41, 3225–3234.

Luoma, M., Pasanen, A.L., Pasanen, P., Fan. Y., 1993. Duct cleaning. A literature survey. AIVC Air Infiltration Rev. 14(4): 1-5.

Marklund, A., Andersson, B., Haglund, P., 2005. Organophosphorus flame retardants and plasticizers in air from various indoor environments. *J Environ Monitoring*, 7, pp 814-819.

Mattson, J., Carlson, O.E., Engh, IB., 2002. Negative influence on IAQ by air movement from mould contaminated constructions into buildings. In Proceedings of Indoor Air '02, vol. 1. Monterey, California, USA, p. 764–769.

Mendell, M.J. and Smith, A.H., 1990. Consistent pattern of elevated symptoms in air-conditioned office buildings: a reanalysis of epidemiologic studies. *Am J Public Health* 80(10): 1193-9.

Mendell, M.J., Cozen, M. et al., 2006. Indicators of moisture and ventilation system contamination in U.S. office buildings as risk factors for respiratory and mucous membrane symptoms: analyses of the EPA BASE data. *J Occup Environ Hyg* 3(5): 225-33.

Mendell, M.J., Lei-Gomez, Q., Mirer, A., Seppänen, O., Brunner, G., 2007. Risk Factors in Heating, Ventilating, and Air-Conditioning Systems for Occupant Symptoms in U.S. Office Buildings: the U.S. EPA BASE Study. Lawrence Berkeley National Laboratory. Report LBNL-61870.

Mendell, M.J., Naco, G.M. et al., 2003. Environmental risk factors and work-related lower respiratory symptoms in 80 office buildings: an exploratory analysis of NIOSH data. *Am J Ind Med* 43(6): 630-41.

Mølhave, L., 1985. Indeklimamålninger i seks lavenergihuse, Energispareprojekt, EM2/0020 (17-63), projekt IIb, Aarhus universitet (in Danish).

Morrison, G., and Hodgson, A., 1996. Evaluation of ventilation system materials as sources of volatile organic compounds, Proceedings of the 7th International Conference of Indoor Air Quality and Climate, vol 3 pp 585-590

Morrison, G., Nazaroff, W., Cano-Cruiz, A., Hodgson, A., Modera, M., 1998. Indoor air quality impacts of ventilation ducts: ozone removal and emissions of volatile organic compounds. *Journal of the Air & Waste Management Association*, 48:941-952.

Morrison, G.C., Nazaroff, W.W., 2000. The rate of ozone uptake on carpets: experimental studies. *Environmental Science and Technology* 34, 4963–4968.

Morrison, G.C., Nazaroff, W.W., 2002a. Ozone interactions with carpet: secondary emissions of aldehydes. *Environmental Science & Technology* 36, 2185–2192.

Morrison, G.C., Nazaroff, W.W., 2002b. The rate of ozone uptake on carpet: mathematical modelling. *Atmospheric Environment* 36, 1749–1756.

Nazaroff, W. and Klepeis, N., 2003. Environmental tobacco smoke particles. In: Indoor Environment; Airborne Particles and settled Dust. Morawska L and Salthammer T (Ed.). pp 245-274. Wiley-VCH, Weinheim.

Nazaroff, W. and Weschler, C., 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. *Atmospheric Environment*, 38 2841-2865.

Nevalainen, A. 2002. Of microbes and men. In: Levin H (Ed) Proceedings of the 9th International Conference on Indoor Air Quality and Climate, Vol 3:1-9.

Nonaka, T., Okawa, N., Ohashi, K., Takeda, K. and Fujimoto, T., 2005. Examination of emission test method for VOC evaluation from printer. In Proceedings of Indoor Air 2005, 2185-2188, Beijing.

Norback, D., Wieslander, G., Strom, G., Edling, C., 1995. Exposure to Volatile Organic Compounds of Microbial Origin (MVOC) during indoor application of water-based paints. *Indoor Air*, 5: 166-170.

Nordic Ecollabelling, 2007. Swan labelling of copying machines, Fax machines and Multifunctional devices, version 4. (www.svanen.nu).

Oliveira Fernandes, E., 2001. Materials for healthy indoor spaces and more energy efficient buildings. Final report of EEC project MATHIS, Non-Nuclear Energy Programme JOULE III. Contract JOR3-CT97-0194, Porto (P), IDMEC, Instituto de Engenharia Mecânica.

Page, C.L. and Vennesland, Ö., 1983. Pore solution composition and chloride binding capacity of silica fume cement pastes, *Material and Structures*, 16, 19-25.

Pejtersen, J., Bluyssen, P., Kondo, H., Clausen, G., and Fanger, P.O., 1989. Air pollution sources in ventilation systems. In Proceedings of CLIMA 2000, Sarajevo, Vol. 3, p. 139–144.

Pessi, A-M., Suonketo, J., Pentti, M., Kurkilahti, M., Peltola, K. and Rantio-Lehtimäki, A., 2002. Microbial growth inside insulated external walls as an indoor air biocontamination source, *Applied and Environmental Microbiology* 68(2):963-967

RCEP, 2003. Chemicals in products; safeguarding the environment and human health. The Royal Commission on Environmental Pollution, The Stationary Office (Cm 5827), London.

Risholm-Sundman, M., 1981. Ftalathalt i småhusområde, 81 AC 0140, Kema Nobel Analyscentrum, (in Swedish).

Rocha, S., Delgadillo, I., Correia, J.F., 1996. GC-MS study of volatiles of normal and microbiologically attacked cork from Quercus suber L. *J.Agric.Food Chem.*, 44(3), 865-871.

Rosell, L., 1990. High levels of a semi-VOC in indoor air due to emission from vinyl floorings, Proc. 5th Int. Conf. on Indoor Air Quality and Climate, Vol 3, 707-712, Toronto.

Salthammer, T. 1999. Volatile organic ingredients of household and consumer products. In: Organic Air Pollutants: Occurrence, Measurement, Evaluation. pp 219-232. Wiley- VCH.

Salthammer, T. and Fuhrmann, F., 2000. Release of Acetic Acid and Furfural from Cork Products. *Indoor Air*; 10: 133–134.

Salthammer, T., Fuhrmann, F., Uhde, E., 2003. Flame retardants in the indoor environment—part II: release of VOCs (triethylphosphate and halogenated degradation products) from polyurethane. *Indoor Air* 13, 49–52.

Salthammer, T., Schwarz, A., Fuhrmann, F., 1999. Emission of reactive compounds and secondary products from wood-based furniture coatings. *Atmospheric Environment* 33, 75-84.

Säteri, J., Kovanen, K., and Pallari, M-L., 1999. Kerrostalojen sisäilmaston ja energiatalouden parantaminen (/Improvements of indoor air quality and energy efficiency in high-rise residential buildings, in Finnish)/, VTT Research Notes 1945, Espoo, Finland

SCHER, 2006. Opinion on the report 'Emissions of chemicals by air fresheners'. Scientific Committee on Health and Environmental risks, European Commission.

Schriever, E. and Marutzky, R., 1990. VOC Emissions of coated parqueted floors, 5th Int. Conf. on Indoor Air Quality and Climate, Vol 3, 551-555.

Seifert, B. and Ullrich, D., 1987. Methodologies for evaluating sources of volatile organic chemicals (VOC) in homes, *Atmospheric Environment*. 21, 395-404.

Seppänen, O.A. and Fisk, W.J., 2002. Association of Ventilation System Type with SBS symptoms in Office Workers. *International Journal of Indoor Environment and Health*, 12, pp. 98-112.

Shields, H.C. and Weschler, C.J., 1990. Three years of indoor/outdoor VOC measurements, In Proc. 5th Int. Conf. on Indoor Air Quality and Climate. Vol 2, 771-776.

Sieber, W.K., Stayner, L.T. et al., 1996. The National Institute for Occupational Safety and Health indoor environmental evaluation experience. Part Three: Associations between environmental factors and self-reported health conditions." *Applied Occupational and Environmental Hygiene.* 11(12): 1387-1392.

Singer, B.C., Destaillats, H., Hodgson, A. T., Nazaroff, W.W., 2006. Cleaning products and air fresheners: emissions and resulting concentrations of glycol ethers and terpenoids, *Indoor Air*; 16: 179–191.

Smedje, G., Norback, D., Wessen, B., Edling, C., 1996. Asthma among school employees in relation to the school environment. In Indoor Air'96. S. Yoshizawa, K. Kimura, K. Ikeda, S. Tanabe e T. Iwata (Eds.). Nagoya, 1: 611-616.

Spruyt, M., Bormans, R., Geyskens, F., Poelmans, D., Verbeke, L. and Goelen, E., 2006. Influence of air fresheners on the indoor air quality. Research Unit Environmental Measurement, report 2006/MIM/R/032. Belgian Federal Public Service of Health, Food Chain safety and Environment.

Sundell, J., Kolarik, B., Naydenov, K., Larsson, M., Hagerhed-Engman, L., Bornehag, C.G., 2007. Asthma and allergies: The role of the home environment. In: Proceedings of the 1st EnVIE Conference on Indoor Air Quality and Health for EU Policy, Helsinki, pp. 81-90.

Thogersen, K., Gunnarsen, L., Nielsen, P.A., 1993. The effect on indoor air quality by water damaged chipboards. In Indoor Air'93. O. Seppanen, J. Railio and J. Sateri (Eds.). Espoo, 2: 537-542.

Todd, A.S., 1987. A unique source of PCB contamination in public and other nonindustrial buildings, Practical control of indoor air problems, In Proc. ASHRAE Conf. IAQ 87, 104-109, Arlington, USA.

Toftum, J., Freund, S., Salthammer, T., Weschler, C.J., 2008. Secondary organic aerosols from ozone-initiated reactions with emissions from wood-based materials and a ''green'' paint. *Atmospheric Environment* 42, 7632–7640.

Tuomainen, M., Heinonen, J., Björkroth, M., Holopainen, R., Kukkonen, E., Asikainen, V., and Kosonen, R., 2000. The effect of end units on supply air quality. In Proceedings of Healthy Buildings 2000, Vol. 2, 169–174.

Turiel, I. et al., 1983. The effect of reduced ventilation on indoor air quality in an office building, *Atmospheric Environment*, Vol 17, 51-64.

Uhde, E., Salthammer, T., 2007. Impact of reaction products from building materials and furnishings on indoor air quality—A review of recent advances in indoor chemistry. Atmospheric Environment 41, 3111–3128.

Ullrich, D. et al., 1982. Einfluss von Lackanstrichen auf die Innenraumluftqualität am Beispiel von Heizkörperlacken, In Luftqualität in Innenräumen, Ed by Aurand K. et al, S. 283-298, Gustav Fischer Verlag, Stuttgart.

van der Wal, J. et al., 1987. Thermal insulation as a source of air pollution, In Proc. 4*th* Int. Conf. on Indoor Air Quality and Climate, Vol. 1, 79-83, Berlin West.

Vedel, A. and Nielsen, P.A., 1984. Phthalate esthers in the indoor environment, In Proc. 4th Int. Conf. on Indoor Quality and Climate, Vol 3, 309-314, Stockholm.

Wallace, L. et al., 1987. Volatile organic chemicals in 10 public access buildings, In Proc. 4th Int. Conf. on Indoor Air Quality and Climate, Vol 1, 188-192, Berlin West.

Wang, L. and Morawska, L., 2008. Analysis of particle number concentration in a mechanically ventilated office equipped with a printer. In Proceedings of Indoor Air 2008, Copenhagen, Denmark, paper ID: 196.

Wargocki, P., Wyon, D., Fanger, P., 2000. Pollution source control and ventilation improve health, comfort and productivity, In Proceedings of Cold Climate HVAC '2000, Sapporo, pp. 445-450.

Wargocki, P., Wyon, D.P. and Fanger, P.O., 2004. The performance and subjective responses of call-center operators with new and used supply air filters at two outdoor air supply rates. *Indoor Air*. 14 Suppl 8: p. 7-16.

Weschler, C., 2003. Indoor chemistry as a source of particles. In: Indoor Environment; Airborne Particles and settled Dust. Morawska L and Salthammer T (Ed.). pp 167-189. Wiley-VCH, Weinh.

Weschler, C.J and Shields, H.C., 1987. The accumulation of "additives" in office air, Proc. 79th Annual Meeting of the Air Pollution Control Association, Minneapolis.

Weschler, C., 2006. Ozone's Impact on Public Health: Contributions from Indoor Exposures to Ozone and Products of Ozone-Initiated Chemistry. The National Institute of Environmental Health Sciences. National Institute of Health U.S. Department of Health and Human Services. 41 pages.

Weschler, C.J., Hodgson, A.T. and Wooley, J.D. 1992. Indoor chemistry: ozone, volatile organic compounds and carpets. *Environmental Science and Technology* 26, 2371-2377.

Weschler, C.J. and Shields, H.C., 1997. Potential reactions among indoor pollutants. *Atmospheric Environment* Vol. 31, No. 21, pp. 3487 3495.

WHO, 1997. Flame Retardants: A General Introduction. Environmental Health Criteria 1997; 192: 1-76.

Wolkoff, P., 1987. Analyse of organiske luftforureninger i provesal B på det Kgl. teater, 86-432-2635, Arbejdsmiljöinstitutet, Danmark.

Wolkoff, P., 1990. Proposal of methods for developing healthy building materials: laboratory and field experiments, *Env Tech*, Vol. 11, 327-338.

Wolkoff, P. and Nielsen, P., 1985. Luftkvalitet i nybyggeri, Dansk VVS 11 (in Danish).

Wolkoff, P. et al., 1990. The Danish Twin Apartment Study: Part 1 Formaldehyde and long term VOC-measurements, In Proc. 5th Int. Conf. on Indoor Air Quality and Climate, Vol 2, 657-662.

Wolkoff, P. et al., 1995. Application of Field and Laboratory Emission Cell "FLEC" -Performance Study, Intercomparison Study, and Case Study of Damaged Linoleum in an Office, *Indoor Air*, Vol. 5, pp. 196-203.

Wolkoff, P., Clause, P.A., Norgaard, S.W., Hammer, M., Larsen, S.T. and Nielsen, G.D. 2008. Airway effects of ultra-fine particles formed in the ozone-limonene system, In Proceedings of Indoor Air 2008, Copenhagen, Denmark, paper ID: 115.



https://dspace.org/

ENVIE Co-ordination action on indoor air quality and health effects; WP3 Final report – Characterisation of spaces and source

de Oliveira Fernandes, Eduardo; Gustafsson, Hans; Seppanen, Olli; Crump, Derrick; Ventura Silva, Gabriela

2012-02-16

http://dspace.lib.cranfield.ac.uk/handle/1826/7005

Eduardo de Oliveira Fernandes, Hans Gustafsson, Olli Seppänen, Derrick Crump,Gabriela Ventura Silva. ENVIE Co-ordination action on indoor air quality and health effects; WP3 Final report – Characterisation of spaces and source. 2008.

Downloaded from a DSpace repository. https://dspace.org/