Chapter 11

Emissions of Formaldehyde and VOC from Wood-based Panels

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CHAPTER SUMMARY

Indoor air quality and product emissions from building products have become a subject to broad public concern in recent years. Emissions from wood products in buildings and constructions may cover formaldehyde and volatile organic compounds (VOC).

Formaldehyde originates mainly from the urea formaldehyde aminoplastic resins, which are used in the production of wood based panels (e.g. particleboard, fibreboard, plywood) used in furniture, flooring, wall partitions and ceilings. This chapter presents the formaldehyde emission property of wood-based panels and its evolution during the last decades, in connection with the evolution of the related international standards and regulations as well as the efforts devoted to formaldehyde emission limitation.

For another group of emissions, the volatile organic compounds, new testing and evaluation methods are under consideration with respect to the Construction Products Directive. This chapter also discusses the approaches as well as the experience with wood products carried out so far.

1 FORMALDEHYDE RELEASE FROM WOOD-BASED PANELS

The issue of formaldehyde release from composite wood panels is mainly related to the use of urea-formaldehyde (UF) resins as bonding adhesives for their production. These high reactivity and cost effective polymers are contributing to the panel formaldehyde emission by their low resistance to hydrolysis and the presence of free non-reacted formaldehyde. Resin copolymers produced with the use of melamine either at low (urea-melamine-formaldehyde resins, UMF) or at high levels (melamine-urea-formaldehyde resins, MUF) have improved hydrolytic stability but yet questionable performance in regard to very low formaldehyde emission levels.

Urea-formaldehyde resins have traditionally been used in the production of wood-based panels (mainly particleboard, fibreboard, plywood) and related products for decades. Indoor air quality and formaldehyde emissions from composite wood products first became subject to broad public and governmental concern in the late 1970s, when the energy crisis encouraged energy saving through tight sealing of homes. This reduced the rate of outdoor air infiltration and overall ventilation rates leading to the entrapment of gaseous pollutants inside home air atmosphere. With Europe, North America and Japan as pioneers, test methods to accurately measure formaldehyde emissions from panels were developed and product emission guidelines were established. These were combined with work place exposure limits for formaldehyde. A change in the formulation of UF resins was made by the resin industries to meet the low panel emission guidelines. Moreover, competitive bonding systems such as phenol-formaldehyde resins or polymeric diphenyl methane diisocyanate (PMDI) binders were proposed.

1.1 Formaldehyde classification

Until recently, formaldehyde was classified by the World Health Organization (WHO) as probably carcinogenic to humans (Group 2A). In 2004, the International Agency for Research on Cancer (IARC) of WHO, decided to recommend the reclassification of formaldehyde as "carcinogenic to humans (Group 1)", on the basis of available scientific data (IARC 2004). This recommendation, although not legally binding, was received with concern and immediate reactions from worker and consumer associations, "green" organisations, regulatory authorities and the industry (producers and users of formaldehyde) associations (FormaCare and European Panel Federation in Europe, Formaldehyde Council and Composite Panel Association in N. America). The latter indicated that the decision of IARC had been based on studies regarding the exposure in 30-60 years ago, while the work place emission levels have declined dramatically the past three decades due to the technological progress made (Composite Panel Association 2004, Formaldehyde Council 2004). Moreover, they stressed that the IARC classification was an "hazard identification" and not a full risk assessment.

In 2005, new toxicological and cancer studies were initiated by FormaCare and the Formaldehyde Council, involving various independent research institutes in Europe and the USA. In the meantime, there were proposals to reclassify formaldehyde in Europe by the French institute for occupational risk prevention (INRS) and the German Federal Institute for Risk Assessment (BfR). However, the European Chemicals Bureau (ECB) postponed its decision on the reclassification of formaldehyde until the results of the new studies were available (FormaCare 2006). Also the U.S. Environmental Protection Agency

(EPA) delayed formaldehyde reclassification until the completion of the follow-up study of the National Cancer Institute.

The IARC recommendation was finally published in December 2006 through its monograph series Volume Number 88. In this report, it is stated that "there is sufficient evidence in humans and in experimental animals for the carcinogenicity of formaldehyde" and that "formaldehyde is carcinogenic to humans (Group 1)" (IARC 2006). It is further mentioned that the highest occupational exposure to formaldehyde were measured in varnishing, production of textiles, garments, furs, in certain jobs in board mills and foundries. Lower exposure levels have been encountered in formaldehyde production (mean concentration < 1 ppm). A wide range of exposure levels has been observed in the production of resins (all data were derived from the 1980s). In wood products manufacture, exposure occurs during glue mix preparation, laying of mat, hot pressing and sanding – all data were derived from the 1960s-70s-80s. The reported mean concentrations in the air were greater than 1 ppm in particleboard mills and approximately 2 ppm in plywood, however, recent studies reported concentrations lower than 0.4 ppm in plywood and less than 0.16 ppm in OSB and fibreboard plants.

In September 2007, an International Formaldehyde Science Conference took place in Barcelona, Spain, organized by FormaCare (the European Formaldehyde Industry Association, sector group of CEFIC, the European Chemical Industry Council). The results of newly available scientific studies on the epidemiology and toxicology of formaldehyde were presented and discussed by representatives of institutes from Europe, the USA and Brazil, European Commission representatives and industry scientists (FormaCare 2007, Press Release). Main conclusions include the following points: a) the evidence for NasoPharyngealCancer formation is highly ambiguous, b) the leukemia formation related to formaldehyde exposure is highly improbable, c) no mutagenic effects were observed in experiments and d) in the normal living environment or at the workplace, formaldehyde exposure is not expected to lead to sensory irritation. The threshold for sensory irritation is clearly lower than that leading to cell death. Concentrations of 0.5 ppm or 0.3 ppm with peaks of 0.6 ppm will not lead to objective signs of sensory irritation. The bottom line of the conference was that "the common use of formaldehyde in consumer products and other applications does not pose a risk to human health". The IARC recommendation was challenged by presenting the weak points of the studies on which it was based: old data, lack of statistical robustness of data analysis, no consideration of confounding effects (also in FormaCare 2007, Scientific fact sheet). Such weak points and the newly available data suggest that there is no clear connection between formaldehyde exposure at current levels of exposure and cancer in humans.

In October 2007, a study on the "Socio-Economic Benefits of Formaldehyde to the European Union (EU 25) and Norway" was released by FormaCare, quantifying the value of formaldehyde to society and the contribution of the formaldehyde industry to the economies of these countries (Global Insight 2007). The study indicated that "consumers would have to spend an additional €29.4 billion per year if formaldehyde-based products were replaced by substitute chemicals" and that alternative products are of inferior quality and often of higher cost than the formaldehyde-based products, leading to a pronounced consumer preference for these latter products. Prior to this European study a report had been released on the "The Economic Benefits of Formaldehyde to the United States and Canadian Economies", showing even higher economic benefits from the use of formaldehyde products (Global Insight 2005). It was found that "people use products that contain formaldehyde every day, and that formaldehyde and the products made from it provide an enormous contribution to the U.S. and Canadian economies".

Within the EU, formaldehyde is currently classified as a Category 3-R40 substance ("limited evidence of carcinogenic effect"), which is the lowest available EU category for suspected carcinogens. According to the findings of the Barcelona conference this category is still appropriate (Gelbke 2008). The classification of formaldehyde in the EU will be reviewed under the new regulation "Registration, evaluation, authorisation and Restriction of Chemicals" (REACH) on chemicals and their safe use. In the U.S. the current classification by Environmental Protection Agency (EPA) is that of a probable human carcinogen.

1.2 Determination of formaldehyde from wood based panels

Key element for the efforts to evaluate or control the contribution of wood products on the quality of indoor air is the means of measuring the actual formaldehyde emissions of a product. Measurement of a product's potential to emit formaldehyde is the basis for determining indoor air quality through modelling. A variety of test methods for measuring product emission levels are applied worldwide, producing a corresponding variety of test results. Each method measures a slightly different emission characteristic and frequently produces results in different and non-interchangeable units. This proliferation of test methods and incomparable results often creates confusion among government regulators, consumers and industry personnel. One of the most common misunderstandings is that citing a formaldehyde level of a wood product is meaningless unless the test method and conditions are also cited. Over the past several years there has been an increasing effort to bridge these differences in testing methods between Europe and North America mainly.

Formaldehyde emissions from pressed wood products come from two sources within the product: free formaldehyde (formaldehyde molecules left non-reacted) and the long-term relatively steady-state breakdown of the urea-formaldehyde bond (resin hydrolysis). Furthermore, there are two types of factors influencing the level of formaldehyde emissions from panel products: internal and external factors. Internal factors comprise of the type of wood and resin employed, the parameters and conditions of panel production, and the panel age as well. External factors represent the temperature, relative humidity, air exchange rate, and total panel area in relation to the total volume of the space in which the panels are placed. All these factors are taken into consideration when measuring formaldehyde emission.

Formaldehyde test methods were developed along two tracks: large test chambers designed to imitate a room in a home, and smaller, quicker tests suitable for lab bench and plant quality control. The large chambers, due to their perceived accuracy with which they simulate human environments, became known as "reference" tests and were frequently cited in government regulations and standards. The smaller tests became known in Europe as "derived" test methods (Marutzky and Margosian 1995).

In industrial practice, the perforator method is the most widespread test procedure for measuring formaldehyde content from particleboards and MDF in Europe, and is also employed worldwide with the exception of North America. It is accurate, reproducible, and its application cost as compared to the gas analysis and large chamber methods has been calculated to rate at 0.5 : 8 : 100 respectively. In the case of very low formaldehyde emissions, however, the perforator method is not considered as a reliable method. Small chambers are also widely utilised in Europe and North America and can be very accurate, relatively easy to adapt at both laboratory and plant environments, and correlate well to large chambers.

An overview of selected test methods and related standards in use is presented in Table 1.

1.3 Occupational exposure limits

Ever since formaldehyde emission was identified as a potential contributor to low indoor air quality, efforts were made by both the government and industry to reduce exposure to it. One of the measures taken was the establishment of both occupational and residential exposure limits for formaldehyde.

The Occupational Exposure Limits (OELs) for formaldehyde are presented in Table 2. In countries with higher limits there are discussions to lower them following the recommendation of the International Agency for Research on Cancer (IARC) (e.g. in Australia, the OEL of 1.0 ppm will be set to 0.3 ppm within 2008).

The maximum exposure limits for formaldehyde in the living space environment of some selected countries are given in Table 3. The German value of 0.1 ppm was already established in 1977 by BGA (Anonymous 1977) and was confirmed by BfR in 2004 (Anonymous 2004).

Table 1: Formaldehyde test methods (Athanassiadou 2000, Marutzky 2008)

Test method	Standard, standard draft or method name
Chamber	EN 717-1, ASTM E 1333, ASTM D 6007, JIS A 1901, JIS A 1911, ISO 12460-1, ISO 12460-2
Gas analysis	EN 717-2, ISO 12460-3
Flask method	EN 717-3, AWPA method
Desiccator	ASTM D 5582, JIS A 1460, JAS 235, JAS 233, AS/NZS 4266.16, ISO 12460-4
Perforator	EN 120, ISO 12460-5
Other	Field and Laboratory Emission Cell "FLEC", Dynamic Microchamber "DMC"

1.4 Formaldehyde emission standards for wood based panels

Apart from regulations governing formaldehyde concentration in workplace and living environments, guidelines for panel formaldehyde emission levels have been established. Germany pioneered in this field as well as in reducing panel formaldehyde emissions in actual industrial practice. In 1980, the world's first formaldehyde regulation for wood products was published in Germany (ETB-Richtlinie). That guideline combined the formaldehyde steady state concentration, determined by a large chamber test, and the formaldehyde content, determined by the perforator method, classifying particleboards according to their formaldehyde release into three different emission classes, E1, E2 and E3 (Table 3).

Table 2: Occupational Exposure Limits (OELs) for formaldehyde (IARC 2006, FormaCare 2007, Q&A on formaldehyde)

Country	Concentration (ppm)	Type[a]
Australia	1.0	TWA
Austria	0.3	TWA
Belgium	0.3	Ceiling
Brazil	1.6	Ceiling
Canada-Alberta	2.0	Ceiling
Canada-Ontario	0.3	Ceiling
Canada-Quebec	2.0	Ceiling
Denmark	0.3	TWA & STEL
Finland	0.3	TWA
France	0.5	TWA
Germany	0.3	TWA
Greece	2.0	TWA
Hong Kong	0.3	Ceiling
Ireland	2.0	TWA
Italy	0.3	Ceiling
Japan	0.5	TWA
Malaysia	0.3	Ceiling
Mexico	2.0	Ceiling
Netherlands	1.0	TWA
New Zealand	1.0	Ceiling
Norway	0.5	TWA
South Africa	2.0	TWA
Spain	0.3	STEL
Sweden	0.5	TWA
Switzerland	0.3	TWA
United Kingdom	2.0	TWA
USA-ACGIH[b]	0.3	Ceiling
USA-NIOSH[b]	0.016	TWA
USA-OSHA[b]	0.75	TWA

[a] *TWA: time-weighted average, STEL: short-term exposure limit.*

In 1989, there was a new regulation determining a more stringent E1 level (photometric average perforator value = 6.5 mg/100g dry board). This E1 level is valid till today and has been adopted, more by trade than by regulation, by a lot of other European countries. Table 4 summarizes the current classification of wood-based panels in respect to formaldehyde emission according to the European, Australian, U.S.A. (also valid in Canada) and Japanese standards.

Table 3: Formaldehyde maximum exposure limits (MEL) in the living space in various countries (as in 1999).

Country	HCHO MEL, living space (ppm)
USA	0.10
Denmark	0.12
Finland	0.12
Norway	0.10
Sweden	0.20
Austria	0.10
Germany	0.10
Switzerland	0.10
UK	--
Belgium	--
France	--
Greece	--
Australia	0.10
Canada	0.10

Table 4: Classification of particleboards according to their formaldehyde emission (ETB-Richtlinie, Roffael 1993)

Emission class	Equilibrium concentration in a 40 m^3 test chamber (ppm)	Iodometric Perforator value (mg/100g dry board)
E1	≤ 0.1	≤ 10
E2	0.1 - 1.0	10 - 30
E3	1.0 - 2.3	30 - 60

Currently the German regulation requires compliance with E1 emission limits. Also other European countries like Austria, Denmark and Sweden followed Germany in producing boards of only E1 levels. However, most European countries still have legislation allowing the production and distribution of E2 boards (according to EN 13986).

Recently, the members of EPF agreed to only produce E1 boards and that compliance should be monitored through a system of internal and external checks (EUWID 2007). At the same time, the members firmed up the E1 limit values for ongoing production monitoring. However, the discussions on a new emission class in Europe still continued favouring limits similar to that of the Blue Angel certification for environmentally-friendly products and services = wood-based panels with formaldehyde emission at least 50 % below the value of 0.1 ppm set out in class E1, thus emissions of less than 0.05 ppm. In 2008, EPF decided to draw up its own formaldehyde emission standard (4 mg/100g for PB, 5 mg/100g for MDF, EUWID 2008). This decision came after IKEA had announced that it will introduce new formaldehyde emission limits for a number of types of wood-based panels from September 2008. These IKEA limits correspond to a perforator (EN 120) value of max. 4.0 mg/100 g for particleboards (5.0 mg/100g for MDF > 8 mm) correlating to 0.06 ppm chamber value (EN 717-1).

Table 5: Current formaldehyde emission standards for wood-based panels in Europe, Australia, the U.S.A. and Japan

Country	Standard	Test method	Board class[a]	Limit value
Europe	EN 13986	EN 717-1 EN 120	E1-PB, MDF, OSB	≤ 0.1 ppm ≤ 8 mg/100g
		EN 717-1 EN 717-2	E1-PW	≤ 0.1 ppm ≤ 3.5 mg/(h m^2)
		EN 717-1 EN 120	E1-PB, MDF, OSB	> 0.1 ppm > 8 - ≤ 30 mg/100g
		EN 717-1 EN 717-2	E2-PW	> 0.1 ppm > 3.5 - ≤ 8.0 mg/(h m^2)
Australia & New Zealand	AS/NZS 1859-1 & 2	AS/NZS 4266.16 (Desiccator)	E0-PB, MDF	≤ 0.5 mg/L
			E1-PB	≤ 1.5 mg/L
			E1-MDF	≤ 1.0 mg/L
			E2-PB, MDF	≤ 4.5 mg/L
USA	ANSI A208.1 & 2	ASTM E1333 (large chamber)	PB, MDF Industrial PW	≤ 0.3 ppm
			PW wall panels	≤ 0.2 ppm
Japan	JIS A 5908 & 5905	JIS A 1460 (Desiccator)	F**	≤ 1.5 mg/L
			F***/E0	≤ 0.5 mg/L
			F****/SE0	≤ 0.3 mg/L

[a]PB: particleboard, MDF: medium density fibreboard, OSB: oriented strand board, PW: plywood

The emission limit of the Japanese F** class is more or less equivalent to European E1-class, while the F*** and F**** emission limits are much lower than the E1-class. The emission of F**** boards is close to the emission of solid untreated wood (e.g. between 0.008 - 0.01 ppm or 0.5-2.0 mg/100g for spruce wood flakes, Marutzky *et al.* 2004).

The Air Resources Board of California (CARB) adopted a new regulation in April 2007 to reduce the formaldehyde emissions from composite wood products, including particleboard, MDF and hardwood plywood (Airborne Toxic Control measure, ATCM, CARB 2007). The modified version of this regulation was finally approved in April 2008. This regulation proposes the reduction of formaldehyde emission standards in two phases (Table 6). Phase 1 limits (effective from January 2009) are roughly equivalent to the European E1 emission class that is the Japanese F** class (Table 7). Phase 2 limits (effective from January 2010 and January 2011) are comparable to the Japanese F*** limits, the so-called E0 levels in Europe. The new regulation will establish the most stringent formaldehyde emission limits on wood products in the United States. The measure requires that wood panels and products manufactured from wood panels be certified by a "third party" laboratory (Third Party Certifier, TPC) approved by the CARB. These new emission standards apply to panels sold, supplied, offered for sale, or manufactured for sale in California, also to panels used in finished goods and there are special provisions for manufacturers using NAF (No-Added Formaldehyde) & ULEF (Ultra-Low-Emitting Formaldehyde) resins.

1.5 Reduction of panel formaldehyde emissions-the industry response

Facing the developments in formaldehyde re-classification and new emission standards, the wood panel manufacturers provided products with reduced formaldehyde release (Figure 3).

For the production of low emission boards, the following means are employed:

i. aminoplastic resins with low molar ratios F/U or $F/(NH_2)_2$, respectively;

ii. introduction of formaldehyde scavengers in the resin mix;

iii. addition of formaldehyde scavengers during the production of the boards, e.g. to the wet or to the dried chips;

iv. post manufacture treatment of the boards;

v. application of a diffusion barrier by coating or laminating or veneering of the board;

vi. alternative gluing systems (PF, PMDI, resins based on biomass products or by-products e.g. soy, tannin, lignin).

Table 6: The California Air Resources Board new standards (CARB 2008), Phase 1 and Phase 2 Formaldehyde Emission Standards for Hardwood Plywood (HWPW), Particleboard (PB), and Medium Density Fibreboard (MDF)[a]

Effective Date	Phase 1 (P1) and Phase 2 (P2) Emission Standards (ppm)				
	HWPW-VC	HWPW-CC	PB	MDF	Thin MDF
01.01.2009	P1: 0.08	-	P1: 0.18	P1: 0.21	P1: 0.21
01.07.2009	-	P1: 0.08	-	-	-
01.01.2010	P2: 0.05	-	-	-	-
01.01.2011	-	-	P2: 0.09	P2: 0.11	-
01.01.2012	-	-	-	-	P2: 0.13
01.07.2012	-	P2: 0.05	-	-	-

[a] Based on the primary test method [ASTM E 1333-96 (2002)] in ppm. HWPW-VC = veneer core; HWPW-CC: composite core.

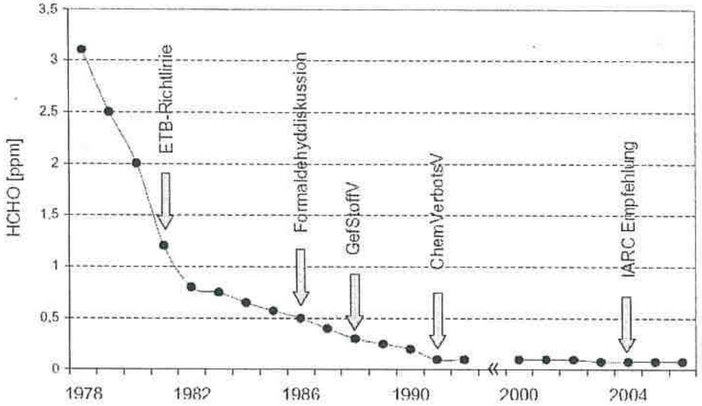
Table 7: CARB versus European and Japanese standards (CARB 2008, h)

P1 (ppm)	**E1**	**F*** **	**F**** **
HWPW (0.08)	more	comparable	less
PB (0.18)	less	less	less
MDF (0.21)	less	less	less
P2 (ppm)	**E1**	**F*** **	**F**** **
HWPW (0.05)	more	more	comparable
PB (0.09)	more	comparable	less
MDF (0.11)	comparable	less	less

Values in parentheses are the Phase 1 or Phase 2 standards in ppm. "More" means the proposed standard is "more stringent" than applicable E1, F***, or F**** standards.

Such efforts and products aimed to meet the new demands for very low formaldehyde emission from composite panel products without any deterioration in panel performance or significant modification of manufacturing plant operating conditions and above all with due respect to production costs. Lately, formaldehyde-based resin products providing panels with formaldehyde emission values at the level of natural wood were offered (Athanassiadou *et al* 2007, Kantner 2008).

As in the case of all chemicals, the wise use of formaldehyde together with the respect of formaldehyde emission standards and exposure limits are the means for safeguarding the worker and consumer health and quality of life levels.



ETB-Richtlinie: ETB-Guideline
Formaldehydediskussion: Formaldehyde discussion
IARC Empfehlung: IARC recommendation
GefStoffV: German Regulation on hazardous substances
ChemVerbV: German Regulation on prohibition of chemicals

Figure 1: Formaldehyde reduction for particleboards between 1978-2006 (Marutzky 2008)

2 EMISSIONS OF VOLATILE ORGANIC COMPOUNDS (VOC) FROM WOOD PRODUCTS

2.1 Background

In the developed countries of northern America and Europe indoor spaces are the most important environments. Depending on age and profession people spend between 12 and 19 hours of the day indoors (Krause and Schulz 1998).

Due to a better thermal insulation of buildings the average air exchange rate decreased significantly in the past. A study in Sweden showed that 60 % of the multi family houses and about 80 % of the single-family houses did not fulfil the minimum requirements regarding the ventilation rate in the Swedish building code – which is 0.5 air exchanges per hour (Bornehag *et al.* 2005). This can lead to an accumulation of indoor air pollutants, which generates potential risks to the health of the inhabitants. Major sources of contaminants are occupants themselves (e.g. smoking, bioeffluents), building materials (e.g. VOC, formaldehyde) and outdoor pollutants brought in through ventilation or by infiltration (ECA 2000).

Chemical indoor air pollution is usually characterized by a large number of chemicals for which only a few dose-response-relationships are known. Formaldehyde, a well-investigated substance, was recently reclassified by the international agency for research on cancer (IARC 2004) as carcinogenic to humans (see above). Another crucial but yet unknown aspect in this context is the effect of substance mixtures (ECA 1997).

Often, the concentration of most indoor pollutants is below official limit values for the working environment. But the exposure indoors lasts longer and affects more sensitive groups of society (e.g. children) as well.

Indoor air pollution and its sources are considered as possible causes for the sick building syndrome (SBS) and building related illnesses (BRI) (ECA 1997). Therefore, several national and international initiatives have been launched in order to minimize any health risks and improve the indoor air quality. Their main task is the assessment and control of chemical emissions from building products, which are considered to be one major source of indoor air pollution. Central tools for this purpose are assessment schemes for evaluating emissions and sensory effects (e.g. ECA 1997, AgBB 2008, AFSSET 2004). Beside such quasi-official actions low emissions are at least one requirement for the accreditation by most of the European eco-logos (e.g. Blauer Engel [D], natureplus [D], DICL [DK], FISIAQ [Fin]).

Furthermore, the Construction Products Directive ("CPD", Council Directive 89/106/EEC) states the following six Essential Requirements ("ER") to be fulfilled by construction / building products:

1. Mechanical resistance and stability
2. Safety in case of fire
3. Hygiene, health and the environment
4. Safety in use
5. Protection against noise
6. Energy economy and heat retention

Products must be suitable for construction works which (as a whole and in their separate parts) are fit for their intended use, account being taken of economy, and in this connection satisfy the following essential requirements where the works are subject to regulations containing such requirements. Such requirements must, subject to normal maintenance, be satisfied for an economically reasonable working life. The requirements generally concern actions, which are foreseeable.

According to ER No 3 „Hygiene, health and the environment“ the construction work, must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours, in particular as a result of any of the following:

- the giving-off of toxic gas,□
- the presence of dangerous particles or gases in the air.□
- the emission of dangerous radiation□
- pollution or poisoning of the water or soil,□
- faulty elimination of waste water, smoke, solid or liquid wastes, □
- the presence of damp in parts of the works or on surfaces within the works.

The implementation of this requirement under consideration of ETAs (European Technical Approval) and harmonised Standards (EN 13986) is performed by the standardisation process of CEN/TC 351 “Construction Products: Assessment of release of dangerous substances”, which was established in 2006.

2.2 Definitions

According to the World Health Organization (WHO) organic indoor air pollutants are classified by boiling points, which correlates fairly well with the volatility. The substances are categorized into four groups as indicated in Table 7 (WHO 1989).

A more practical and analytical definition of VOC is given in ISO 16000-6 (2004): Total Volatile Organic Compounds (TVOC) are defined as all compounds detected between n-hexane (C6) and n-hexadecane (C16) on a non-polar column of the gas chromatography system.

2.3 Methods-testing of VOC-emissions

Testing of product emissions is typically characterised by the following process steps: Under defined conditions a sample is placed in a suitable chamber, air samples are taken by accumulating substances on an absorbing material, which analysed in GC/MS- or GC/FID-system. This facilitates the identification and quantification of air borne substances emitting from the sample material.

According to ISO 16000-9 (2006) the size of the chamber is not defined, it may vary from 20 dm^3 up to a volume of some cubic meter, typically 1 m^3 chambers are in use. The applicability of small chambers (23 dm^3) for wood-based panels was proved by Makowski and Ohlmeyer (2006c). In order to avoid emissions from the chamber material itself and sink effects inert material should be utilised to design these chambers. The conditions in the chamber are defined for testing: temperature of 23 °C, relative humidity of 50 %, and air velocity on the sample surface of 0,1 … 0,3 $m\ s^{-1}$. Additionally, the air exchange rate n and the product loading factor L are fixed, but depending on the type of materials tested the following area specific air flow rate ($q = n/L$) may be applied:

- floor area: $q = 1{,}2\ m^3\ m^{-2}\ h^{-1}$
- wall area: $q = 0{,}4\ m^3\ m^{-2}\ h^{-1}$
- sealant area: $q = 44\ m^3\ m^{-2}\ h^{-1}$
- based on a model room with a volume $V = 17{,}4\ m^3$, area $A = 7\ m^2$ and air exchange rate $n = 0{,}5\ h^{-1}$

The concentration C of a volatile organic compound in the chamber air is depending on:

a) area specific emission rate SER_a of the tested material
b) material surface F
c) chamber volume V
d) air exchange rate n

Table 8: Classification of indoor air pollutants

	Description	Abbreviation	Boiling-point range (°C)	Sampling method typically used
1	Very Volatile (gaseous) organic compounds	VVOC	< 0 to 50-100	Adsorption on charcoal
2	Volatile organic compounds	VOC	50-100 to 240-260	Adsorption on Tenax, carbon molecular black or charcoal
3	Semi volatile organic compounds	SVOC	240-260 to 380-400	Adsorption on polyurethane foam or XAD-2
4	Organic compounds associated with particulate matter or particulate organic matter	POM	> 380	Collection on filters

and can be calculated by the following equation (1) under steady state conditions:

$$C = \frac{SER_a \cdot F}{n \cdot V} = \frac{SER_a}{n} \cdot L = \frac{SER_a}{q} \qquad (1)$$

where C is the concentration of a substance in µg m^{-3}, SER_a is the area specific emission rate of the tested material in µg m^{-2} h^{-1}, F is the surface of the tested material in m^2, V is the chamber volume in m^3, n is the air exchange rate in h^{-1}, L is the product loading factor in m^2/m^3, and q is the area specific air flow rate in m^3 m^{-2} h^{-1}.

The air exchange rate and product loading factor have a direct impact on the concentration. At constant conditions and emission rate the concentration is proportional to the size of the product surface and inversely proportional to the air exchange rate.

Another option for the determination of the emissions of VOC from building products is the test cell method according to ISO 16000-10 (2006).

The air sampling is performed according to ISO 16000-6 (2004). For VOC substances air samples are typically collected on Tenax TA (200 mg, 60 … 80 mesh) using an air sample pump with an electronic flow controller. A sample flow rate of 50 … 200 mL min^{-1} may be used not exceeding 80 % of the air flow rate of the chamber. Depending on the sampling time, usually a total air volume of 0.5 up to 5 litres are taken. The accuracy of the sampling air flow should be ± 1%.

After air sampling the absorbent tubes are thermally desorbed with a thermal desorbing system, characterized and quantified with a gas chromatograph and mass spectrometer. A quantitative assessment is achieved by multiplying the chromatogram peak area of each compound with the response factor of the relevant standard substance.

2.4 VOC-emissions from wood based composites

Organic emissions from wood and wood products can be ascribed to numerous causes. While very volatile formaldehyde emissions originate mainly from free parts of the used adhesives other components are volatile extractives of the wood itself. Beside its interlinked main components (lignin, cellulose and hemicelluloses) wood contains several free compounds. Their quantitative and qualitative composition depends mainly on the wood species. In this context and in regard to indoor air quality the mononoterpenes of coniferous wood play an essential role.

Due to the wide spread use of coniferous woods and their high vapour pressures terpenes are often detected in indoor air (Schriever and Marutzky 1991). Additionally wood and wood products can release short-chained fatty acids (e.g. acetic acid) as well as saturated and unsaturated aldehydes. Such compounds can derive from degradation of main components or extractives of the wood, e.g. autoxidation of fatty acids (Roffael 1989, Makowski *et al.* 2005). Although, none of the mentioned compounds is hazardous possible irritating effects of terpenes (Sagunski and Heinzow 2003) and low odour thresholds of aldehydes (Larsen *et al.* 2000) must be taken into account.

The predominant emissions from the OSB are monoterpenes and aldehydes. Terpene emissions decrease continuously, whereas aldehyde concentrations initially increased and subsequently decayed. Aldehydes are formed by the autoxidative splitting of unsaturated fatty acids contained in the wood. Due to the delayed release of aldehydes, a comparison of different emission test results is only possible if age and storage conditions are clearly specified. For a reduction in VOC emissions from wood-based materials, wood properties, manufacturing process, and storage conditions have to be considered (Makowski *et al.* 2005).

Correlations between process parameters and VOC emissions from an oriented strand board (OSB) made of Scots pine (*Pinus sylvestris* L.) are demonstrated by Makowski and Ohlmeyer (2006a). Terpene and aldehyde emissions were affected by the pressing time factors in different ways: terpene emissions were lowered with elevated pressing times, whereas the formation of volatile aldehydes was accelerated. Drying temperature mainly affected the dynamics of aldehyde formation, with a clear rise and fall in aldehyde concentration after drying at elevated temperatures (170 °C and 200 °C). As a consequence of lower temperatures (120 °C), aldehyde emissions from OSB constantly increased over the testing period. In spite of this context, a sustainable reduction in aldehyde emissions by adjusting the relevant process parameters does not seem to be feasible, as the concentrations released from all panels converged during emission testing.

As a consequence of high temperatures during hot pressing, terpene emissions from OSB are reduced (Makowski and Ohlmeyer 2006b). Aldehyde emissions are initially lowered after pressing at a high temperature (260 °C). Furthermore, emissions are influenced by the surface structure. If the surface consists of fine particles, terpene emissions are lowered and the course of aldehyde formation is altered. Nevertheless, a reduction in VOC emissions by adjustment of the parameters investigated in this work seems to be restricted to terpenes.

Aldehyde emissions from all panels converge during emission testing and in the final stages no clear distinction is possible according to the pressing temperature or surface structure.

2.5 Outlook

Wood product are strongly affected from the general quest for healthy buildings and therewith the reduction of emissions.

After reclassification of formaldehyde much stricter regulations may come up in the future. In Europe the emission class E1 (0,1 ppm) for wood-based panels became widely accepted. With ascending emission requirements the use of formaldehyde-based adhesives will be more and more restrained. To a certain extent a substitution of the deployed adhesives may be successful to fulfil future requirements. But in this context, it is essential to keep in mind that wood itself emits minor amounts of formaldehyde and will never be a product absolutely free of formaldehyde.

The public focus on VOC emissions and especially the consideration of requirements for hygiene, health and environment in the European Construction Products Directive (CPD) influence the future use of indoor relevant building products. Besides already existing voluntary eco-logos for building products, which includes wood products, further and more official procedures to assess the emissions of organic substances will be established. In combination with a probable tendency to lower formaldehyde release the emission behaviour has to be generally contemplated as new property. Therefore, the emission performance of building products will be one important aspect of competition. In order to make wood more competitive research about feasible strategies to lower or prevent VOC and formaldehyde emissions from wood products is necessary.

3 RESEARCH NEEDS

- sources of compounds from the wood substrate
- influencing factors on the emissions of the production
- possible consequences with respect to working space thresholds
- interactions of compounds from wood and other materials such as surface coating
- strategies to avoid and to reduce emissions from wood products

4 REFERENCES

AFSSET (2004) Relatif à une procédure d'évaluation des risques sanitaires concernant les composés organiques volatils (COV) et le formaldéhyde émis par les produits de construction. Avis de l'Agence Française de Sécurité Sanitaire de l'Environnement et du Travail Saisine Afsset n° 2004/011

AgBB (2008) Vorgehensweise bei der gesundheitlichen Bewertung der Emissionen von flüchtigen organischen Verbindungen (VOC) aus Bauprodukten - mit aktualisierten NIK-Werten. Ausschuss zur gesundheitlichen Bewertung von Bauprodukten, http://www.umweltbundesamt.de/ bauprodukte/voc.htm.

Anonymous (1977): Bewertungsmaßstab für Formaldehyd in der Innenraumluft. Presseinformation des BGA (Bundesgesundheitsamt) vom 12.10.1977

Anonymous (2004): Formaldehyd – Gefährlicher als bisher angenommen? Stellungnahme des BfR (Bundesinstitut für Risikobewertung) vom 29.11.2004

Athanassiadou, E. (2000) Formaldehyde free aminoplastic bonded composites. In: *Proceedings of the 5th International Conference on Environmental Pollution*, Aristotelian University, pp. 770. Thessaloniki, Greece.

Athanassiadou, E., Tsiantzi, S. and Markessini, C. (2007) Towards composites with formaldehyde emission at natural wood levels, Proceedings of the 2nd Conference of COST Action E49, Measurement and Control of VOC Emissions from Wood-Based Panels, 28-29 November 2007, Braunschweig, Germany.

Bornehag, C. G., Sundell, J., Hägerhed-Engman, L. and Sigsgaard, T. (2005) Association between ventilation rates in 390 Swedish homes and allergic symptoms in children. Indoor Air 15, 275-280

CARB (2007) http://www.arb.ca.gov/toxics/compwood/compwood.htm

CARB (2008, h) http://www.arb.ca.gov/regact/2007/compwood07/apph.pdf

CARB (2008) http://www.arb.ca.gov/regact/2007/compwood07/fro-final.pdf

Composite Panel Association (2004) IARC Decision on Formaldehyde Carcinogenicity. Release 21-04.

ECA (1997) European Collaborative Action "Indoor Air Quality and its Impact on Man": VOC-Emissions from Building Products - Solid Flooring Materials. Report No. 18, EUR 16284 EN. European Commission, Joint Research Centre, Enviroment Institute. pp. 1-48

ECA (2000) European Collaborative Action "Urban Air, Indoor Environment and Human Exposure" Report No 22. Risk Assessment in Relation to indoor air quality. European Commission. Joint Research Centre - Environment Institute - Air Quality Unit. pp. 1-100

EUWID (2007) Wood-based panels industry wants to end talks on emissions soon. *Wood Products and Panels,* 81(31), 1 & 13.

EUWID (2008) EPF planning to draw up its own formaldehyde emissions standard. *Wood Products and Panels,* 82(30), 1 & 10.

FormaCare (2006) Formaldehyde Toxicology – Scientific Update information (December 2006). http://www.formaldehyde-europe.org/

FormaCare (2007) Press Release: International Science Conference in Barcelona, Formaldehyde on the way to rehabilitation. http://www.formaldehyde-europe.org/ pages/fileadmin/formaldehyde/Word_docs/2007-09-21_FormaCare_Press_Release_english_ final.doc

FormaCare (2007) Q & A on formaldehyde. http://www.formaldehyde-europe.org/pages/ Q___A_on_formaldehyde.130.0.html#420

FormaCare (2007) Scientific fact sheet: Formaldehyde Toxicology – Scientific Update information (September 2007). http://www.formaldehyde-europe.org/pages/scientific_ fact_sheet.scientificfactsheet0.0.html

Formaldehyde Council (2004) Answers to Your Questions About IARC's Reclassification of Formaldehyde. http://www.formaldehyde.org/pdfs/IARCQA.pdf

Gelbke H.P. (2008) Formaldehyde: The Toxicological Profile and Regulatory Issues, Proceedings of the Technical Formaldehyde Conference, WKI, 13-14 March 2008, Hannover, Germany.

Global Insight (2005) The Economic Benefits of Formaldehyde To the United States and Canadian Economies, August 2005.

Global Insight (2007) Socio-Economic Benefits of Formaldehyde to the European Union (EU 25) and Norway, October 2007.

http://www.inrs.fr/

IARC (2004) International Agency for Research on Cancer (IARC), *Press Release Number 153,* 15 June 2004. http://www.iarc.fr/ENG/Press_Releases/archives/

IARC (2004) IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxy-2-propanol. International Agency for Research on Cancer (IARC), http://iarc.fr, zuletzt besucht am 14.09.2005.

IARC (2006) Monographs Vol 88: *Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol.* IARC Monographs , Lyon, France.

Kantner, W. (2008) Adhesive Developments Concerning Formaldehyde in Europe, Proceedings of the Technical Formaldehyde Conference, WKI, 13-14 March 2008, Hannover, Germany.

Krause, C. and Schulz, C. (1998) Aufenthaltszeiten der deutschen Bevölkerung im Innenraum, im Freien, im Straßenverkehr. Umweltmedizin in Forschung und Praxis 3, 249.

Larsen, A., Frost, L. and Funch, L. W. (2000) Emission of Volatile Organic Compounds from Wood and Wood-based Materials. Arbeitsbericht Danish Technological Institute. Wood Technology, p. 70.

Makowski, M. and Ohlmeyer, M. (2006a) Impact of drying temperature and pressing time factor on VOC emissions from OSB made of Scots pine. Holzforschung, 60, 417–422.

Makowski, M. and Ohlmeyer, M. (2006b) Influences of hot pressing temperature and surface structure on VOC emissions from OSB made of Scots pine. Holzforschung, 60, 533–538.

Makowski, M. and Ohlmeyer, M. (2006c) Comparison of a small and a large environmental test chamber for measuring VOC emissions from OSB made of Scots pine (Pinus sylvestris L.). Holz als Roh- und Werkstoff, 64(6), 469-472 & Erratum: 64 (6), 473-474.

Makowski, M., Ohlmeyer, M. and Meier, D. (2005) Long-term development of VOC-emissions from OSB after hot-pressing. Holzforschung 59, 519-523

Marutzky, R. (2008) Opening and Thematic Introduction, Proceedings of the Technical Formaldehyde Conference, WKI, 13-14 March 2008, Hannover, Germany.

Marutzky, R. and Margosian, R. (1995) Measuring formaldehyde emissions from pressed wood products: an international perspective. Measuring and Controlling Volatile Organic Compound and Particulate Emissions from Wood Processing Operations and Wood-Based Products. Forest Products Society. Proceedings 7301, 62-73.

Marutzky, R. and Dix, B. (2004) Adhesive related VOC- and Formaldehyde-Emissions from Wood products: Tests, regulations, standards, future developments. In: *Proceedings of the COST E34 Conference, Innovations in Wood Adhesives*, ed. Milena Properzi, Frederic Pichelin and Martin Lehmann, pp. 91-106. University of Applied Sciences Bern, HSB, Biel, Switzerland.

Roffael, E. (1989) Abgabe von flüchtigen organischen Säuren aus Holzspänen und Holzspanplatten. Holz als Roh- und Werkstoff 47, 447–452.

Roffael, E. (1993) Formaldehyde release from particleboard and other wood based panels. Khoo K.C., Koh M.P. and Ong C.L. Forest Research Institute Malaysia, 263-264.

Roffael, E. (2006) Volatile organic compounds and formaldehyde in nature, wood and wood based panels. *Holz als Roh- und Werkstoff*, 64, 144-149.

Sagunski, H. and Heinzow, B. (2003) Richtwerte für die Innenraumluft: Bicyclische Terpene (Leitsubstanz a-Pinen). Bundesgesundheitsblatt 46, 346–352.

Schriever, E. and Marutzky, R. (1991) Geruchs- und Schadstoffbelastungen durch Baustoffe in Innenräumen in Nr. 24, WKI-Bericht, 1991, pp. 1–10, 75–79.

WHO - Indoor Air Quality: Organic pollutants. EURO Reports and Studies No. 111. World Health Organisation, 1989. pp. 2-39.