EUROPEAN COLLABORATIVE ACTION

INDOOR AIR QUALITY & ITS IMPACT ON MAN

Environment and Quality of Life

Report No 18

Evaluation of VOC Emissions from Building Products

Solid Flooring Materials

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE - ENVIRONMENT INSTITUTE

1997

EUR 17334 EN

EUROPEAN COLLABORATIVE ACTION

INDOOR AIR QUALITY & ITS IMPACT ON MAN

(ECA-IAQ)

Environment and Quality of Life

Report No 18

Evaluation of VOC Emissions from Building Products

Solid Flooring Materials

prepared by

WORKING GROUP 10 - co-ordinating group

Philomena BLUYSSEN, TNO, Department of Indoor Environment, Delft, The Netherlands
Christian COCHET, C.S.T.B., Marne la Vallee Cedex, France
Manfred FISCHER, Institute for Water, Soil and Air Hygiene of the Federal Environmental Agency, Berlin, Germany
Helmut KNÖPPEL, European Commission, Joint Research Centre, Ispra,Varese, Italy
Leonard LEVY, MRC Institute for Environment and Health, University of Leicester, Leicester, U.K.
Bjørn LUNDGREN, SP, Swedish National Testing & Research Institute, Borås, Sweden
Marco MARONI, Institute of Occupational Health, University of Milan, Milan, Italy
Lars MØLHAVE (co-ordinator), Inst. of Environmental & Occupational Medicine, Aarhus, Denmark
Heinz ROTHWEILER, Umwelt und Gesundheit, Stadt Kloten, Kloten, Switzerland
Kristina SAARELA, Technical Research Centre of Finland, VTT, Espoo, Finland
Bernd SEIFERT, Institute for Water, Soil and Air Hygiene of the Federal Environmental Agency, Berlin, Germany

and by sub-groups

10A - Emission Measurements,
10B - Human Effects Evaluation
10C - Exposure Assessment
(for members see Appendix 11)

reviewed by

The STEERING COMMITTEE

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE - ENVIRONMENT INSTITUTE

1997

EUR 17334 EN

Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1997

ISBN 92-828-0384-8

Printed in Italy

Many building materials emit volatile organic compounds (VOCs) which have the potential to affect health and well-being.

This report presents key elements of a strategy to assess chemical emissions from building materials. It proposes a procedure which applies the strategy to the labelling of flooring materials with respect to their VOC emissions. Experience with using the procedure will assist in extending it to the labelling of other building materials.

The proposed procedure will enable designers, manufacturers, consumers and other decision makers to develop and select better products with lower and safer emission levels. This will lead to improved indoor air quality and reduced waste of energy, and will promote sustainable development.

In this series the following reports have already been published

- Report No. 1: Radon in indoor air. (EUR 11917 EN) *
- Report No. 2: Formaldehyde emission from wood-based materials: guideline for the determination of steady state concentrations in test chambers. (EUR 12196 EN) *
- Report No. 3: Indoor pollution by NO_2 in European countries. (EUR 12219 EN)
- Report No. 4: Sick building syndrome - a practical guide. (EUR 12294 EN) *
- Report No. 5: Project inventory. (S.P.I. 89.33) *
- Report No. 6: Strategy for sampling chemical substances in indoor air. (EUR 12617 EN)
- Report No. 7: Indoor air pollution by formaldehyde in European countries. (EUR 13216 EN) *
- Report No. 8: Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. (EUR 13593 EN)
- Report No. 9: Project inventory - 2nd updated edition. (EUR 13838 EN) *
- Report No. 10: Effects of indoor air pollution on human health. (EUR 14086 EN)
- Report No. 11: Guidelines for ventilation requirements in buildings. (EUR 14449 EN)
- Report No. 12: Biological particles in indoor environments. (EUR 14988 EN)
- Report No. 13: Determination of VOCs emitted from indoor materials and products. Interlaboratory comparison of small chamber measurements. (EUR 15054 EN)
- Report No. 14: Sampling strategies for volatile organic compounds (VOCs) in indoor air. (EUR 16051 EN)
- Report No. 15: Radon in indoor air. (EUR 16123 EN)
- Report No. 16: Determination of VOCs emitted from indoor materials and products; second interlaboratory comparison of small chamber measurements. (EUR 16284 EN)
- Report No. 17: Indoor Air Quality and the Use of Energy in Buildings. (EUR 16367 EN)

* out of print

Abstract

ECA-IAQ (European Collaborative Action 'Indoor Air Quality and Its Impact on Man'), 1997. Evaluation of VOC emissions from building products - solid flooring materials. Report No 18. EUR 17334 EN. Luxembourg: Office for Official Publications of the European Community

This report outlines the principles of a general evaluation procedure for emissions of volatile organic compounds (VOCs) from building materials with respect to their potential effects on health and comfort. Using available knowledge, the principles have been applied to a simplified case, i.e a procedure for the evaluation of VOC emissions from solid flooring materials. The procedure is intended for the classification and/or labelling of these materials and may serve for both voluntary and regulatory purposes. The procedure includes (i) the selection and handling of appropriate test specimens; (ii) the determination of emission factors of individual VOCs and of TVOC (Total Volatile Organic Compounds) using small test chamber measurements; (iii) modelling of indoor relevant VOC concentrations; (iv) their toxicological evaluation and (v) measurements of sensory irritation and odour or perceived air quality of the emissions.

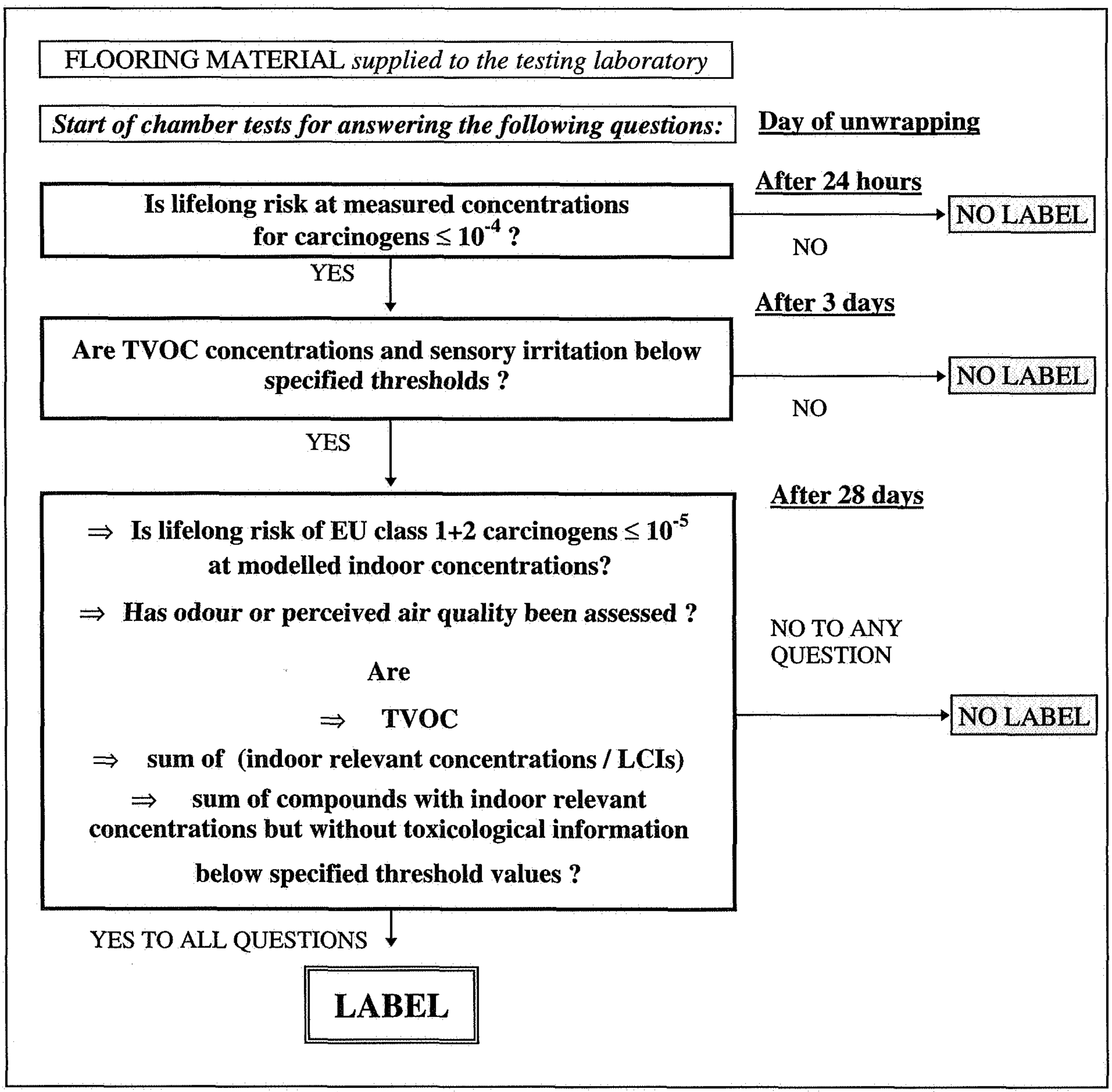
An overall scheme of how to combine the different elements of the procedure and rules how to use the information obtained for labelling of building materials have been established

TABLE OF CONTENTS

SUMMARY

Many building materials emit volatile organic compounds (VOCs) which have the potential to affect health and well-being. Therefore building materials need to be evaluated with respect to their VOC emissions. Considering this need and the different evaluation approaches taken in various European countries, the Steering Committee of the European Collaborative Action "Indoor Air Quality & Its Impact on Man" (ECA-IAQ) decided to tackle the problem in a European cooperation effort. As a result, this report outlines principles for the evaluation of VOC emissions from building materials with respect to their potential effects on health and comfort. Using these principles and available knowledge, an evaluation procedure for a special case has been designed, i.e the VOC emission from solid flooring materials. This procedure consists of the following steps:

- Determination of emission factors of individual VOCs and of TVOC (Total Volatile Organic Compounds) using small test chamber measurements.
- Modelling of indoor relevant VOC and TVOC concentrations using emission factors and simple exposure scenaria.



Scheme of the evaluation/labelling procedure for VOC emissions from flooring materials

- Toxicological evaluation of the indoor relevant concentrations. Available air quality guidelines (AQGs), no observed effect levels (NOELs) and other relevant information are used for the definition of "lowest concentrations of interest" (LCIs) with which the relevant indoor VOC concentrations are compared.
- Sensory evaluation of the material emissions. A test panel assesses first sensory irritation and subsequently the odour or perceived quality of the emissions.

A scheme (see page 1) has been established which fixes the sequence in time of the various tests described above and the rules on how to use the information obtained for labelling of building materials with respect to the potential impact of their VOC emissions on human health and comfort.

1. INTRODUCTION

1.1 Background

Health and indoor air quality. In recent years, a large number of incidents have been reported where occupants' health and comfort problems have been associated with their homes or with the buildings where they spend part of their time. These problem cases have normally been attributed to one of two different situations: Sick-Building-Syndrome (SBS) or Building-Related-Illness (BRI). For further information concerning SBS, the reader is referred to a previous report in this series (ECA-IAQ, 1989). Research has shown that building materials play a significant role in causing these problems (Gustafsson, 1992). In the case of BRI, it is usually possible to find the cause of illness or a problematic situation linked directly to the building, and in many instances, even to the material causing the effect. In the case of SBS, it is difficult to find a direct connection between a single cause and the problems associated with health or discomfort. However, following a thorough investigation it is not uncommon to find that air pollution originating from a building material is at least one of the reasons contributing to the observed problem. Thus, indoor air pollution and its sources, such as building materials, must be considered as possible causes of both BRI and SBS.

Control of sources of indoor air pollutants. Rules for regulating the properties of building materials have been established by the Council directive 89/106/EEC on construction products (EEC, 1989). An interpretative document of this directive (CEC, 1993) specifies which requirements apply to construction products, and which properties of building materials are essential with respect to hygiene, health and the environment. One requirement mentioned in the document concerns "a healthy indoor environment for occupants and building users" and specifies that one of the ways to achieve this objective is "the control of sources, eliminating or limiting the release of pollutants in the air." According to the interpretative document however, a prerequisite for implementing source control will be the formulation of standardized technical specifications for the measurement of pollutants and emissions. These standardized technical specifications are not yet available, however, the Technical Committee 264 (Air Pollution Control) of the European Standardization Committee (CEN) has charged a working group (WG7) to prepare a standardized method.

In principle, fulfilling the intentions of the essential requirement "hygiene, health and the environment" may mean regulating or even banning certain materials. An alternative and probably more efficient approach, is the promotion of construction products having no effects, or at least, only negligible effects on human health and comfort. To accomplish this objective, a system of positive labelling may be used to identify "healthy" building products.

Control of emissions. Until the last decade, building products have not usually been suspected as potential sources of health and comfort problems. As a result, they have been specified and certified for other considerations, but not regarding their impacts on health and comfort. More recent experience however, has shown air pollution by volatile organic compounds (VOCs) originating from building materials may be involved in the health and comfort problems of building occupants. Currently, there is very little information available for a consumer who wishes to select materials with no, or low pollutant emissions. Besides the lack of standardized methods of measurement (see above), a further reason for the unavailability of information has been the lack of a standardized procedure of evaluating emissions with respect to their potential effects on human health and comfort.

During the last few years, techniques for measuring emissions of volatile organic compounds (VOCs) from building materials have been developed (ECA-IAQ, 1991; Gustafsson and Jonsson, 1991; Wolkoff et al., 1993a; Gunnarsen et al., 1994). Besides being used for research purposes (see e.g. Clausen et al., 1995), these techniques have also proved useful for product development and for improvements in production.

However, validation of measurement techniques and data needed for evaluating the impact of emissions on occupants' health and comfort are lacking. While this calls for more research, validation requirements will depend on the purpose of an evaluation. As a matter of fact, evaluation of VOC emissions from building materials may be needed for different purposes. For example, it may be used for voluntary labelling of building materials satisfying health and comfort requirements, or for classification or ranking of building materials with respect to some specified characteristics. Alternatively, it may be used to estimate human exposures or their effects for given indoor scenarios, or for a regulatory purpose where certain specifications have to be met. The validation process for the techniques and data used must be progressively more stringent as the voluntary character of the evaluation process decreases.

Several attempts to promote the development of low emitting building materials have been made. A group of European carpet manufacturers (GuT - Association of Environmentally Friendly Carpets) have introduced a labelling system for carpets with respect to VOC emissions (Schröder, 1993). Two other systems have been introduced in Denmark and Sweden respectively.

The most elaborate system, called "Danish Indoor Climate Labeling" (DICL; Wolkoff et al., 1993b; Wolkoff and Nielsen, 1996), has been developed in Denmark.. The DICL is based on the time that concentrations of emitted VOCs need to decay below “indoor relevant” levels. These levels are determined using available toxicological information (e.g. occupational exposure limits) and published odour thresholds. Normally, the odour thresholds become the determining factor for labelling. The labelling system uses the only comprehensive literature source with standardized odour thresholds (Devos et al., 1990). The large uncertainty in available odour thresholds (literature values may differ by more than three orders of magnitude) has been the primary target for criticism of the DICL. Occasionally test times of several months may be required (Wolkoff and Nielsen, 1995). At present, the DICL does not include panel tests of the perceived quality of emissions (Wolkoff and Nielsen, 1996).

In Sweden, a trade standard for "Measurement of Chemical Emissions from Flooring Materials" was developed in 1993 by the Swedish National Flooring Trade Association and the Swedish National Testing and Research Institute. The Swedish procedure provides emission rate data obtained under specified conditions, but at present it does not include a toxicological evaluation. More recently, in Finland a voluntary classification system, supported by the government, has been introduced. It differs essentially from the Danish system, but follows the guidelines given in this report (FiSIAQ et al., 1995).

Considering the obvious need for classification of building materials and the different approaches taken in various European countries, the ECA-IAQ Steering Committee decided to join forces in a European effort to develop criteria for the evaluation of building material emissions which, in a pre-normative way, could serve for both voluntary and regulatory purposes, e.g., positive labelling of construction products. It should be recognised that manufacturers have problems in meeting different criteria established in different countries. Whilst experience and needs may vary slightly between different countries, there should be broad consensus about the principles used for the evaluation of building materials. A wide acceptance of the criteria used for evaluation would motivate manufacturers to provide products satisfying the evaluation criteria.

1.2 Objective

A generally applicable, validated procedure for the evaluation of all types of building materials for all purposes cannot be established immediately. Development of the procedure will still take some time. Meanwhile, many new and even older materials are being brought into buildings without any evaluation being made concerning their impact on health and comfort. This situation convinced the Steering Committee of the European Collaborative Action "Indoor Air Quality and its Impact on Man" (ECA-IAQ), that instead of waiting for a complete understanding it would be preferable to assemble available knowledge into an evaluation procedure now. Although incomplete, it would allow an evaluation to be made in special cases. As the required information becomes available, the procedure should be developed into an evaluation scheme which is more generally applicable.

As a result, this report outlines the principles of a general evaluation procedure regarding VOC emissions from building materials with respect to their potential effects on health and comfort, and using available knowledge to apply the principles to a simplified case (as described below).

The intended use of the evaluation procedure is to compare, classify and/or label solid flooring materials with respect to their VOC emissions. The procedure is primarily intended for voluntary use. It should serve to inform the consumer about flooring materials that are not likely to interfere with health and sensory comfort as far as chemical emissions are concerned. This information will be communicated by a positive label attached to products successfully passing the evaluation procedure described here.

The report also identifies some areas where information is needed to strengthen the basis of the evaluation procedure. At present, in these areas it appears preferable to reach a consensus on reasonable approximations or on shortcuts in the evaluation process for these areas, rather than awaiting data for scientifically complete solutions.

1.3 Steps of an Evaluation of Building Products

The evaluation of VOC emissions from building materials with respect to their effects on health and comfort may be broken down into five main steps.

(1) An inexpensive procedure for the chemical analysis of VOC emissions has to be established for emission factors of individual VOCs and of TVOC (Total Volatile Organic Compounds). Small test chamber measurements of chemical emissions from solid materials have shown acceptable results for some purposes, measurements of emissions from pasty or liquid materials still show unacceptably large disparities (see Chapter 2).

(2) The second step of the evaluation process requires the definition of an exposure scenario which is relevant for the purposes of the evaluation. For indoor spaces where people spend part of their time, the scenario should provide standard values for all exposure related environmental parameters, such as room area and volume, type and amount of materials and/or activities in the spaces, ventilation and temperature. Based on the selected scenario, on the emission rates determined in step (1) above, and on time/activity patterns, models may be used to estimate exposures of occupants to chemicals. Although exposure models for relatively complex scenarios have been proposed, only models for very simple scenarios have been validated (see Chapter 3).

(3) In the third step, chemical exposures estimated in step (2) have to be evaluated with respect to their potential health effects. For this purpose, relevant toxicological data have to be collected. Currently, only limited data exist on the effects of individual compounds, on effects of mixtures of compounds, and on validated methods for their estimation. This situation requires there be a number of approximations and the introduction of safety margins (see Chapter 4). Presently, the proposed evaluation procedure is for flooring materials only, because the availability of chemical emission data for these materials creates the possibility of testing the consequences of the proposed toxicological evaluation. However, it can be applied to other solid surface materials with minor modifications (see sections 2.2 and 3.3).

(4) VOCs may have effects on the human senses even at concentrations that are not detectable using the current chemical measurement techniques utilized in step (1) above. With present knowledge, sensory effects of many VOCs and to a greater extent those of their mixtures cannot be predicted from concentration measurements. It is known that such effects play an important role in the reaction of humans to indoor VOC pollution (Mølhave, 1991). Sensory evaluation by test panels is required in order to assess the perceived quality of VOC emissions. Whereas the chemical characterisation is widely applied, and generally accepted (although not completely validated) methods are available, sensory evaluation of emissions from building materials is still a matter of discussion and for the time being, no generally accepted methods exist (see chapter 5). In particular, modelling of perceived air pollution in real environments based on sensory emission measurements is an unresolved problem. Difference in quantity of available knowledge becomes also visible in this report where sensory evaluation has been treated in a single chapter whereas, by contrast, chemical evaluation can be found in different chapters related to emission measurement, modelling and evaluation.

(5) Finally, a rule or a scheme has to be developed on how to use the information obtained in steps 1-4 to characterize or label building materials with respect to the potential impact of their VOC emissions on human health and comfort.

1.4 Limitations of the Proposed Procedure

Taking into account both the aforementioned gaps in knowledge and the urgent need to control indoor sources of VOCs, the working group set up by the Steering Committee of the ECA-IAQ is proposing a procedure for the evaluation of VOC emissions which follows the five steps outlined above. The limitations of the proposed evaluation procedure are that it:

- currently, only refers to solid flooring materials;
- is only intended for the purpose of the labelling or ranking of these materials;
- is based on a simplified exposure scenario; and
- makes simplifying assumptions for estimating health effects.

Steps (1), (2), (3) and (4) of the proposed procedure have been drafted by three sub-groups., whereas a co-ordinating group has guided the sub-groups and decided on step (5) of the procedure. The Steering Committee of the ECA-IAQ has on several occasions reviewed the work and has charged two task forces with finalizing steps (3) and (4) of the procedure.

1.5 References

CEC (Commission of the European Communities), 1993. Council Directive 89/106/EEC on construction products: Essential requirement n° 3 "Hygiene, Health and the Environment'. Interpretative Doument. Brussels: Directorate-General for Internal Market and Industrial Affairs.

Clausen, G., Pejtersen, J., Saarela, K., Tirkkonen, T., Tähtinen, M., and Dickson D. (eds), 1995. European data base on indoor pollution sources in buildings: Protocol for testing of building materials. Version 1.0, November 28, 1995.

Devos, M., Patte, F., Ronault, J., Laffort, P., and Van Gemert, L.J., 1990. Standardized human olfactory thresholds. New York: IRL Press at Oxford University Press. ISBN 0-19-963146-8.

ECA-IAQ (European Concerted Action "Indoor Air Quality and Its Impact on Man"), 1989. Sick building syndrome - a practical guide. - Report No. 4, EUR 12294 EN. Luxembourg: Office for Official Publications of the European Communities.

ECA-IAQ, European Concerted Action "Indoor Air Quality and Its Impact on Man", 1991. Guideline for the characterisation of volatile organic compounds emitted from indoor materials and products using small test chambers. Report Nr. 8 (EUR 13593 EN). Luxembourg: Office for Official Publications of the European Communities.

EEC (European Economic Community), 1989. Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products. O.J. No L 40, 11.02.89, pp.12-25.

FiSIAQ (Finnish Society for Indoor Air Quality and Climate), Finnish Association of Construction Clients RAKLI, Finnish Association of Architects SAFA, Finnish Association of Consulting Firms SKOL, 1995. Classification of indoor climate, construction, and finishing materials. FiSIAQ Publication 5E. Espoo, Finland.

Gunnarsen, L., Nielsen, P.A., Wolkoff, P., 1994. Design and characterisation of the CLIMPAQ chamber for laboratory investigations of materials, pollution and air quality. Indoor Air, 4, 56-62.

Gustafsson, H. and Jonsson, B., 1991. Review of small-scale devices for measuring chemical emission from materials, Report 1991:25, Swedish National Testing and Research Institute.

Gustafsson, H., 1992. Building materials identified as major emission sources for indoor air pollutants - a critical review of case studies. Document D10: 1992, ISBN 91-540-5471-0. Stockholm, Sweden: Swedish Council for Building Research.

Mølhave, L., 1991. Volatile organic compounds, indoor air quality and health. Indoor Air 4: 357-376.

Schröder, E., 1993. GuT - Association for Environmentally Friendly Carpets - A practical example for safeguarding ecological and consumer interests. In: B. Seifert (editor) 'Methods of risk assessment for the indoor environment', Report on a joint NATO/CCMS and ECA-IAQ workshop. Berlin: Institute for Water, Soil and Air Hygiene, pp. 115-118.

Wolkoff, P., Clausen, P.A., Nielsen, P.A. and Gunnarsen, L., 1993a. Documentation of field and laboratory emission cell "FLEC" - Identification of emission processes from carpet, linoleum, paint, and sealant by modelling". Indoor Air 3, 291-297.

Wolkoff, P. and Nielsen, P.A., 1993b. "Indoor Climate Labelling of Building Materials, Chemical emission testing, modelling and indoor relevant odour thresholds". National Institute of Occupational Health, Copenhagen, Denmark, ISBN: 87-7534-443-2.

Wolkoff, P. and Nielsen, P.A., 1995. Indoor climate labelling of building materials. The experimental approach for a prototype. In: Methods for Characterising Indoor Sources and Sinks, ASTM STP 1287 (B.A. Tichenor, ed.). Philadelphia, U.S.A.: American Society for Testing and Materials.

Wolkoff, P. and Nielsen, P.A., 1996. A new approach for indoor climate labeling of building materials - emission testing, modeling and comfort evaluation. Atmospheric Environment 30B (15), 2679-2689.

2. CHEMICAL EMISSION MEASUREMENTS

The chemical characterization of VOC emissions from building materials requires the emitting material be isolated from other known or potential sources of VOCs. For chemical characterization, isolation is accomplished in environmental test chambers: containers where the environmental conditions, i.e. temperature, humidity, purity and flow rate of supply air and the air velocity/turbulence can be controlled. Once the emitting material is placed in the test chamber, the chamber air must be analysed in order to identify and quantify the VOCs emitted. Results from the quantitative analysis may be used as input for a model which will allow emission rates to be calculated from the measured vapour concentrations.

The term "test chamber" may designate a great variety of devices, with sizes (internal volume) extending over several orders of magnitude up to 50 m^3. However, most source characterization work is carried out using "small" test chambers, i.e. chambers with a volume no larger than about 2 m^3.

The following section 2.1 proposes a procedure for the chemical characterization of VOC emissions from solid flooring materials which forms the basis of the current standardization work of CEN/TC264/WG7. Section 2.2 briefly outlines additional factors that need to be taken into consideration for an emission measurement which is more generally applicable. Section 2.3 suggests some supplementary information that may be useful for the characterization of VOC emissions. Section 2.4 and Appendix 5 give information on different chemical classes and the more frequently encountered chemical compounds in emissions from flooring materials. Examples of measured emission factors are given in Appendix 6. References are listed in section 2.5.

2.1 Procedure for the Chemical Characterization of VOC Emissions from Solid Flooring Materials.

Several guidelines and methods have been published on how to perform emission measurements in small test chambers. These are reviewed in Appendix 1. They differ in many respects, such as: the objectives of the intended measurements; the materials and products to which they refer; their scope, i.e. whether all steps of the testing procedure are taken into account (including sampling, packaging, transport and conditioning of the test specimen, chamber design and construction, placement of the test specimen in the chambers, control of experimental parameters, sampling and analysis of chamber air, data reporting and quality assurance/quality control) or whether they only refer to part; and the detail in which these steps are described or prescribed.

None of the published guidelines and methods have been appropriately validated. Only the guidelines prepared by Tichenor (1989), ASTM (1990) and ECA-IAQ (1991) have been tested by inter-laboratory comparison experiments (ECA-IAQ, 1993; 1995). The results of these experiments demonstrate that the guidance provided does not guarantee a satisfactory degree of accuracy or the reproduction of emission measurements for all compounds emitted. While the experiments have identified some weak points in emission testing, validation is lacking regarding suggestions on how to overcome such limitations.

Following, is a procedure largely based on the work of Tichenor (1989), the Carpet Policy Dialogue Group (CPDG 1991) and the ECA-IAQ guideline for the characterization of VOC emissions from indoor materials and products (ECA-IAQ 1991). In addition, it attempts to include experience gained during the inter-laboratory comparison experiments previously mentioned. The terms "guideline" and "method" have been avoided because some of the following recommendations are (i) more detailed or precise than guidelines require; and (ii) use of the term "method" suggests a degree of validation which is still lacking. As a result, the existing uncertainties do not always allow for recommendations that are sufficiently precise.

The procedure includes recommendations for choosing parameters that influence the outcome of an emission measurement. Where deemed appropriate, and together with the recommendations, the rationales they are based on and uncertainties or simplifications are indicated. The recommended procedure is **limited to solid flooring materials** and intended for their ranking and labelling as described in Chapter 6. In its present form, the procedure does not consider composite flooring systems, paints/varnishes or maintenance products.

2.1.1 Chamber construction and operation

Chamber size

The following procedure refers to small chambers with volumes $\leq 2\ m^3$.

Wall material and treatment, sealants

Chamber walls are made of low emitting/sorbing materials; recommended is polished stainless steel or glass. Exposed surfaces of sealants/gaskets should be as small as possible and preferably covered by an inert material, such as PTFE (polytetrafluoroethylene).

Chamber tightness

Chamber tightness should be checked by pressure drop measurements using the equation

$$LR = ROP \times \ln 2 / t_{1/2} \cong 0.7 \times ROP / t_{1/2} \qquad (2.1)$$

where LR [chamber volumes per hour] is the leakage rate, ROP (chamber minus ambient pressure divided by ambient pressure) is the relative overpressure, and $t_{1/2}$ [hour] is the time during which an overpressure in the sealed chamber decays to half its initial value. A value of $\mathbf{t_{1/2} \geq 8\ min}$ should be obtained.

Chamber air mixing

The chambers should be designed to ensure complete mixing of the chamber air. It is preferable to use chamber designs which enforce complete chamber air mixing and allow air velocity/turbulence control (see 2.1.2 "Air velocity across the emitting surface"). In any case, adequate mixing of chamber air should be checked (see section 2.1.5 below).

Supply and chamber air quality/cleaning

The supply air and/or the chamber have to be cleaned until the chamber background satisfies the following conditions:

(1) Background concentrations of individual compounds known to be emitted from the test material and which after 28 days of testing give rise to chamber concentrations $\geq 5\ \mu g\ m^{-3}$, must be smaller than $0.5\ \mu g\ m^{-3}$ or below the detection limit (whichever is greater). This condition may require a preliminary knowledge of the major constituents of the test material emissions, e.g. by head space analysis.

(2) Background concentrations of carcinogenic compounds listed in Table 4.1 (see section 4.4) must be smaller than $0.5\ \mu g\ m^{-3}$ or 10 % of the limit concentration specified in the Table, (whichever is smaller).

(3) Background concentrations of all other compounds have to be $< 2\ \mu g\ m^{-3}$, measured as toluene equivalent.

(4) The sum of the concentrations of all background compounds (TVOC; see definition in section 2.1.7) as determined by an FID applying the response factor of toluene, has to be smaller than $10\ \mu g\ m^{-3}$.

Background contributions due to the analytical procedure, e.g, from the adsorbent used for chamber air sampling, may be subtracted if this background contribution is fairly stable, regularly determined, and the average value and its standard deviation is known. (For chamber cleaning see Appendix 1, section 4.9.1, and Appendix 2).

2.1.2 Choice of environmental parameters

Temperature

The test **temperature** should be controlled to **23°C ± 0.5°C** (accuracy).

Relative humidity

The **relative humidity** for the chamber test should be **45 % ± 5 %** (accuracy).

Ratio of air exchange rate and product loading or specific ventilation rate

The air exchange rate n [h^{-1}] is defined as the mass flow rate [m^3 h^{-1}] of clean air through the chamber divided by the chamber volume V_c [m^3]. Product loading or the loading factor L [m^2m^{-3}] is the ratio of the emitting surface area A [m^2] of the test specimen and the chamber volume V_c. The specific ventilation rate q_c [m^3 $h^{-1}m^{-2}$] is the ventilation rate [m^3 h^{-1}] per unit emitting surface area [m^2] and is equal to n/L.

The **specific ventilation rate** should be $q_c = n/L =$ **1.25 m^3 $h^{-1}m^{-2}$**. If microchambers are used with a different q_c, it should be demonstrated that the influence on the emission rate is negligible.

Air exchange rate

The **air exchange rate** during emission testing should be **0.5 ± 0.015 h^{-1}** (accuracy). Larger rates may be used with proportionally larger loading factors (see above).

Product loading or loading factor

The **loading factor** should be **0.4 m^2m^{-3}**. Larger factors may be used with proportionally larger air exchange rates (see above).

Air velocity across the emitting surface

A **surface air velocity** of **0.1-0.3 m s^{-1}** is recommended. Micro-chambers not allowing for separate control of air exchange rate and air velocity or mixing, require special consideration.

2.1.3 Test material/specimen collection, handling and preparation

Test material collection

VOC emissions from new flooring products have to be determined for labelling/ranking purposes. Therefore, test materials should be collected directly from the manufacturer's production line and packaged immediately (see below) in order to ensure the test material's chemical integrity during transportation to the testing laboratory. The size of the material to be collected depends on the surface area of the test specimen(s) to be introduced into the test chamber (chamber volume [m^3] times loading factor). Test specimens should be circular or quadratic in order to minimise the length of edges. For rolled products such as broad loom carpet, sufficient test material should be collected so that there is an internal layer of the rolled material from which a minimum of two test specimens can be collected. Other products such as floor tiles should be obtained and packaged so that internal pieces of appropriate size are sandwiched between two outer pieces.

The material collected for testing must be accompanied by an information form on which details regarding the type, colour and dimension, etc. of product; date of manufacture and packaging (preferably the same date and not more than one day difference); and the respective production number are reported. Further dates and details of the test materials' history should be recorded on the form, such as: type of packaging; dates and climatic conditions of transportation and storage before unpacking (see also section "transport and storage" below), and date of unpacking etc.

Packaging of test material

Test materials should be packaged in such a way that permeation of VOCs from either the interior or exterior will not significantly change the emissions upon unpacking. Aluminised packaging (shiny side out) lined with polyethylene or Tedlar® has given acceptable results (CPDG, 1991). This packaging has to be hermetically sealed (e.g. by soldering). Alternatively, stainless steel containers with an air tight cover (sealants with low emission and absorption properties such as PTFE coated o-rings) may be used. These containers are reusable. Their size has to correspond to the required test specimen size and number. Materials used for packaging (tested according to the method described here) must have a consistent TVOC background emission factor less than 0.010 mg $h^{-1}m^{-2}$.

Transport and storage prior to unpacking at the laboratory

Once a test material is collected and packaged, it should arrive at the testing facility as soon as possible. A maximum of 7 days is allowed for transport and handling prior to unpacking at the laboratory. Air transport of test material should be avoided. If necessary, pressure containers with specified and constant pressure should be used.

During transport and storage, temperatures should not exceed normal indoor levels, i.e. 25°C. A small maximum thermometer should be placed into the package in order to provide information on unsuitable thermal conditions during transportation. Similarly, a passive sampler for VOCs could be fixed to the outer side of the test material package in order to provide information about potential contamination of the test material. If the most abundant compounds collected on this sampler are found in the material emission above background level (see section 2.1.1, heading "Chamber preparation/cleaning"), this could be seen as a warning sign requiring further investigation of test material contamination.

Test specimen preparation

If not all surfaces of the test specimen have the same emission factor (e.g. edges of a plywood board or a PVC tile, the under side of carpet material) and only the emission from the normally exposed surface(s) has to be determined (e.g. the top-side of a carpet), the other surfaces need to be covered. For example, edges may be sealed with a low emitting, self-adhesive, aluminium tape to eliminate excessively high edge emissions. A stainless-steel plate may be used as a support for a test specimen, if the emission from one side is to be tested only. The mounting must have the ability to seal the edges of the test specimen. For this, a stainless steel tray is recommended (CPDG, 1991).

Conditioning of test specimens prior to and between emission measurements

Upon unpacking the test material at the testing laboratory, test specimens have to be prepared immediately (see "Test specimen preparation" above) and introduced into the test chamber at test conditions (see section 2.1.2). The date and time of introduction of a test specimen into the chamber has to be regarded as the starting time of emission testing.

The test temperature and humidity must also be applied if the test specimen is removed from the test chamber and placed in a conditioning room or chamber between the emission measurements (see section 2.1.4, heading "Sampling time and frequency"). In the conditioning room or chamber, the emitting surface(s) must be exposed to clean air (see section 2.1.1, heading "Supply air quality / treatment"). Cross contamination with any other test specimen or material must be avoided. The specific ventilation rate has to be adjusted to the value q_c=1.25 m^3 $h^{-1}m^{-2}$ (see section 2.1.2, heading "Ratio of air exchange rate and product loading"). If the test specimen is removed from the test chamber between emission measurements, it has to be re-introduced at least 72 hours before the next emission measurement.

Specimen location in the test chamber

The test specimen should be positioned in the test chamber so that the emitting surface is parallel to the direction of the air flow (in particular if a fan is installed) and in such a way that the air flow is evenly distributed over the emitting surface.

2.1.4 Chamber air sampling

The selection of the factors involved in chamber air sampling is discussed below. Sampling techniques and analytical procedures are not included. For these items, reference is made to Chapter 3 and Chapter 5D of the ECA-IAQ guideline on VOC emission testing (ECA-IAQ, 1991).

Sampling location

Chamber air samples have to be collected from the exhaust flow (i.e. at the chamber air outlet).

Sampling lines and manifold

Any ducting between the chamber and the sampling device should be as short as possible and maintained at least at the same temperature as the test chamber. A multiport sampling manifold can be used to provide flexibility for duplicate samples. The parts of the sampling system that come in contact with the vapours should be constructed of inert material (e.g., stainless steel, glass, Tedlar). The exhaust from the sampling system should be ducted into a fume hood ensuring any hazardous chemicals emitted by the test material are isolated from the laboratory environment.

Sample recovery

Recovery tests for sampling and analysis have to be performed by sampling atmospheres with known and realistic concentrations of VOCs, and by comparing the results of the analysis with the expected values. If calibration atmospheres are not available, the sampling tubes can be spiked with known and realistic amounts of the compounds to be analysed, followed by flushing the tubes with a volume of pure air corresponding to the normal sampling volume.

Because recovery may depend on the chemical nature of a compound, tests have to be carried out with all the types of compounds subject to the study.

Sampling times

Chamber air samples have to be collected at times

$$\mathbf{t_{s1} = 24\ h \pm 1h;\ /\ t_{s2} = 72\ h\ (3d) \pm 3h;\quad and\ /\ t_{s3} = 28\ d \pm 1d}$$

after the start of emission testing, i.e. after the test specimen has been introduced into the test chamber and the chamber has been closed. For reasons of quality assurance, at least two samples have to be collected.

Sampling duration

Sampling duration (the time it takes to collect a sample of the chamber air), depends on the sampling and analytical method. The relevant parameters are;

- the air volume required in view of the sensitivity of the analytical method and;
- the permitted air sample flow rate in relation to chamber ventilation.

For the usual sampling and analytical methods, i.e., active sampling on solid sorbents combined with thermal elution and GC-FID or GC-MS analysis, the sampling duration is typically between a few and about 30 minutes, depending on the chamber concentrations.

Sorbent sampling combined with solvent elution usually requires the sampling of larger air volumes resulting in a sampling duration of up to 2 hours. For these longer time periods, sampling should be started so that the total sampling duration is centred around the sampling times t_{si} specified above.

Sample air flow rate

The sample air flow rate should not exceed half the air flow rate through the chamber and has to be low enough to guarantee complete retention of VOCs on the sorbent used for sampling.

Emission test duration

The duration of the emission test is at least 28±1 days (see Chapter 6).

2.1.5 Chamber performance control

Temperature and relative humidity

Temperature and relative humidity should be controlled to the values specified in section 2.1.2 using appropriate sensors and feedback designs. Several types of sensors may be used, including thermocouples and thermistors for temperature control, and dew point detectors and thin film capacitors for humidity control. The sensors used for temperature and relative humidity control should be checked at regular intervals against independent instruments traceable to certified standards.

Air exchange rate

The air exchange rate n [h^{-1}] is determined by measuring the air flow rate [$m^3\ h^{-1}$] through the test chamber and dividing it by the chamber volume V_C. Before each emission measurement, the air flow rate has to be controlled with a volumetric device which is traceable to a certified standard. Importantly, if the test is carried out with an instrument not permanently installed, note that the backpressure introduced by the instrument can lower the flow rate through the chamber. In this case, the control measurement has to be repeated until a steady state value is obtained for the air flow rate.

Efficiency of the air mixing in the test chamber

Efficiency of the air mixing in the chamber should be tested following the tracer gas method proposed by Tichenor (1989, see Appendix 2). A difference between the "apparent" chamber volume determined by this method and the actual chamber volume of >5% is not acceptable.

Background concentrations

Background concentrations have to be controlled before each experiment and must satisfy the conditions outlined in section 2.1.1, heading "Supply and chamber air quality/cleaning".

Air velocity/turbulence in the chamber

Since research on air velocity/turbulence measurements is scarce, only preliminary indications are possible. Air velocity/ turbulence in the chamber should be measured close to the emitting surface (a distance of approx. 1 cm may be appropriate) and with a specimen of the material to be tested in the same position as the emission test specimen. Small sensors (e.g. *STREAMLINE* hot wire anemometer, DANTEC Measurement Technology A/S, Skovlunde, Denmark) should be used for the measurement in order to disturb the air flow as little as possible. Depending on the size of the specimen, several measurement points should be chosen. The average air velocity should be adjusted to 0.1 m s^{-1}.

Sink effects

Emission factors determined by concentration measurements in small test chambers (see section 2.1.7) may be smaller than the true emission factors because of sorption to internal test chamber surfaces (see Appendix 2, section 2.1.5).

Therefore, before using a chamber for the determination of emissions from flooring materials, the chamber should be checked for sink effects by introducing known amounts of test compounds as described in Appendix 2, section 2.1.5. Test compounds of a similar volatility as the expected emissions should be used. The emitted compounds should be introduced into the chamber for a period of 72 hrs. If, at the end of this period, the differences between the expected and the measured concentrations are greater than 20 percent of the expected concentrations, the sink effect is considered significant for compounds of similar or lower volatility. In this case, the sink effect has to be reduced, e.g. by increasing the air exchange rate (which would require a proportional increase of the loading factor; see section 2.1.2) or the chamber cannot be used for emission measurements according to the procedure described here.

2.1.6 Reporting on details of the test procedure

The report should contain test objectives; facilities and equipment; test material/specimen descriptions; experimental procedures; discussion and conclusions; and information on QA/QC.

Test Objectives. Describe the purpose of the test programme.

Facilities and equipment. Describe the test chambers (volume, wall material, sealing material), clean air system, air sampling location, environmental measurement and control, sample collection (including sorbents if used), analytical instrumentation (e.g., GC/MS); and standards generation and calibration.

Test material/specimen descriptions. Describe the tested material/specimen(s) including type of material/product; size or amount of the test specimen(s); product history; brand name (if appropriate); and the selection process of the test material (e.g., random). Also, provide information on the preparation of the test specimen(s) including edge sealing, its location in the test chamber, and on test specimen conditioning, i.e., duration and environmental conditions if the sample has not remained during the entire 28 day period in the test chamber.

Experimental procedures. Give details of the sampling and analysis techniques and references to published methods.

Quality assurance / quality control. Describe the data quality objectives and discuss adherence to the acceptance criteria. In particular provide;

- results of measurements to control appropriate chamber operation (see section 2.1.1) including chamber tightness; and a report on overpressure and decay time $t_{1/2}$;
- the results of measurements of environmental variables and of measurements aimed at verifying the appropriate performance of sensors used to control the variables including:
  temperature,
  relative humidity,
  air exchange rate; (in addition to flow meter measurements use dilution measurements with inerttrace gas such as SF_6),
  air velocity across the emitting surface;

- the results of temperature measurements during transport of the test specimen from the producer to the test laboratory;
- results of measurements to control chamber performance including;
  - *chamber background* before placement of the test specimen: report TVOC concentration (for definition see section 2.1.7) and concentration (expressed as toluene equivalent) of highest individual background peak. If concentrations of compounds originating from the analytical procedure are subtracted from analysis results, their names, average concentrations occurring and the respective standard deviations must also be reported;
  - *efficiency of air mixing*: report the difference between "apparent " and actual chamber volume in percent as described in section 2.1.5, heading "Efficiency of air mixing";
  - *chamber sinks*: report results of sink measurements performed according to section 2.1.5, section "Sink effects". Provide names and expected concentrations of the test compounds, and for each test compound report the difference of the expected and measured concentrations after 72 h testing, expressed as a percentage of the expected concentrations.

Discuss the outcome of any audits.

2.1.7 Data reporting/calculation

The final results of the chemical emission testing are **emission factors** for individual compounds [$\mu g\ h^{-1}m^{-2}$] and of the total VOC emission (TVOC) [$mg\ h^{-1}m^{-2}$]. However, emission factors can not be measured directly, but must be calculated from measured chamber concentrations using models like those described below. As part of the quality assurance procedure not only the emission factors, but also the concentration measurements used for their calculation, should be reported.

Data to be reported

The following data are needed as input for the emission evaluation procedure (see Chapters 4 and 6).

24 h ± 1 h after the beginning of the test, i.e. after introduction of the test specimen(s) into the test chamber:

- concentration [$\mu g\ m^{-3}$] and emission factor [$\mu g\ h^{-1}m^{-2}$] of all compounds contained in Table 4.1 (see section 4.4) with chamber concentrations above the detection limit or a limit concentration reported in the table;

72 h (3d) ± 3 h after the beginning of the test

- TVOC concentration [$mg\ m^{-3}$] and emission factor [$mg\ h^{-1}m^{-2}$] as defined below.

TVOC (total volatile organic compounds) is a quantity for which no generally accepted definition yet exists.

For the purpose of this procedure, the following definition is adopted until a definition under preparation by an ECA-IAQ working group becomes available:

TVOC is the sum of the masses of all compounds above their respective detection limits eluting from an apolar (OV1 type) gas chromatographic (GC) column in the elution range from n-hexane to n-hexadecane, divided by the sampled chamber air volume. The masses are detected with a flame ionization detector (FID) and determined using the FID response factor of toluene. The detection limits (three times noise level) for toluene and for 2-butoxyethanol (butyl glycol) have to be given together with the TVOC value and must be $\leq 0.5\ \mu g\ m^{-3}$ *for toluene and* $\leq 2.5\ \mu g\ m^{-3}$ *for 2-butoxyethanol.*

The TVOC value determined according to this definition will tend to underestimate the emissions, but unless large quantities of halogenated aliphatic hydrocarbons are emitted or a GC column that has not been appropriately deactivated is used, the uncertainty will generally be smaller than a factor of 2. The TVOC value defined above, also depends on the parameters used for the integration of FID signals for individual compounds. The detection limits of toluene and of 2-butoxyethanol reflect this dependence.

28±1 days after the beginning of the test:

- Identity, chamber concentration [µg m^{-3}] and emission factor [µg $h^{-1}m^{-2}$] of all compounds with a chamber concentration ≥ $5 \times q_e/q_c$ µg m^{-3} (see sections 4.4 and 6.4.4). Here, q_c is the area specific ventilation rate during the chamber test (see section 2.1.2) and q_e is the area specific ventilation rate characterizing the simplified scenarios as discussed in Chapter 3, section 3.4 and used for the evaluation of VOC emissions. For the three scenarios or area specific ventilation rates taken in consideration, q_e/q_c assumes the values 0.5, 1 and 2 which requires determining emission factors for all compounds with chamber concentrations ≥ 2.5, 5 and 10 µg m^{-3} respectively. It should be noted here already that determining emission factors for all compounds with chamber concentrations ≥ 2.5 µg m^{-3} allows to perform the toxicological evaluation of the VOC emissions according to sections 4.4 and 6.4.4 for all three scenarios.

  Identification of compounds requires that at least one chamber air sample be analysed by combined gas chromatography-mass spectrometry (GC-MS);
- TVOC concentration [mg m^{-3}] and emission factor [mg $h^{-1}m^{-2}$].

Chamber concentrations

At least two chamber air samples have to be collected and analysed at each of the above given times. If not more than 3 samples are analysed, concentrations of all identified compounds (≥5 µg m^{-3}) and of TVOC have to be reported for each of the samples. In addition, the mean concentrations have to be reported. If more than 3 samples are analysed, the number, mean and relative standard deviation of the measured individual and TVOC concentration values have to be reported.

Emission factors

Emission factors are calculated from chamber concentrations using the following mass balance equation:

$$V_c \times \frac{dC}{dt} = E \times A - n \times V_c \times C \qquad (2.2)$$

or

$$E = \left[\frac{dC}{dt} + n \times C\right] \times V_c / A = \left[\frac{dC}{dt} + n \times C\right] / L \qquad (2.3)$$

where E [µg $h^{-1}m^{-2}$] is the emission factor; C [µg m^{-3}] is the chamber concentration; A [m^2] is the emitting surface area; V_c [m^3] is the chamber volume; L [m^2m^{-3}] is the loading factor; and n [h^{-1}] is the air exchange rate.

If the chamber concentrations are constant or if their variations per unit time are negligible compared to their measured values multiplied by the air exchange rate n, i.e. if the condition:

$$\left|\frac{dC}{dt}\right| \ll n \times C \qquad (2.4)$$

is fulfilled, equation (2.3) has a particularly simple form:

$$E = C \times n \times V_c / A = C \times n / L = C \times q_c \qquad (2.5a)$$

where q_c [m^3 $h^{-1}m^{-2}$] is the area specific ventilation rate as applied during the emission test (to be distinguished from q_e which is the area specific ventilation rate of the exposure scenario selected for the evaluation of the emissions as discussed in section 3.4, p. 27).

If relation (2.4) does not hold, equation (2.3) should be used for the calculation of emission factors. However, emissions of solid flooring materials generally decrease with time. On the other hand, after the introduction of a material into the test chamber, the chamber concentrations increase until the mass flow out of the test chamber ($n \times V_c \times C$) is equal to the emission rate $ER = E \times A$.

As a result, chamber concentrations increase up to a maximum value and then decrease. Experience shows that with the test conditions described in this chapter the maximum concentration is reached well before 24 hours, and that therefore, the chamber concentrations are decreasing, i.e., dC/dt is negative at the time of the first measurements. In this case, equation (2.5a) will overestimate the emission factor E. Furthermore, the contribution of the term dC/dt will usually contribute not more than 10 % to the emission factor. This contribution will be even smaller after 30 days of testing. Therefore (and because the potential error would be in the safe direction), the Working Group decided to apply equation (2.5a) for the evaluation procedure proposed here.

The emission factors E that have to be reported are calculated inserting the **mean value** {C} of the chamber concentrations measured at a given test time in equation (2.5a). This yields

$$E_i = \{C\}_i \times q_c \quad [\mu g\, h^{-1} m^{-2}] \qquad (2.5)$$

for the emission factor of an individual compound i and

$$E_{TVOC} = \{C\}_{TVOC} \times q_c \quad [mg\, h^{-1} m^{-2}] \qquad (2.6)$$

for TVOC emission factors where $\{C\}_{TVOC}$ is the mean value of the measured TVOC concentrations in the chamber [$mg\, m^{-3}$]. Because of the proportionality of E and {C}, relative standard deviations of the emission factors are equal to those of the concentration values.

2.2 Extension to Other Materials

The method described in section 2.1 has many features applicable to testing VOC emissions from materials and products other than solid flooring materials. Application to other solid surface materials such as wall coverings or curtains requires only an adaptation of the loading factors and area specific ventilation rates. Modifications may be needed regarding the measurement of emissions from liquid or pasty materials such as paints, lacquers, glues, and waxes or detergents that are applied to solid supports. Some modifications are also required if an emission measurement has an objective that is different from the objective of this proposal. The necessary modifications are briefly discussed in the following sections.

2.2.1 Measurements of emissions from liquid, pasty or composite products

Emission from liquid or pasty products occurs in real life mostly during or after their application as a thin film to some support. As a result, they have been called "thin film sources". For these products, emission measurements should be performed under similar conditions, i.e. after application to a support as a thin film. This requires a consideration of the following additional features.

(1). The procedure for applying the products to a support material.

In order to render emission measurements reproducible, the materials need to be applied as a film of known, homogeneous thickness. Interlaboratory comparison experiments (ECA-IAQ, 1993; 1995) have shown that current methods cannot sufficiently reproduce results. Promising methods are under development for paints and lacquers, whereas major problems still exist for liquids such as cleaning products or waxes. Measurement of emissions from bulk material may offer a way around these problems, however, the question remains that the emissions may be different from those of thin films.

(2) The type of support material to be used.

Support materials may absorb or even react with liquid or pasty products. The choice of support material will mostly depend on the objective of a measurement. For ranking or labelling purposes usually an inert, non-absorbing material will be preferred. However, if pollutant concentrations or exposures in a real environment have to be estimated, the material the product is applied to in the environment of concern should also be chosen for emission testing.

(3) The time dependence of emissions.

Emissions from thin film sources usually have concentration vs. time curves which differ considerably from those of solid materials. Initial emissions or chamber concentrations are higher, or even very much higher than those of solid materials, but most will also decay more rapidly. Depending on the objective of an emission measurement (e.g. estimating exposures of people applying a product or of occupants entering a room only hours or days after application of the product) different time programmes for chamber air sampling will be required. Also, the required sampling volumes may vary over time.

(4) The packaging, transportation and storage of test materials.

Packaging and transportation of test materials will require different procedures depending on whether the product is applied in the testing laboratory or at a remote production site.

(5) Emissions from composite materials.

Emitting materials such as flooring systems (see section 3.2.1) may consist of different layers. Their emission may be different from the emission of any of the isolated layers. Testing such composite materials or systems needs particular guidance with respect to the test specimen preparation.

Validation of small chamber emission measurements of composite materials with large chamber measurements will be important if real world indoor concentrations are to be estimated.

2.2.2 Emission measurements for other objectives

There are possible objectives for emission measurements that differ from the one considered in this proposal. Examples are (i) the measurement of emission data for the prediction of exposures and their variations over time in real environments, and (ii) the validation of models describing or predicting emission or adsorption behaviour of materials or products. In particular, the features that have to be modified with respect to the procedure described in section 2.1 are: the times at which chamber air has to be sampled and analysed, the emission test duration, and the data treatment and reporting.

Sampling times must take into account the rate of change of the chamber concentrations of the collected compounds, and if models have to be used or tested account for the requirements of model fitting.

Duration of an emission test depends on the time dependence of the emission factor and the test objective. In general the test objective will explicitly or implicitly determine the test duration.

2.3 Supplementary Information on Materials or Products

Supplementary information on specific brands of a material or product that can give useful hints on constituents, additives (such as plasticizers) or impurities which may contribute to VOC emissions are not readily available. The best way to retrieve such information is to contact the producer who may provide information on volatile organic compounds or other constituents of this product (e.g. phthalates). However, producers are not always aware of the identity of VOCs in their products, in particular, of impurities or solvents used during the production process.

Some information on potential emissions may be obtained from books describing certain products or product classes (see, e.g., .Karsa, 1990 and Curwell & March, 1986).

The Danish Product Register also contains information on toxic chemicals in products and may be consulted at the National Institute of Occupational Health, Lersø Parkallé 105, DK-2100 Copenhagen Ø, Denmark.

2.4 VOC Classes and More Frequently Encountered Compounds Detected in Emissions from Flooring Materials

Reported in Appendix 5, are different chemical classes of VOCs detected in emissions from flooring materials. In addition, examples are reported of compounds and their emission factors detected in 27 flooring materials (Saarela et al., 1994). The Appendix is intended to indicate which VOCs require toxicological and sensory data most urgently in the framework of the evaluation of emissions from flooring materials. No attempt has been made to systematically collect published data, as it is quite scarce. Some TVOC values are included and are referenced at the end of the table.

Wherever available, CAS numbers have been included in the Appendix.

2.5 References

ASTM, American Society for Testing and Materials, 1990. Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products. ASTM Designation D 5116-90. Philadelphia, PA: American Society for Testing and Materials.

CPDG, Carpet Policy Dialogue Group, 1991. Test method for determining total volatile organic compound emission factors from carpet under defined test conditions using small environmental chambers. Carpet Policy Dialogue Compendium Report EPA/560/2-91-002, Appendix E. Office of Toxic Substances (TS-778). U.S. Environmental Protection Agency, September 1991.

Curwell, S.R. and March, C.G. (eds.), 1986. Hazardous building materials: a guide to the selection of alternatives. ISBN 0 419 13730 0 and 0 419 13740 8. London: E. & F.N. Spon Ltd.

ECA-IAQ, European Concerted Action "Indoor Air Quality and Its Impact on Man", 1991. Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. Report Nr. 8 (EUR 13593 EN). Luxembourg: Office for Official Publications of the European Communities.

ECA-IAQ, European Collaborative Action "Indoor Air Quality and Its Impact on Man", 1993. Determination of VOCs emitted from indoor materials and products. Interlaboratory comparison of small chamber measurements. Report No. 13 (EUR 15054 EN). Luxembourg: Office for Official Publications of the European Communities.

ECA-IAQ, European Collaborative Action "Indoor Air Quality and Its Impact on Man", 1995. Determination of VOCs emitted from indoor materials and products: 2nd interlaboratory comparison of small chamber measurements. Report Nr. 16 (EUR 16284 EN). Luxembourg: Office for Official Publications of the European Communities.

Karsa, R.D. (ed.), 1990. Additives for water based coatings. Special publication no. 76, ISBN 0-85186-607-7. Cambridge CB4 4WF: The Royal Society of Chemistry.

Saarela, K., Tirkkonen, T. and Tähtinen, M., 1994. Preliminary data base for material emissions. NKB Committee and Work Reports 1994: 04E, ISBN 951-47-9858-9. Helsinki: Painatuskeskus Oy

Tichenor, B.A., 1989. Indoor air sources; using small environmental test chambers to characterize organic emissions from indoor materials and products. EPA-600 8-89-074, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency.

3. EXPOSURE ASSESSMENT

In principle, the toxicological evaluation of the VOC emission from a building material requires an estimate of the exposure an individual may experience due to the emission, and also an estimate of its contribution to the total exposure. This estimate would have to be based on an exposure scenario and model which takes into account all of the features of indoor spaces influencing VOC concentrations (including emission factors of all materials used therein) and also, of the time an individual spends in the spaces.

Section 3.1, highlights the complexity of a realistic exposure scenario. For the time being, there is no available model allowing an estimation of exposures to be made based on such a complex scenario. Therefore, in section 3.2, somewhat drastic simplifications are outlined leading to the straightforward exposure model and scenarios described in sections 3.3 and 3.4 and adopted for the evaluation procedure presented in this report.

3.1 Scenario for the Contribution of Material Emissions and Other Factors to Indoor VOC Exposure

Figure 1 shows the flow chart of an essentially complete scenario for the contribution of emissions of a single volatile organic compound (VOC_i) from floor covering materials in an indoor space to the time weighted average (TWA) exposure of a given individual. In view of the complexity of the situation and the restricted amount of information available for some parts depicted in the figure, simplifications must be made to arrive at an exposure scenario and model for labelling or classification of building products (in particular, solid flooring materials). The complexity of the scenario shown in Figure 1 stems from the following facts;

- the VOC_i emission of a floor not only depends on the flooring material, but on what is under the material and on finishings applied to the material;
- the floor may not be the only source of VOC_i in a room;
- the concentration of VOC_i in a room not only depends on emissions, but on sorption/desorption processes on surfaces other than the flooring material, and on chemical reactions;
- emission and sorption of VOC_i depends on temperature, and possibly on humidity;
- the concentration VOC_i in a room may not be homogeneous due to incomplete mixing, and finally;
- the exposure of a given individual to VOC_i not only depends on the concentration of VOC_i in that particular room, but on the VOC_i concentrations in all other microenvironments the individual visits, including the time that he/she spends in each of them.

Obviously, the same individual may well be exposed to hundreds of VOCs and other air pollutants at levels which could affect his/her health or well-being. Complete models for individual exposures are not available because they would be extremely complex, requiring too many data that are unavailable or have prohibitive measurement costs.

3.2 Simplifications of the VOC Exposure Scenario

3.2.1 Composite flooring systems versus single material solid floor coverings

VOC emissions from floors in real rooms may differ from the emissions of a single solid floor covering material if it is only the uppermost layer of a more complex flooring system. For a better understanding of the different layers of these systems, their function and their potential role for VOC emissions, this chapter gives a brief introduction to flooring systems. Also highlighted, is the ultimate need for an extension of the procedure for the evaluation of emissions from flooring materials set out in this report.

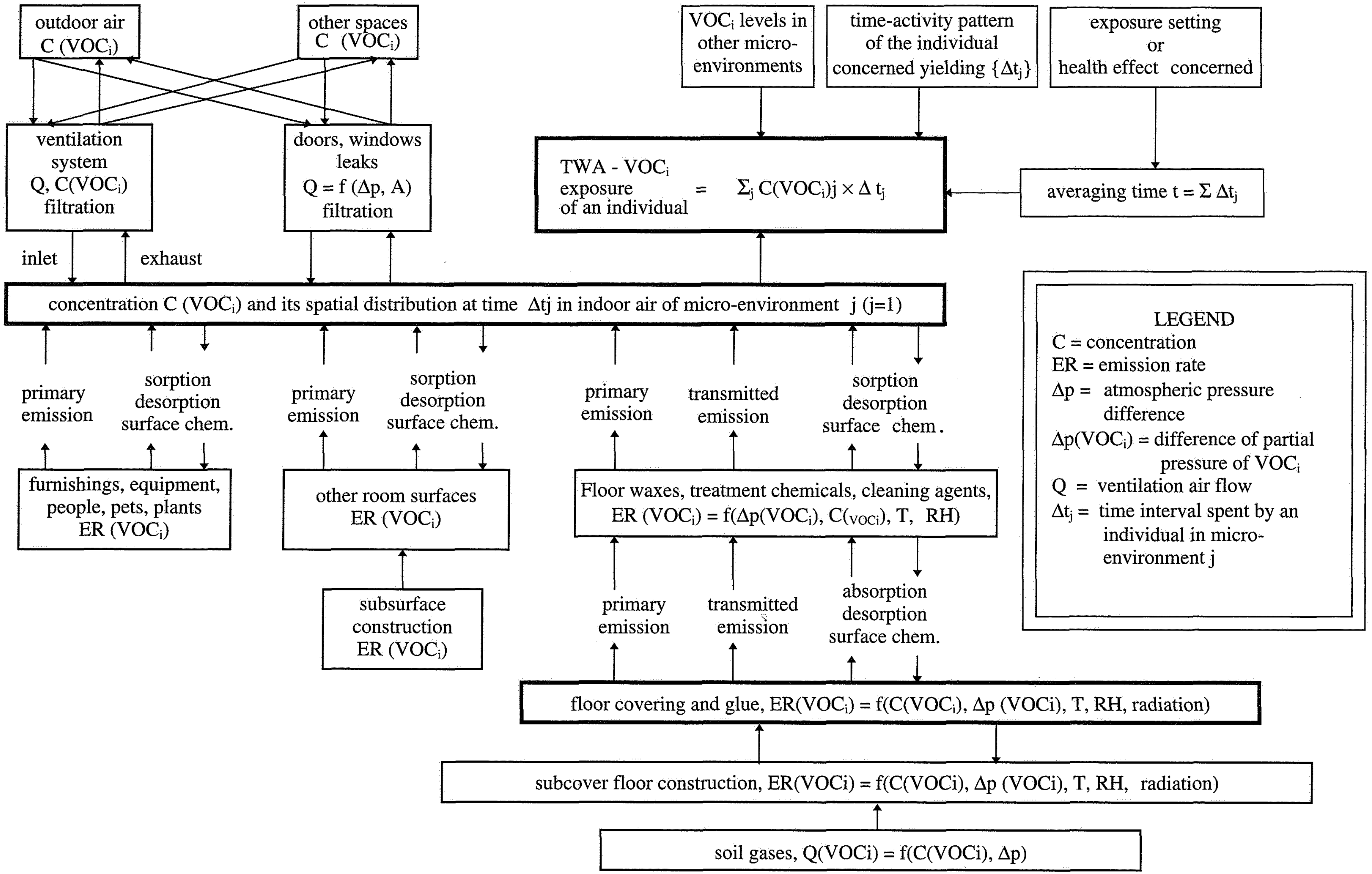


Figure 3.1 **Flow chart of factors influencing the indoor concentration of a specific compound VOC_i emitted from flooring material and other sources and the resulting exposure**

Flooring systems may be broken down into layers which have different functions;

- the coating layer protects the load-bearing layer and is an element of the aesthetic finish;
- the connection layer anchors the coating layer to the next following layer;
- the flattening layer smoothes the underlying layer;
- the levelling layer gives flatness to the underlying layer, and in some cases provides an appropriate level for the coating layer;
- the load distribution layer distributes concentrated loads in case of a very compressible or degradable coating layer;
- the separation layer allows the sliding of continuous layers;
- the thermal insulation layer: provides the required global thermal resistance of the partition;
- the acoustic insulation layer protects against the direct transmission of vibrations from the coating layer to the floor slab;
- the waterproofing layer provides a target level for waterproofing;
- the floor slab supports the total floor loading.

In practice, flooring systems consist of different combinations of some, or all of the layers. Regularly used combinations, also called functional models, are;

- flooring without thermal insulation and acoustic insulation;
- flooring with thermal insulation;
- flooring with acoustic insulation;
- flooring with thermal insulation and acoustic insulation;
- flooring with waterproof layer and thermal insulation;
- flooring with radiant panels in the floor slab;
- flatform flooring.

A functional model may be realized by different technical solutions. Technical solutions encompass the choice of materials and account for the design conditions determined by the environmental and technological requirements requested for a specific situation. Any technical solution uses different assemblies.

Technical solutions in general require preparation and/or installation of some layer(s) on-site. For the time being, no guidance exists for preparing test specimens for technical solutions. Materials from different producers may also be involved. For these reasons **the evaluation procedure described in this report is limited to individual solid flooring materials.** If they are produced as such, they include composite flooring materials consisting of different layers. As an example, wood parquet treated by the producer with an oil or varnish may be subject to the evaluation procedure provided the treatment leads to reproducible VOC emissions, in contrast to an in-situ treatment during construction.

3.2.2 The problem of source apportionment

Sources in a room other than flooring materials may contribute to VOC$_i$ exposure. Other surface materials; furniture or equipment; products used or carried in the room by occupants; air exchanged with neighbouring rooms; or outdoor air supplied by ventilation can be contributing factors. The exposure scenario used for the evaluation procedure described here neglects all these additional sources.

To a certain extent, this simplification is motivated by the fact that emissions evaluated from new materials are often the predominant sources in a room. For the same reason, it may be supposed that air exchange with neighbouring rooms does not lead to a substantial increase of the VOC_i concentration, because there will be no important net flow of VOC_i into the room. However, if several new building materials (or other products) emitting the same VOC_i are introduced simultaneously into a room, consideration of only one source material will lead to an underestimate of indoor concentrations. **The safety factor introduced in section 4.4 (d) (see p. 34) accounts also for this underestimate.**

3.2.3 The influence of sorption/desorption processes and of chemical reactions on exposure estimates

The indoor concentration of a VOC_i emitted from a flooring material not only depends on the emission and ventilation rate, but may be influenced by sorption/desorption processes, or by reaction with other indoor air constituents.

There are many surfaces in real rooms other than floors on which VOCs may be sorbed, such as walls, ceilings, furniture or equipment, and from which they may be re-emitted. The concentration of a VOC_i emitted from a new flooring material may be decreased by sorption to indoor surfaces during the initial emission phase, but afterwards may be increased by desorption. This was shown by Zellweger et al. (1995). Although present knowledge means rules cannot be fixed, the work of Zellweger et al. indicates that the emission factors of new materials determined in test chambers, yield predicted concentrations in the first few days that are higher than the concentrations measured in indoor environments. Later, desorption may lead to a measured VOC_i concentration that is higher than predicted. The time at which this happens, and the difference between the measured and predicted concentrations, may vary widely. In general, neglecting sorption/desorption processes leads to an overestimate of exposures in real indoor environments if emission factors determined by chamber experiments after 24 h and 3 days are used (see chapter 6). However, chamber measurements of emission factors made after 28 days may lead to an underestimation of concentrations. More experimental data are needed in order to assess whether, and (in which cases), an underestimate warrants a higher safety factor than the one introduced in Chapter 4.

A particular situation may occur in modern air-conditioned buildings, such as most office buildings, where occupants generally are not exposed to steady-state concentrations. It is customary in these buildings to turn off the ventilation at night and during weekends to save energy. At the resulting low ventilation rates, the concentrations of VOCs emitted from building materials will increase. With an air exchange rate provided by the HVAC system of e.g. $0.5\ h^{-1}$, it will take 4-6 hours after switching on the system to bring the increased concentrations down to the daytime level. This process is slowed down further by room surfaces which adsorb VOCs from the more polluted air during the night, and desorb them back into the cleaner air during the day. For compounds causing concern due to irritation or odour effects, even a short exposure peak in the first working hour may significantly affect the occupants' comfort and productivity for the rest of the day. **This situation is not considered by the evaluation procedure described here, in view of the higher specific ventilation rates in office buildings compared to residences, and because the evaluation procedure is based on the lower range of specific ventilation rates occurring in residences** (see Chapter 3.4).

There is experimental evidence that the reaction with ozone of some VOCs emitted from flooring materials may significantly decrease their indoor air concentrations. Whereas this effect leads to an overestimate of the indoor concentrations of reacting VOCs if determined using chamber emission data, the concentrations of other compounds (e.g. aldehydes) have been reported to increase, and as a result, could be underestimated (Weschler et al., 1992). Therefore, **elevated concentrations of ozone in indoor air combined with flooring material emissions, may cause exposures which are not considered by the evaluation procedure presented here.**

3.2.4 The influence of temperature and humidity on exposure estimates

According to section 2.1.2, emission factors are determined at a temperature of 23 °C and a relative humidity of 45 %. As outlined in Appendix 2, section 2, flooring materials in rooms with floor heating, or which are exposed to sun irradiation, may reach higher temperatures at which emissions may increase significantly. Exposure estimates used for the evaluation procedure described here, will be based on emission factors determined according to section 2.1, i.e. on a scenario with a unique temperature of 23°C which may lead to an underestimate of the exposure. Therefore, **the communication of a positive result of the evaluation procedure should be accompanied by a warning that: floor heating and exposure to sun irradiation may lead to elevated VOC emissions from flooring materials, and that such occurrences have not been considered during the evaluation.**

As outlined in Appendix 2, section 2, only in exceptional cases does relative humidity appear to have an influence on VOC emissions. There are very few observations available but they suggest this dependency is weak, and therefore, it is not considered by the evaluation procedure described here.

3.2.5 The influence of air mixing on exposure estimates

At a given VOC emission factor E (see section 2.1.7) of a flooring material in a room, and neglecting sorption/desorption processes or reactions (see section 3.2.3 above), the VOC concentration, and hence exposure caused by the emission, depends on the (area) specific ventilation rate q, and is homogeneous throughout the room if the air is well mixed.

In reality, rooms are not usually compartments that are completely mixed. Furniture, loose carpets, curtains and other items that develop temperature gradients and affect the air flows (controlled by temperature gradients), may create sub-compartments with different air exchange rates and pollutant concentrations. In principle, an individual staying in the room may be exposed to air quality which is better or worse than the modelled average air quality.

Sub-compartment formation may also affect the indoor air quality in the entire room. A sub-compartment at elevated temperature (e.g. formed by a wall, radiator and a sofa), may be an enhanced VOC source. A cold sub-compartment (between a thick carpet and a cold floor, or between a bookshelf and a poorly insulated wall) may condense moisture and lead to microbial deterioration and/or hydrolysis of the moist surfaces. As a result, there may be emissions of microbial VOCs, formaldehyde, ammonia or organic sulphur compounds, depending on the materials and microbe cultures.

Air mixing may also be incomplete because of a high ceiling-to-floor temperature gradient, combined with inappropriate ventilation air diffuser locations and designs, may result in the whole room being divided into horizontal zones with different air exchange rates. This phenomenon is deliberately facilitated in large and high rooms using displacement ventilation, where cool air is blown at a low velocity (to avoid mixing) through large diffusers at the floor level, and the warmer air that has risen towards the ceiling being collected at that location. Whereas the ventilation efficiency ε_v measured in the breathing zone of a completely mixed room is 1.0, it may be 0.5 - 0.9 in an incompletely mixed room, and even larger than 1.0 in a room with well-functioning displacement ventilation (ECA-IAQ, 1992). Therefore, in order to account for incomplete mixing an effective specific ventilation rate $q_{eff} = \varepsilon_v \times q$ may be used, where q is the specific ventilation rate at complete mixing.

For the purpose of the evaluation procedure proposed here, a value of ε_v=1 will be used and this choice will be compensated for by adopting realistically low specific ventilation rates for the determination of concentrations and exposures (see section 3.4 below).

3.2.6 Approximation of exposure to VOC_i in multiple micro-environments by concentrations of VOC_i in dwellings

Usually, exposure to air pollution does not occur in a single micro-environment or room because people are spending portions of their time in different micro-environments, such as the bedroom, living room or kitchen of their dwelling; in transportation vehicles; schools; offices; or other working environments; or outdoors. A simple and realistic upper estimate of the exposure to a VOC emitted from a flooring material may be based on the following considerations:

In offices, occupants are exposed for 35-40 hours per week and approximately the same exposure time may be assumed to take place in schools. This overestimates the exposure time for small school children, but is realistic for high schools and colleges. University students may be exposed for up to 60 hours per week. In general, people are spending most of their time in dwellings. The very young, very old and the infirm may spend all their time at home, i.e. 24 hours per day, 168 hours per week. Therefore, the duration of the exposure to a VOC_i emitted from a flooring material will usually be greatest if the material is installed in a dwelling.

The concentration of a VOC emitted from flooring materials is inversely proportional to the ventilation rate per unit of floor area, or the area specific ventilation rate (see equation (2.5), section 2.1.7 and equation (3.1) below).

A reasonably safe evaluation may be based on a specific ventilation rate at the low end of the distribution of actually occurring ventilation rates. In the wake of energy concerns arising in the early '70s, ventilation rates declined, and the question of 'minimum ventilation rates' was discussed internationally (IEA, 1987).

In order to provide healthy air for people, ventilation is necessary for three reasons;

- the dilution of pollutants and odours;
- the reduction of moisture to avoid vapour condensation;
- the provision of oxygen for internal combustion and occupant metabolism.

Each of these three functions may require some minimal ventilation, and the quantity depends on the type of building, users' behaviour, outdoor climate or heating system.

In many countries minimum ventilation rates have been recommended and in principle, these rates should be appropriate for the evaluation procedure. Recommended minimum ventilation rates are usually different for different types of buildings and may vary from country to country. In Table 3.1, minimum values of the area specific ventilation rate recommended by some organizations and governments in the EU for different building types, have been collated. As the table shows, the lowest area specific ventilation rates are recommended for dwellings, because people are often considered the prevailing, if not the only source of pollutants and odours (ECA-IAQ, 1992); and/or dwellings are supposed to have the lowest occupant density.

For the above mentioned reasons, the assumption of full time exposure in dwellings will provide a safe and simple estimate of exposure for the purpose of evaluation of VOC emissions from flooring materials aimed at protecting people and identifying healthy products.

For the purpose of protecting people and identifying healthy products with regard to the evaluation of VOC emissions, an assumption is made that 24 h exposure occurs in dwellings. This ensures the provision of a safe and simple estimate.

As discussed in sections 4.2 and 4.4, exposure to individual VOCs below threshold concentrations is not supposed to cause adverse health effects. Carcinogens such as benzene, for which no threshold concentrations can be established require special consideration. The metabolic breakdown of most VOCs in the human body, with the exception of substances such as PCBs, will lead after relatively short times to a steady-state body burden that no longer depends on exposure time, but on the VOC concentration only. Therefore, exposure thresholds are usually expressed as concentration thresholds whereby concentrations are averaged for occupational exposures over 8 hours, and for exposures of the general population over 24 h. The exposure time per week is assumed to be 35-40 h for professional exposures, whereas a safe estimate for the residential environment is assumed to be 168 h.

Table 3.1 Recommended minimum values for the area specific ventilation rate $[m^3 h^{-1} m^{-2}]$ in various building types and countries

Type of building or space	DIN 1946 1994	CIBSE guide 1978	French values for new buildings [1]	SCAN-VAC Classified indoor climate systems 1991 [2]	NKB No.61E Indoor climate and air quality 1991	National building code of Finland, 1987	ASHRAE 62 1989
Dwellings	1 - 1.5 [3]	n.i.*	2.1 - 3.3	5.8 (20) [4] 2.5 (8.8) [4]	2.5	1.8 (2.5) [5]	0.875 [6]
Single office	4	n.i.*	2.5	11.5 5	4	3.6	3.6
Landscaped office	5.8	4.7	1.8	9.7 4.3	3.6	5.4	2.5
Conference room	10-20	21.5	9	35 15	12.5	14.5	18
Class room	15	n.i.*	7.5	35 15	17.6	14.5	14.5
Kindergarten	n.i.*	n.i.*	7.5	35 15	17.6	7.2	n.i.*
Department store	3-12	10.8	4.3	20 9	4.3	7.2	3.6

* n.i. = not indicated

[1] values based on French standards (specified as total exhaust air flow rate) and particular assumptions with respect to room size and type

[2] minimum values for two air quality classes corresponding to 10 % and 20 % dissatisfied respectively

[3] depending on floor area of dwellings; kitchen and bathrooms not included

[4] assuming an occupant density of 0.05 persons/m^2 and low (medium) emission materials

[5] minimum value for rooms of 2.5 m height (0.5 ach for rooms of normal height)

[6] assuming an average room height of 2.5 m

It follows, that for the purpose of the evaluation procedure described here, exposure to the VOC emission from a solid flooring material will be approximated by the exposure over 24 h per day to the VOC concentration resulting from the emission in a space with a (low) area specific ventilation rate typical for dwellings.

3.2.7 Conclusion

In view of the above arguments and simplifications, and because VOC emissions from flooring materials are usually decreasing with time (see section 2.1.7), a safe and simple evaluation of the exposures caused by emissions with regard to the health of the building occupants may be based on the following:

- calculation of steady state concentrations of VOCs using the emission factors as determined according to section 2.1;
- the assumption of complete mixing and a reasonable worst case ventilation scenario for a residential space and;
- an exposure duration of 24 h/day, 168 h/week.

Carcinogenic and accumulating VOCs should not occur in building materials. If benzene or other carcinogens are detected, lifelong exposure to the steady-state concentration as determined above is assumed and evaluated using the unit risk approach (see section 4.4).

3.3 Simplified Model for Calculating Steady State Concentrations

As a result of the simplifications outlined above, the steady state concentration C [$\mu g\ m^{-3}$] of a VOC emitted from a flooring material with an emission factor E [$\mu g\ h^{-1}\ m^{-2}$] and covering the entire surface area F [m^2] of a room of volume V [m^3] and with an air exchange rate n [h^{-1}] is calculated from:

$$C = \frac{E \times F}{n \times V} = \mathbf{E / q} \quad [\mu g\ m^{-3}] \qquad (3.1)$$

where $q = n \times V / F$ [$m^3\ h^{-1}\ m^{-2}$] is the ventilation rate per unit of floor area or the **area specific ventilation rate** (see also section 2.1.2).

Equation (3.1) assumes *complete mixing of the air* and *steady state*, i.e. constant or slowly changing emissions and concentrations or validity of the relations (see Chapter 2.1.7)

$$\left|\frac{1}{E} \times \frac{dE}{dt}\right| \ll 1 \quad \text{and} \quad \left|\frac{1}{C} \times \frac{dC}{dt}\right| \ll 1.$$

If portions F_1^*, F_2^*, F_3^*, ..., of the total floor area F would be covered by different flooring materials with the emission factors E_1, E_2, E_3, ..., then equation (3.1) takes the more general form:

$$C = \frac{1}{q} \sum_m E_m \frac{F_m^*}{F} \quad [\mu g\ m^{-3}] \qquad (3.2)$$

where

q is the (floor) area specific ventilation rate [$m^3\ h^{-1}\ m^{-2}$]

E_m is the emission factor [$\mu g\ m^{-2}\ h^{-1}$] of product m, m = 1, 2, 3,.....

F_m^*/F is a coverage factor or the emitting surface of product m divided by the floor surface area F. For materials covering the total floor area of a room $F_m^*/F = 1$.

Equation (3.2) can also be applied to calculate steady state concentrations caused by emissions from other surface materials m. In this case F_m^* is the emitting surface area of the material, e.g. a wall paper or a gypsum board.

3.4 Definition of Simplified Exposure Scenarios

The steady state concentrations calculated according to equation (3.1) and providing the basis for the toxicological evaluation of VOC emissions from flooring materials depends on only two variables: the emission factor E determined by chamber measurements (see section 2.1), and the specific ventilation rate q at which the flooring material is supposed to be used.

Consequently, the described evaluation procedure assumes that exposure occurs in a micro-environment or room, the floor of which is completely covered by the flooring material under evaluation and by the area specific ventilation rate in the microenvironment or room. The definition of the exposure scenario to be adopted for the evaluation procedure is therefore reduced to the definition of an area specific ventilation rate, that reflects the lower end of the distribution of actually occurring rates in the residential environment.

Because of climatic and cultural differences encountered in Europe, different values of minimum ventilation rates are justified. As an example, the more humid climate found in the U.K. may require an increased minimum ventilation rate of 1.75-2 $m^3 h^{-1} m^{-2}$ in order to prevent wall condensation and mould growth (IEA, 1987). Because of the different impact of ventilation on energy consumption and cost in cold and mild climates, actually occurring ventilation rates may be lower or higher than recommended minimum values. Representative values of actually occurring specific ventilation rates in European dwellings are only available for Sweden (Norlén and Andersson, 1993), a country with a relatively cold climate and assumed to be representative of Northern Europe. Here in fact, ventilation in as much as 86% of single-family houses and in approximately 50% of multi-family buildings is below the recommended minimum level of 1.25 $m^3 h^{-1} m^{-2}$ (0.35 $l\ h^{-1} m^{-2}$). In slightly more than 40 % of single-family houses and in 20 % of multi-family houses, ventilation rates are below even half the recommended minimum ventilation rate (Norlén and Andersson, 1993).

Because of «possible differences in geographical or climatic conditions or in ways of life, as well as different levels of protection that may prevail at national, regional or local level» within the European Union, the framework directive 89/106/EEC (EEC, 1989) on building products establishes that building products may be divided into classes with respect to properties that relate to essential requirements. One such property mentioned in Annex I to the directive, is the «giving-off of toxic gas». Following this concept, in areas with different climate and ventilation habits, different area specific ventilation rates or scenarios may be used for the determination – according to equation (3.1) – of the steady state concentrations likely to be caused by VOC emissions from flooring materials and used for their toxicological evaluation (see Chapters 4 and 6). The same specific ventilation rates should also then be applied for the sensory evaluation of flooring material emissions (see Chapter 5).

Following the above arguments, it has been decided to introduce **three exposure scenarios and three area specific ventilation rates q_e respectively**, for the evaluation of VOC emissions as reported in Table 3.2.

Table 3.2 Exposure scenarios and area specific ventilation rates q_e to be used for the toxicological and sensory evaluation of VOC emissions

Scenario or class	Area specific ventilation rate q_e [$l\ s^{-1}m^{-2}$]	Area specific ventilation rate q_e [$m^3 h^{-1} m^{-2}$]	Air exchange rate[1] [h^{-1}]
1	0.175	0.625	0.25
2	0.35	1.25	0.5 [2]
3	0.7	2.5	1.0

[1] at a room height of 2.5 m. [2] minimum ventilation rate in Denmark, Finland and Sweden

Depending on the scenario or area specific ventilation rate applied for the evaluations described in Chapters 5 and 6, a material fulfilling the conditions set out in chapter 6 may be labelled as class 1, 2 or 3 material, as indicated in Table 3.2 and discussed in section 6.5.

VOC emission factors are determined at a specific ventilation rate of 1.25 $m^3 h^{-1} m^{-2}$ (see section 2.1.2). As outlined in Appendix 2, VOC emission factors may increase with increasing specific ventilation rate. For solid flooring materials, the variation of the emission factor measured at 1.25 $m^3 h^{-1} m^{-2}$ in the range covered in Table 3.2, can be assumed not to exceed ± 20-25 %. This error is deemed negligible in comparison to the uncertainties of the toxicological evaluation procedure.

3.5 References

ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers), 1989. ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality. Atlanta: ASHRAE Publications Sales Department.

CIBSE (The Chartered Institute of Building Services Engineers), 1986. CIBSE Guide, Volume A: Design data; Volume B: Installation and equipment data; Volume C: Reference data. London: Chartered Institute of Building Services Engineers

DIN (Deutsches Institut für Normierung e.V.), 1994. Richtlinie DIN 1946-6 : Raumlufttechnik - Teil 6: Lüftung von Wohnungen, Anforderungen, Ausführung, Abnahme (VDI-Lüftungsregelungen). [Ventilation and air conditioning - Part 6: Ventilation for residential buildings - Requirements, performance, acceptance (VDI Ventilation code of practice)]

ECA-IAQ (European Collaborative Action "Indoor Air Quality and its Impact on Man"), 1992. Guidelines for ventilation requirements in buildings. Report Nr. 11, EUR 14449 EN. Luxembourg: Office for Official Publications of the European Communities.

EEC (European Economic Community), 1989. Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products. O.J. NoL 40, 11.02.89, pp.12-25.

IEA, 1987. Minimum ventilation rates: International Energy Agency, Energy conservation in buildings and community systems programme, Annex IX.

National Building Code of Finland, 1987. Indoor climate and ventilation of buildings. National Building Code of Findland, part D2. Helsinki: Ministry of the Environment, p. 15.

NKB (Nordic Committee on Building Regulations), 1991. Indoor climate and air quality,. NKB, Indoor Climate Committee, NKB Committee and Work Reports, 1991:61E.

Norlén, U. and Andersson, K. (eds.), 1993. The indoor climate in the Swedish housing stock. Document D10: 1993, ISBN 91-540-5569-5. Stockholm, Sweden: Swedish Council for Building Research.

SCANVAC (Scandinavian Organizations for Ventilation and Air Conditioning), 1991. Classified indoor climate systems. Stockholm: The Swedish Indoor Climate Institute.

Weschler, C.J., Hodgson, A.T. and Wooley, J.D., 1992. Indoor chemistry: ozone, volatile organic compounds, and carpets. Environ. Sci. Technol. 26, 2371-2377.

Zellweger, C., Gehrig, R., Hill, M. and Hofer, P., 1995. VOC emissions from building materials: comparison of chamber emission data with concentrations in real rooms. *Healthy Buildings '95*, Proc. International Conference on Healthy Buldings in Mild Climate, Vol. 2, pp. 845-850.

4. EVALUATION OF THE EFFECTS OF VOC EMISSIONS ON HUMAN HEALTH

4.1 Background

Indoor air pollution (IAP) in buildings such as residences, offices and schools, is widely recognized as an environmental risk to human health. IAP may consist of a complex mixture of fibres, particles, radon, microbiological agents, allergens, volatile organic chemicals (VOCs), environmental tobacco smoke (ETS) and other combustion products. These pollutants - and the products of their interaction - may affect human health and comfort in many ways. Exposure may affect the respiratory system; cause allergies and other effects on the immune systems (NKB, 1993); may increase the risk of lung cancer; affect reproduction; cause irritation effects on the skin and mucous membranes; bring about sensory effects and other effects on the nervous system; and may also increase the risk of cardiovascular diseases (ETS and CO) (ECA, 1991).

Regarding exposure to emissions from building materials, important effects of IAP concern the skin and mucous membranes in the eyes, nose and throat, as well as the sensory nervous system. These effects may be caused by formaldehyde and VOCs such as acetone; benzene; toluene; cyclohexane; n-hexane; styrene; chlorinated and other solvents, that are emitted by many indoor building materials (e.g. paints, stains, adhesives). Chemicals may affect the mucous membranes directly by their sensitizing and irritating effects, or by increasing the effect of allergens, infectious agents or other irritating substances. Examples of the latter are the potential interactions between fibreglass and styrene on airway irritation (Mølhave et al., 1986, 1991) and between NO_2 and bacterial and viral infections (Kjaergaard et al., 1989, 1991). Effects on the nervous system can be produced by several organic chemicals present as pollutants in the indoor environment. Several of them are known to be neurotoxic, but their general effects have only been shown at high exposure levels in occupational settings (Harving et al., 1991). These compounds include acetone; benzene; toluene; cyclohexane; n-hexane; styrene and chlorinated solvents.

4.2 Sources of Toxicological Information on Individual VOCs

Very few of the VOCs emanating from building materials have been evaluated for toxic effects when appearing in mixtures. Most available information is derived from observations and studies on humans or experimental animals exposed to single chemicals at concentrations ranging from those below which no adverse effects are observed (NOEL or NOAEL), up to exposures that have caused death within minutes. It should be noted that even for single substances, very few toxicological data are available for the vast range of VOCs likely to be emanating from building materials.

The toxicological evaluation of chemicals requires that dose-effect and dose-response relationships are established. These are used to identify the thresholds of toxic action or 'no observed effect levels' (NOELs). Together with exposure estimates and assumptions on the sensitivity of the exposed population, these thresholds are then used for defining occupational exposure limits (OELs), air quality guidelines (AQGs) or other regulatory or guideline values for individual chemical compounds. Exposure limits are usually expressed as concentration thresholds, whereby concentrations are mainly averaged over a daily exposure duration (8 hours for OELs, 24 hours for AQGs) and where the days of exposure per week (5 days for OELs, 7 days for AQGs) are taken into account. Most contemporary OELs are health based and set from the NOELs with safety factors or from other similar sources of information on human effects.

Non-occupational air quality guidelines are available for only a few indoor pollutants (WHO, 1987). The setting of such guidelines is a tedious process which will take years. Until then, OELs are the best available starting point for deriving surrogates of indoor guideline values for VOCs. However, because in indoor situations exposure may last 24 hrs/day, 7 days/week and the exposed population includes infants, the elderly and sick as well as healthy adults, the application of additional safety factors is required (WHO, 1987; Shoaf, 1991; Nielsen et al., 1995, 1996).

4.3 Interactions between VOCs - Additivity at Indoor Concentrations

When dealing with emissions from flooring materials, multiple chemical exposure is the rule rather than the exception. Therefore, interactions must be considered. There are very few available data on toxicological interactions obtained from controlled multiple exposures, although in early toxicological studies additiv joint toxicity was found for most combinations of 27 commercial organic chemicals (Smyth et al., 1969). As a result, several organisations (including the ACGIH) have adopted the additive approach for deriving occupational exposure limits for mixtures as a "rule of thumb" (ACGIH, 1996). Recently, scientific arguments have been brought forward in favor of additivity for respiratory tract effects of noncarcinogenic pollutants at the low concentration found indoors (Nielsen et al., 1995).

Therefore, in the absence of other specific information, it is reasonable to adopt such an "additive" approach for complex low level exposures. It is practical and probably affords a reasonable degree of protection (Levy & Lunau, 1990). Applying this approach for determining the toxic potential of a mixture of compounds, the concentrations of individual compounds divided by their respective air quality guideline values or their surrogates are added.

Typically indoor air contains many VOCs each at a low concentration (few micrograms/m^3). In view of the limited number of VOCs for which experimental toxicological data exist and for which OELs have been established, various models have been proposed for predicting toxicological data. These include QSAR models (see Appendix 7), and “guesstimates” based on the similarity of chemical structures. When exposure limits are not available for a chemical substance, it seems to be reasonable to use as a provisional proxy-estimate of the exposure limit, the one established for the most similar chemical compound.

Among the methods suggested to predict toxic properties of chemicals, a mouse assay has been used for detecting upper respiratory tract irritation (Alarie, 1984). However, this approach has limited use for the purpose of predicting more general toxicological properties.

A practical way to assess exposure to VOCs consists of measuring the total concentration of VOCs (TVOC). TVOC have been measured for various purposes using different techniques which give different results. For the purpose of the evaluation procedure proposed in this report, a definition is given in section 2.1.7 (see p. 14). A new definition of TVOC is presently being developed by an ECA expert group (WG 13). This definition will be substituted for the one given in section 2.1.7 as soon as it becomes available.

There is a consensus that it is not possible to define an effects based threshold for TVOC. However, there is an agreed need for improved source control to reduce the pollution load on the indoor environment from health, comfort, energy efficiency and sustainability viewpoints. Therefore, TVOC levels in indoor air should be kept as low as reasonably achievable (ALARA) and should not exceed the typical levels currently found in non-industrial buildings, i.e. 0.1 - 0.5 mg m^{-3} (Krause et al., 1987, 1991). In order to maintain levels at the lower end of this range, the contribution from a single material should be limited. In the test, **calculated TVOC concentrations should not have exceeded 5 mg m^{-3} after 3 days and should have fallen to 0.2 mg m^{-3} after 28 days**. Such limits are intended to encourage the production of low-emitting materials.

4.4 Toxicological Evaluation of Individual VOCs Emitted from Flooring Materials

When assessing health risks from chemical exposures, the duration of the exposure (whether short term or long term) has to be taken into consideration. In the case of emissions from flooring materials, consideration has to be given to both exposures resulting immediately after the application (which has traditionally given rise to complaints by the exposed occupants), as well as to exposures occurring weeks or months later, which is representative of the long term emission that may continue for the lifetime of a material.

Many health effects are not related to single exposures triggering an acute response, but are chronic, and induced either by bioaccumulation of a toxicant reaching a critical level in the target organ or tissue, or by repeated exposure causing acute episodes which ultimately lead to a chronic response.

For the purpose of developing the evaluation procedure proposed here, the following groups of VOCs have been distinguished:

(a) Known or suspected human carcinogens - The carcinogenicity of chemicals to humans can be derived either from human studies or extrapolated from animal studies. As a result of such assessments, the chemical substances have been classified by different organizations into various groups expressing different potential risks for man. The criteria for such classifications are not universally agreed upon, and this has resulted in the development of different classification schemes by, for example, the E.U., the IARC and the U.S. EPA.

The cancer risk linked to exposure to carcinogens can be quantified by using the "unit risk" concept applied by the U.S. EPA and by WHO (1987). Unit risks are defined as the excess risk caused by exposure to the unit concentration (1μg m^{-3}) of a substance over a *lifetime.* Although there are uncertainties in the accuracy of lifetime unit risk (LUR) estimates, the LURs can be helpful in public health as they allow at least a relative quantitative assessment of risks.

For the purpose of the evaluation procedure proposed here, it was considered appropriate to use the EU scheme which classifies the carcinogenic substances in three categories (EU, 1994; see also Appendix 8). For the substances belonging to categories 1 and 2, the unit risk concept will be applied. Substances of categories 1 and 2 considered to be relevant to this work are those potentially present in VOC emissions. They are reported in Table 4.1.

Table 4.1 VOCs classified as category 1 or 2 carcinogens of Annex I of Council Directive 67/548/EEC and potentially present in flooring material emissions

Substance	**EU category** (1)	**LUR** (2) per μg m^{-3}	**Limit concentrations [μg m^{-3}] for a lifetime inhalation risk of:**	
			10^{-4} (3)	10^{-5} (4)
benzene	1	4×10^{-6}	25	2.5
vinylchloride	1	1×10^{-6}	100	10

(1) See Appendix 8 for the meaning of categories
(2) lifetime inhalation unit risk (per μg m^{-3}) source: EPA's Integrated Risk Information System (IRIS) or WHO (1987)
(3) derived from LUR using equation (4.1): Limit Concentration = 10^{-4}/LUR
(4) derived from LUR using equation (4.4): Limit Concentration = 10^{-5}/LUR

Materials emitting a carcinogenic compound, VOC_{ci}, as listed in Table 4.1 will be excluded from further evaluation if:

(1) the emission factor determined after 24 hours testing leads – under the conditions of the scenario or area specific ventilation rate selected from Table 3.2 (see chapter 3, section 3.4 and chapter 6) – to a predicted concentration $C_{ci}(24h)$ causing a risk of cancer

$$LUR\,(\,C_{ci}\,(24h)) > 10^{-4}; \qquad (4.1)$$

This condition is aimed at protecting the members of a sensory test panel which will evaluate the emissions after 3 days (see chapter 5.3.1).

(2) the emission factor determined after 28 days of testing leads, under the above mentioned conditions, to a predicted concentration $C_{ci}(28d)$ causing a risk of cancer

$$\mathrm{LUR}\,(C_{ci}\,(28d)) > 10^{-5}; \qquad (4.2)$$

This condition is aimed at protecting the general public.

The concentration limits which must not be exceeded by $C_{ci}(24h)$ and $C_{ci}(28d)$ are reported respectively in columns 4 and 5 of Table 4.1.

An alternative approach to air quality standards for carcinogens has recently been proposed (Maynard et al., 1995). In this approach, a standard can be derived by using the best possible toxicological and mechanistic knowledge and by the application of safety factors. At present, however, insufficient data are available for application of this procedure.

Class 3 carcinogens will be dealt with according to point d) below.

(b) Reproductive toxicants (chemical substances with potential for reproductive effects) are of particular concern when toxicological risks are assessed. In general these effects are taken into account when permissible exposure limits are set. For the purpose of the evaluation procedure proposed here, compounds with (suspected) reproductive effects are dealt with applying an additional safety factor as described under d) below.

(c) VOCs or related chemicals known to be particularly toxic even at very low concentrations (e.g. sensitizing agents). The presence of these chemicals in emissions from indoor materials should be carefully considered as they may pose a risk even if present in very low concentrations (trace amounts) in the indoor environment. For the time being, however, the Working Group is not aware of flooring material emissions containing such chemicals.

(d) VOCs which have been assessed by national or international committees and for which air quality guidelines (AQGs) or occupational exposure limits (OELs) such as Threshold Limit Values (TLVs™) have been established. These values are used in the development of "lowest concentrations of interest" (LCIs), i.e. the lowest concentration above which, according to best professional judgment, the pollutant may have some effect on people in the indoor environment.

In case an AQG exists for a VOC, the LCI is essentially set equal to the AQG. If AQGs have been established by different organizations or for different target effects or populations or different reference periods (e.g. 30 min. versus 24 h), the lowest value is adopted.

Unfortunately, AQGs have been established for only very few VOCs, whereas for a considerably larger number of compounds, OELs have been established by various authorities or organizations. For these, LCIs have been derived from OELs as follows:

OELs established by national authorities in Denmark (DK; Arbejdstilsynet, 1994), Germany (D; DFG, 1995), the United Kingdom (UK; HSE, 1995) and by the American Conference of Governmental Industrial Hygienists (ACGIH, 1995) have been compared and for each compound the lowest value has been selected. The selected OELs were divided by a safety factor (SF) which accounts for the different exposure conditions between the populations exposed indoors and in the occupational environment as outlined in chapter 4.2 above and for the fact that simultaneous exposure to the same VOC emitted from different sources may occur. This safety factor has been set to

- SF = 100 for normal compounds and to
- SF = 1000 for teratogenic or reprotoxic compounds and for category 3 carcinogens according to the EU classification (EU, 1994)

The LCI is then obtained by rounding off the OEL/SF value to one significant digit. This is motivated by:

(i) the approximate character of the LCI approach, and more importantly,

(ii) the intention to favor the production of healthy building materials, i.e. of building materials the VOC emissions of which are as low as possible. This appears justified in view of our still limited knowledge of potential effects of VOCs, and in particular, of their interactions.

Table 4.2 shows the resulting list of LCI values. In addition, in column 5 of the table the AQG- and the OEL/SF-values from which they are derived, and in column 6 the origin of the AQGs and the OELs, is also reported.

The LCI values reflect odour thresholds only in so far as they are used for setting AQGs or OELs. Odour is included in a separate sensory evaluation (see Chapter 5).

(e) The VOCs present in emissions not classifiable in the above classes have to be considered "toxicologically unknown" and thus not assessable as to the risk to human health. However, recent low emitting products may contain chemical compounds (e.g. Texanol™) which have not yet been assessed by national or international committees for which, however, toxicological data, evaluations and recommendations for AQGs have been published in the open literature (e.g. Nielsen et al., 1996). In these cases, when it is deemed justified, the recommended AQGs may be adopted as LCIs applying an additional safety factor of 10.

Moreover, to several of the "not assessable" compounds, LCI values may be attributed using chemical analogy based on the chemical classes and groups shown in Table 4.2. Where it was deemed justifiable, the presently lowest LCI derived from an AQG or OEL for a group of compounds (mostly homologues) was assigned to those members of the group for which no AQG or OEL is available. These LCIs are also reported in Table 4.2 together with a reference to Table 4.3. In Table 4.3, the rationales for the choice of the LCI values established by chemical analogy are given.

LCI values established according to the procedures described under d) and e) above are only intended to be used for the purpose of the evaluation procedure described in Chapter 6. They are not intended as surrogates for (indoor) air quality guidelines.

Table 4.2 "Lowest Concentrations of Interest" (LCIs) of VOCs detected in emissions from flooring materials. Letters in the column "Reference" refer to explanations in table 4.3

LCI values in this Table are only intended to be used for the purpose of the evaluation procedure described in Chapter 6. They are not intended as surrogates for (indoor) air quality guidelines.

Chemical Compounds	CAS No.	LCI [$\mu g\ m^{-3}$]	Reference to table 4.3	AQG or OEL/SF [$\mu g\ m^{-3}$]	Origin
AROMATIC HYDROCARBONS					
Toluene	108-88-3	**1 000** [1]		1 000 [1]	WHO
Ethylbenzene	100-41-4	**1 000**		1 000	DK
Xylenes	1330-20-7	**1 000**		1 500	DK
p.-Xylene	106-42-3	**1 000**		1 500	DK
m.-Xylene	108-38-3	**1 000**		1 500	DK
o-Xylene	95-47-6	**1 000**		1 500	DK
Isopropylbenzene (cumene)	98-82-8	**1 000**		1 200	DK, UK
n-Propylbenzene	103-65-1	**1 000**	a		
1-Propenylbenzene	637-50-3	**1 000**	b		
Trimethylbenzene		**1 000**	a		

[1] guideline values based on sensory effects or annoyance reactions given by WHO (1987), p. 26

Chemical Compounds	CAS No.	LCI [µg m^{-3}]	Reference to table 4.3	AQG or OEL/SF [µg m^{-3}]	Origin
AROMATIC HYDROCARBONS (cont'd)					
1,3,5-Trimethylbenzene	108-67-8	**1 000**		1 200	DK, UK
1,2,4-Trimethylbenzene	95-63-6	**1 000**		1 200	DK, UK
1,2,3-Trimethylbenzene	526-73-8	**1 000**		1 200	DK,UK
2-Ethyl toluene	611-14-3	**2 000**		2 170	DK
1-Methyl-2-propylbenzene	1074-17-5	**1 000**	a		
1-Methyl-3-propylbenzene	1074-43-7	**1 000**	a		
1,2,4,5-Tetramethylbenzene	95-93-2	**1 000**	a		
n-Butylbenzene	104-51-8	**1 000**	a		
1,3-Diisopropyl benzene	99-62-7	**1 000**	a		
1,4-Diisopropyl benzene	100-18-5	**1 000**	a		
2-Phenyl octane	777-22-0	**1 000**	a		
5-Phenyl decane	4537-11-5	**1 000**	a		
5-Phenyl undecane	4537-15-9	**1 000**	a		
4-Phenyl cyclohexene (4-PCH)	31017-40-0	**800**	c		
Styrene	100-42-5	**70** 1)		70 1)	WHO
Ethynylbenzene	536-74-3	**800**	c		
a-Methylstyrene	98-83-9	**1 000**		1 200	DK
o-Methylstyrene	611-15-4	**1 000**		1 200	DK
m.p.-Methylstyrene m: p:	100-80-1 622-97-9	**1 000**		1 200	DK
Naphtalene	91-20-3	**500**		500	DK, UK
SATURATED ALIPHATIC HYDROCARBONS					
2-Methylbutane	78-78-4	**10 000**		15 000	DK
n-Pentane	109-66-0	**10 000**		15 000	DK
3-Methylpentane	96-14-0	**7 000**		7 000	D, DK
n-Hexane	110-54-3	**700**		700	UK
2-Methylhexane	591-76-4	**8 000**		8 200	DK
3-Methylhexane	589-34-4	**8 000**		8 200	DK
n-Heptane	142-82-5	**8 000**		8 200	DK
n-Octane	111-65-9	**9 000**		9 350	DK
C 9 Hydrocarbons		**10 000**	d	12 000	UK
2-Methyloctane	3221-61-2	**10 000**	d	12 000	UK
3-Methyloctane	2216-33-3	**10 000**	d	12 000	UK
n-Nonane	111-84-2	**10 000**		10 500	DK
C 10 Hydrocarbons		**3 000** 2)		3 500 2)	DK
3,5-Dimethyloctane	15869-93-9	**3 000**		3 500	DK

1) guideline values based on sensory effects or annoyance reactions given by WHO (1987), p. 26
2) with the exception of n-decane

Chemical Compounds	**CAS No.**	**LCI** [µg m^{-3}]	**Reference to table 4.3**	**AQG or OEL/SF** [µg m^{-3}]	**Origin**
SATURATED ALIPHATIC HYDROCARBONS (cont'd)					
2-Methylnonane	871-83-0	**3 000**		3 500	DK
n-Decane	124-18-5	**2 000**		2 500	DK
C 11 Hydrocarbons		**10 000**	d	12 000	UK
2,4,6-Trimethyloctane	62016-37-9	**10 000**	d	12 000	UK
4-Methyldecane	2847-72-5	**10 000**	d	12 000	UK
n-Undecane	1120-21-4	**10 000**	d	12 000	UK
C 12 Hydrocarbons		**10 000**	d	12 000	UK
Isododecane	112-40-3	**10 000**	d	12 000	UK
2,2,4,6,6-Pentamethylheptane	30586-18-6	**10 000**	d	12 000	UK
n-Dodecane	112-40-3	**10 000**	d	12 000	UK
C 13 Hydrocarbons		**10 000**	d	12 000	UK
4,5-Diethylnonane		**10 000**	d	12 000	UK
n-Tridecane	629-50-5	**10 000**	d	12 000	UK
n-Tetradecane	64036-86-3	**10 000**	d	12 000	UK
n-Pentadecane	629-62-9	**10 000**	d	12 000	UK
C 16 Hydrocarbons		**10 000**	d	12 000	UK
n-Hexadecane	544-76-3	**10 000**	d	12 000	UK
C 17 Hydrocarbons		**10 000**	d	12 000	UK
n-Heptadecane	629-78-7	**10 000**	d	12 000	UK
C 18 Hydrocarbons		**10 000**	d	12 000	UK
n-Octadecane	593-45-3	**10 000**	d	12 000	UK
n-Eicosane C20	112-95-8	**10 000**	d	12 000	UK
2,6,10,14-tetramethylhexadecane (phytane)	638-36-8	**10 000**	d	12 000	UK
Pristane	1921-70-6	**10 000**	d	12 000	UK
UNSATURATED/CYCLIC ALIPHATIC HYDROCARBONS					
Cyclohexane	100-82-7	**3 000**		3 400	UK
Methyl cyclohexane	108-87-2	**8 000**		8 050	DK
Cyclohexane, 1,4-dimethyl	70688-47-0	**8 000**		8 000	UK
1-Methyl 4- methylethylcyclohexane cis: trans:	6069-98-3 1678-82-6	**8 000**		8 000	UK
TERPENES					
3-Carene	13466-78-9	**1 000**	e		
Camphene	79-92-5	**1 000**	e		
alpha-Pinene	80-56-8	**1 000**	e		
beta-Pinene	18172-67-3	**1 000**	e		

Chemical Compounds	**CAS No.**	**LCI** [µg m^{-3}]	**Reference to table 4.3**	**AQG or OEL/SF** [µg m^{-3}]	**Origin**
TERPENES (cont'd)					
Limonene	138-86-3	**1 000**	e		
Longifolene	475-20-7	**1 000**	e		
Caryophyllene-*trans*	13877-93-5	**1 000**	e		
a-cedrene	469-61-4	**1 000**	e		
Turpentine	9005-50-7	**1 000**		1 400	DK
ALIPHATIC ALCOHOLS					
1-Propanol	71-23-8	**5 000**		5 000	DK, UK
2-Propanol	67-63-0	**4 000**		4 900	DK
tert-Butanol, 2-methyl-2-propanol	75-65-0	**1 000**		1 500	DK, UK
2-Methyl-1-propanol	78-83-1	**1 000**		1 500	DK, UK
1-Butanol	71-36-3	**1 000**		1 500	DK, UK
1-Pentanol	71-41-0	**3 000**		3 600	DK
1-Hexanol	111-27-3	**1 000**	f		
Cyclohexanol	108-93-0	**2 000**		2 000	D, DK, UK
2-Ethyl-1-hexanol	104-76-7	**1 000**	f		
1-Octanol	111-87-5	**1 000**	f		
2,2,4-trimethyl-1,3-pentanediol, monoisobutyrate (Texanol®)	25265-77-4	**1 000**	g		
AROMATIC ALCOHOLS					
Phenol	108-95-2	**400**		400	DK
BHT (2,6-di-tert-butyl-4-methyl phenol)	128-37-0	**400**	h		
GLYCOLS AND GLYCOLETHERS					
Propylene glycol	57-55-6	**4 000**		4 700	UK
2-Methoxyethanol	109-86-4	**10**		15[3]	D
Dimethoxymethane	109-87-5	**30 000**		31 000	D, DK, UK
Dimethoxyethane	110-71-4	**1 000**	i		
2-Ethoxyethanol (ethylglycol)	110-80-5	**10**		18[3]	USA
2-Butoxyethanol (butylglycol)	111-76-2	**1 000**		1 000	D
Diethylenglycol-n-monobuthyl-ether; 2-(2-butoxyethoxy)-ethanol	112-34-5	**1 000**		1 000	D
ALDEHYDES					
Formaldehyde	50-00-0	**10**[4]		10[4]	WHO
Acetaldehyde	75-07-0	**40**		45[5]	DK

3) A safety factor SF=1000 has been applied to the OEL because of the suspected reprotoxic property of the compound.

4) Value under consideration by WHO as new air quality guideline for sensitive groups, also taking the risk of upper respiratory tract cancer into account.

5) A safety factor SF=1000 has been applied to the OEL because the substance is classified as category 3 carcinogen.

Chemical Compounds	**CAS No.**	**LCI** [µg m^{-3}]	**Reference to table 4.3**	**AQG or OEL/SF** [µg m^{-3}]	**Origin**
ALDEHYDES (cont'd)					
Propanal	123-38-6	**400**	j		
Butanal	123-72-8	**400**	j		
Pentanal	110-62-3	**400**	j		
Hexanal	66-25-1	**400**	j		
Heptanal	111-71-7	**400**	j		
2-Ethyl-hexanal	123-05-7	**400**	j		
Octanal	124-13-0	**400**	j		
Nonanal	124-19-6	**400**	j		
Decanal	112-31-2	**400**	j		
2-Butenal, (crotonaldehyde)	123-73-9	**60**		60	DK
2-Pentenal	1576-87-0	**60**	k		
2-Heptenal cis: trans:	57266-861 18829-55-5	**60**	k		
2-Nonenal (trans)	188-29-56	**60**	k		
2-Decenal (cis)	2497-25-8	**60**	k		
2-Undecenal	1337-83-3	**60**	k		
2-Furancarboxaldehyde, furfural	98-01-1	**79**		79	DK
KETONES					
Acetone	67-64-1	**6 000**		6 000	DK
2-Butanone (methyl ethylketone)	78-93-3	**1 000**		1 450	DK
3-Methyl-2-butanone	563-80-4	**1 000**	l		
4-Methyl-2-pentanone	108-10-1	**1 000**	l		
Cyclopentanone	120-92-3	**900**		900	DK
Cyclohexanone	108-94-1	**1 000**		1 000	D, DK, UK
2-Methylcyclopentanone	1120-72-5	**900**	m		
2-Methylcyclohexanone	583-60-8	**2 000**		2 300	D, DK, UK
ACIDS					
Acetic acid	64-19-7	**250**		250	D, DK, UK
Propanoic acid	79-09-4	**300**		300	D, DK, UK
Isobutyric acid	79-31-2	**300**	n		
Butyric acid	107-92-6	**300**	n		
2,2-Dimethylpropanoic acid	75-98-9	**300**	n		
Pentanoic acid	109-52-4	**300**	n		
Hexanoic acid	142-62-1	**300**	n		
Heptanoic acid	111-14-8	**300**	n		
Octanoic acid	124-07-2	**300**	n		
Hexadecanoic acid	57-10-3	**300**	n		

. Chemical Compounds	CAS No.	LCI [µg m^{-3}]	Reference to table 4.3	AQG or OEL/SF [µg m^{-3}]	Origin
CHLORINATED HYDROCARBONS					
Dichloromethane	75-09-2	**400**		430 $^{6)}$	WHO
Carbon tetrachloride	56-23-5	**10**		13 $^{5)}$	DK, UK
1,2-Dichloroethane	107-06-2	**700**		700	WHO
Trichloroethene	79-01-6	**50**		55 $^{5)}$	DK
Tetrachloroethene	127-18-4	**70**		70 $^{5)}$	DK
1,4 dichlorobenzene	106-46-7	**600**		600	ACGIH
ESTERS					
Methylformate	107-31-3	**2 000**		2 500	D, DK, UK
Ethylacetate	141-78-6	**5 000**		5 100	DK
Vinylacetate	108-05-4	**300**		300	DK, UK
Isopropylacetate	108-21-4	**6 000**		6 250	DK
Propylacetate	109-60-4	**6 000**		6 250	DK
Butyl formate	592-84-7	**2 000**	o		
Methacrylic acid methyl ester	80-62-6	**2 000**		2 050	DK
Isobutylacetate	110-19-0	**7 000**		7 000	UK
Butylacetate	123-86-4	**7 000**		7 100	DK, UK
2-Methoxyethylacetate	110-49-6	**20**		24 $^{3)}$	UK
2-Ethoxyethylacetate	111-15-9	**20**		24 $^{3)}$	DK
2-Ethylhexyl acetate	103-09-3	**200**		270	DK
1,6-Octadien-3-ol,-3,7-dimethyl acetate (linalool acetate)	115-95-7	**300**	p		
PHTHALATES					
Dimethyl phthalate	131-11-3	**30**		30	DK
Dibutyl phthalate	84-74-2	**30**		30	DK
Alkyl-phthalates (saturated)		**30**	q		
OTHERS					
1,4-Dioxane	123-91-1	**30**		36 $^{5)}$	DK
N-Methyl-2-pyrrolidone	872-50-4	**800**		800	D
Caprolactam	105-60-2	**50**		50	D
Indene	95-13-6	**450**		450	DK, UK

3) A safety factor SF=1000 has been applied to the OEL because of the reprotoxic property of the compound.

4) A safety factor SF=1000 has been applied to the OEL because the substance is classified as category 3 carcinogen

5) Value under consideration by WHO as new air quality guideline for weekly average concentrations

Table 4.3 Rationales for attributing LCIs to VOCs for which no AQGs or OELs have been established.

Refs. in col. 4 of Table 4.2	Rationales for attributing LCI - values
a	LCI value attributed to all saturated alkylbenzenes for which no AQG or OEL is defined. The value is set equal to the lowest LCI of this class derived from a toxicity-based AQG or an OEL.
b	Compound assimilated with respect to its toxic properties to methylstyrenes.
c	Compound assimilated with respect to its toxic properties to styrene. The LCI is therefore set to the toxicity based AQG for styrene defined by WHO (1987).
d	Based on fall back OEL value for saturated hydrocarbons (see HSE, 1995, p. 9).
e	LCI value attributed to all terpenes. The value is derived from the OEL for turpentine established in Denmark.
f	LCI value attributed to all saturated aliphatic alcohols for which no OEL is defined. The value is set equal to the lowest LCI of this class (butanol isomers) derived from an OEL.
g	Tentative indoor exposure limit for Texanol estimated by Nielsen et al. (1996)
h	LCI value of phenol attributed to all saturated alkylphenols for which no OEL is defined.
i	LCI value attributed to all compounds of this group for which no OEL is defined. The value is set equal to the lowest LCI of this class for non-reprotoxic substances.
j	LCI value attributed to all saturated aliphatic aldehydes for which no AQG or OEL is defined. The value is derived from the OEL of acetaldehyde however with an uncertainty factor UF=100.
k	LCI value attributed to all 2-unsaturated aliphatic aldehydes for which no OEL is defined. The value is set equal to the LCI of 2-butenal.
l	Assimilated to 2-butanone, which has the lowest LCI in this group.
m	Assimilated to cyclopentanone, which has the lowest LCI in this group.
n	Assimilated to propanoic acid.
o	LCI value attributed to all saturated alkylformates for which no OEL is defined. The value is set equal to the LCI of methylformate.
p	LCI value attributed to all unsaturated alkylacetates for which no OEL is defined. The value is set equal to the LCI of vinylacetate.
q	LCI value attributed to all saturated alkylphthalates for which no OEL is defined. The value is set equal to the LCI of dimethyl- and dibutylphthalate.

4.5 References

ACGIH (American Conference of Governmental Industrial Hygienists), 1995. 1995-1996; Threshold Limit Values (TLVs™) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs™). ISBN 1-882417-110-9. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists Inc.

Alarie, Y., 1984. Establishing threshold limit values for airborne sensory irritants from an animal model and the mechanisms of olfaction of sensory irritants. Adv. Environ. Toxicol. 8, 153-164.

Arbejdstilsynet, 1994. Grænseværdier for stoffer og materialer. At-anvisning Nr. 3.1.0.2, July 1994.

DFG (Deutsche Forschungsgemeinschaft), 1995. Maximale Arbeitsplatzkonzentrationen und Biologische Arbeitsstofftoleranzwerte 1995. Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe, Mitteilung 31, ISBN 3-527-27569-X. Weinheim (D): VCH Verlagsgesellschaft mbH.

ECA (European Concerted Action "Indoor Air Quality and its Impact on Man"), 1991. Effects of indoor air pollution on human health. Report No. 10, EUR 14086 EN. Luxembourg: Office for Official Publications of the European Communities.

EU (European Union), 1994. Substances classified in Annex I of Council Directive 67/548/EEC, including all substances up to the 21st Adaptation to Technical Progress, O.J. L381, Vol. 37, 31.12.1994.

Harving, H., Dahl, R., and Mølhave, L. 1991. Lung fuction and bronchial reactivity in asthmatics during exposure to volatile organic compounds. Am. Rev. Respir. Dis. 143:751-754.

HSE (Health & Safety Executive), 1995. Occupational exposure limits 1995. Document EH40/95, ISBN 071760876X. Sudbury, Suffolk CO 106FS: HSE Books (PO Box 1999)

Kjaergaard, S.K., Mølhave, L. and Pedersen, O.F, 1989. Human reactions to indoor air pollutants: n-Decane. Environm.Internat. 15:473-482.

Kjaergaard, S.K., Mølhave, L. and Pedersen, O.F, 1991. Human reactions to a mixture of indoor air volatile organic compounds. Atmosph.Environm. 25a:1417-1426.

Krause, C., Mailahn, W., Nagel, R., Schulz, C. Seifert, B. and Ullrich, D., 1987. Occurence of volatile organic compounds in the air of 500 homes in the Federal Republic of Germany. In: Seifert B., Esdorn H., Fischer M., Rüden H. and Wegner J. *Indoor Air'87. Proceedings of the 4th International Conference on Indoor Air Quality and Climate*. Berlin, 17 - 21 August, vol. 1, pp. 102 - 106.

Krause C., Chutsch, M., Henke, M., Huber, M., Kliem, C., Leiske, W. Mailahn W., Schulz, C., Schwarz, E., Seifert, B. and Ullrich, D., 1991. Umwelt-Survey, Band IIIc, Wohn-Innenraum: Raumluft. Deskription flüchtiger organischer Verbindungen in der Raumluft der Bundesrepublik Deutschland 1985-86. WaBoLu-Hefte 4/1991. Institut für Wasser-, Boden- und Lufthygiene, Berlin, 278 S. ISBN 3-89234-104-3

Levy, L.S. and Lunau, F.W., 1990. Occupational limits for mixtures. In: Indoor Air Quality and Ventilation. Lunau F.W. and Reynolds G.L. (eds). London: Selpher Ltd., pp. 15-21.

Maynard, R.L., Cameron, K.M., Fielder, R., McDonald, A. and Wadge, A., 1995. Setting air quality standards for carcinogens: an alternative to mathematical quantitative risk assessment - discussion paper. Human and Experimental Toxicology 14, 175-186.

Mølhave, L. (1991). Volatile organic compounds, indoor air quality and health. Indoor Air 1, 357-376.

Mølhave, L., Bach, B., and Pedersen, O.F, 1986. Human reactions to low concentrations of volatile organic compounds. Environm.Internat. 12:167-175.

Mølhave, L., Jensen, J.G. and Larsen, S., 1991. Subjective reactions to volatile organic compounds as air pollutants. Atmosph.Environm. 25a: 1283-1293..

Nielsen, G.D., Alarie, Y., Poulsen, O.M., Nexø, B.A., 1995. Possible mechanisms for the respiratory tract effects of noncarcinogenic indoor-climate pollutants and bases for their risk assessment. Scand. J. Work Environ. Health 21, 165-178

Nielsen, G..D., Frimann Hansen, L., Hammer, M., Vejrup, K.V., Wolkoff, P., 1996. Chemical and biological evaluation of building material emissions I. A screening procedure based on closed emission systems. Indoor Air, accepted for publication.

NKB (Nordic Committee on Building Regulations), 1993. Allergy Hypersensitivity and Chemical Substances - Summary and Conclusions - NKB Committee and Work Reports 1993: 01E, ISBN 951-47-8197-X. Helsinki: Painatuskeskus Oy.

Shoaf, C.R., 1991. Current assessment practices for noncancer end points. Environ. Health Perspect. 95, 111-119

Smyth, H.F.Jr., Weil, C.S., West, J.S. and Carpenter, C.P., 1969. An exploration of joint toxic action: twenty-seven industrial chemicals intubated in rats in all possible pairs. Toxicol. appl. Pharmacol., 14, 340-347.

WHO (World Health Organization), 1987. Air quality guidelines for Europe. WHO Regional Publications, European Series No. 23. Copenhagen: WHO Regional Office for Europe.

5. SENSORY EVALUATION OF EMISSIONS FROM FLOORING MATERIALS

5.1 Background

The use of human observers is an indispensable tool for the measurement of sensory effects of indoor air quality because chemical analysis cannot be used to predict how chemicals will be perceived. Moreover, chemical methods of characterization are usually unsuitable or insufficient for integrating different types of sensory exposures and effects. Therefore, at present, sensory methods are the only tools available for evaluating perceived air quality.

Ideally, the final goal of the sensory evaluation of emissions from building materials would be to predict from laboratory evaluations, the consequences of the use of a material for the perceived air quality in actual buildings. Comparing such predictions with established standards or guidelines would provide the criterion for labelling or classification of the material.

However, models are required for predicting human reactions to real life exposures (usually originating from several sources) from the results of laboratory tests of individual materials. These models are needed, e.g.

- to transform sensory source characterisations in small scale settings into sensory characterizations of indoor air quality in full scale, actual environments;
- to predict the relation between sensory responses and air pollutant concentrations which is expected to be non linear;
- to predict the sensory perception of emissions from a combination of sources using measurements made individually for each contributing source; and
- to predict occupant responses in buildings using test panel responses in the laboratory.

For the time being, no widely accepted and validated models for all of these purposes exist. Therefore, only in exceptional cases will laboratory evaluations be useful for an estimate of the consequences of a material emission for the perceived air quality in actual environments. An example of such an exceptional case may be the emission of a flooring material in the very first few days after installation in an otherwise unmodified environment when these emissions are high and predominant.

Similarly, it is only in exceptional cases, such as the one mentioned above, that a comparison of sensory measurements of material emissions under laboratory conditions with guideline values of perceived indoor air quality may provide an acceptable criterion for labelling or classification of the material.

For these reasons, there are no guideline or target values for the sensory effects of material emissions available at present. A further complicating factor is, that several approaches are described in the literature and used in practice to study the perceived air quality of building material emissions (e.g., Berglund and Lindvall, 1979; VDI, 1986; Fanger, 1988; Gunnarsen et al., 1994, Knudsen et al., 1996). Some are based on olfactory measurements whereas others are intended to measure a broader range of perceptions. The approaches have not been intercalibrated.

Discomfort (or acceptability) attributed to air quality reflects not only perceptual information but also depends on psychological and social values. Therefore, reliable measures of discomfort (or acceptability) are not easily achieved since the outcome, to a large extent, depends on context factors and calibration is difficult. However, a reasonable assumption is that the perceived intensity of odours plays the major role in the generation of odour discomfort.

Considering the problems outlined above (not allowing for the indication of a satisfactory and generally accepted method for labelling of indoor materials with respect to the sensory effects of their chemical emissions) and in view of the fact that not all relevant open questions can yet be answered, the ECA Steering Committee has decided to establish a separate Working Group to address and hopefully answer these questions.

Consequently, for the purpose of the labelling procedure proposed in this report, a simplified, provisional approach to the evaluation of sensory emissions from flooring materials is presented in the following.

5.2 Simplified Sensory Assessment Procedure for Labelling of Flooring Materials with Respect to their Emissions to Indoor Air.

The simplified procedure consists of two steps.

5.2.1 Testing of sensory irritation.

The purpose of the evaluation procedure proposed in this report is to identify "healthy" flooring materials. The emissions into indoor air of these materials should not give rise to sensory irritation. However, due to the large variations of sensitivity in the population (also including hypersensitive subjects), this requirement cannot be satisfied in absolute terms but needs to be specified in terms of a defined maximum percentage of the population that perceive sensory irritation from the material emission.

In view of the lack of sensory emission standards and related standard measurement methods, it has been deemed appropriate to base the evaluation criterion proposed here on the recommendation of a task force from the World Health Organization (1989) that indoor air pollution sources should not cause more than a maximum of 10 % of building occupants to perceive sensory irritation. Accordingly,

⇒ a material will only be eligible for receiving a label based on the procedure proposed here if not more than 10 % of the test panel members (i.e. not more than one out of 10-15 panel members) assessing the material emission perceive sensory irritation.

Because chemical emissions are usually highest for new materials and decay with time and also because people installing a material should be protected from irritation, the sensory irritation test should be made as early as possible in the test procedure. However, the members of the test panel should also be protected from inhaling carcinogenic compounds (see sections 4.4 and 6.2). Therefore,

⇒ the test has to be performed on the third day of testing (3rd day after the introduction of the test specimen in the test chamber).

Further requirements are:

⇒ The material has to be tested with a clean air flow through the test chamber corresponding to an area specific ventilation rate q_e [$m^3 h^{-1} m^{-2}$] specified in Table 3.2 (see section 3.4) and the same as selected for the evaluation of chemical emissions (see Chapter 6).

The test conditions are intended to reflect low-medium ventilation rates. The perception of sensory irritation, contrary to perceived odour, may increase with exposure time. This increase will not be detected by the members of a panel who are only exposed for a short time. For details of the chamber method see section 5.2.3 below.

⇒ The evaluation method and results have to be displayed as well as the false positive rate for background air conditions, the traceability of the method and the results of quality assurance assessments.

At present, it is up to the authority or body establishing and/or granting a label to select a scientifically sound test design, choosing the measurement method(s) and the calibration procedure, identifying inter-individual variation, reproducibility and validity and assuring the quality of the methodology and the results.

5.2.2 Testing of odour or perceived air quality.

As outlined in section 5.1, there is no generally accepted or standard method for characterizing odour and/or perceived air quality caused by material emissions nor are there guideline or limit values for the sensory effects of these emissions.

Moreover, in contrast with sensory irritation, odour and air quality whilst causing discomfort for some people may be perceived as indifferent or even pleasant by others. Therefore, it was not deemed appropriate to exclude materials from labelling based on the mere detection of these sensory characteristics.

On the other hand, strong and longer lasting odours may not be tolerable to most people and the presence and/or strength of odorous emissions may be an important argument for the choice of flooring materials by consumers. Therefore,

⇒ the evaluation procedure of material emissions described here has to include, on the 28th day of testing (28th day after the introduction of the test specimen in the test chamber), a sensory test of odour or perceived air quality. The result of this test should enable consumers to compare the emissions from different materials, or to rank the materials, with respect to odour detectability, perceived odour intensity, percentage of test panel members dissatisfied with the perceived air quality or equivalent quantities.

However, at present,

⇒ it is up to the authority or body establishing and/or granting a label to select and prescribe an appropriate test method among those described in the literature and used in practice to study odour and/or the perceived air quality of building material emissions.

It is further established that

⇒ materials have to be tested with a clean air flow through the test chamber or other device containing the test specimen corresponding to an area specific ventilation rate q_e [$m^3\ h^{-1}m^{-2}$] specified in Table 3.2 (see section 3.4) and the same as selected for the evaluation of chemical emissions (see Chapter 6);

⇒ the evaluation method and results have to be displayed as well as the false positive rate for background air conditions, the traceability of the method and the results of quality assurance assessments.

At present, it is up to the authority or body establishing and/or granting a label to select a scientifically sound test design, choosing the measurement method(s) and the calibration procedure, identifying inter-individual variation, reproducibility and validity and assuring the quality of the methodology and the results.

5.2.3 General requirements for sensory emission tests

Minimum air flow and test specimen area: For sensory (irritation, odour or perceived air quality) testing, each test panel member has to be exposed to a minimum flow of about 0.9 $l\ s^{-1}$ or 3.2 $m^3\ h^{-1}$ of chamber air. This requirement entails a minimum emitting surface area A of flooring material test specimens which is given by

$$A = 3.2\ m^3 h^{-1} / q_e\ m^3 h^{-1} m^{-2} \qquad (5.1)$$

assuming that the entire air flow through the test chamber is delivered to one test panel member.

Values of the minimum surface area of flooring material specimens calculated according to equation (5.1) are reported in Table 5.1 for the three values of the specific ventilation rate q selected for the evaluation of flooring material emissions.

Table 5.1. The three specific ventilation rates q_e reported in Table 3.2 and the corresponding minimum surface areas A of test specimens required for sensory testing

area specific ventilation rate q_e [$m^3 h^{-1} m^{-2}$]	0.625	1.25	2.50
Minimum surface area of test specimen [m^2]	5.1	2.6	1.3

The table shows that for sensory measurements at the lowest specific ventilation rate, chamber sizes at the upper range of small test chambers (as defined in section 2.1.1) are required.

Test chamber cleanliness: It is important for chemical measurements that the chamber surfaces do not absorb and re-emit pollutants and this requirement is even more important in the case of sensory measurements. Also, the chamber must be cleaned thoroughly and checked for cleanliness before every test. A proper test sequence introducing low emitting materials before strongly emitting materials can reduce the rigour needed in the cleaning procedure.

Blanks: To ensure good control of the procedure and be able to display the false positive rate of the background air, the use of blank exposures (approx. 30 %) during the assessment procedures is recommended. The blanks do not exclude the need to check the background before each test session.

Surroundings: A well-ventilated, low odour test room is required for performing the sensory tests. The same requirements apply to the waiting room where test persons spend their time between assessments.

Exposure equipment: The air exhausted from the test chamber must be delivered to a test person at an exposure flow rate that ensures she/he only inhales polluted air. Air from the close surroundings should not dilute the polluted air during the deepest inhalations. An exposure air flow rate of $0.9\ l\ s^{-1}$ ($3.24\ m^3 h^{-1}$) is considered the minimum requirement.

Panel: A panel size of 10-15 panel members is recommended and not less than 10.

5.3 References

Berglund, B., Lindvall, T., 1979. Olfactory evaluation of indoor air quality. In: Fanger and Valbjørn (Eds.), Indoor Climate, Danish Building Research Institute, Copenhagen, pp. 141-157.

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.

Gunnarsen, L., Nielsen, P.A., Wolkoff, P., 1994. Design and characterization of the CLIMPAQ, Chamber for Laboratory Investigation of Materials, Pollution and Air Quality. Indoor Air 4, 56-62.

Knudsen, H.N., Clausen, G., Fanger, P.O., 1997. Sensory characterization of emissions from materials. Indoor Air, in press.

VDI (Verein Deutscher Ingenieure), 1986. Olfactometry; Odour threshold determination; Fundamentals. VDI-Richtlinie 3881, Blatt 1, Düsseldorf.

WHO (World Health Organization), 1989. Indoor air quality: Organic pollutants. EURO Reports and Studies No. 111. Copenhagen: WHO Regional Office for Europe, p.38.

6. EVALUATION AND CLASSIFICATION OF FLOORING MATERIALS WITH RESPECT TO HEALTH AND COMFORT EFFECTS OF THEIR VOC EMISSIONS

In the following sections 6.1 - 6.4 an overall evaluation procedure for emissions of VOCs from solid flooring materials is outlined, taking into account both health and comfort effects. The evaluation is based on:

- the emission factors determined by the test procedure described in section 2.1;
- the simplified exposure scenarios defined in section 3.4;
- the concentrations of total volatile organic compounds (TVOC) and individual VOCs resulting from the exposure scenarios, the emission factors and the simple model for calculating steady state concentrations outlined in section 3.3;
- the rules for evaluating TVOC concentrations established in section 4.3;
- the rules, established in section 4.4, for evaluating individual VOCs and their concentrations with respect to carcinogenic (point (a)) and other effects (points (d) and (e)); and
- the simplified procedure for the sensory evaluation of emissions from flooring materials described in section 5.2.

The uses intended for the evaluation procedure are comparison, classification and/or labeling of solid flooring materials with respect to their VOC emissions. Uses and potential users are discussed in section 6.5. Products successfully passing the evaluation procedure described here may be positively labelled with the relevant information.

The evaluation procedure is schematically summarized in Figure 6.1 and consists of the following steps.

6.1 Preparatory Steps

The following preparatory steps are required:

6.1.1 Determination of the scenario or area specific ventilation rate for emission evaluation

The evaluation procedure proposed here combines a toxicological and a sensory evaluation. Both evaluations are based on one of three exposure scenarios which are each characterized by an area specific ventilation rate q_e (see section 3.4). For the reasons explained in the following, the scenario to be used for an evaluation has to be selected before starting the evaluation procedure.

The *toxicological* evaluation is based on concentration measurements of emitted VOCs that are, as a rule, performed at the area specific ventilation rate $q_c = 1.25\ m^3\ h^{-1}\ m^{-2}$ (see section 2.1.2). These concentrations can be transformed into the concentrations expected at the exposure scenario or the area specific ventilation rate selected for evaluation (in the following called ***'exposure concentrations'***) using a simple model (see section 3.3, equation 3.1). In fact, the transformation of the measured chamber concentrations into the exposure concentrations occurs in two steps: (i) transformation of the chamber concentration into an emission factor E (see equation 2.5, section 2.1.7)

$$E = \{C\} \times q_c \ [\mu g\, h^{-1} m^{-2}]$$

where {C} is the average of at least two measurements of the chamber concentration and (ii) transformation of the emission factor into the exposure concentration C (see equation 3.1, section 3.3)

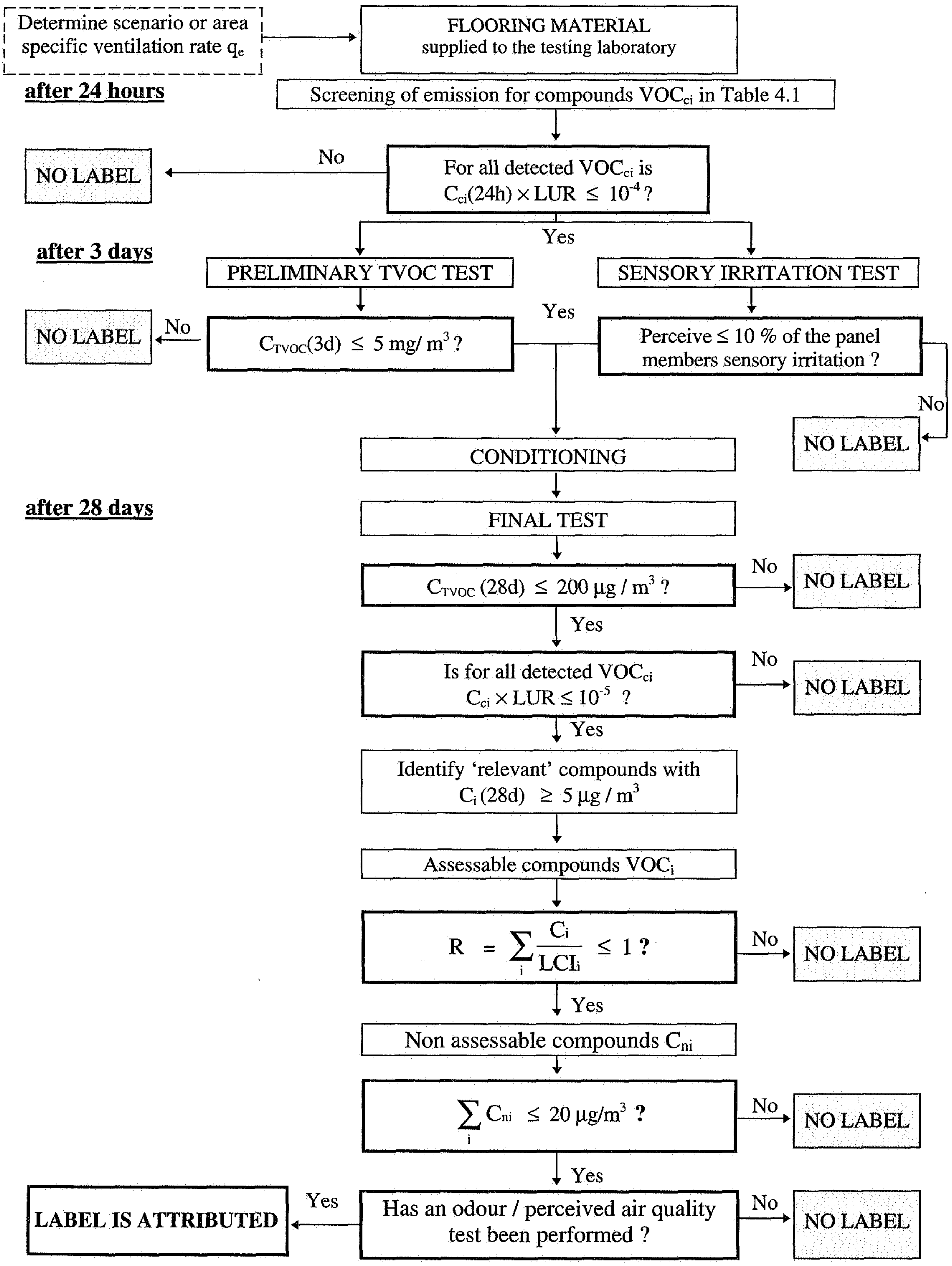


Fig. 6.1 Flow chart of the procedure for testing, evaluating and labelling of flooring materials

The average {C} of the measured chamber concentrations is therefore linked to the exposure concentration C by the simple equations

$$C = \{C\} \times q_c / q_e \qquad \text{or} \qquad \{C\} = C \times q_e / q_c \qquad (6.1)$$

Table 6.1 repeats for the three scenarios the area specific ventilation rates q_e and reports the factors q_e/q_c linking the chamber and exposure concentrations. The evaluation procedure requires identification and quantification of all VOCs with exposure concentrations equal to or greater than 5 µg m^{-3} (see section 6.4.4 below). The corresponding chamber concentrations depend on the scenario selected for the evaluation procedure according to equation (6.1). Their values are also given in Table 6.1.

Table 6.1. The three scenarios for material evaluation and respective experimental and modelling parameters

scenario	1	2	3
area specific ventilation rate q_e [$m^3 h^{-1} m^{-2}$]	0.625	1.25	2.50
ventilation rate (air changes per hour) for rooms with a height of 2.5 m	0.25	0.5	1
factors q_e/q_c linking chamber and exposure concentrations according to equation (6.1)	0.5	1	2
minimum chamber concentrations [µg m^{-3}] of VOCs corresponding to relevant exposure concentrations according to section 6.4.4	2.5	5	10
Minimum surface area [m^2] of test specimens for sensory measurements	5.1	2.6	1.3

Also the *sensory* evaluation of material emissions requires that the scenario or the area specific ventilation rate q_e respectively is selected before starting the evaluation procedure. This is necessary, because there is no generally accepted model for predicting the dependence of sensory perceptions on VOC concentrations or area specific ventilation rates respectively (see section 5.1). Therefore, in principle, sensory measurements have to be performed at the area specific ventilation rate selected for the evaluation of a material emission. However, it is anticipated that sensory perceptions of a material emission measured at a higher area specific ventilation rate will be less or at least not more intense than the perceptions measured at a lower area specific ventilation rate. Therefore, the result of a sensory evaluation performed at a low area specific ventilation rate will also be valid for evaluations at higher area specific ventilation rates.

6.1.2 Size and supply of material specimens

The amount of freshly manufactured flooring material needed for testing is supplied by the producer to the testing laboratory. This amount has to be specified by the testing laboratory and depends on the area specific ventilation rate used during testing (see above), the test chamber size and the sink properties of the test chamber that may require high material loading and air flow through the test chamber (see section 2.1.5, heading “sink effects”). In addition, for sensory testing a minimum air flow through the test chamber is required that entails a minimum surface area of the test specimens (see section 5.2.3). The minimum surface areas are also included in Table 6.1.

For sample collection and packaging the producer applies the rules described in section 2.1.3. As a prerequisite for being admitted to the evaluation procedure, the material submitted by the producer must conform with existing national and European regulations (e.g. with respect to fire resistance).

For the time being, only solid floor coverings will be tested, i.e., without taking into account the underlying layers of the total flooring system or any surface treatment except in cases where it is applied to the floor covering as part of the production process (see section 3.2.1).

Following the procedure described in section 2.1, the specimen is unwrapped, then put immediately into the test chamber and testing is started. The first 24 h of testing serve to condition the test specimen.

6.2 Measurements and Evaluations after 24±1 Hours of Testing

As outlined in section 4.4, point a), after 24±1 hours of testing, a sample of chamber air is analysed for the presence of carcinogenic compounds. This test is used to protect test panel members during the first sensory evaluation (see section 6.3.2). In the context of this proposal, a carcinogenic compound is a VOC_{ci} which is listed in Table 4.1. In principle, carcinogens should be avoided. Whenever a carcinogen VOC_{ci} is detected, its emission factor $E_{ci}(24h)$ is determined according to section 2.1.7. Subsequently, the concentration $C_{ci}(24h)$ predicted from the emission factor E_{ci} (24a) and the area specific ventilation rate q_e selected for sensory testing (see section 6.1.1 above) is determined using the equation 3.1 (see section 3.3):

$$\mathbf{C_{ci}(24h) = E_{ci}(24h) / q_e} \qquad \mathbf{(6.2)}$$

The concentration $C_{ci}(24h)$ [$\mu g/m^3$] has to fulfil the condition:

$$\mathbf{C_{ci}(24h) \times LUR \leq 10^{-4}.} \qquad \mathbf{(6.3)}$$

where LUR is the lifetime unit risk reported in Table 4.1, column 3.

The limit concentrations that must not be exceeded by $C_{ci}(24h)$ are reported in column 4 of Table 4.1. Products emitting carcinogenic substances VOC_{ci} at a level not fulfilling condition (6.2) will not be tested further and are excluded from labelling.

6.3 Measurements and Evaluations after 72h (3d)±3h of Testing

6.3.1 Measurement of the TVOC concentration.

The TVOC test chamber concentration is measured following the procedure described in section 2.1.7, and the emission factor $E_{TVOC}(3d)$ is calculated by means of equation (2.6), section 2.1.7. Using this emission factor and equation (3.1) (see above or section 3.4), the concentration $C_{TVOC}(3d)$ is calculated for the selected exposure scenario:

$$\mathbf{C_{TVOC}(3d)\ [\mu g/m^3] = E_{TVOC}(3d)\ [\mu g/(h \times m^2)] / q_e\ [m^3/(h \times m^2)]} \qquad \mathbf{(6.4)}$$

where q_e is the area specific ventilation rate of the selected scenario (see sections 3.4 and 6.1.1 above). If the concentration $C_{TVOC}(3d)$ fulfils the condition (see section 4.3):

$$\mathbf{C_{TVOC}(3d) \leq 5\ mg/m^3} \qquad \mathbf{(6.5)}$$

testing is continued. Otherwise the material will not be tested further and is excluded from labelling.

6.3.2 Measurement of sensory irritation

Following the indications of section 5.2.1, a panel of 10-15 members or more will be exposed to the air of a test chamber containing an appropriately sized specimen of the test material and ventilated with an area specific ventilation rate q_e [$m^3 h^{-1} m^{-2}$] as specified in section 5.2.1 and 6.1.1 above. Chamber air has to be delivered to each panel member at a flow rate of at least 0.9 $l\ s^{-1}$ or 3.24 $m^3\ h^{-1}$. The specific ventilation rate and the minimum air flow rate as specified above, entail a minimum surface area of the test specimen as reported in Tables 5.1 and 6.1.

If, under these conditions:

$$\leq 10\ \%\ \textbf{of the panel members perceive sensory irritation} \qquad (6.6)$$

(i.e. not more than one out of 10-15 panel members), testing of the material will be continued. Otherwise, the material will not be tested further and is excluded from labelling.

6.4 Measurements and Evaluations after 28±1 Days of Testing

6.4.1 Measurement of the TVOC concentration

The TVOC test chamber concentration is measured and the TVOC emission factor $E_{TVOC}(28d)$ is calculated in the same way as outlined in section 6.3.1 above. Again, using the emission factor $E_{TVOC}(28d)$, the area specific ventilation rate q_e (see 6.1.1 above) and equation (3.1), the concentration $C_{TVOC}(28d)$ is calculated. It is then determined whether the concentration $C_{TVOC}(28d)$ fulfils the condition (see section 4.3)

$$C_{TVOC}\ (28d)\ \leq\ 200\ \mu g / m^3. \qquad (6.7)$$

If condition (6.7) is fulfilled, testing is continued. Otherwise, the material will not be tested further and is excluded from labelling.

6.4.2 Measurement of carcinogenic compounds

Test chamber air is again analysed for the presence of carcinogenic compounds VOC_{ci} , (i.e. of the compounds in Table 4.1), and their emission factors $E_{ci}(28d)$ are determined as described in section 2.1.7. The concentrations $C_{ci}(28d)$ predicted from the emission factors E_{ci} (28d) and the area specific ventilation rate q_e (see section 6.1.1 above) have to fulfil the condition:

$$LUR \times C_{ci}(28d)\ \leq\ 10^{-5} \qquad (6.8)$$

or, by using equation (6.1),

$$\{C_{ci}\}(28d) \times q_c/q_e \times LUR\ \leq\ 10^{-5} \qquad (6.9)$$

where LUR is the lifetime unit risk reported in Table 4.1, column 3.

The limit concentrations which must not be exceeded by $C_{ci}(28d)$ are reported in column 5 of Table 4.1. Products emitting carcinogenic substances VOC_{ci} at a level which do not fulfil condition (6.10) will not be tested further and are excluded from labelling.

6.4.3 Testing of odour or perceived air quality

Following the indications given in sections 5.2.2 and 5.2.3, a test of the odour or perceived quality of the test chamber air has to be performed. The result of this test has to be reported in a way that enables consumers to compare the emissions from different materials, or to rank the materials, with respect to the measured perceptions (e.g. odour detectability, perceived odour intensity, percentage of test panel members dissatisfied with the perceived air quality or equivalent quantities).

6.4.4 Measurement of concentrations of individual VOCs

Identification of relevant VOCs. For those products for which conditions (6.7), and (6.8/9) are fulfilled, individual VOCs (VOC_i) are identified and quantified if their exposure concentrations $C_i(28d)$ fulfil the condition:

$$\mathbf{C_i(28d)} = \frac{E_i(28d)}{q_e} \geq \mathbf{5\,\mu g/m^3} \qquad \mathbf{(6.10)}$$

where $E_i(28d)$ are the emission factors as determined by the chamber test and q_e is the area specific ventilation rate adopted for the evaluation procedure (see eq. (3.1)). Condition (6.10) is justified by the fact that the smallest value of the "lowest concentrations of interest" (LCIs) (see Table 4.2 and below) is still two times the limit concentration value in condition (6.10) and hence, that at this level of concentration no effects of individual compounds are expected.

According to equation (6.1), condition (6.10) is equivalent to the condition

$$\mathbf{\{C_i\}(28d) \geq 5 \times q_e/q_c\ \mu g/m^3.} \qquad \mathbf{(6.11)}$$

where $\{C_i\}(28d)$ is the average of at least two measurements of the chamber concentration of VOC_i after 28 days and q_e/q_c is the factor chamber and exposure concentration given in Table 6.1. Compounds fulfilling conditions (6.10) and (6.11) are called 'relevant' compounds with respect to the toxicological evaluation.

The toxicological evaluation of relevant compounds VOC_i present in the emissions measured on day 28 is performed by comparing their exposure concentration with the "lowest concentrations of interest" (LCIs) defined in section 4.4 and reported in Table 4.2, i.e. calculating the ratios:

$$R_i = \frac{C_i}{LCI_i}.$$

VOCs for which a LCI value is reported in Table 4.2 are called "assessable". A VOC_i is supposed to have no effect if R_i does not exceed the value 1. For more than one relevant compound, additivity of effects is assumed as explained in section 4.3, and it has to be determined if:

$$\mathbf{R} = \sum_i R_i = \sum_i \frac{C_i}{LCI_i} \leq \mathbf{1.} \qquad \mathbf{(6.12)}$$

R is termed "risk index" of assessable emitted compounds.

Relevant VOCs for which no LCI exists are considered "not assessable" compounds VOC_{ni}. The sum of the concentrations C_{ni} of these compounds should only contribute a small fraction to the total VOC concentration, i.e.

$$\sum_i C_{ni} \leq \mathbf{20\,\mu g/m^3.} \qquad \mathbf{(6.13)}$$

If condition (6.13) is not fulfilled, no label will be granted to the tested material, because the risk due to their VOC emission cannot be evaluated.

If condition (6.13) is fulfilled, the tested material has successfully passed the evaluation procedure and a quality label may be granted to it.

6.5 Use of the Evaluation Procedure and Responsibilities

This report discusses the principles of a procedure for the evaluation of health and comfort consequences of VOC emissions from building materials. The report contains a synthesis of the currently available knowledge required for such a procedure. In view of the identified gaps in available knowledge, the evaluation procedure in its present form is directly applicable only to solid flooring materials (see section 2.2 and end of section 3.2.1).

The report provides regulatory bodies at all levels (regional, national, European) and/or industrial associations with guidance and with a tool for establishing quality certification or labelling systems that will assist building designers, constructors and owners or other users of flooring materials in selecting products the VOC emissions of which - according to available knowledge - do not cause health and comfort problems. The proposed procedure is intended also to help producers of flooring materials in developing healthy and comfortable products.

The procedure proposed in this report has a prenormative character and, therefore, is not a final product directly applicable to quality certification or labelling. Regulatory authorities and other bodies interested in quality certification or labelling of flooring materials have to decide on several elements of a labelling procedure that have not been established or addressed in this report. These elements need to be decided in the light of such issues as cultural or climatic characteristics of the country or region where a label has to be applied, public health policies or the needs or requests of target users.

The authority or body establishing a quality certificate or label based on the procedure proposed in this report have in particular to decide on the following points:

Exposure scenario or area specific ventilation rate. The proposed procedure offers two possibilities.

(a) The authority or body establishing a quality certificate or label selects a single scenario or area specific ventilation rate from the three choices offered by the proposed procedure. The authority or body may then request or recommend that only labelled materials are used for certain specified applications. In this case evaluations have to be performed with the prescribed area specific ventilation rate.

(b) The authority or body establishing a quality certificate or label introduces three quality classes corresponding to the three exposure scenarios or area specific ventilation rates. Authorities may then request or recommend that in areas or countries of their competence for specified applications only labelled materials belonging to one, two or all three classes are used. In this case, usually the producer of a material applying for a label will decide which area specific ventilation rate is used for evaluating his material(s).

Test method for odour or perceived air quality. It is the responsibility of the authority or body establishing a quality certificate or label to select and prescribe an appropriate test method among those described in the literature and used in practice to study odour and/or the perceived air quality of building material emissions and satisfying the conditions described in sections 5.2.2 and 5.2.3 of this report. The authority or body has also to decide on how the results of the test can be communicated in a way that comparison of different materials having passed the same test becomes possible.

Communication of the content/meaning of the quality certificate or the label. A material passing the proposed evaluation procedure has – under the conditions of the selected exposure scenario – the following properties: (a) there are no indications that volatile organic compounds emitted from the material may cause health effects; (b) gaseous emissions from the material do not cause sensory irritation to most people; (c) odour or perceived air quality of the material's emissions have been tested and the material can be compared for these properties with other materials having passed the same test.

It will be responsibility of the authority or body establishing a quality certificate or label based on the proposed procedure to decide on the symbol(s), text and/or other graphic means to convey this message to the interested public.

APPENDICES

Appendix 1

Survey of existing emission test methods and guidelines with respect to experimental variables influencing emission in test chambers (H. Gustafsson).

1. Purpose and scope

The purpose of this survey is to highlight the extent to which published chamber methods for the characterization of VOC emissions from indoor materials consider and/or establish rules for the experimental variables or parameters influencing the emission. This survey is partially based on an earlier review of a number of small chambers, their characteristics and use (Gustafsson and Jonsson, 1991).

The survey focussed on:

- variables influencing the emission in the chamber;
- general performance criteria of emission measurements, but not examples of details of technical arrangements, e.g. how to achieve a specific air quality.

The survey does not cover:

- size of chambers or arrangements which are dependent on the volume or shape of the chamber, e.g. dimensions of test specimen and position of sensors;
- screening techniques, e.g. headspace;
- precision of e.g. analytical procedures;
- procedures in common terms related to Good Laboratory Practice (GLP).

2. Reviewed methods and guidelines

The review is based on the following emission test methods and guidelines:

Indoor Air Sources; using Small Environmental Test Chambers to characterize organic Emissions from Indoor Materials and Products, (ref. Tichenor 1989); referred to as ***"US EPA".***

Guideline for the Characterization of Volatile organic Compounds Emitted from Indoor Materials and Products using Small Test Chambers, (ref. ECA 1991); ***"ECA VOC".***

Standard Guide for Small-Scale Environmental Chamber Determinations of organic Emissions from Indoor Materials/Products, (ref. ASTM 1990): ***"ASTM".***

Chamber Method; Building Materials: Emission of Volatile organic Compounds, Nordtest Method NT Build 358 (ref. Nordtest 1990): ***"Nordtest Chamber"*** Field and Laboratory Emission Cell; Building Materials: Emission of Volatile organic Compounds. Draft Nordtest Method being sent out for approval (ref. Nordtest 1993): ***"Nordtest FLEC".***

Standard Test Method for Determing Total Volatile organic Compound Emission Factors from Carpet under Defined Test Conditions Using Small Environmental Chambers, Carpet Policy Dialogue Group (ref. CPDG 1991): ***"CPDG".***

Formaldehyde Emissions from Wood Based Panels: Guideline for the Determination of Steady State Concentrations in Test Chambers (ref. ECA 1989): ***"ECA Formaldehyde".***

The abbreviations of the reviewed documents (reported above) together with the number of the paragraph in question, are used as references.

The test methods are naturally more precise than the guidelines. Several recommendations originate from "US EPA", which is used as the main reference. Otherwise, similar recommendations from later documents are used to describe the procedure more precisely. If a requirement/recommendation is given twice or more in the same document, reference is made to the most precise description.

3. General comments about some variables reflected in the guidelines

3.1 Requirements on materials used for chamber construction, etc.

In all the documents, it is presumed chambers and sampling systems have inert interior surfaces.

3.2 Chamber internal volume

Environmental test chambers are designed to permit sample testing of various types of building materials and consumer products. Chambers can range in size from mL to several m^3. A comparison of results between two ventilated chambers, differing in volume as much as six orders of magnitude, mL to m^3, respectively, has been carried out (Hoetjer and Koerts, 1986).

3.3 Temperature and relative humidity

Temperature and relative humidity are normally the same during conditioning and testing. Background measurements are usually performed at testing climate.

An international standard for climate (23°C, 50% RH), "ISO 554, Standard atmospheres for conditioning and/or testing" is preferred for most standard methods. This standard is frequently used for polymers, wood products, and other materials.

3.4 Specimen storage / conditioning

Usually, test specimen have to be conditioned before testing, applying the same environmental conditions as those used for testing. At the least, a sufficient time period is need to allow the emissions to equilibrate to the test conditions. Special care must also be taken in testing materials which have been stored with other materials. "ECA VOC" recommends wrapping materials in this category in aluminium foil, in order to avoid the adsorption of VOC emitted from other materials.

3.5 Specimen loading factor

In all documents, the loading factor is calculated using the exposed surface area of the specimen, with the exception of sealed edges. Sealing of edges is usually applied when the emission from the edges may differ from the large surface of the test specimen.

In "Nordtest Chamber", a model room is used to determine loading factors for various types of materials. The model room (2.2 x 3.2 x height 2.4m = $17m^3$) agrees with the requirements on the minimum size of a room in several European countries (10).

3.6 Chamber air mixing

The evaporative mass transfer of a given organic compound from the surface of the material to the overlying air can be expressed as:

$$E = k_m (Cs - Ca)$$

where: E = emission rate

k_m = mass transfer coefficient

Cs = concentration at the surface of the material

Ca = concentration in the air above surface

Thus, the emission rate is proportional to the difference in VOC concentration at the surface and in the overlying air. The mass transfer coefficient is a function of the diffusion coefficient (in air) for the specific compound examined and of the thickness of the boundary layer. This in turn depends on the level of turbulence in the boundary layer above the surface of the material and/or the air velocity across the emitting surface. Therefore, chamber air mixing and the air velocity across the emitting surface may influence the emission rate. (ASTM 4.2.1)

3.7 Air sampling

In the methods "CPDG", (paragraph 10.4) and "Nordtest FLEC", (8.4.2) a time is defined for air sampling (24h) after the start of the test procedure. The guidelines are less specific with respect to the sampling time. Various rules or recommendations have been given in "US EPA", (paragraph 5D); "ECA VOC", (5D); "Nordtest Chamber", (6.4); "ECA Formaldehyde", (4.5). Also included is the variation of emissions over time.

4. Survey of emission test methods and guidelines with respect to experimental variables influencing the emission in test chambers

The main headings of this survey are arranged according to "Rules for the drafting and presentation of European Standards, IR, CEN/CENELEC, Ed. 1991-09". This means that some headings are included which do not cover variables influencing the emission in the chamber.

4.1 Scope

4.2 Normative references

4.3 Definitions

4.4 Sampling of material

"Newly produced material shall be manufactured, handled in the normal manner and if possible, delivered in unopened standard packages. The samples are packed immediately after production and sent to the testing laboratory". (Nordtest FLEC,3)

"During collection, storage and transport, temperature and humidity have to be maintained at normal indoor level and the surface of the material shall be thoroughly protected from chemical or other contamination. For most materials, this can be achieved by wrapping each test specimen in aluminium foil and a polyethylene bag. Each test specimen shall be delivered and wrapped separately." (Nordtest FLEC,3)

"... materials (must) be collected directly from the manufacturer's production line, and packaged immediately". (CPDG, 6.2.1)

"Aluminized packaging (shiny side out) lined with polyethylene or Tedlar...". (CPDG, 6.3)

"The sample background on the packaging material, . . . must have a consistent TVOC background emission factor less than 0.010 mg/m^2 ´ hr.". (CPDG, 6.3)

4.5 Principle of testing

4.6 Apparatus

4.6.1 Chamber wall material

"non-adsorbent ... smooth interior surfaces". (US EPA, 2A)

"polished stainless steel" (Nordtest Chamber, 6.2)

"... stainless steel (DIN 17 440 / x5CrNiMo 17 13 / AISI 316)". ... "The inner surface ... is lathe made and hand polished". (Nordtest FLEC, 5)

"The sealing materials are ... emission-free silicon rubber foam tolerating temperatures up to 100°C". (Nordtest FLEC, 5)

"Surfaces shall be sufficiently chemically inert that the recovery rates of a representative mixture of VOCs including hexanol, toluene, cyclohexane and decane is greater than 95% at a mixture concentration of 40 mg/m^3 (10 mg/m^3 of each)". (CPDG, 5.1)

"stainless steel (treated by sandblowing and electropolishing)". (ECA Formaldehyde, 2.3)

4.6.2 Location of air sampling ports

"The exhaust flow (for example chamber outlet) is normally used as the sampling point, although separate sampling ports in the chamber can be used". (ASTM, 6.2)

"... sampling in the outlet is particularly beneficial ..." (ECA VOC, 2A)

"Any ducting between the chamber and the sampling device should be as short as possible and maintained at least at the same temperature as the test chambers". (ECA VOC, 3A)

"Sample ports must be affixed to the outlet exhaust of the chamber in a manner that does not adversely affect the chamber flow". (CPDG, 5.7)

"Air samples should be collected in the air outlet duct of the chamber, as close as possible to the chamber in order to minimize losses due to ad- or absorption in the duct tubing". (ECA Formaldehyde, 4.3)

4.6.3 Chamber air tightness

"Leaks should be checked, e.g. by pressure drop measurements, by measuring occasionally the air flowrate simultaneously at the inlet and outlet port...." (ECA VOC, 2A)

"Uncontrolled air exchange due to leaks must be ≤ 1% of the controlled air exchange". (ECA VOC, 2B)

"The chamber must be operated under slight positive pressure (less than 1 inch of water) relative to atmospheric pressure". (CPDG, 5.6)

"The air leakage is less than 0,001% of the volume of the climate chamber per minute when an overpressure of 1000 Pa is used". (Nordtest Chamber, 6.2)

"The air exchange rate due to leaks determined by tracer gas dilution is ≤1% of the air exchange rate ... or if the air flow leaking from the closed chamber at an overpressure of 1000 Pa is 10-4 chamber volumes per minute". (ECA Formaldehyde, 2.4)

4.6.4 Determination of chamber air mixing

"The chambers should be designed to ensure adequate mixing of the chamber air. ...one approach for determining if the chamber air is adequately mixed is to blend a tracer gas (e.g. SF6) with the inlet air at constant concentration and flow and measure the concentration in the chamber outlet over time. The chamber concentration vs. time plot is then compared to the theoretical curve for a completely mixed chamber...". (US EPA, 2A)

"If the measured data closely follow the theoretical curve, the chamber is well mixed. When the measured data lie above the theoretical curve, short circuiting of the flow is occurring and the chamber air is not well mixed. Short circuiting is probably caused by poor placement of the air inlet and/or outlet ports. If the measured data fall below the theoretical curve, some of the tracer gas may be adsorbing on the chamber surfaces, the chamber may be leaking, or incomplete mixing may be occurring. Tests to determine the adequacy of mixing should be conducted not only in an empty chamber, but also with inert substrates of the types of samples to be tested to ensure that placement of the samples in the chamber will not result in inadequate mixing.(US EPA, 2A)

Quantitative guidance on the mixing is unavailable. One method might be to "force" the measured data through the theoretical curve using the chamber volume (V) as a variable. One could then compare the actual chamber volume to the "apparent" chamber volume based on the curve fit. A difference of >10% between the actual and "apparent" volumes might be considered unacceptable". (US EPA, 2A)

"Tests to dermine the adequacy of mixing should be conducted not only in an empty chamber, but also with inert supports of the types of samples to be tested...". (ECA VOC, 2A)

"If the surface air velocity remains constant or is sufficient to avoid limiting evaporative transfer, the effect of varying the air exchange rate will only be on concentrations". (ECA VOC, 2A)

"Internal chamber air must be well-mixed and must comply within 5% of the theoretical well-mixed model". (CPDG 5.3) "The reciprocals of the formaldehyde concentrations (at four different values of L/n) obtained are plotted versus the n/L values adopted: In a well mixed chamber, a straight line should be obtained....". (ECA Formaldehyde, 5.4)

4.7 Preparation of test specimens

"The test specimen is prepared immediately prior to loading", (CPDG, 8.1.2.0)

"Substrate area ± 1.0% (precision)" (CPDG, 11.3.2)

4.7.1 Edge sealing of solid samples

"If emissions from edges may differ considerably from the normal exposed surface, the edges should be sealed...". (ECA VOC, 5C)

"... low-emitting, self adhesive aluminium tape ... (e.g. Tesametal 4501)". (Nordtest Chamber, 6.2)

"For edge sealing (of boards) coverage with self adhesive aluminium tape or two layers of a two-component polyurethane lacquer with a low solvent content....". (ECA Formaldehyde, 4.1)

4.7.2 Semi-solid materials / "wet" materials

For wet products "... an aluminium or glass ... support has to be coated...". (ECA VOC, 5B)

"Liquids of low volatility can be introduced in a small open vial, which is placed upright ..." (ECA VOC, 5B)

"Wet" materials are applied to a clean sheet of stainless steel". (Nordtest Chamber, 6.3) "Semi-solid or rugged materials can be applied to a disc of glass or accomodated in a Petri dish (e.g. Anumbra 1042/15) ...". (Nordtest FLEC, 5)

4.8 Conditioning

4.8.1 Age of test specimen prior to testing

"Once the sample is collected and packaged, it must arrive at the testing facility ASAP, with a maximum allowable delivery time of 36 hours following collection. It should then be stored in its packaged state in an environmentally controlled interior space for a maximum period of 48 hours prior to testing. The sample is to remain sealed until it is to be tested". (CPDG, 6.4)

4.8.2 Climatic conditions / Product storage

"Ideally, the sample should be conditioned over its complete life cycle up to the time of testing. If this is not possible, conditioning should be conducted for a period of time sufficient to allow the emissions to equilibrate to the test conditions ...". (US EPA, 5C)

"... materials which have been used or stored with other materials ... could have ... absorbed organic compounds from the other materials". ... "A good way of preserving samples for later tests is wrapping them with aluminium foil". (ECA VOC, 5C)

"Conditioning should occur under the same environmental parameters (temperature, humidity, air exchange rate and product loading) as those used for chamber tests. If this is not possible, the conditioning of environmental parameters should be well documented". (ASTM, 8.3.4)

"Store samples in a conditioning room at a temperature of 23 ± 2°C and 50 ± 5% RH before and between measurements". (Nordtest FLEC, 7.2)

"Store the samples without packaging so that the test surfaces are exposed to the air in the conditioning room. The concentration of impurities in the air shall be as low as possible". (Nordtest FLEC, 7.2)

"Following testing, the product should be repackaged and stored for a 6-month time period ... in an environmentally conditioned interior environment. The test specimen packaging must be air-tight and VOC free as required of the original packaging...". (CPDG, 6.5)

4.9. Test Procedure

4.9.1 Cleaning of the apparatus

"... scrubbing the inner surfaces with an alkaline detergent followed by thorough rinsing with tap water. Deionized water is used as a final rinse. Chambers are then dried ...and purged at test conditions". (US EPA, 5C)

"Sponge-washing the test chamber with 1-2% Extran MA-01 (Merck Art. 7555) in de-ionized water and leaving it for 2 hours. The chamber is then washed with de-ionized water three times and wiped with a clean piece of fabric. After this, the chamber is closed and ventilated with clean air from the air supply". (Nordtest chamber, 6.4)

"If the concentration of the gases and vapours in question exceeds 10% of the expected concentration, the cleaning procedure is repeated". (Nordtest chamber, 6.4)

"Wash the inner surface ... with a diluted alkaline washing agent and with pure water. Then wash the inner surface with ethanol. Place the (chamber) into an oven at 100°C or in a vacuum oven at 75°C and 50 mBar, for at least one hour". (Nordtest FLEC, 8.1)

"If the background concentration of formaldehyde in the chamber is higher than 12 mg/m^3, appropriate cleaning procedures must be adopted". (ECA Formaldehyde 2.6)

4.9.2 Quality of supply air

"The required purity of the air must also be determined based on the type of samples to be evaluated". (US EPA, 2A)

"The water used for humidification must not contain interfering organic material". (US EPA, 2A)

"... deionized (or HPLC grade distilled) water ..." (US EPA, 2A)

"The supply air shall be of a high level of cleanliness, e.g. synthetic air from a gas bottle (containing less than 0,1 ppm hydrocarbons), or equivalent". (Nordtest FLEC, 8.2.1)

"Purified air must not have a background contributing concentrations greater than 2 mg/m^3 of TVOC". (as defined in CPDG 9.4) (CPDG 5.4)

"The air supplied to the chamber must not contain formaldehyde at a level higher than 6 mg/m^3 (5 ppb) ... ". (ECA Formaldehyde, 2.5)

4.9.3 Background measurements

"A chamber background sample is ... taken to quantify any contribution of organic compounds from the clean air system or the empty chamber, or both". (ASTM, 8.3.2)

"... uncoated support should be placed in the chamber during background tests to determine the magnitude of its organic emissions". (ECA VOC, 2A)

"A chamber background test conducted on the chamber must confirm a TVOC background level less than 2.0 mg/m3". (CPDG, 8.1.1)

"If the background concentration of formaldehyde in the chamber is higher than 12 mg/m^3, appropriate cleaning procedures must be adopted". (ECA Formaldehyde, 2.6)

4.9.4 Positioning and support of the test specimen in the chamber

"Parallel ... to the direction of the air flow". (ECA Formaldehyde, 2.2)

"The test specimen ... centered and does not interfere with the flow of the supply air". (CPDG, 8.1.2)

"To support the test specimens ... a stainless steel rack is recommended". (Nordtest Chamber, 6.1)

"Stainless steel plate .. The mounting must have the ability to seal the edges of the test specimen ..". (CPDG, 7.1)

4.9.5 Air velocity

"... use a relative high air velocity ..." (US EPA, 2A)

"The point where air velocity is measured should be as close as possible to the sample surface and roughly in the centre thereof". (ECA VOC, 2A)

"During the test, the air flow is evenly distributed over the test material surface". (Nordtest FLEC, 4)

"Air velocity of 0,3 ± 0,1 m/sec ... closest to the centre of the loaded chamber and simultaneously a minimum velocity of 0,1 m/sec ... at all other measurement points ...". (ECA Formaldehyde, 2.2)

4.9.6 Time of emission measurements on test specimen

"The start of the test (time = 0) is set when the door to the chamber is closed". US EPA, 5C) ".... emission measurement 28 ± 2 days after the start of the conditioning period ...". (Nordtest FLEC, 8.4)

4.9.7 Temperature

"23°C" (US EPA, 4E)

"23°C" (US EPA, 1B)

"23°C ± 0,2°C" (Nordtest Chamber, 6.1)

"23°C ± 1°C" (Nordtest FLEC, 8.2)

"23°C ± 1.0°C" (precision standard deviation) (CPDG, 5.5)

"± 0.5°C" (accuracy) (CPDG, 11.3.2)

"23°C ± 0.5°C" (precision standard deviation) (ECA Formaldehyde 3.1)

"... cold spots (and condensation) ... avoided" (ECA VOC, 2A)

4.9.8 Relative humidity

"45 - 50 %" (US EPA, 4E)

"45 % ± 5% (precision), ± 10% (accuracy)" (ECA VOC, 4E)

"45 ± 3% RH" (Nordtest Chamber, 6.4)

"50 ± 5 % R.H.". (Nordtest FLEC, 8.2.1)

"50 ± 5 % (standard deviation) Relative Humidity". (CPDG, 8.1.3)

"± 5.0 % RH, accuracy" (requirement) (CPDG, 11.3.2)

"± 10.0% RH, accuracy" (example) (ASTM, Table 3)

"45 ± 3 % RH" (ECA Formaldehyde 3.2)

"Initial variance in the chamber may be observed after loading a product as a result of (1) outside air entrance of differing humidity, and of (2) moisture contribution from the product being tested. These variances should be recorded)." (CPDG, 5.5)

"Acceptable accuracy levels are 5 % average relative standard deviation based on twelve measurements over a 24-hour period as measured within the ETC (Environmental Test Chamber) supply air". (CPDG 5.5)

"If the flow is controlled/measured before the humidification step, the possible correction for volume increase due to the water vapour should be considered". (ECA VOC, 2B)

"No water condensation must occur in the chamber under test conditions". (ECA Formaldehyde, 2.2)

4.9.9 Air exchange rate

"1.0 hr-1" (US EPA, 4E)

"0.5 and / or 1.0 h-1" (ECA VOC, 2A)

"If the surface air velocity remains constant or is sufficient to avoid limiting evaporative transfer, the effect of varying the air exchange rate will only be on concentrations". (ECA VOC, 2A)

"0,50 ± 0,013 h-1" (Nordtest Chamber, 6.4) "Supply air must be ... maintained at a rate of 1.00 ± 0.05 (precision standard deviation) air changes per hour. The accuracy of this air exchange rate must be confirmed using procedures similar to that presented in ASTM method 741 for tracer gas applications, and found to have less than 10 % relative error". (CPDG, 5.4)

"± 2.0%, accuracy" (example) (ASTM, Table 3)

"± 5%, accuracy" (requirement) (CPDG, 11.3.2)

"Air exchange rate n =1 ± 0,03 chamber volumes per hour"... "In any case the air exchange rate ... must not vary by more than ± 3 %". (ECA Formaldehyde, 3.3)

4.9.10 Specimen loading factor

"The surface area of the test specimens is exposed to the chamber air with the same area to volume ratio 0.414 (loading factor, m^2/m^3) as in the model room". (Nordtest Chamber, 6.1)

"The loading factor (L, m^2/ m^3), i.e. the ratio of the surface area (m^2) of the test material to the total chamber volume (m^3) should be L = 1. In order to ease sample preparation ... a deviation of up to ± 10% from the value of L = 1 is admitted, on condition that the ratio L/n=1 is maintained, i.e. that the air exchange rate n is appropriately adjusted" (ECA Formaldehyde, 3.4)

4.10 Calculations and expression of results

4.11 Reporting test results

5. References

ASTM (1990). Standard Guide for Small-scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products. ASTM Designation D 5116. Philadelphia, PA: American Society for Testing and Materials.

CPDG, Carpet Policy Dialogue Group (1991). Test Method for Determining Total Volatile Organic Compound Emission Factors from Carpet Under Defined Test Conditions using Small Environmental Chambers. Carpet Policy Dialogue Compendium Report EPA/560/2-91-002, Appendix E. Office of Toxic Substances (TS-778), U.S. Environmental Protection Agency, September 1991.

ECA, European Concerted Action ”Indoor Air Quality and Its Impact on Man” (1989). Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers. Report No. 2 (EUR 12196 EN). Luxembourg: Office for Official Publications of the European Communities.

ECA, European Concerted Action ”Indoor Air Quality and Its Impact on Man” (1991). Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. Report Nr. 8 (EUR 13593 EN). Luxembourg: Office for Official Publications of the European Communities

Gustafsson, H. (1988). Proposal of a European Reference Room for Testing Formaldehyde and Other Indoor Air Pollutants. WKI-Bericht Nr. 19; Braunschweig: Frauenhofer Institut für Holzforschung.

Gustafsson, H. and Jonsson, B. (1991). Review of Small-scale Devices for Measuring Chemical Emission from Materials, Report 1991:25, Swedish National Testing and Research Institute.

Hoetjer, J.J. and Koerts, F. (1986); A Model for formaldehyde release for particle-board.

ACS Symposium Series 316, Formaldehyde Release from Wood Products, Washington DC: American Chemical Society, pp. 125-144.

Nordtest (1990). Building Materials: Emission of Volatile Compounds, Chamber Method. Nordtest Method NT Build 358, Approved 1990-06. Esbo, Finland: Nordtest

Nordtest (1993). Building materials: Emission of Volatile Compounds - Field and Laboratory Emission Cell, Draft Nordtest method 93-10-13. Esbo, Finland: Nordtest

Tichenor, B.A. (1989). Indoor air sources; using small environmental test chambers to characterize organic emissions from indoor materials and products, EPA-600 8-89-074, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency, 1989.

Appendix 2

Rationales for the choice of parameters/procedures for chemical emission measurements

(for references see also chapter 2)

1. Chamber construction and operation

Chamber size. Currently, it has not been demonstrated that chamber size influences the result of emission measurements, with the exception of a tendentially higher standard deviation encountered for smaller chambers because of the decreasing test specimen size (ECA, 1991). This effect may be counterbalanced by increasing the number of tested specimens. In principle, usable chambers range from large, walk-in type chambers right down to micro-chambers.

There is a clear tendency to favour small chambers with volumes of up to about 2 m^3 because these chambers and their operation are less expensive and require less space. This facilitates working simultaneously with several chambers.

Wall material and treatment, sealants. Wall materials should have low adsorption capacity. For surface materials, glass, Teflon, and surface treated (polished) stainless steel have been used.

Despite this selection aiming to minimize adsorption, experience shows (ECA, 1993) adsorption on chamber walls may significantly influence emission measurements. To account for the variable, tests must be used to assess the potential influence of wall adsorption on emission measurements.

It should be noted, that decreasing the volume of a chamber whilst leaving its proportions and surface materials unchanged, increases its wall surface to volume ratio, and possibly contributes to adsorption on the chamber walls regarding the overall mass flow. However, the equation,

ratio of the mass flow to internal chamber surfaces and the flow out of the chamber

$$= k_{ad} \times A_{cs} / (n \times V_c) \qquad (2.1)$$

where k_{ad} = adsorption rate constant, A_{cs} = area of internal chamber surfaces, n = air exchange rate and V_c=chamber volume

suggests that an increase in adsorption due to an increased ratio of chamber wall surface to volume, may be compensated by increasing the air exchange rate n appropriately. It has not been demonstrated that a significant correlation exists between adsorption and wall surface/volume ratio in small chambers (ECA, 1993).

Chamber tightness. Chamber tightness should be checked by pressure drop measurements. Measuring the time $t_{1/2}$ (hour) during which an overpressure in the sealed chamber decays to half its initial value, is a simple way to check the chamber tightness. For a specific leak, the leak rate LR (chamber volumes per hour) is proportional to the relative overpressure ROP (chamber minus ambient pressure divided by ambient pressure). It can be determined by the equation,

$$LR = ROP \times \ln 2 / t_{1/2} \cong 0.7 \times ROP / t_{1/2} \qquad (2.2)$$

If at a relative overpressure $ROP=10^{-3}$ (corresponding to an overpressure of 100 Pa) the leak rate is $5 \cdot 10^{-3}$ chamber volumes per hour, then $t_{1/2}$ is 0.139 h (~8 min). $t_{1/2}$ is characteristic for a given leak. $T_{1/2} \geq 8$ min corresponds to a leak rate of $\leq 1\%$ of the supply air flow at an air exchange rate of 0.5 ach (see chapter 2.1.2 "air exchange rate") and a typical chamber overpressure of 100 Pa. $t_{1/2} \geq 8$ min also conforms to the requirements in the ECA guideline (ECA, 1991), and the Nordtest methods (Nordtest, 1990; see Appendix 1, section 6.3).

Chamber air mixing. The chambers should be designed to ensure complete mixing of the chamber air. Currently, no guidelines exist on chamber design which guarantees adequate chamber air mixing.

Recently, designs for two small chambers were proposed (Gunnarsen et al. 1994; Zhang and Haghighat, 1994). The designs are intended to enforce complete mixing and simultaneously create laminar air flows, along with ensuring adjustable air velocities across the surface of the emitting test specimen (see section "surface air velocity" below). The designs incorporate low speed (axial) mixing fans and/or multi-port inlet and outlet diffusers. Recently, a different type of chamber - the micro-chamber FLEC (Wolkoff et al., 1993) - was designed to ensure a reproducible, although incomplete mixing of chamber air. This design, however, does not allow either independent control of the air exchange rate or control of the surface air velocity.

Supply and chamber air quality/cleaning. Before an emission test, measurements must be made of the VOC concentrations in the supply air and in the air of the test chamber (including all the support materials to be used during the test). These background concentrations must be low enough not to interfere with the emission determinations beyond QA limits. In view of the evaluation procedure (see chapter 4), the following background concentration limits are required:

(1) Background concentrations of individual compounds emitted from the test material giving rise to chamber concentrations ≥ 5 µg/m^3 after 28 days testing, must be smaller than 0.5 µg/m^3, or below detection limit (whichever is greater). This may require preliminary knowledge of the major constituents of test material emissions, e.g. by head space analysis. A separate sample of the test material may be needed for this purpose. In general, after 3 days of testing, these compounds will have the chamber concentrations ≥ 15 mg/m^3 .

(2) Background concentrations of all compounds contained in Table 4.2 (see chapter 4.2) must be smaller than 0.5 µg/m^3 or 10 % of the limit concentration specified in the Table, whichever is smaller.

(3) Background concentrations of all other compounds must be < 2µg/m^3 measured as toluene equivalent.

(4) The sum of the concentrations of all background compounds (TVOC; see definition in Chapter 2, section 2.1.7) determined by an FID applying the response factor of toluene, must be smaller than 10 µg/m^3 .

If necessary, the supply air and /or the chamber must be cleaned. The supply air can be cleaned by passing it through an appropriately sized charcoal filter. Cleaning devices for the supply air of small chambers are also commercially available. Appropriate cleaning procedures include washing or scrubbing the inner surface with an alkaline detergent followed by rinsing with pure and de-ionised water and then purging with clean air (see Appendix 1, section 4.9.1).

The analysis of chamber air samples may contain contributions of compounds originating from the analytical procedure, e.g., from the adsorbent used for chamber air sampling. Generally, these types of background compounds are present in reproducible amounts and are not dependent upon chamber air contamination. Background subtraction may be applied if the background contribution is regularly determined, and the average value and standard deviation known.

2. Choice of environmental parameters

Temperature. Temperature affects the vapour pressures and diffusion coefficients of VOCs and consequently, their emissions. It may also influence reactions in materials and lead to VOC emissions. Temperature has a major impact on the emission rate of VOCs from all indoor materials and products. This relationship was demonstrated by several bake-out studies, where the VOC concentrations were enhanced by increasing the temperature (Girman, 1989).

Although indoor temperatures are generally limited to a range of between approx. 17 - 28°C, high temperatures due to sun irradiation and floor heating can create exceptional conditions in flooring materials. For example, at the interface between concrete screed and carpets, floor heating can create temperatures of 50-60°C.

Because of this interdependence, the relationship between temperature and emissions from flooring materials is particularly interesting. Since all processes with a potential to contribute to the emission, i.e., diffusion within a material, desorption, evaporation and chemical reactions, are enhanced (speeded up) when temperature is raised, the expectation follows that the emission must also increase. Increases of VOC emissions observed during experimentation are reported in Appendix 3. At increased temperatures, an approximately proportional increase of the emission from PVC flooring, a carpet and a water based paint, was observed by Van der Wal (1994). The emission increased between 23°C and 30°C by a factor of 2 - 2.5, and between 23°C and 50°C by a factor of 10 - 12.5.

Sollinger (1992) and Sollinger and Levsen (1993) have investigated the variation of the equilibrium concentrations of a variety of VOCs emitted from textile carpets with SBR backing under static conditions. When raising the temperature from 20°C to 50.5°C, they observed increases in the equilibrium concentrations by factors of 1.6 - 8.7 (depending on the boiling point and polarity of the individual VOCs), and by a factor of 16 for 2-ethylhexanol, which probably mainly originated from a hydrolysis reaction of di-isooctylphthalate. An increase of the emission at elevated temperatures is often, but not always, accompanied by a more rapid decrease of the emission over time. The latter has been observed, e.g. for the emissions of 4-PC from carpet (Van der Wal, 1994).

Despite the evidence that temperature will influence emissions from flooring materials, for the purpose of the proposed method (emission evaluation aimed at labelling of flooring materials), and for the sake of simplicity, emission tests will be performed at only one temperature. The temperature 23°C has been set, and is proposed in all related guidelines and standards (see Appendix 1, section 4.9.7).

Relative humidity. In general, the influence of relative humidity on VOC emissions from building materials appears low at between 0 and 45% relative humidity. Sollinger and Levsen (1993) found no significant differences in the emissions of 22 different VOCs from textile carpet with SBR backing. Only aniline showed a small (30%) increase of the emission, and this was attributed to hydrolytic dissociation of an SBR vulcanisation catalyst.

Existing guidelines and standards for emission testing recommend or prescribe relative humidities between 45 % and 50 % (see Appendix 1, section 4.9.8).

Ratio of air exchange rate and product loading - specific ventilation rate. The air exchange rate n [h^{-1}] is defined as the mass flow rate of clean air to the chamber, divided by the chamber volume V_c. The air exchange rate reflects the amount of dilution and flushing that occurs in indoor environments. Product loading or the loading factor L, is the ratio of the emitting surface area A of the test specimen and the chamber volume V_c. This variable allows use of the products in test chambers to correspond with normal use patterns for the same product in real ("full scale") environments. The ratio n/L or $n \cdot V_c/A$ defines the specific ventilation rate q_c, i.e. the ratio of the ventilation rate $n \cdot V_c$ of the test chamber and the emitting surface area A, or the ventilation rate per unit of emitting surface area.

Both air exchange rate and product loading have a major impact on chamber concentrations (ECA, 1991). At a given emission factor E, and when other conditions are constant, the chamber concentration of a compound is proportional to the emitting surface area or to the loading factor L, and inversely proportional to the air exchange rate n. It follows that in most cases, simultaneous changes of both quantities will not alter the chamber concentration if their ratio, i.e. the specific ventilation rate q_c, remains unchanged. Note, that if the loading ratio is changed, particular attention must be given to the effect of edges (see Chapter 2.1.3, section "Sample preparation").

The chamber concentration of a compound may influence its emission rate (Myers, 1985; Matthews et al., 1987; Reponen et al., 1991; Tichenor et al., 1993; Clausen et al., 1993). At constant temperature, relative humidity, and surface air velocity (see below), the emission factor will increase as the chamber concentration decreases, and as the specific ventilation rate increases. For solid flooring materials, the influence of chamber concentrations on emission rates is not well assessed. Measurements by Sollinger (1992) show an increase in the chamber concentration of 2,2,6,6-tetramethyl-4-methylideneheptane emitted from a carpet with SBR backing by about 14 %, compared to the increase expected at a constant emission factor if the specific ventilation rate is doubled from 1.125 to 2.25. Therefore, the following assumption appears reasonably safe: the emission factor measured at $q_c = 1.25\ m^3\ h^{-1}\ m^{-2}$ will not vary by more than ± 20-25 % if the specific ventilation rate varies within the range 0.63-2.5 $m^3\ h^{-1} m^{-2}$ adopted for the toxicological evaluation of flooring material emissions (see Table 3.2, Chapter 3.4). An error of this magnitude appears acceptable in view of other, much larger uncertainties regarding the toxicological evaluation of VOC emissions.

Air exchange rate. Existing giduelines propose values of 0.5 or 1 h^{-1} (see Appendix 1, section 4.9.9).

Product loading or loading factor. A loading factor L = 0.4 is recommended here. This value corresponds to the loading factor for flooring materials as proposed by Nordtest (1990). Larger test specimens are recommended to reduce the influence of edges, inhomogeneities and of adsorption on chamber walls on the measured VOC concentrations and the derived emission factors.

Air velocity across the emitting surface. VOC emission from most materials result in a concentration gradient across a boundary layer above the emitting surface. The thickness of the boundary layer is smaller and the concentration gradient larger, the greater the turbulence or the air velocity across the emitting surface. (ASTM, 1990; Tichenor et al., 1993). Therefore, evaporative (diffusive) mass transfer through the boundary layer will be influenced by air movement. Emissions will increase with increasing turbulence or surface air velocity until the concentration gradient has been shifted into the emitting material. In the case of evaporation of liquid films (Clausen, 1993), the level of turbulence or surface air velocity will have a particularly important influence on the rate of emission. If, on the other hand, the emission is completely controlled by a concentration gradient within the emitting material, the surface air velocity will have no influence on the rate of emission, as confirmed by experiments carried out by Sollinger (1992).

There are few experimental data available dealing with the dependence of the emission rate on the surface air velocity, and on the practical extent to which the surface air velocity or the level of turbulence can be controlled in small test chambers. A major difficulty lies in the measuring of the surface air velocity. Measuring is particularly difficult in the case of turbulent air movement, as the anemometer itself may introduce turbulence. Therefore, the use of chamber designs which enforce a laminar air flow across the emitting surface will probably allow for better control of the surface air velocity and its impact on emissions (see section "chamber design" above).

For emission measurements, whenever possible, the surface air velocity should be in agreement with air velocities really occurring in indoor environments and not exceed values compatible with comfort requirements. A value of 10 cm/s (0.1 m/s) has been proposed as an appropriate surface air velocity for small chamber measurements (Girman, 1993).

3. Test material/specimen collection, handling and preparation

Sample collection. For inhomogeneous materials additional directions may be required to allow for an estimation of the degree of inhomogeneity. This problem has not been addressed in any of the reviewed guidelines or methods. It will be more important the smaller the test specimens are (i.e., in general, the smaller the test chambers are). A tentative direction might be: "For insufficiently homogeneous materials, at least N_I pieces of material have to be collected from different parts of a production lot. If the material is produced as tiles, N_I is the number of tiles which have to be selected randomly out of a total of N_X tiles. For rolled materials the distance between the sample pieces has to be not less than N_2 m. N_I and N_2 may be different for various types of flooring materials." N_1, N_2 and N_X are numbers which would have to be specified.

No comments on the remaining items of this chapter

4. Chamber air sampling

No additional comment.

5. Chamber performance control

Temperature and relative humidity: No comment

Air exchange rate: Correct measurement of the air flow rate is important according to equation (2.3) (see Chapter 2.1.7) because any error in measurement translates into a proportional error in the calculated emission factor.

Efficiency of the air mixing in the test chamber: Incomplete mixing of chamber air may lead to errors in determining the emission rates. The efficiency of the air mixing depends on the design of the chamber and the operation of fans in the chamber. Since operating fans will influence the air velocity in the chamber (see section 2 "air velocity across the emitting surface" above), the use of fans may be limited in obtaining complete mixing.

A generally accepted method for the quantitative assessment of mixing is not available. Tichenor (1989) proposes that the supply air be blended with an inert tracer gas (e.g. SF_6) at constant concentration and flow, and the concentration in the chamber outlet measured over time. The chamber concentration vs. time plot is then compared to the theoretical curve for a completely mixed chamber. If the measured data closely follow the theoretical curve, the chamber is regarded as well mixed. When the measured data lie above the theoretical curve, short circuiting of the flow is occurring resulting in chamber air which is poorly mixed. Poor placement of the air inlet and/or outlet ports probably creates short circuiting. If the measured data fall below the theoretical curve, the chamber may be leaking (however, see section 1 "chamber tightness"), or incomplete mixing may be occurring. Tests to determine whether mixing occurs adequately should be conducted (i) in an empty chamber, and (ii) using sample substitutes in the chamber. This ensures that when samples are placed in the chamber, they will not cause inadequate mixing.

If the concentration vs. time curve of the tracer gas deviates from the theoretically expected curve, the measured data may be "forced" through the theoretical curve using the chamber volume (V_c) as a variable. It is then necessary to compare the actual chamber volume to the "apparent" chamber volume at which the measured concentration data fit the theoretically expected curve. The difference between the actual and "apparent" volumes may be taken as a measure of the deviation between actual and complete mixing. Tichenor (1989) proposes a difference of $\geq 10\%$ as unacceptable, whereas a difference of $>5\%$ is considered unacceptable by the Carpet Policy Dialogue Group (CPDG, 1991; see also Appendix 1).

Background concentrations: No comment.

Air velocity/turbulence in the chamber: Air velocity/turbulence may be controlled by regulating the speed of fans.

Sink effects: Although surfaces in a chamber, such as the chamber walls and the surfaces of supports, sensors or fans may be "smooth" and built of "inert" materials like glass or stainless steel, they can still act as sinks which reduce the chamber concentrations of emitted compounds. Emission factors calculated from the chamber concentrations (see section 2.1.7) are therefore smaller than the true emission factors. The size of a sink effect depends (see equation (2.1) in section 1 "wall material and treatment, sealants") on the ratio of the mass flow to the internal surfaces of the chamber (which is proportional to a sorption rate constant and to the surface area) and the mass flow out of the chamber (which is proportional to the air exchange rate and the chamber volume). It may also depend on the air flow pattern in the chamber. In general, the lower the volatility or the higher the boiling point of a compound, the more pronounced the sink effect (i.e., the sorption rate constant is the larger).

Sink effects can be identified and quantified by introducing known amounts of test compounds into the chamber, e.g. by using sources with known emission rates, such as permeation tubes or diffusion vials, and by comparing the measured concentration vs. time curves with the theoretically expected curves without sink (Tichenor et al., 1991; ECA, 1993). The emission rates of the test sources are normally determined gravimetrically (weight loss). The influence of a sink effect on the chamber concentrations, i.e. the relative difference between the measured and the theoretically expected concentrations, decreases with time (De Bortoli et al., 1996).

Few experimental data on chamber sinks are available. Using the method mentioned above, for a 450 l glass chamber after 48 hrs, relative differences between expected and measured concentrations have been found, of between 10 and 20% for compounds such as n-decane, n-dodecane, butoxyethanol and ethylhexanol, but of more than 30% for 1,4 dichlorobenzene (Colombo et al., 1993; De Bortoli et al., 1996). In an interlaboratory comparison experiment (ECA, 1993), it was observed that after 48 hrs for n-dodecane, differences between the measured and expected concentrations ranged from about 0-80%. It can be concluded from these data that after 72 hrs testing (see Chapter 2.1.4, section "sampling times"), emission rate determinations based on chamber concentration measurements may be affected by substantial errors.

6. References

ASTM, American Society for Testing and Materials, 1990. Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products. ASTM Designation D 5116-90. Philadelphia, PA: American Society for Testing and Materials.

Clausen, P.A., Lauersen, B., Wolkoff, P., Rasmusen, E. and Nielsen, P.A., 1993. Emission of volatile organic compounds from a vinyl floor covering. In: Nagda, N.L. (eds) Modelling of Indoor Air Quality and Exposure. ASTM STP 1205, Philadelphia: American Society for Testing and Materials, pp. 3-13.

Clausen, P.A., 1993. Emission of volatile and semi-volatile organic compounds from waterborne paints - The effect of the film thickness. Indoor Air 3, 269-275.

Colombo, A., De Bortoli, M., Knöppel, H., Pecchio, E. and Vissers, H., 1993. Adsorption of selected volatile organic compounds on indoor surfaces. Indoor Air 3, 276-282.

CPDG, Carpet Policy Dialogue Group, 1991. Test method for determining total volatile organic compound emission factors from carpet under defined test conditions using small environmental chambers. Carpet Policy Dialogue Compendium Report EPA/560/2-91-002, Appendix E. Office of Toxic Substances (TS-778). U.S. Environmental Protection Agency, September 1991.

De Bortoli, M., Knöppel H., Colombo, A., Kephalopoulos S., 1996. Attempting to characterize the sink effect of a small stainless steel test chamber. *Characterizing Sources of Indoor Air Pollution and Related Sink Effects, ASTM STP 1287.* Bruce A. Tichenor, Ed., American Society for Testing and Materials, Philadelphia, pp. 307-320.

ECA, European Concerted Action "Indoor Air Quality and Its Impact on Man", 1991. Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. Report Nr. 8 (EUR 13593 EN). Luxembourg: Office for Official Publications of the European Communities.

ECA, European Collaborative Action "Indoor Air Quality and Its Impact on Man", 1993. Determination of VOCs emitted from indoor materials and products. Interlaboratory comparison of small chamber measurements. Report No. 13 (EUR 15054 EN). Luxembourg: Office for Official Publications of the European Communities.

Girman, J.R., 1993. Simple modelling to determine approprite operating conditions for emission testing in small chambers. In: Nagda, N.L. (ed) Modelling of Indoor Air Quality and Exposure, ASTM STP 1205. Philadelphia: American Society for Testing and Materials, Philadelphia, pp. 145-148.

Gunnarsen, L., Nielsen, P.A., Wolkoff, P., 1994. Design and characterization of the CLIMPAQ, chamber for laboratory investigations of materials, pollution and air quality. Indoor Air, 4, 56-62.

Matthews, T.G., Hawthorne, A.R. and Thompson, C.V., 1987. Formaldehyde sorption and desorption characteristics of gypsum wallboard. Environmental Science Technology 21, 629-634.

Myers, G.E., 1985. The effects of temperature and humidity on formaldehyde emissions from UF-bonded boards: a literature critique. Forest Products Journal 35, 20-31.

Nordtest, 1990. Building materials: emission of volatile compounds, chamber method. NT Build 358. Nordtest, Postbox, Esbo, Finland.

Reponen, T., Raunemaa, T., Savolainen, T. and Kalliokoski, P., 1991. The effect of material ageing and season on formaldehyde levels in different ventilation systems. Environment International 17, 349-355.

Sollinger, S., 1992. Methoden und Verfahren zur Charakterisierung der Emissionen aus Innenraummaterialien. Dissertation. University of Hannover, pp. 92-97.

Sollinger, S. and Levsen, K., 1993. Investigation of indoor air pollution sources in climate chambers: emissions from textile floor coverings. In: Mohr, U. et al. (eds), Advances in Controlled Clinical Inhalation Studies, Heidelberg: Springer-Verlag.

Tichenor, B.A., 1989. Indoor air sources; using small environmental test chambers to characterize organic emissions from indoor materials and products. EPA-600 8-89-074, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency.

Tichenor, B.A., Guo, Z., Dunn, J.E., Sparks, L.E. and Mason, M.A., 1991. The interaction of vapour phase organic compounds with indoor sinks. Indoor Air 1, 23-35.

Tichenor, B.A., Guo, Z. and Sparks, L.E., 1993. Fundamental mass transfer models for indoor air pollution sources. Indoor Air 3, 263-268.

Van der Wal, J.F., 1994. Private communication.

Wolkoff, P., Clausen, P.A., Nielsen, P.A. and Gunnarsen, L., 1993. Documentation of field and laboratory emission cell "FLEC" - Identification of emission processes from carpet, lineoleum, paint, and sealant by modelling". Indoor Air 3, 291-297.

Zhang, Y. and Haghighat, F., 1994. A small velocity-controlled test chamber for source characterization. Paper presented at the ASTM Symposium on Methods for Characterizing Indoor Sources and Sinks, September 25-28, Washington, DC.

Appendix 3

Temperatures at the interface between concrete screed and various floor coverings (1) (when floor heating is switched off), for a range of room air temperatures and switch-off of the floor heating at an exposed surface temperature of the floor covering of 29.4°C (2)

Floor Coverings		**Temperature at Screed/Covering Interface [°C] at an air temperature of**			
Type	**Thickness [inches]**	**16°C**	**18.3°C**	**20.6°C**	**22.8°C**
Linoleum	0.15	31.7	31.1	31.1	30.6
Carpet	0.4	50.0	46.7	43.3	
Carpet + underlay	0.7	63.3	57.8	51.7	46.1
Wood blocks	1.0	50.6	46.7	43.3	39.4
Cork tiles	0.5	41.1	38.9	37.2	35.0
Cork tiles + new carpet	0.9	61.7	56.1	51.1	45.6
Thermoplastic tiles	0.13	30.6	30.0	30.0	30.0
Thermoplastic tiles + new carpet	0.53	51.1	47.2	43.9	40.0

(1) adapted from U.K. Electricity Council "Electric Floor Warming Design Manual", 1969;

(2) Maximum allowable floor surface temperature. For well insulated bulildings and/or mild weather, floor surfaces will be at lower temperatures than 29.4°C.

Appendix 4

Increase in temperature of the emission of organic compounds from various materials

Reference	Material	Emitted compounds	Temp. range [°C]	Ratio of Emissions	Type of emission increase observed
Myers, 1985 (1)	particle board and plywood	formaldehyde	23 - 40	5.2	exponential (2)
			23 - 50	12.5	(B = 8930)
Gehrig et al. 1994	polystyrene	styrene	23 - 40	3.4	exponential (2)
		ethylbenzene	"	3.7	
		TVOC	"	3.2	
Van der Wal, 1994	PVC flooring	2-ethylhexanol	23 - 30	~2	linear (~9% increase per °C)
			23 - 50	10	
	carpet	alkanes C_8 - C_{14}	23 - 30	2 - 2.5	linear
		toluene	"	2 - 2.5	
		trimethylbenzene	"	2 - 2.5	
		4-PC (3)	"	2.5	
	water-based paint	texanol (2 isom.)	23 - 30	2 - 2.5	linear (10 - 15% increase per °C)
		butyldiglycol	"	2 - 2.5	
Sollinger, 1992 (6)	carpet with SBR backing	styrene	23-50.5	1.6 (6)	not specified
		1.3.5-TMB(5)	"	2.1	
		1.3-diethylbenzene	"	2.5	
		n-dodecane	"	5.6	
		n-tridecane	"	5.7	
		n-tetradecane	"	7.7	
		hexanal	"	2.6	
		aniline	"	5.5	
		2-ethylhexanol	"	16.1	
		benzothiazol	"	7.4	
		BHT (4)	"	8.7	

(1) Meta-analysis of published results, the derived exponential relationship covers a larger temperature range;

(2) emission increase follows approximately the equation $E(T_1) / E(T_2) = \exp.[-B(1/T_1 - 1/T_2)]$, T_1 and T_2 in °K;

(3) 4 - PC = 4 - phenylcyclohexene;

(4) BHT = 2.6 - di - tert.butyl - 4 - methyl - phenol;

(5) 1.3.5-TMB = 1.3.5-trimethylbenzene;

(6) instead of the ratio of emissions, in this publication, the ratio of equilibrium concentrations has been determined in static experiments

Appendix 5

Compound classes emitted from flooring materials and examples of emission factors of compounds emitted from 27 flooring materials (Saarela et al. 1994)

N* = Number of occurrences in 27 material emissions

Chemical Compound Emitted	CAS No.	Emission factors		N*
		mean [$\mu g/(m^2 \cdot h)$]	max. [$\mu g/(m^2 \cdot h)$]	
AROMATIC HYDROCARBONS				
Benzene	71-43-2	1	3	3
Toluene	108-88-3	20	170	17
Ethylbenzene	100-41-4	8	45	12
Xylenes	1330-20-7	25	34	3
m.p.-Xylene	106-42-3	19	123	9
o-Xylene	95-47-6	9	48	8
Isopropylbenzene	98-82-8	6	10	3
n-Propylbenzene	103-65-1	9	23	8
1-Propenylbenzene	637-50-3	4	6	4
1,3,5-Trimethylbenzene	108-67-8	10	35	4
1,2,4-Trimethylbenzene	95-63-6	20	98	9
1,2,3-Trimethylbenzene	526-73-8	13	28	4
1,2,4,5-Tetramethylbenzene	95-93-2	1	5	
n-Butylbenzene	104-51-8	1	4	
1,3-Diisopropyl benzene	99-62-7		53	1
1,4-Diisopropyl benzene	100-18-5		28	1
4-Phenyl cyclohexene	31017-40-0		190	1
Styrene	100-42-5	6	20	5
Ethynylbenzene	536-74-3	3	4	3
a-Methylstyrene	98-83-9	8	16	5
Naphtalene	91-20-3	14	19	2
SATURATED ALIPHATIC HYDROCARBONS				
3-Methylpentane	96-14-0	8	10	2
n-Hexane	110-54-3	4	6	5
n-Octane	111-65-9	16	41	3
C 9 Hydrocarbons		3	4	
n-Nonane	111-84-2	16	355	3
C 10 Hydrocarbons		20	135	

Chemical Compound Emitted	CAS No.	Emission factors mean [µg/(m^2·h)]	 max. [µg/(m^2·h)]	N*
3,5-Dimethyloctane	15869-993-9		1	1
n-Decane	12604-18-5	104	514	9
C 11 Hydrocarbons		15	78	
4-Methyldecane	2847-1672-5		3	1
n-Undecane	1120-21-4	43	269	11
C 12 Hydrocarbons		9	20	
2,2,4,6,6-Pentamethylheptane	30586-18-6	60	104	4
n-Dodecane	112-40-3	39	99	7
C 13 Hydrocarbons		16	38	
n-Tridecane	629-50-5	43	69	4
n-Tetradecane	64036-86-3	34	143	10
n-Pentadecane	629-62-9	30	123	5
n-Hexadecane	544-76-3	11	25	4
Octadecane	593-45-3		1	1
n-Octadecane	593-45-3		5	1
Tridecene	2437-56-1	44	75	3
UNSATURATED/CYCLIC ALIPHATIC HYDROCARBONS				
1,3,5,7-Cyclooctatetraene	629-20-9		53	1
TERPENES				
3-Carene	13466-78-9	21	94	7
Camphene	79-92-5		4	1
alpha-Pinene	80-56-8	14	29	9
Limonene		13	51	6
Longifolene	475-20-7		48	1
Caryophyllene	87-44-5		16	1
ALIPHATIC ALCOHOLS				
1-Propanol	71-23-8		6	1
2-Propanol	67-63-0		33	1
1,2-Propanediol	57-55-6	151	891	8
1-Butanol	71-36-3	16	60	10
1-Pentanol	71-41-0		13	1
1-Hexanol	111-27-3		18	1
Cyclohexanol	108-93-0	10	15	2
2-Ethyl-1-hexanol	104-76-7	121	268	11
1-Octanol	111-87-5	14	31	4

Chemical Compound Emitted	CAS No.	Emission factors		N*
		mean $[\mu g/(m^2 \cdot h)]$	max. $[\mu g/(m^2 \cdot h)]$	
AROMATIC ALCOHOLS				
Phenol	108-95-2	143	400	4
BHT (2,6-di-tert-butyl-4-methyl phenol)	128-37-0	14	26	2
GLYCOLS AND GLYCOLETHERS				
2-Methoxyethanol	109-86-4		56	1
Propylene glycol	57-55-6	151	891	8
2-Ethoxyethanol	110-80-5	6	13	6
2-(2-butoxy)ethoxy) ethanol	111-76-2	151	666	10
ALDEHYDES				
Formaldehyde	50-00-0	11	25	13
Acetaldehyde	75-07-0	10	29	12
Pentanal	110-62-3	43	181	6
Hexanal	66-25-1	36	189	9
Heptanal	111-71-7		13	1
Octanal	124-13-0		9	1
Nonanal		8	39	
2-Butenal	123-73-9		74	1
Benzaldehyde	100-52-7	40	64	3
2-Furancarboxaldehyde	98-01-1		8	1
KETONES				
Acetone	67-64-1	14	31	8
Cyclopentanone	120-92-3		31	1
2-methylcyclopentanone	1120-72-5	264	626	4
ACIDS				
Propanoic acid	79-09-4	33	113	
Isobutyric acid	79-31-2		26	1
2,2-Dimethylpropanoic acid	75-98-9		1	1
Hexadecanoic acid	57-10-3		5	1
CHLORINATED HCs				
	127-18-4	57	86	2

Chemical Compound Emitted	CAS No.	Emission factors mean [µg/(m^2·h)]	Emission factors max. [µg/(m^2·h)]	N*
ESTERS				
Ethylacetate	141-78-6		14	1
Propylacetate	109-60-4		1	1
Methacrylic acid methyl ester	80-62-6	255	509	2
TXiB (2,2,4-Trimethyl-1, 3-pentanediol, di-isobutyrate)	6846-50-0	363	1431	7
OTHERS				
TVOC (after 4 weeks testing)		364 (1)	1118 (1)	30
TVOC (after 26 weeks testing)		130 (1)	573 (1)	30

(1) Emission factors [µg m^{-2} h^{-1}] for 30 vinyl floorings reported by Gustafsson, H. and Jonsson, B., 1993. Trade standards for testing chemical emissions from building materials. Part I: Measurements of flooring materials, Proc. Indoor Air '93, Vol. 2, pp. 437-443, Helsinki, Finland.

Reference

Saarela, K., Tirkkonen, T. and Tähtinen, M., 1994. Preliminary data base for material emissions. NKB Committee and Work Reports 1994: 04E, ISBN 951-47-9858-9. Helsinki: Painatuskeskus Oy

Appendix 6

Examples of VOC Emission Measurements from Flooring Materials (Saarela et al., 1994, see p.76) and their Toxicological Evaluation according to the Procedure Described in Chapter 6

CUSHION VINYL 3,9 mm						
Compound Name	**CAS No**	**Emission factor [mg m^{-2} h^{-1}] after:**				**LCI**
		3 days	**14 days**	**28 days ***	**56 days**	[µg m^{-3}]
hexanal	110-54-3	0	4	**4**	4	400
1-butanol	71-36-3	11	10	**8**	5	1 000
1,2-dimethylcyclopentane	2452-99-5	2	0	0	0	
2-ethoxyethanol	110-80-5	9	7	**6**	4	10
methylcyclohexane	75-07-0	5	1	1	0	
toluene	108-88-3	3	14	**11**	4	1 000
3-methyleneheptane	1632-16-2	3	2	2	2	
xylenes	1330-20-7	0	3	2	1	
cyclohexanone	108-94-1	121	127	**124**	119	1 000
2-ethoxyethylacetate	110-80-5	24	19	**17**	13	20
benzaldehyde	100-52-7	0	2	2	2	
phenol	108-95-2	29	31	**31**	31	400
N-methyl-2-pyrrolidone	872-50-4	21	4	**4**	3	800
benzylalcohol	100-51-6	4	4	**4**	4	
2-ethyl-1-hexanol	104-76-7	76	71	**70**	68	1 000
2-propenoic acid, 6-methyl heptylester	54774-91-3	1	0	0	1	
4-methyl-4-phenyl-2-pentanone	7403-42-1	0	0	0	0	
benzene, 1,1-dimethylnonyl-	55191-25-8	3	2	2	2	
5-methylphenyl-2-hexanone	14128-61-1	2	3	3	2	
benzene, 1,1-dimethyldecyl	27854-40-6	5	0	0	0	
benzene, 1,1-dimethyltetradecyl	29138-94-1	3	0	0	0	
benzene, 1,1,4,6,6-pentamethyl-heptyl	55134-07-1	0	2	1	0	
TVOC		**361**	343	**331**	311	

* calculated with the linear interpolation: E(28d) = E(14d) - 0.33 [E(14d) - E(56d)].

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e [m^3 h^{-1} m^{-2}]**		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.578	.289	0.144
TVOC (30 d) = E_{TVOC}(28 d) / q_e [µg m^{-3}]	≤ 200 µg m^{-3}	**530**	**265**	132
R = $\{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	**2.84**	**1.41**	0.45
ΣE_{ni} (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	11.2	0	0
Result		**no label**	**no label**	label

This product fulfils the conditions of the toxicological evaluation procedure <u>only</u> for the highest area specific ventilation rate

CUSHION VINYL 2,5 mm						
Compound Name	**CAS No.**	**Emission factor [mg m^{-2} h^{-1}] after:**				**LCI**
		3 days	**14 days**	**28 days***	**56 days**	[μg m^{-3}]
benzene	*71-43-2*	*2*	*2*	*2*	*1*	*Table 4.1*
dichloromethane	75-09-2	17	0	0	0	
hexane	110-54-3	1	0	0	1	
1-butanol	71-36-3	9	3	3	2	
methylcyclohexane	108-87-2	4	1	1	0	
toluene	108-88-3	5	12	**9**	3	1 000
2-ethyoxyethylacetate	111-15-9	24	7	**5**	0	20
cyclohexanone	108-94-1	159	77	**74**	69	1 000
o-xylene	95-47-6	0	2	1	0	
benzaldehyde	100-52-7	3	2	2	1	
1,3,5-trimethylbenzene	108-67-8	1	0	0	1	
octanal	124-13-0	0	0	0	1	
benzene, pentadecyl	2131-18-2	0	0	1	3	
benzylalcohol	100-51-6	0	1	1	2	
2-ethyl-1-hexanol	104-76-7	28	15	**15**	16	1 000
nonanal	124-19-6	0	0	1	2	
decanal	112-31-2	0	0	1	2	
2-propenoic acid-, 6-methylheptylester	54774-91-3	1	0	0	1	
benzene, 1,1-dimethyldodecyl-	27854-41-7	4	0	0	1	
benzene, 1,1-dimethylbutyl-	1985-57-5	0	1	1	2	
benzene, 1,1-dimethyldecyl	27854-40-6	3	0	1	2	
5-methylphenyl-2-hexanone	14128-61-1	5	3	3	2	
benzene, 1,1-dimethylnonyl-	55191-25-8	3	0	1	3	
benzene, 1,1-dimethyltetradecyl	29138-94-1	0	1	1	2	
benzene, 1,1,4,6,6-pentamethylheptyl-	55134-07-1	0	0	2	7	
TVOC		**322**	179	**181**	183	

* calculated with the linear interpolation: E(28d) = E(14d) - 0.33 [E(14d) - E(56d)].

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e [m^3 h^{-1} m^{-2}]**		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.515	0.258	0.129
TVOC (30 d) = E_{TVOC}(30 d) / q_e [μg m^{-3}]	≤ 200 μg m^{-3}	**290**	145	72
Condition (6.10) for benzene	$< 10^{-5}$	**1.3×10^{-5}**	6.4×10^{-6}	3.2×10^{-6}
R = $\{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	0.56	0.08	0.04
ΣE_{ni} (30 d) / q_e [μg m^{-3}]	≤ 20 μg m^{-3}	0	0	0
Result		**no label**	label	label

This product fulfils the conditions of the toxicological evaluation procedure only for the two higher area specific ventilation rates

FLOOR WAX (on prefabricated beech parquet)						
COMPOUND	**CAS No.**	**Emission factor [mg h^{-1} m^{-2}] after:**				**LCI**
		3 days	**14 days**	**28 days***	**42 days**	[µg m^{-3}]
hexane	110-54-3	5	3	3	3	
heptane	142-82-5	2	1	1	1	
toluene	108-88-3	17	17	**18**	19	1 000
hexanal	66-25-1	9	5	4	3	400
ethylbenzene	100-41-4	12	5	3	1	
p-xylene	106-42-3	19	16	**11**	7	1 000
styrene	100-42-5	24	1	0	0	
o-xylene	95-47-6	17	5	4	2	1 000
nonane	111-84-2	244	18	**8**	1	10 000
alpha-pinene	80-56-8	7889	2940	**1583**	227	1 000
propylbenzene	103-65-1	188	31	**16**	2	1 000
camphene	79-92-5	433	109	**58**	7	1 000
beta-pinene	127-91-3	3861	1288	**699**	111	1 000
trimethylbenzene		323	72	**43**	14	1 000
decane	124-18-5	1345	209	**112**	15	2 000
limonene	138-86-3	2108	322	**179**	36	1 000
dimethylnonane		143	26	**14**	5	10 000
5-methyldecane	13151-35-4	141	25	**15**	7	10 000
2-methyldecane	6975-98-0	216	35	**16**	2	10 000
4-methyldecane	2847-72-5	299	36	**17**	2	10 000
3-methyldecane	13151-34-3	473	42	**23**	8	10 000
terpinolene	586-62-9	156	20	**10**	3	1 000
undecane	1120-21-4	1265	142	**78**	30	10 000
alpha-terpineol	10482-56-1	443	32	**16**	4	---
alpha-cubenene	17699-14-8	70	10	**5**	2	1 000
longipinene	5989-08-2	84	13	**7**	3	1 000
ylangene	14912-44-8	96	9	**6**	3	1 000
junipene	475-20-7	681	111	**64**	29	1 000
caryophyllene	87-44-5	635	86	**44**	13	1 000
TVOC		**27628**	6604	**3677**	750	

* calculated with the linear interpolation: E(28d) = E(14d) - 0.5 [E(14d) - E(42d)].

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e [m^3 h^{-1} m^{-2}]**		
		0.625	**1.25**	**2.50**
TVOC (3 d) = $E_{TVOC}(3\ d) / q_e$ [mg m^{-3}]	≤ 5 mg m^{-3}	**44.20**	**22.10**	**11.05**
TVOC (28 d) = $E_{TVOC}(30\ d) / q_e$ [µg m^{-3}]	≤ 200 µg m^{-3}	**5883**	**2942**	**1471**
$R = \{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	**4.53**	**2.26**	**1.12**
ΣE_{ni} (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	**25.6**	12.8	6.4
Result		**no label**	**no label**	**no label**

This product does not fulfil the conditions of the toxicological evaluation procedure

FLOOR OIL (on prefabricated beech parquet)						
COMPOUND	**CAS No.**	**Emission factor** $[\mu g\ m^{-2}\ h^{-1}]$ **after:**				**LCI** $[\mu g\ m^{-3}]$
		3 days	**14 days**	**28 days***	**42 days**	
pentanal	110-62-3	38	9	**8**	6	400
heptane	142-82-5	10	2	2	3	
1-pentanol	71-41-0	11	2	2	3	
toluene	108-88-3	9	16	**11**	6	1 000
hexanal	66-25-1	171	37	**20**	3	400
octane	111-65-9	14	3	3	3	
ethylbenzene	100-41-4	25	5	**5**	5	1 000
p-xylene	106-42-3	80	14	**19**	23	1 000
m-xylene		26	1		0	
o-xylene	95-47-6	41	8	**7**	6	1 000
nonane	111-84-2	185	23	**16**	8	10 000
ethylmethylcyclohexane	696-29-7	100	10	**5**	0	800
3-methylnonane	5911-04-6	84	25	**18**	11	3 000
propylbenzene	103-65-1	84	26	**19**	11	1 000
ethylmethylbenzene		75	36	**30**	23	1 000
trimethylbenzene		215	58	**46**	34	1 000
decane	124-18-5	542	195	**137**	78	2 000
2,6-dimethylnonane	17302-28-2	180	127	**85**	42	10 000
methylpropylbenzene		416	20	**18**	15	1 000
ethyldimethylbenzene		28	21	**19**	16	1 000
5-methyldecane	13151-35-4	31	19	**18**	16	10 000
3-methyldecane	13151-34-3	52	26	**26**	26	10 000
nonanal	124-19-6	10	12	**14**	15	400
undecane	1120-21-4	465	136	**118**	100	10 000
dodecane	112-40-3	32	10	**11**	12	10 000
TVOC		**6765**	2761	**1866**	971	

* calculated with the linear interpolation: E(30d) = E(14d) - 0.5 [E(14d) - E(42d)].

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate** q_e $[m^3\ h^{-1}\ m^{-2}]$		
		0.625	**1.25**	**2.50**
TVOC (3 d) = $E_{TVOC}(3\ d) / q_e$ $[mg\ m^{-3}]$	$\leq 5\ mg\ m^{-3}$	**10.82**	**5.41**	2.71
TVOC (28 d) = $E_{TVOC}(30\ d) / q_e$ $[\mu g\ m^{-3}]$	$\leq 200\ \mu g\ m^{-3}$	**2986**	**1493**	**746**
$R = \{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	0.62	0.30	0.14
$\Sigma E_{ni} (30\ d) / q_e$ $[\mu g\ m^{-3}]$	$\leq 20\ \mu g\ m^{-3}$	0	0	0
Result		**no label**	**no label**	**no label**

This product <u>does not</u> fulfil the conditions of the toxicological evaluation procedure.

DRIED SPRUCE PLANK (Nordic Wood Project)					
Compound name	**CAS No.**	**Emission factor [µg m^{-2} h^{-1}]**			**LCI** [µg m^{-3}]
		3 days	**13 days**	**28 days**	
Hexane	110-54-3	4	4	1	
Pentanal	110-62-3	7	3	3	
Toluene	108-88-3	6	3	**7**	1 000
Hexanal	66-25-1	18	8	**8**	400
Benzene, 1,4-dimethyl	106-42-3		3	2	
Styrene	100-42-5	6	5	**4**	70
Alpha-pinene, (-)-	80-56-8	66	23	**15**	1 000
2-Beta.-pinene	127-91-3	26	9	**5**	1 000
Decane	124-18-5	13	4		
d3-Carene	13466-78-9	8	3	3	
Limonene	138-86-3	22	7	**5**	1 000
TVOC		**226**	94	**72**	

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e** [m^3 h^{-1} m^{-2}]		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.36	0.18	0.09
TVOC (28 d) = E_{TVOC}(30 d) / q_e [µg m^{-3}]	≤ 200 µg m^{-3}	115	58	29
R = $\{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	0.175	0.034	0.006
ΣE_{ni} (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	0	0	0
Result		label	label	label

DRIED BIRCH PLANK (Nordic Wood Project)					
Compound name	**CAS No.**	**Emission factor [µg m^{-2} h^{-1}] after:**			**LCI** [µg m^{-3}]
		3 days	**13 days**	**28 days**	
Hexane	110-54-3	3	3	0	
Pentanal	110-62-3	8	4	**6**	400
1-Pentanol	71-41-0	9	4	**6**	3 000
Benzene, methyl-	108-88-3	9	4	3	
Hexanal	66-25-1	23	12	**21**	400
Styrene	100-42-5	3	2	2	
TVOC		**104**	36	**47**	

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e** [m^3 h^{-1} m^{-2}]		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.166	0.083	0.042
TVOC (28 d) = E_{TVOC}(30 d) / q_e [µg m^{-3}]	≤ 200 µg m^{-3}	75	38	19
R = $\{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	0.11	0.042	0.021
ΣE_{ni} (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	0	0	0
Result		label	label	label

These products fulfil the conditions of the toxicological evaluation procedure

DRIED PINEWOOD PLANK (Nordic Wood Project)					
Compound name	**CAS No.**	**Emission factor [μg m^{-2} h^{-1})] after:**			**LCI** [μg m^{-3}]
		3 days	**13 days**	**28 days**	
Hexane	110-54-3	3	4	2	
Pentanal	110-62-3	10	2	2	
Toluene	108-88-3	4			
1-Pentanol	71-41-0	3			
Toluene	108-88-3	5			
Hexanal	66-25-1	34	6	**6**	400
α-Pinene, (-)-	80-56-8	125	39	**17**	1000
Camphene	79-92-5	3			
2-β-Pinene	127-91-3	47	15	**7**	1000
β-Myrcene	123-35-3	4			
2,2,4,6,6-Pentamethylheptane	30586-18-6	16			
3-Carene	13466-78-9	24	9	**6**	1000
dl-Limonene	1795-16-0	48	16	**10**	1000
TVOC		**361**	158	**69**	

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e** [m^3 h^{-1} m^{-2}]		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.578	0.289	0.144
TVOC (28 d) = E_{TVOC}(30 d) / q_e [μg m^{-3}]	≤ 200 μg m^{-3}	110	55	28
R = $\{\Sigma (E_i / LCI_i)\} / q_e$	≤ 1	0.088	0.027	0.007
ΣE_{ni} (30 d) / q_e [μg m^{-3}]	≤ 20 μg m^{-3}	0	0	0
Result		label	label	label

This product fulfils the conditions of the toxicological evaluation procedure.

VARNISHED OAK PLANK PARQUET (Nordic Wood Project)					
Compound name	**CAS No.**	**Emission factor** $[\mu g\ m^{-2}\ h^{-1}]$ **after:**			**LCI** $[\mu g\ m^{-3}]$
		3 days	**13 days**	**28 days**	
Hexane	110-54-3	2	3	1	
Benzene	71-43-2	3	2	2	
Benzene, methyl-	108-88-3	5	5	**9**	1 000
Cyclohexanone	108-94-1	4	2		
Styrene	100-42-5	3	2	1	
Benzaldehyde	100-52-7	8	3	1	
α-pinene	80-56-8	25	13	**6**	1 000
β-pinene	18172-67-3	13	8	**4**	1 000
3-Carene	13466-78-9	3	2	1	
di-Limonene	138-86-3	4	4	2	
TVOC		**104**	85	**76**	

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate** q_e $[m^3\ h^{-1}\ m^{-2}]$		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	0.166	0.083	0.042
TVOC (28 d) = E_{TVOC}(30 d) / q_e [µg m^{-3}]	≤ 200 µg m^{-3}	122	61	30
R = $\{\Sigma\,(E_i / LCI_i)\} / q_e$	≤ 1	0.030	0.007	0
$\Sigma\, E_{ni}$ (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	0	0	0
Result		label	label	label

***This* product fulfils the conditions of the toxicological evaluation procedure.**

PINE FLOOR VARNISHED WITH A MIX OF NATURAL WAX & VEGETABLE OIL (EU Database Project)				
Compound name	**CAS No.**	**Emission factor** $[\mu g\ m^{-2}\ h^{-1}]$ **after:**		**LCI** $[\mu g\ m^{-3}]$
		3 days	**28 days**	
Pentanal	110-62-3	14	**13**	400
1-Heptene	592-76-7	2	1	
Heptane	142-82-5	3	1	
1-Pentanol	71-41-0	3	3	
Benzene, methyl-	108-88-3	1	**4**	1 000
Hexanal	66-25-1	34	**37**	400
Acetic acid, butyl ester	123-86-4	0	1	
Octane	111-65-9	2	2	
Benzene, ethyl-	100-41-4	0	0	
Pentanoic acid	109-52-4	2	0	
Benzene, 1,3-dimethyl-	108-38-3	0	1	
2-Heptanone	110-43-0	1	1	
Heptanal	111-71-7	3	3	

α-pinene, (-)-	80-56-8	1499	**1371**	1 000
Camphene	79-92-5	25	**27**	1 000
Hexanoic acid	142-62-1	6	2	
Benzene, 1-methyl-3-(1-methylethyl)-	535-77-3	5	**6**	1 000
Sabinene	3387-41-5	2	2	
β-Pinene (l)	18172-67-3	132	**139**	1 000
β-Myrcene	123-35-3	16	**17**	1 000
Benzene, 1,3,5-trimethyl-	108-67-8	0	0	
Decane	124-18-5	7	**11**	2 000
3-Carene	13466-78-9	388	**375**	1 000
Benzene, 1-methyl-4-(1-methylethyl)-		6	**7**	1 000
Nonane, 2,6-dimethyl-	17302-28-2	4	3	
dl -Limonene	138-86-3	67	**75**	1 000
γ-Terpinene	99-85-4	5	3	
Decane, 5-methyl-	13151-35-4	6	3	
Decane, 4-methyl-	2847-72-5	6	**4**	10 000
Decane, 2-methyl-	6975-98-0	14	**8**	10 000
Decane, 3-methyl-	13151-34-3	11	**7**	10 000
Benzene, methyl (1-methylethenyl)-	26444-18-8	2	2	
Nonanal	124-19-6	9	**8**	400
α-Terpinolene	586-62-9	9	**6**	1 000
Undecane	1120-21-4	77	**43**	10 000
3,6-Dimethyldecane		4	2	
Undecane, 5-methyl-	1632-70-8	17	**9**	10 000
Undecane, 4-methyl-	2980-69-0	14	**9**	10 000
Undecane, 2-methyl	7045-71-8	14	**9**	10 000
Undecane, 3-methyl-	1002-43-3	11	**6**	10 000
Decanal	112-31-2	6	**5**	400
Dodecane	112-40-3	71	**43**	10 000
Tridecane	629-50-5	7	**4**	10 000
TVOC		**2 852**	**2 408**	

Toxicological evaluation of VOC emissions after 28 days testing following the procedure in chap. 6

Quantity to be assessed	**Condition to be fulfilled**	**Area specific ventilation rate q_e [m^3 h^{-1} m^{-2}]**		
		0.625	**1.25**	**2.50**
TVOC (3 d) = E_{TVOC}(3 d) / q_e [mg m^{-3}]	≤ 5 mg m^{-3}	4.48	2.26	1.13
TVOC (28 d) = E_{TVOC}(30 d) / q_e [µg m^{-3}]	≤ 200 µg m^{-3}	**3822**	**1926**	**963.2**
R = {Σ (E_i / LCI_i)} / q_e	≤ 1	**3.53**	**1.74**	0.85
Σ E_{ni} (30 d) / q_e [µg m^{-3}]	≤ 20 µg m^{-3}	0	0	0
Result		**no label**	**no label**	**no label**

This product <u>does not</u> fulfil the conditions of the toxicological evaluation procedure

Appendix 7

Application of QSAR to the Estimation of the Biological Activity of Chemicals: Nasal Pungency as Example

It is often possible to establish a quantitative connection between the biological activity of a series of compounds in a given system, or towards a given organism, and their chemical structure. Such a connection, expressed in mathematical form, is known as a quantitative structure-activity relationship, or QSAR. This definition is usually extended to include connections, not only with indicators of chemical structure, but with any physical or chemical property of the series of compounds. Thus, compound vapour pressure might be used as a property to describe biological activity, even though vapour pressure is not an indicator of chemical structure.

The mathematical nature of the connection can vary; one particular form is that of a multiple linear regression equation (MLRE),

$$\log SP \;=\; c \;+\; x \times X \;+\; y \times Y \;+\; z \times Z + \ldots \qquad (1)$$

where SP is the relative biological response of the series of compounds; X, Y, Z, . . are structural, or chemical, or physical properties of the compounds, and are known as explanatory variables, or just as descriptors. The coefficients c, x, y, z, . . are obtained by the wellknown procedure of multiple linear regression analysis (MLRA), in which a set of known logSB values is matched to the corresponding values of X, Y, Z,... Once these constants have been obtained, values of logSP can be predicted for other compounds outside the series used, if values of descriptors X, Y, Z, . . . are known for the other compounds. In eq(1), not every term may be significant in a particular case, and statistical procedures such as the t-test are used to decide whether to retain or to omit any term.

One particular MLRE, that can be used as a quantitative structure-activity relationship, takes the form,

$$\log SP = c \;+\; r \times R_2 \;+\; s \times \pi_2^H \;+\; a \times \Sigma\alpha_2^H \;+\; b \times \Sigma\beta_2^H \;+\; 1 \times \log L^{16} \qquad (2)$$

Here SP is a physicochemical or biological property of a series of compounds. In the present case, SP will be the nasal pungency threshold in ppm, denoted as NPT. The compound descriptors are as follows: [1,2] R_2 is an excess molar refraction that can be determined simply from a knowledge of the compound refractive index, p_2^H is the compound dipolarity/polarizability, Sa_2^H is the compound overall or effective hydrogen-bond acidity, and Sb_2^H is the compound overall or effective hydrogen-bond alkalinity. $\log L^{16}$ is a descriptor[3] defined such that L^{16} is the compound gas-liquid partition coefficient on hexadecane at 298K. All the descriptors in eq(2) can be determined experimentally for volatile organic compounds (VOCs) by standard procedures based on gas-liquid chromatography. For VOCs that are unavailable, or are difficult to work with, the descriptors can often be estimated by analogy with other compounds. [1,2,4] Eq (2) has been applied to numerous physicochemical processes; we will now give one QSAR application as an example. Cometto-Muniz and Cain, [5-7] have determined nasal pungency thresholds (NPT) of a series of VOCs, using anosmic humans as subjects. In Table 1, values are given of log1/NPT for the compounds studied, with NPT in parts per million (ppm). Log1/NPT is used, rather than logNPT, because the larger the value of 1/NPT, the more potent is the

VOC. All the VOCs in Table 1 are 'non-reactive', in that they exert their influence through transport and interaction with the trigeminal nerve, and not through reaction with components of the biological phase, or through breakdown products. When eq(2) was applied to the set of 31 log1/NPT values, the R_2 descriptor was significant at only the 4% level, and so was discarded. The remaining four descriptors yielded the equation,

$$\begin{array}{llllll} \log 1/NPT =- & 8.670 + 2.396\,\pi_2^H & + 3.636\,\Sigma\alpha_2^H & + 1.352\,\Sigma\beta_2^H & + 0.873\,\log L^{16} & (3) \\ & 0.382 \quad 0.627 & 0.560 & 0.429 & 0.037 & \end{array}$$

$$n = 31 \qquad p = 0{\times}0.9786 \qquad sd = 0{\times}0.26 \qquad F = 147$$

Here, n is the number of data points (VOCs), p is the correlation coefficient, sd is the overall standard deviation in log1/NPT, and F is the F-statistic. The t-test shows that all the terms in eq(2) are significant at, or above, the 99.6% level. The calculated log1/NPT values on eq(3) are in Table 1, together with the descriptors of the 31 volatile organic compounds. The standard deviation of calculated and predicted values is 0.26 log unit, so that eq(3) can be regarded as a good representation of the NPT data of Cometto-Muniz and Cain. In eq(2) the sd values of the coefficients are given below the coefficients.

The predictive power of eq(3) can also be assessed by the technique known as 'leave-one-out'. Using this method, 31 regressions of log1/NPT were run against the descriptors in eq(3), each time leaving out one of the VOCs. In each regression, the estimated value of log1/NPT was calculated for the VOC that was left out. This leads to 31 estimated values that can be compared to the 31 experimental values in Table 1. The standard deviation (n-1) between the two sets was 0.24 log units, almost the same as the value of 0.26 for the sd in eq(3). Hence eq(3) can be used to estimate further values of log1/NPT for a very large number of unreactive VOCs, to within about 0.3 log units, quite sufficient for practical purposes. One advantage of the general eq(1) is that it has been shown to apply across the board. Thus, for the nonreactive VOCs, the equation could be used to estimate NPT values for chemical types not included in the training set of compounds (Table 1). Of course, care should be taken to confine estimations to VOCs with descriptor values within the limits of the training set (or perhaps just outside), but even with this restriction it is possible to estimate NPT values for numerous other VOCs.

The practical use of equations such as eq(3) follows from observations that various measures of the potency of VOCs are linearly related (on a logarithmic scale). Cometto-Muniz and Cain have shown that the nasal pungency thresholds to human subjects, mentioned above, are linearly related to the mouse bio-assay of Alarie (the latter relates to upper respiratory tract irritation in mice[8]), Schaper[9] has recently confirmed the observation of Alarie[8] that $\log RD_{50}$ values for the mouse bio-assay, now used as a standard test procedure[10], are themselves linearly related to the ACGIH threshold limit values[11] as logTLV, for VOCs. Hence, now that it is shown that a QSAR based on eq(2) can be obtained for one of these measures of potency, eq(3), it follows that (i) QSARs based on eq(2) can be obtained for the other measures of potency, and (ii) that an estimation of VOC potency (as a value of logNPT) through eq(3) can be translated immediately into a potency as either a value of the mouse bio-assay $\log RD_{50}$, or as a logTLV value.

Table 1. Descriptors for VOCs, and values of log1/NPT used in the calculations[a]

Compound	R_2	p_2^H	Sa_2^H	Sb_2^H	$\log L^{16}$	obs	calc[b]
Methanol	0.28	0.44	0.43	0.47	0.970	-4.53	-4.57
Ethanol	0.25	0.42	0.37	0.48	1.485	-3.91	-4.37
Propan-1-ol	0.24	0.42	0.37	0.48	2.031	-3.49	-3.90
Propan-2-ol	0.21	0.36	0.33	0.56	1.764	-4.26	-4.31
Butan-1-ol	0.22	0.42	0.37	0.48	2.601	-3.20	-3.40
Butan-2-ol	0.22	0.36	0.33	0.56	2.338	-3.76	-3.81
t-Butanol	0.18	0.30	0.31	0.60	1.963	-4.52	-4.30
Pentan-1-ol	0.22	0.42	0.37	0.48	3.106	-3.21	-2.96
Hexan-1-ol	0.21	0.42	0.37	0.48	3.610	-2.62	-2.52
Heptan-1-ol	0.21	0.42	0.37	0.48	4.115	-2.32	-2.08
Heptan-4-ol	0.18	0.36	0.33	0.56	3.850	-2.53	-2.49
Octan-1-ol	0.20	0.42	0.37	0.48	4.619	-1.99	-1.64
Methyl acetate	0.14	0.64	0.00	0.45	1.911	-5.05	-4.86
Ethyl acetate	0.11	0.62	0.00	0.45	2.314	-4.83	-4.56
Propyl acetate	0.09	0.60	0.00	0.45	2.819	-4.24	-4.17
Butyl acetate	0.07	0.60	0.00	0.45	3.353	-3.56	-3.70
Pentyl acetate	0.07	0.60	0.00	0.45	3.844	-3.22	-3.27
Hexyl acetate	0.06	0.60	0.00	0.45	4.351	-2.80	-2.83
Heptyl acetate	0.05	0.60	0.00	0.45	4.865	-2.49	-2.38
Octyl acetate	0.03	0.60	0.00	0.45	5.364	-1.95	-1.94
Decyl acetate	0.03	0.60	0.00	0.45	6.373	-0.70	-1.06
Dodec acetate	0.01	0.60	0.00	0.45	7.381	-0.10	-0.18
Propanone	0.18	0.70	0.04	0.49	1.696	-5.12	-4.71
Pentan-2-one	0.14	0.68	0.00	0.51	2.755	-3.47	-3.95
Nonan-2-one	0.12	0.68	0.00	0.51	4.735	-2.53	-2.22
Oct-1-yne	0.16	0.23	0.12	0.10	3.521	-4.49	-4.48
Toluene	0.60	0.52	0.00	0.14	3.325	-4.47	-4.33
Ethylbenzene	0.61	0.51	0.00	0.15	3.778	-4.00	-3.95
Propylbenzene	0.60	0.50	0.00	0.15	4.230	-3.17	-3.58
Chlorobenzene	0.72	0.65	0.00	0.07	3.657	-4.02	-3.83
Pyridine	0.63	0.84	0.00	0.52	3.022	-3.11	-3.32

[a] Descriptor values from refs. 1 and 2,and observed values of log1/NPT from refs. 5-7.

[b] On equation 3.

References

1. M.H. Abraham, Chem. Soc. Revs., 22 (1993) 73.
2. M.H. Abraham, Pure Appl. Chem., 65 (1993) 2503.
3. M.H. Abraham, P.L. Grellier and R.A. McGill, J. Chem. Soc. Perkin Trans 2, (1987) 797.
4. P. Havelec and J.G.K. Sevik, J. Chromatogr. A, 677 (1994) 319.
5. J. E. Cometto-Muniz and W.S. Cain, Physiol. Behav., 48 (1990) 719.
6. J. E. Cometto-Muniz and W.S. Cain, Pharmacol. Biochem. Behav., 39 (1991) 983.
7. J.E. Cometto-Muniz and W.S. Cain, Am. Ind. Hyg. Assoc. J., 55 (1994) 811.
8. Y. Alarie, CRC Crit. Rev. Toxicol., 2 (1973) 299.
9. M. Schaper, Am. Ind. Hyg. Assoc. J., 54 (1993) 488.
10. ASTM Designation E 981-84, ASTM, Philadelphia, 1984.
11. ACGIH: Documentation of the Threshold Limit Values and Biological Exposure Indices, 6th rev, ed., ACGIH, Cincinnati, OH, 1991.

Appendix 8

Classification of carcinogens

1. EU - European Union

Category 1

Substances known to be carcinogenic to man.

There is sufficient evidence to establish a causal association between human exposure to a substance and the development of cancer.

Category 2

Substances which should be regarded as if they were carcinogenic to man.

There is sufficient evidence to provide a strong presumption that human exposure to a substance may result in the development of cancer, generally on the basis of: appropriate long-term animal studies, (ii) other relevant information.

Category 3

Substances which cause concern for man owing to a possible carcinogenic effect, but where the available information is not adequate for making a satisfactory assessment. There is some evidence from appropriate animal studies, but this is insufficient to place the substance in Category 2.

2. IARC - International Agency for Research on Cancer

Group 1 - The agent (mixture) is carcinogenic to humans.

The exposure circumstance entails exposures that are carcinogenic to humans.

This category is used when there is **sufficient evidence** of carcinogenicity in humans. Exceptionally, an agent (mixture) may be placed in this category when evidence in humans is less than sufficient, but where there is **sufficient evidence** of carcinogencity in experimental animals and strong evidence in exposed humans that the agent (mixture) acts through a relevant mechanism of carcinogenicity.

Group 2

This category includes agents, mixtures and exposure circumstances for which, at one extreme, the degree of evidence of carcinogenicity in humans is almost sufficient, as well as those for which, at the other extreme, there are no human data but for which there is evidence of carcinogenicity in experimental animals. Agents, mixtures and exposure circumstances are assigned to either 2A (probably carcinogenic to humans) or 2B (possibly carcinogenic to humans) on the basis of epidemiological and experimental evidence of carcinogenicity and other relevant data.

Group 2A - The agent (mixture) is probably carcinogenic to humans.

The exposure circumstance entails exposures that are probably carcinogenic to humans.

This category is used when there is **limited evidence** of carcinogenicity in experimental animals. In some cases, an agent (mixture) may be classified in this category when there is **inadequate evidence** of carcinogenicity in humans and **sufficient evidence** of carcinogenicity in experimental animals and strong evidence that the carcinogenesis is mediated by a mechanism that also operates in humans. Exceptionally, an agent, mixture or exposure circumstance may be classified in this category solely on the basis of carcinogenicity in humans and **sufficient or limited evidence** of carcinogenicity in humans.

Group 2B - The agent (mixture) is possibly carcinogenic to humans.

The exposure circumstance entails exposures that are possibly carcinogenic to humans.

This category is used for agents, mixtures and exposure circumstances for which there is **limited evidence** of carcinogenicity in humans and **less than sufficient evidence** of carcinogenicity in experimental animals. In some instances, an agent, mixture or exposure circumstance for which there is inadequate evidence of carcinogenicity in humans but limited evidence of carcinogenicity in experimental animals together with supporting evidence from other relevant data, may be placed in this group.

Group 3 - The agent (mixture or exposure circumstance) is not classifiable regarding carcinogenicity to humans.

This category is used most commonly for agents, mixtures and exposure circumstances for which the evidence of carcinogenicity is inadequate in humans and inadequate or limited in experimental animals.

Exceptionally, agents (mixtures) for which the evidence of carcinogenicity is inadequate in humans but sufficient in experimental animals may be placed in this category when there is strong evidence that the mechanism of carcinogenicity in experimental animals does not operate in humans.

Agents, mixtures and exposure circumstances that do not fall into any other group are also placed in this category.

Appendix 9

List of Symbols and Abbreviations

A	emitting surface area of a test specimen or material in a room
A_{cs}	internal surface area of a test chamber
ACGIH	American Conference of Governmental Industrial Hygienists
b.p.	boiling point
c, C	VOC concentration in room or chamber air [$\mu g/m^3$]
C_{ci}	concentration of a carcinogenic compound VOC_{ci} contained in Table 4.1
C_i	concentration of compound i
$C_i(28d)$	concentration of compound i in the test chamber after 28 days of testing
C_{TVOC}	concentration of TVOC (for definition see chapter 2.1.7)
$\{C\}_i$	mean or average of the test chamber concentration values of VOC_i measured at a given test time
$\{C\}_{TVOC}$	mean or average of the TVOC concentration values measured at a given test time
COPD	chronic obstructive pulmonary disease.
DPF	deviation performance factor
E	emission factor or emitted mass per unit surface area and time [$\mu g\ m^{-2}\ h^{-1}$] of an unspecified VOC
E_i	emission factor of VOC_i or X_i [$\mu g\ m^{-2}\ h^{-1}$]
$E_i(28d)$	emission factor of VOC_i [$\mu g\ m^{-2}\ h^{-1}$] determined after 28 days testing
E_{TVOC}	emission factor calculated using TVOC instead of single VOC concentration [$mg\ m^{-2}\ h^{-1}$]
ECA-IAQ	European Collaborative Action "Indoor Air Quality and Its Impact on Man"
ER	emission rate [$\mu g\ h^{-1}$]
ETS	environmental tobacco smoke
FID	flame ionization detector
F	floor area of a room
F_m*/F	coverage factor: emitting surface area of a product m in a room divided by the floor area of the room; for flooring materials $F_m^*/F = 1$
GC	gas chromatograph(ic)
H	height of a room [m]
IAQ	indoor air quality
IAS	indoor air science
k_{ad}	adsorption rate constant of a compound on the internal test chamber surface [$m \times h^1$]
L	loading or loading factor [m^2/m^3] = emitting surface area A [m^2] of a test specimen divided by the chamber volume V [m^3]
LCI	lowest concentration of interest (see section 4.4 (d))

LR	leak rate of a test chamber expressed as chamber volumes per hour [h^{-1}]
LUR	lifetime (inhalatory) unit risk
MAK	Maximale Arbeitsplatz Konzentration (maximum admitted workplace air concentration) measured as ppm or mg/m^3
MS	mass spectrometer, mass spectrometric
n	air exchange rate in a room or test chamber measured as air changes per hour [h^{-1}]
NOEL	no-observed effect level
OEL	occupational exposure limit (such as MAK or TLV) measured as ppm or mg/m^3
OEL_i	OEL of compound i
PPD	predicted percent of dissatisfied (persons)
Q	ventilation rate [$l\ s^{-1}$]
q	area specific ventilation rate [$m^3\ h^{-1}\ m^{-2}$], i.e. ventilation rate [$m^3\ h^{-1}$] per m^2 of emitting surface
q_c	area specific ventilation rate in the test chamber (q_c=1.25 $m^3\ h^{-1}\ m^{-2}$)
q_e	area specific ventilation rate [$m^3\ h^{-1}\ m^{-2}$] used for evaluating VOC emissions, i.e. for calculating 'exposure concentrations' (see appendix 10) from emission factors (see section 6.1.1)
QSAR	quantitative structure-activity relationship
R	Index summarizing the estimated health risk of a material emission.
ROP	relative overpressure in a test chamber or chamber minus atmospheric pressure divided by the atmospheric pressure
SF	safety factor, i.e. factor by which an OEL is divided in order to account for differences of exposure and population at risk when using an OEL for estimating LCI values
SVOC	semi-volatile organic compound
$t_{1/2}$	time during which the overpressure in a sealed test chamber decays to half its initial value
t_s	time after introduction of a material specimen into a test chamber at which chamber air samples are taken for analysis
TLV ™	threshold limit value for workplace air concentrations measured as ppm or mg/m^3
TVOC	total volatile organic compounds
TWA	time weighted average (exposure/concentration)
V_c	volume of the test chamber
VOC(s)	volatile organic compound(s) (general)
VOC_{ci}	carcinogenic VOC contained in Table 4.1
VOC_i	individual VOC
VOC_{ni}	individual VOC with an 'exposure concentration' (see appendix 10) $\geq 5\ \mu g\ m^{-3}$ for which no LCI is available

Appendix 10

Glossary

Absorption: 1. General: A physical process in which one material (the absorbent) takes up and retains molecules of a gas or vapour (the absorbate) with the formation of an homogeneous mixture having the attributes of a solution. Chemical reaction may accompany or follow absorption. In this latter case the process may be irreversible.
2. The uptake of toxic agents through eye or skin contact.

Additivity of effects: A condition that exists if the effect of changing the level of an independent variable, A, is not influenced by the level of another independent variable, B, and vice versa. This definition can be extended to more than two variables. It is important to observe that the property of additivity depends on the scales in which the measured value and the independent variables are expressed.

Adsorption: A physical process in which molecules of a gas or vapour adhere to a solid surface with which they are in contact in an extremely thin (mono- or multi-molecular) layer. Chemical reaction may accompany or follow adsorption (chemisorption). In this latter case the process may be irreversible.

Air exchange rate: The number of times per hour the air in an indoor space or room is renewed by fresh (outdoor or treated indoor) air.

Antagonism: The case when the combined exposure to given concentrations of two or more substances causes an effect which is smaller than the sum of the effects of the exposure to each individual substance at the same concentration. Antagonism is the opposite of synergism (see also → additivity).

Annoyance: In indoor air sciences (IAS), a term describing a mood state which may be associated with environmental stress. It is in IAS referring to problematic, provocational, or displeasing environmental exposures.

Biocides: Chemical compounds or preparations containing them which are able to reduce or eliminate the presence or activity of plants (herbicides), fungi (fungicides), microbes or insects (insecticide).

Building material: An identifiable material that may be used in construction, such as brick, concrete, metal or lumber.

Climate chamber. In IAS a room with one or more controlled atmospheric conditions or elements. A climate chamber is often used in IAS for human or animal exposure experiments or for source emission characterization.

Comfort: (1) A state of optimal health, i.e. optimal physical and psychological well-being of humans considering all relevant covariables. (2) A state of being free from annoyance.

Common chemical sense. A set of senses including n. Trigeminus, and non-myelinated nerves in the skin areas and in the eyes, face, and in part of the nose and mouth cavity. Mostly found in the facial skin, the mucosal membranes of eyes, nose, and mouth. These nerves respond in an unspecific way to chemical or physical stimulation. The stimulation is generally perceived as itching, feeling of dryness or pain.

Conditioning (environmental): The storage of a test specimen under specified conditions of temperature, humidity, supply air quality, air exchange and air velocity for a specified time prior to testing.

Decipol: Unit of perceived air quality (see chapter 2.3.1).

Emission factor: Mass of air pollutants released (emitted) per unit time and unit emitting surface area from a given source.

Emission rate: Mass of air pollutants released (emitted) per unit time from a given source.

Environmental tobacco smoke (ETS): side stream smoke of a cigarette or smoke exhaled by a smoker to which non-smokers are also exposed (passive smoking).

Exposure: Any measurable environmental factor, which results in a measurable dose received by a target organism from the atmospheric environment.

Exposure concentration: VOC concentrations predicted from emission factors using the exposure scenario or the area specific ventilation rate selected for the evaluation of VOC emissions (see equation (3.1) in sections 3.3 and 6.1.1)

Guideline value: In environmental hygiene, recommended threshold levels or concentrations of a harmful or noxious agent consistent with the maintenance of good health.

Health: 1. Generally: A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity (WHO). 2. In medicine: The state of optimal functioning of the organism without evidence of disease or abnormality (1). 3. In IAS: A state of complete physical, mental, and social well-being taking into account relevant cofactors such as age, gender, etc.

Indoor air quality (IAQ): The ensemble of all features of indoor air having an impact on man. It is mainly determined by the atmospheric environment, in particular by the presence of indoor air pollutants. However, other components of the indoor environment may interact with the perception of indoor air quality, e.g. the thermal environment.

Indoor climate: The ensemble of physical properties of the indoor environment (e.g. temperature, humidity, air movement and exchange rate, actinic and radiation properties) which may affect health and/or comfort of the occupants and their perception of IAQ. The physical properties of particular interest in the context of this report: temperature and humidity, air movement and air exchange rate.

Labelling: Assignment of a visible sign or indication to a material or product testifying or guaranteeing a defined quality of one or several of its properties.

Lowest concentration of interest (LCI): In this report the lowest concentration of a pollutant which, according to best professional judgement, might have an effect on people in the indoor environment.

Leak: A hole, or void in the wall of an enclosure, capable of passing liquid or gas from one side of the wall to the other under action of a pressure or concentration differential existing across the wall, independent of the quantity of fluid flowing.

Lifetime (inhalatory) unit risk (LUR): Risk of getting cancer after a lifelong exposure to a cancerogenic air pollutant per mg/m^3 of the pollutant; LURs have been established by the U.S. Environmental Protection Agency.

Loading factor: The ratio between the emitting (adsorbing) surface area or amount of a source (sink) material and the volume of the room or test chamber into which emitted pollutants are released measured as [m^2/m^3] or [ml/m^3] or [g/m^3].

Material: Any physical or chemical substance used for the production of consumer products.

No-observed-adverse-effect level (NOAEL): NOAEL refers to that dose rate of a chemical [mg/kg body weight/day] at which there are no statistically or biologically significant increases in frequency or severity of adverse effects between the exposed and control groups. Statistically significant effects may be observed at this level, but they are not considered to be adverse.

No-observed-effect level (NOEL): NOEL refers to the dose rate of a chemical [mg/kg body weight/day] at which there are no statistically or biologically significant increases in frequency or severity of effects between the exposed and control groups.

Occupational exposure limit (OEL): The maximum concentration of a chemical agent to which a worker may be exposed, determined either as a time-weighted average (TWA), usually over an 8 h period, or as a short term ceiling value. OELs are determined by national or international authorities.

Olf: A unit for the sensory emission rate due to bioeffluents and other indoor air pollutants. The olf is defined as the perceived air pollution caused by emissions from a standard sedentary person in thermal comfort and ventilated by 10 l/s unpolluted air (Fanger 1988).

Potentiation: Enhancement of the effect of one agent by another so that the combined effect is greater than the sum of the effects of each one alone.

Quantitative structure-activity relationship (QSAR): A mathematical model which allows prediction of physico-chemical properties from structural features or elements of a chemical compound, or biological activities from both physico-chemical properties and structural features or elements.

Safety factor: Factor by which an OEL is divided if the toxicological information contained in the OEL is to be used for protecting people in the indoor environment. The factor takes account of the different exposure conditions and populations in the indoor environment compared to the working environment.

Semi-volatile organic compound (SVOC): Organic compound with a boiling point above 260-280°C.

Sensory panel: A group of individuals that may be selected on the basis of sensitivity to stimuli, reliability, or whose perceptions are judged to be representative of some larger population. It is used to obtain information concerning the sensory attributes of physical stimuli.

Sink effect: Sorption of air pollutants on internal surfaces of test chambers.

Small chambers/large chambers: In this report small chambers are defined as chambers with a volume $\leq 2m^3$. In principle, chambers defined as large are greater than this limit. However, in practice, large chambers are of a walk-in type with volumes ≥ 11 m^3.

Sorption: The process of →ad- and/or →absorption.

Standard: Broadly, something used as a basis for comparison, often a unit of reference.

Steady state concentration: Concentration of a compound in a (test chamber) atmosphere which does not change over time because of a balance between the rates of emission into the atmosphere and removal from it.

Synergism: Opposite of →antagonism.

Test material: A product or an aliquot thereof that is subject to a test; here an aliquot of a solid flooring material from which, at the test laboratory, → test specimens are prepared for the chemical and sensory tests described in this report.

Test specimen: A piece of a → test material that is subject to a test, here to a VOC or sensory emission test.

Toxicology: The study of the effects, in nature of and detection of poisons in living organisms. This also includes substances that are otherwise harmless but prove toxic under particular conditions. The basic assumption of toxicology is that there is a relationship between the dose (amount taken up by an organism) of a poison, its concentration at the affected site, and the resulting effects.

Total volatile organic compounds (TVOC): A measure of the total content, in the vapour phase, of organic compounds in an air sample. For the definition used in this report see chapter 2.1.7.

Threshold limit value (TLV®): maximum air concentration of chemical substances and physical agents in the work environment issued by the ACGIH.

Validation: The process of substantiating specified performance criteria.

Ventilation: 1. The process of supplying and removing air by natural or mechanical means to and from any space. 2. The provision of air to an enclosed space sufficient for the needs of the occupants or process.

Ventilation efficiency: A quantity describing the ability of a mechanical (or natural) ventilation system to remove pollution originating in a room, either of a steady state or transient nature. Relative ventilation efficiency, absolute ventilation efficiency.

Volatile organic compounds (VOCs): In this report: organic compounds eluting on an apolar gas chromatographic column between and including n-hexane and n-hexadecane.

Appendix 11

Members of the sub-groups of Working Group 10

Working Group 10A - Emission Measurements

Olav **Bjørseth**, Institutt for Organisajons- og Arbeidslivsfag, Trondheim, Norway
Robert **Gehrig**, Materialprüfungs- und Forschungsanstalt, Dübendorf, Switzerland
Hans **Gustafsson**, SP, Swedish National Testing & Research Inst., Borås, Sweden
Antonius **Kettrup**, GSF, Institut für Ökologische Chemie, Oberschleissheim, Neuherberg, Germany
Séverine **Kirchner**, C.S.T.B., Marne la Vallee Cedex, France
Helmut **Knöppel** (co-ordinator), European Commission, Joint Research Centre, Ispra, Varese, Italy
Heinz **Rothweiler**, Umwelt und Gesundheit, Stadt Kloten, Kloten, Switzerland
Kristina **Saarela**, Technical Research Centre of Finland, VTT, Finland
Peder **Wolkoff**, Arbeijdsmiljøinstituttet, Copenhagen, Denmark
Jan F. **van der Wal**, TNO, Department of Indoor Environment, Delft, The Netherlands

Working Group 10B - Human Effects Evaluation

Michael H. **Abraham**, University College London, Chemistry Dept, London, U.K.
Jan **Bakke**, Arbeidstilsynet 3. distrikt, Gjøvik, Norway
Birgitta **Berglund**, Dept. of Psychology, Stockholm University, Stockholm, Sweden
Philomena **Bluyssen**, TNO, Dept. of Indoor Environment, Delft, The Netherlands
Geo **Clausen**, The Indoor Climate Group, Lyngby, Denmark
Klea **Katsouyanni**, Dept. of Epidemiology, Goudi, Athens, Greece
Gerhard **Kobal**, Inst. für Pharmakologie der Universität Erlangen-Nürnberg, Germany
Leonard **Levy**, University of Birmingham, Edgbaston, Birmingham, U.K.
Thomas **Lindvall**, Karolinska Institute, Stockholm, Sweden
Marco **Maroni** (co-ordinator), Institute of Occupational Health, University of Milan, Milan, Italy
Lars **Mølhave**, Inst. of Environmental & Occupational Medicine, Aarhus, Denmark
Gerhard **Winneke**, University of Düsseldorf, Düsseldorf, Germany

Working Group 10C - Exposure Assessment

Philomena **Bluyssen**, TNO, Dept. of Indoor Environment, Delft, The Netherlands
Sten **Dueholm**, Dronningens Tvægade, Copenhagen, The Netherlands
Manfred **Fischer** (co-ordinator), Umweltbundesamt, Berlin, Germany
Matti **Jantunen**, National Public Health Institute, Kuopio, Finland
Helmut **Knöppel**, European Commission, Joint Research Centre, Ispra,Varese, Italy
Jean-Claude **Loewenstein**, Electricité de France, Chatou Cedex, France
Bjørn **Lundgren**, SP, Swedish National Testing & Research Institute, Borås, Sweden
Luisa **Morfini**, C.N.R., S. Giuliano Milanese, Milan, Italy
Peter A. **Nielsen**, Statens Byggeforskningsinstitut, Hørsholm, Denmark
Silvia **Piardi**, Politecnico di Milano, Milan, Italy

Appendix 12

Members of the ECA-IAQ Steering Committee

AUSTRIA

Andrea **SCHEIDL**, Bundesministerium für Umwelt, Jugend und Familie, Wien

Aleksander **ZILBERSZAC**, Bundesministerium für Gesundheit, Sport und Konsumentenschutz, Wien

BELGIUM

Filip **BEIRENS**, EHDAC, I.H.E. - Epidemiology Unit, Brussels

Peter **WOUTERS**, Belgian Building Research Institute, Brussels

DENMARK

P. Ole **FANGER**, Laboratoriet for Varme- og Klimateknik, Danmarks Tekniske Hojskole, Lyngby

Lars **MØLHAVE** (vice chairman), Institute of Environmental & Occupational Medicine, Aarhus Universitet, Aarhus

FINLAND

Matti J. **JANTUNEN**, Division of Environmental Health, National Public Health Institute, Kuopio

Esko **KUKKONEN**, Ministry of the Environment, Physical Planning and Building Dept., Helsinki

FRANCE

Joëlle **CARMES**, Ministère de la Santé et de l'Action Humanitaire, Direction Generale de la Santé, Paris

Yvon **LE MOULLEC**, Laboratoire d'Hygiene de laVille de Paris, Paris

Claude **MOLINA**, Association d'aide aux Insuffisants Respiratoires de la Région Auvergne, Clermont Ferrand

GERMANY

Antonius **KETTRUP**, GSF - Forschungszentrum Umwelt und Gesundheit m.b.H., Institut für Ökologische Chemie, Oberschleissheim

Bernd **SEIFERT** (chairman), Institut für Wasser-, Boden- und Lufthygiene des Umweltbundesamtes, Berlin

GREECE

Panayotis **SISKOS**, Laboratory of Analytical Chemistry, University of Athens, Athens

Matheos **SANTAMOURIS**, Department of Applied Physics, University of Athens, Athens

IRELAND

James P. **McLAUGHLIN**, Department of Physics, University College, Belfield, Dublin

Patrick A. **WRIGHT**, EOLAS, Glasnevin, Dublin

ITALY

Marco **MARONI**, Centro Internazionale per la Sicurezza degli Antiparassitari, Busto Garolfo

Antonio **REGGIANI**, Istituto Superiore di Sanità, Laboratorio Igiene Ambientale, Roma

THE NETHERLANDS

Anton P. M. **BLOM**, Ministry of Housing, Physical Planning & Environment, Air Pollution Department, Leidschendam

Bert **BRUNEKREEF**, Department of Epidemiology & Public Health, Agricultural University, Wageningen

NORWAY

Jan **HONGSLO**, Department of Environmental Medicine, National Institute of Public Health, Oslo

Sten Olaf **HANSSEN,** Institutt for Klima- og kuldeteknikk, Trondheim

PORTUGAL

Edoardo **DE OLIVEIRA FERNANDES**, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Porto

SWEDEN

Birgitta **BERGLUND**, Department of Psychology, University of Stockholm, Stockholm

Thomas **LINDVALL**, Institute of Environmental Medicine, Karolinska Institute, Stockholm

Björn **LUNDGREN**, Swedish National Testing and Research Institute, Borås

SWITZERLAND

Heinz **ROTHWEILER**, Stadt Kloten, Umwelt und Gesundheit, Kloten

Hans-Urs **WANNER**, Institut für Hygiene und Arbeitsphysiologie der ETH, Zürich

UNITED KINGDOM

Paul T. **HARRISON**, MRC Institute for Environment & Health, University of Leicester,Leicester

Linda **SMITH,** Department of the Environment, Toxic Substances Division, London

WORLD HEALTH ORGANIZATION

Michal **KRZYZANOWSKI**, WHO - European Centre for Environment and Health, Bilthoven

EUROPEAN COMMISSION

Maurizio **DE BORTOLI** (secretary), Joint Research Centre, Environment Institute, Ispra, (Varese)

Helmut **KNÖPPEL**, Joint Research Centre, Environment Institute, Ispra, (Varese)

European Commission

EUR 17334 – European collaborative action 'Indoor air quality and its impact on man': Evaluation of VOC EmissionS from Building Products

The Steering Committee

Luxembourg: Office for Official Publications of the European Communities

1997 – 120 pp. – 21.0 x 29.7 cm

Environment and quality of life series

ISBN 92-828-0384-8

This report outlines the principles of a general evaluation procedure for emissions of volatile organic compounds (VOCs) from building materials with respect to their potential effects on health and comfort. Using available knowledge, the principles have been applied to a simplified case, i.e a procedure for the evaluation of VOC emissions from solid flooring materials. The procedure is intended for the classification and/or labelling of these materials and may serve for both voluntary and regulatory purposes. The procedure includes (i) the selection and handling of appropriate test specimens; (ii) the determination of emission factors of individual VOCs and of TVOC (Total Volatile Organic Compounds) using small test chamber measurements; (iii) modelling of indoor relevant VOC concentrations; (iv) their toxicological evaluation and (v) measurements of sensory irritation and odour or perceived air quality of the emissions.

An overall scheme of how to combine the different elements of the procedure and rules how to use the information obtained for labelling of building materials have been established

Venta • Salg • Verkauf • Πωλήσεις • Sales • Vente • Vendita • Verkoop • Venda • Myynti • Försäljning

BELGIQUE/BELGIË

Moniteur belge/Belgisch Staatsblad

Rue de Louvain 40-42/
Leuvenseweg 40-42
B-1000 Bruxelles/Brussel
Tél. (32-2) 552 22 11
Fax (32-2) 511 01 84

Jean De Lannoy

Avenue du Roi 202/
Koningslaan 202
B-1060 Bruxelles/Brussel
Tél. (32-2) 538 51 69
Fax (32-2) 538 08 41
E-mail: jean.de.lannoy@infoboard.be

Librairie européenne/Europese Boekhandel

Rue de la Loi 244/
Wetstraat 244
B-1040 Bruxelles/Brussel
Tél. (32-2) 295 26 39
Fax (32-2) 735 08 60

DANMARK

J. H. Schultz Information A/S

Herstedvang 10-12
DK-2620 Albertslund
Tlf. (45) 43 63 23 00
Fax (45) 43 63 19 69
E-mail: schultz@schultz.dk
URL: www.schultz.dk

DEUTSCHLAND

Bundesanzeiger Verlag

Breite Straße 78-80
Postfach 10 05 34
D-50667 Köln
Tel. (49-221) 20 29-0
Fax (49-221) 20 29 278

GREECE/ΕΛΛΑΔΑ

G.C. Eleftheroudakis SA

International Bookstore
Panepistimiou 17
GR-105 64 Athens
Tel. (30-1) 331 41 80/1/2/3
Fax (30-1) 323 98 21
E-mail: elebooks@netor.gr

ESPAÑA

Mundi Prensa Libros, SA

Castelló, 37
E-28001 Madrid
Tel. (34-1) 431 33 99/431 32 22
Fax (34-1) 575 39 98
E-mail: mundiprensa@tsai.es
URL: www.tsai.es/mprensa

Boletín Oficial del Estado

Trafalgar, 27-29
E-28071 Madrid
Tel. (34-1) 538 22 95 (Libros)/
384 17 15 (Suscripciones)
Fax (34-1) 538 23 49 (Libros)/
384 17 14 (Suscripciones)
URL: www.boe.es

Mundi Prensa Barcelona

Consell de Cent, 391
E-08009 Barcelona
Tel. (34-3) 488 34 92
Fax (34-3) 487 76 59

FRANCE

Journal officiel

Service des publications des CE
26, rue Desaix
F-75727 Paris Cedex 15
Tél. (33-1) 40 58 77 01/31
Fax (33-1) 40 58 77 00

IRELAND

Government Supplies Agency

Publications Section
4-5 Harcourt Road
Dublin 2
Tel. (353-1) 661 31 11
Fax (353-1) 475 27 60

ITALIA

Licosa SpA

Via Duca di Calabria, 1/1
Casella postale 552
I-50125 Firenze
Tel. (39-55) 64 54 15
Fax (39-55) 64 12 57
E-mail: licosa@ftbcc.it
URL: icl382.cilea.it/Virtual_Library/bibliot/vetrina/licosa/tt1.htm

GRAND-DUCHÉ DE LUXEMBOURG

Messageries du livre Sarl

5, rue Raiffeisen
L-2411 Luxembourg
Tél. (352) 40 10 20
Fax (352) 490 661
E-mail: mdl@pt.lu

Abonnements:

Messageries Paul Kraus

11, rue Christophe Plantin
L-2339 Luxembourg
Tél. (352) 499 88 88
Fax (352) 499 888 444
E-mail: mpk@pt.lu
URL: www.mpk.lu

NEDERLAND

SDU Servicecentrum Uitgevers

Christoffel Plantijnstraat 2
Postbus 20014
2500 EA 's-Gravenhage
Tel. (31-70) 378 98 80
Fax (31-70) 378 97 83
E-mail: sdu@sdu.nl
URL: www.sdu.nl.

ÖSTERREICH

Manz'sche Verlags- und Universitätsbuchhandlung Gmbh

Siebenbrunnengasse 21
Postfach 1
A-1050 Wien
Tel. (43-1) 53 161 334 / 340
Fax (43-1) 53 161 339
E-mail: auslieferung@manz.co.at
URL: www.austria.EU.net:81/manz

PORTUGAL

Imprensa Nacional-Casa da Moeda, EP

Rua Marquês de Sá da Bandeira, 16 A
P-1050 Lisboa Codex
Tel. (351-1) 353 03 99
Fax (351-1) 353 02 94/384 01 32

Distribuidora de Livros Bertrand Ld.ª

Rua das Terras dos Vales, 4 A
Apartado 60037
P-2701 Amadora Codex
Tel. (351-1) 495 90 50/495 87 87
Fax (351-1) 496 02 55

SUOMI/FINLAND

Akateeminen Kirjakauppa /

Akademiska Bokhandeln
Pohjoisesplanadi 39/
Norra esplanaden 39
PL/PB 128
FIN-00101 Helsinki/Helsingfors
Tel. (358-9) 121 41
Fax (358-9) 121 44 35
E-mail: akatilaus@stockmann.mailnet.fi
URL: booknet.cultnet.fi/aka/index.htm

SVERIGE

BTJ AB

Traktorvägen 11
PO Box 200
S-22100 Lund
Tel. (46-46) 18 00 00
Fax (46-46) 18 01 25
E-mail: btj_tc@mail.btj.se
URL: www.btj.se/media/eu

UNITED KINGDOM

The Stationery Office Ltd (Agency Section)

51, Nine Elms Lane
London SW8 5DR
Tel. (44-171) 873 9090
Fax (44-171) 873 8463
URL: www.the-stationery-office.co.uk

ICELAND

Bokabud Larusar Blöndal

Skólavördustig, 2
IS-101 Reykjavik
Tel. (354) 55 15 650
Fax (354) 55 25 560

NORGE

NIC Info A/S

Østenjoveien 18
Boks 6512 Etterstad
N-0606 Oslo
Tel. (47-22) 97 45 00
Fax (47-22) 97 45 45

SCHWEIZ/SUISSE/SVIZZERA

OSEC

Stampfenbachstraße 85
CH-8035 Zürich
Tel. (41-1) 365 53 15
Fax (41-1) 365 54 11
E-mail: urs.leimbacher@ecs.osec.inet.ch
URL: www.osec.ch

ČESKÁ REPUBLIKA

NIS CR - prodejna

Konviktská 5
CZ-113 57 Praha 1
Tel. (42-2) 24 22 94 33
Fax (42-2) 24 22 94 33
E-mail: nkposp@dec.nis.cz
URL: www.nis.cz

CYPRUS

Cyprus Chamber Of Commerce & Industry

38, Grivas Digenis Ave
Mail orders:
PO Box 1455
CY-1509 Nicosia
Tel. (357-2) 44 95 00/46 23 12
Fax (357-2) 361 044
E-mail: cy1691_eic_cyprus@vans.infonet.com

MAGYARORSZÀG

Euro Info Service

Európa Ház
Margitsziget
PO Box 475
H-1396 Budapest 62
Tel. (36-1) 11 16 061/11 16 216
Fax (36-1) 302 50 35
E-mail: euroinfo@mail.matav.hu
URL: www.euroinfo.hu/index.htm

MALTA

Miller Distributors Ltd

Malta International Airport
PO Box 25
LQA 05 Malta
Tel. (356) 66 44 88
Fax (356) 67 67 99

POLSKA

Ars Polona

Krakowskie Przedmiescie 7
Skr. pocztowa 1001
PL-00-950 Warszawa
Tel. (48-2) 26 12 01
Fax (48-2) 26 62 40

TÜRKIYE

Dünya Infotel A.S.

Istiklâl Cad. No: 469
TR-80050 Tünel-Istanbul
Tel. (90-212) 251 91 96
(90-312) 427 02 10
Fax (90-212) 251 91 97

BĂLGARIJA

Europress-Euromedia Ltd

59, Bld Vitosha
BG-1000 Sofia
Tel. (359-2) 80 46 41
Fax (359-2) 80 45 41

HRVATSKA

Mediatrade Ltd

Pavla Hatza 1
HR-10000 Zagreb
Tel. (385-1) 43 03 92
Fax (385-1) 44 40 59

ROMÂNIA

Euromedia

Str. G-ral Berthelot Nr 41
RO-70749 Bucuresti
Tel. (40-1) 210 44 01/614 06 64
Fax (40-1) 210 44 01/312 96 46

SLOVAKIA

Slovenska Technicka Kniznica

Nàmestie slobody 19
SLO-81223 Bratislava 1
Tel. (42-7) 53 18 364
Fax (42-7) 53 18 364
E-mail: europ@tbb1.sltk.stuba.sk

SLOVENIA

Gospodarski Vestnik

Zalozniska skupina d.d.
Dunajska cesta 5
SI-1000 Ljubljana
Tel. (386) 61 133 03 54
Fax (386) 61 133 91 28
E-mail: belicd@gvestnik.si
URL: www.gvestnik.si

ISRAEL

R.O.Y. International

17, Shimon Hatarssi Street
PO Box 13056
61130 Tel Aviv
Tel. (972-3) 546 14 23
Fax (972-3) 546 14 42
E-mail: royil@netvision.net.il

Sub-agent for the Palestinian Authority:

Index Information Services

PO Box 19502
Jerusalem
Tel. (972-2) 27 16 34
Fax (972-2) 27 12 19

RUSSIA

CCEC

60-letiya Oktyabrya Av. 9
117312 Moscow
Tel. (095) 135 52 27
Fax (095) 135 52 27

AUSTRALIA

Hunter Publications

PO Box 404
3167 Abbotsford, Victoria
Tel. (61-3) 9417 53 61
Fax (61-3) 9419 71 54

CANADA

Uniquement abonnements/
Subscriptions only:

Renouf Publishing Co. Ltd

1294 Algoma Road
K1B 3W8 Ottawa, Ontario
Tel. (1-613) 741 73 33
Fax (1-613) 741 54 39
E-mail: renouf@fox.nstn.ca
URL: fox.NSTN.Ca/~renouf

EGYPT

The Middle East Observer

41, Sherif Street
Cairo
Tel. (20-2) 39 39 732
Fax (20-2) 39 39 732

JAPAN

PSI-Japan

Asahi Sanbancho Plaza #206
7-1 Sanbancho, Chiyoda-ku
Tokyo 102
Tel. (81-3) 3234 69 21
Fax (81-3) 3234 69 15
E-mail: psijapan@gol.com
URL: www.psi-japan.com

SOUTH AFRICA

Safto

5th Floor Export House,
CNR Maude & West Streets
PO Box 782 706
2146 Sandton
Tel. (27-11) 883 37 37
Fax (27-11) 883 65 69

UNITED STATES OF AMERICA

Bernan Associates

4611-F Assembly Drive
MD20706 Lanham
Tel. (301) 459 2255 (toll free telephone)
Fax (800) 865 3450 (toll free fax)
E-mail: query@bernan.com
URL: www.bernan.com

MÉXICO

Mundi-Prensa Mexico, SA de CV

Río Pánuco, 141
Delegación Cuauhtémoc
ME-06500 México DF
Tel. (52-5) 553 56 58/60
Fax (52-5) 514 67 99
E-mail: 104164.23compuserve.com

RÉPUBLIQUE DE CORÉE

Kyowa Book Company

1 F1. Phyung Hwa Bldg
411-2 Hap Jeong Dong, Mapo Ku
121-220 Seoul
Tél. (82-2) 322 6780/1
Fax (82-2) 322 6782
E-mail: kyowa2@ktnet.co.kr.

ANDERE LÄNDER/OTHER COUNTRIES/ AUTRES PAYS

Bitte wenden Sie sich an ein Büro Ihrer Wahl / Please contact the sales office of your choice / Veuillez vous adresser au bureau de vente de votre choix