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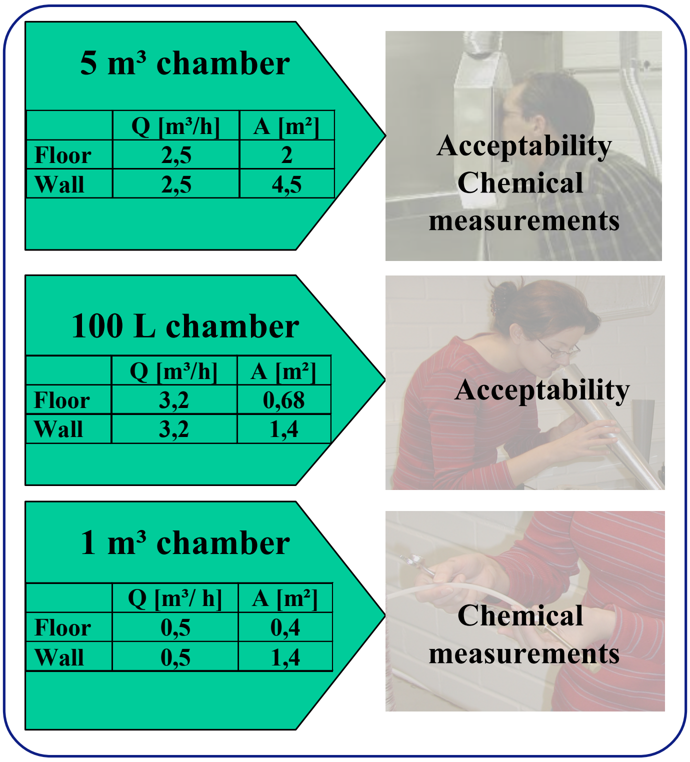

Tiina Tirkkonen, Kristina Saarela &
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Sensory evaluation method of building materials for labelling purposes

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Abstract

It has been shown that odour is an important factor of material emissions and the odour of a product can very seldom be predicted by the chemical emissions. A full size chamber of 5 m³ equipped with a sniffing hood was built to enable both chemical measurements and sensory assessment to be performed using the test conditions of chemical testing. To compare the performance characteristics of the new 5-m³ chamber with the conventional chambers six different materials were tested both in 1-m³ chamber, sensory assessment chamber and in the 5-m³ chamber. The sensory assessment chamber used for the comparison was a 100-litre aluminium chamber, which was operated according to the principles given in Nordtest method NT Build 482 (diffusor). Statistical studies were performed to verify the panel size required for sensory tests for labelling purposes. Chemical and sensory test results obtained with different chambers were in good agreement. Comparing the results with the Finnish building material classification the chamber size would not have affected the labelling decision the materials. Statistical calculations presented here show that for labelling purposes reliable sensory acceptability evaluations can be performed using a relative small naive, untrained panel. When accepting uncertainty of 0.4 on the acceptability scale and a symmetric risk of 10 %, a panel of 5 members can be used. In those cases when the mean acceptability is near the labelling limit value, a bigger panel with 15 members is needed to ensure uncertainty of 0.2 acceptability units and 10 % risk level of making a wrong decision.

Foreword

This project has been funded by The Swedish Council for Building Research under the key action 'The Healthy Building'. As the project leader performed senior research scientist Kristina Saarela from VTT Building and Transport. The project group consisting of VTT Building and Transport/Indoor Air Chemistry group and Esko Kukkonen (Ausum) wants to thank the valuable contribution of the Nordic reference group: professor Birgitta Berglund, University of Stockholm and senior researcher Henrik N. Knudsen, Danish Building and Urban Research.

Contents

1. Introduction

Building products, furniture and other consumables used indoors influence the indoor air quality. The function of ventilation of interior spaces is to reduce the pollutant load caused by humans and materials. An effective way to improve indoor air quality is to decrease the source strength of stationary indoor pollution sources. Indoor climate labelling of materials and building products provides a concept for providing low-emitting products for the market. By using low-emitting products one might even be able to reduce the ventilation and save both money and energy.

Several labelling procedures and principles exist in the Nordic countries, e.g. the Finnish labelling system, Indoor Climate Labelling in Denmark and Norway, the Swedish flooring test method and several others introduced by different organisations and companies. However, the concept behind most of the labelling procedures is the same, i.e., chemical and sensory assessment of the product. In general, labelling methods are a tool for:

- Better understanding of the impact of products used in buildings on the indoor air quality
- Development of more low-emitting products
- Help consumers to find low-emitting products.

Chemical measurements performed to analyse the volatile compounds emitted by the materials are not comprehensive to characterise the impact building products have on the indoor quality. It has been shown that odour is also an important factor and the odour of a product can very seldom be predicted by the chemical emissions. The odour of a material has to be determined by human subjects by performing sensory evaluation for the material.

2. Sensory evaluation

Sensory evaluation methods developed for both indoor air quality and material emissions are comprehensively reviewed and discussed in an ECA report prepared by a group of European experts representing different disciplinary backgrounds /1/. The report gives a short introduction to sensory mechanisms and responses and to the theory of measurement underlying sensory evaluations and discusses in detail available sensory evaluation techniques.

The ultimate goal of the sensory evaluation of emissions from building materials is to predict from laboratory evaluations, the consequences of the use of a material for the perceived air quality in actual buildings. Characterising the emissions from materials in sensory terms to model the perceived air quality in buildings it is necessary to perform the tests in controlled environmental conditions simulating the conditions in a real room. Test chamber technique similar to chemical emission testing fulfils these requirements, i.e., the tested material is placed in a chamber with a known air exchange rate, N, and loading (area of building product/volume of chamber), L. The temperature and relative humidity of the chamber air must also be controlled. Sensory evaluation is made by assessing the air exhausted from the chamber. Depending on the purposes and the use of the test result one has to make a choice between sensory test methods, described e.g. in /1/, taking into account the available resources. Sensory evaluation methods based on costly and laborious scale calibration of human subjects or using an untrained panel of 40 subjects for each test are not practical for routinely performed labelling tests. For material labelling purposes the test method must be simple and reliable enough.

3. Sensory evaluation in material labelling systems

Voluntary, national building material labelling systems are in use, e.g., in Finland, Denmark, Norway and Germany. The systems are aiming at increased indoor air quality by promoting the use of low emitting building products.

Typically the indoor air labelling systems of building products set requirements for the odour of the product and the emissions of chemical compounds. The two variables of the chamber air odour to be evaluated are in most cases acceptability and intensity. Odour acceptability is evaluation of perceived air quality. Odour intensity describes how strong the odour is.

The Finnish building material labelling system (first established in 1995 and revised in 2000) has three categories with M1 representing low emitting materials /2/. Materials are labelled according to the chemical and sensory emissions measured after 4 weeks. The labelling criteria in different M-classes (test specimen age 28 days) are shown in Table 1.

Table 1. The Finnish building material classification requirements of different emission classes /2/.

	M1	**M2**	**M3**
TVOC, µg/(m²h)	<200	<400	≥ 400
Formaldehyde, µg/(m²h)	<50	<125	≥ 125
Ammonia, µg/(m²h)	<30	<60	≥ 60
Sensory assessment, percent of unsatisfied	<15 %	<30 %	≥ 30 %
Carcinogens IARC group 1	<5 µg/(m²h)		

Denmark published its Indoor Climate Labelling (ICL) –scheme at the beginning of 1990. Norway joined the ICL in 1998. ICL is based on indoor-relevant time-values determined for building materials on the basis of chemical emissions. Indoor-relevant time value for a product is determined as the time it takes from the slowest emitting individual chemical substance with the lowest indoor-relevant odour or irritation threshold to reach half of this threshold value in a fictive standard room /3/. If the declared time value is 10 days it means that the probability of the product to cause odour or irritation in eyes, nose and upper respiratory passage is insignificant after 10 days from installation of the product.

Maximum time-values for different product areas are given in specific product standards. To get the label the indoor-relevant time-value of a product must be shorter than the maximum time-value given for that specific product area. The product must also pass a sensory test (intensity and acceptability), which is carried out at the time corresponding to the time-value based on chemical testing.

In the Finnish, Danish and Norwegian labelling systems a CLIMPAQ /4/ or similar small chamber is used for the sensory assessment.

Germany has several different labelling systems, e.g. a GuT system for carpets /5/, an EMICODE® /6/ system for flooring products (such as adhesives, levelling compounds, primers and underlies), under Blue Angel ecolabel RAL UZ 38 for wood and wood-based products, and Health-related evaluation of construction products /7/.

The labelling criteria of GuT (the Association of Environmentally-Friendly Carpets) include chemical emissions and odour testing. The olfactory method for textile floor coverings tries to simulate the odour development at increased temperatures (direct exposure to sunlight, floor heating). For this purpose, a sample is thermostated in a desiccator at 37 °C and 50 % relative humidity. After conditioning the team of test persons specially trained for this method will individually assess the resulting odour development and will try to define the type of odour as well as the intensity and the overall impression. It is the primary objective of such an odour test to ensure a clear distinction between acceptable new-product odour and unacceptable odour formation.

The EMICODE® labelling and the emission part of RAL UZ 38 eco-label are based on chemical emissions only and do not include sensory tests.

Committee for Health-related Evaluation of Building Products in Germany (AgBB) has developed a method to be used to satisfy the hygiene and health requirements of the Construction Products Directive 89/106/EEC /9/. The evaluation method, called Health-related Evaluation of Construction Products, is based on both chemical and sensory testing. However, for the time being, no criterion is set for the sensory evaluation, because of the lack of a generally approved sensory testing method.

ECA (European Collaborative Action) is a scientific network working in the field of urban air, indoor environment and human exposure. ECA WG10 has published a proposal for the evaluation of VOC emissions from building products - focusing on solid flooring materials /10/. The evaluation procedure is based on chemical emissions and sensory evaluation. The proposed sensory method includes two steps: testing of sensory irritation and testing of odour or perceived air quality. The selection of sound test design and choosing the measurement method is left to the authority/labelling body. As general requirements for sensory emission tests minimum airflow and test specimen area is given. A panel size of 10–15 is recommended.

4. Sensory evaluation versus chemical emissions

Chemical compounds emitting from a building material are responsible for the typical smell of the product. It could be concluded that by determining the chemical emissions and using the odour threshold values and odour characteristics of single compounds the smell of the product could be predicted. So far this has not been possible due to the fact that human perception of smell is unique to each individual and the human hose is far more sensitive than any of the analytical instruments when odorous substances are to be detected.

Figure 1 shows the scatter plot of the specific emission rate of total volatile organic compounds, SER_{TVOC}, of 391 building materials in relation to acceptability /11/. For the whole data set there is a very weak negative correlation (Pearson correlation factor -0.16 with confidence level of 0.002) between SER_{TVOC} and acceptability.

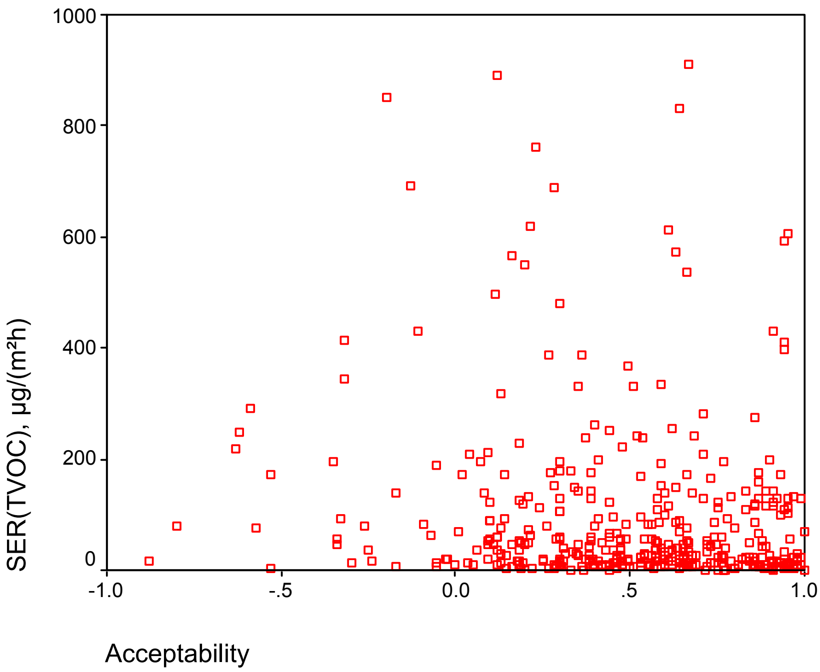

Figure 1. Relation between SER_{TVOC} and acceptability of 391 building materials measured after 28 days.

The correlation between SER_{TVOC} and acceptability in the TVOC emission level higher than 200 µg/(m²h), which is the TVOC limit of the Finnish M1 label, the Pearson correlation factor between TVOC emission factor and acceptability is 0.02 with p-value 0.87.

The poor correlation between SER_{TVOC} and acceptability is demonstrated in more detail in Figure 2 for 82 screeds and plasters, measured at the age of 28 days at VTT. Even within one material group the SER_{TVOC} and acceptability may have large differences.

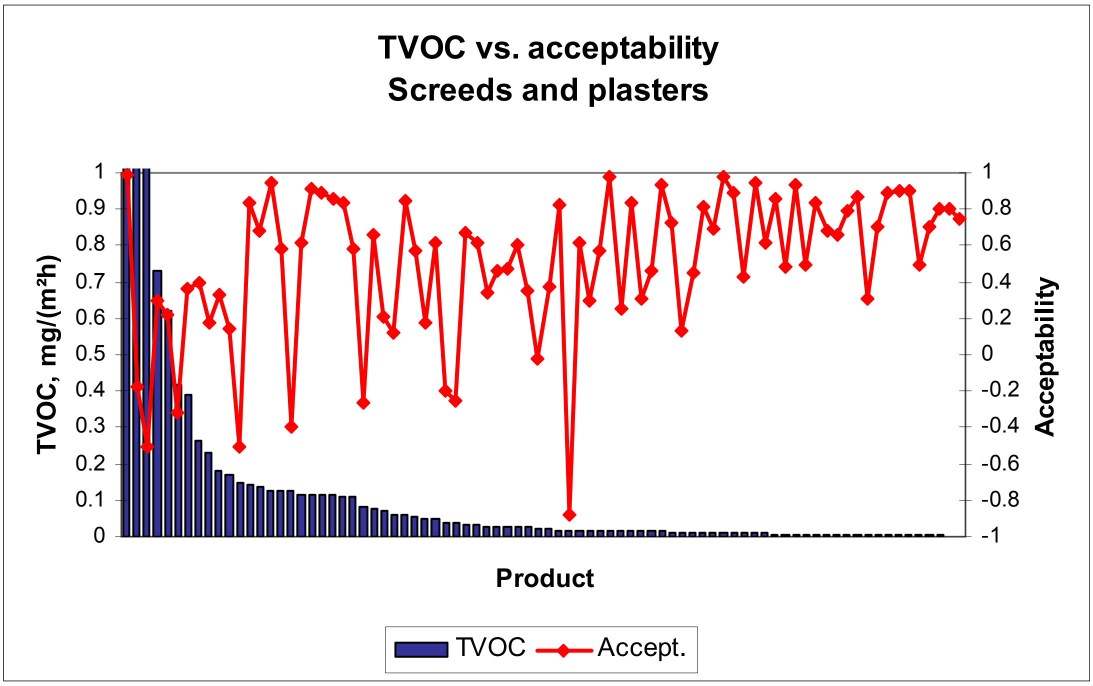

Figure 2. SER_{TVOC} and sensory acceptability of screeds and plasters after 28 days.

TVOC is a measure indicating the level of VOC emissions. Depending on the material it may consist of only few up to more than hundred single VOC compounds. From the 82 screeds and plasters single VOCs exeeded the detection limit in 70 products. In these cases the single VOCs analysed in the emissions showed no statistically significant correlation with sensory acceptability value, as shown in Table 2. The correlation between single VOCs and acceptability was also tested for 59 PVC flooring materials and 34 parquets. The correlation was analysed separately for these material groups, because most of the products have their own relatively characteristic odour and it was tested, if that odour could be attributed to single compounds.

Table 2. Statistical significance of correlation between sensory acceptability value and single VOC compounds detected in the emissions of screeds and plasters. N refers to the number of cases in which the compound has been analysed. The total number of products is 70.

	Sig. (2-tailed)	Pearson Correlation	N N_{tot} =70
Tridecane	0.06	0.43	20
Benzoic acid	0.15	-0.47	11
2-Phenoxyethanol	0.16	-0.55	8
2,2,4-Trimethyl-1,3-pentanedioldiisobutyrate	0.18	0.38	14
Benzaldehyde	0.19	0.31	20
Trimethyldodecane	0.22	-0.40	11
Tetradecane	0.30	0.23	22
Nonanal	0.31	0.18	34
Decanal	0.37	0.18	26
Benzyl alcohol	0.42	0.36	7
1-Hexanol, 2-ethyl-	0.54	-0.24	9
Hexamethylcyclotrisiloxane	0.56	-0.17	14
Octamethylcyclotrisiloxane	0.59	-0.22	8
Pentadecane	0.61	0.14	16
2,6-di-tert-Butylquinone	0.76	-0.10	12
1,2-Propanediol	0.83	0.07	13
2-(2-butoxyethoxy)ethanol	0.85	-0.06	13
Toluene	0.88	0.07	7

Statistical analysis of correlation between single VOC compounds and sensory assessment values confirms that it is not practical to try to evaluate the odour acceptability of a building material on the basis of its emission profile. Knudsen et al. also showed that building products continue to affect the perceived air quality, even when the concentrations of selected odour intensive primary VOCs were well below their respective odour thresholds /12/.

Measurement of chemical emissions only does not give enough information to characterize the impact building materials have on indoor air quality. We do not measure or detect all possible compounds that may be present in the emissions and which may affect the sensory acceptability of the product. Our knowledge of the interaction of odours of single compounds is also very limited. Sensory evaluation must be performed separately using human subjects as detectors as chemical measurements can not substitute human olfaction system, which processes the chemical stimulus resulting to a personal response. Of the 391 materials in Figure 1, 344 fulfilled the Finnish M1 TVOC criterion. Of these 344 materials 18 % of these would have failed the corresponding sensory acceptability requirement.

5. Emission measurement and sensory evaluation of selected materials using two different types of chambers

Emissions of chemical compounds from building materials are determined using emission test chambers. Emission test chamber is defined as an enclosure with controlled operational parameters for determining compounds emitted from building products /13/. The operational parameters include test conditions (air exchange, temperature, humidity and air velocity) and test specimen area, which are selected to simulate model room conditions (Table 3).

Sensory evaluation of building materials is based on the use of human subjects as detectors. The chamber technique methods used today are based on the use of small 50 - 200 litre chambers equipped with a diffusor, Figure 3. Nordtest method NT Build 482 /4/ describes a 50.9 litre glass chamber (CLIMPAQ, Chamber for Laboratory Investigations of Materials, Pollution and Air Quality), which can be used for both chemical and sensory evaluation of materials. CLIMPAQ is widely used for sensory testing of materials in the Nordic countries.

Figure 3. Example of a diffusor-equipped test chamber for sensory testing of building materials.

For materials with a relatively constant emission rate over the test period the emission test chamber concentration depends on the area specific airflow rate /14/, which is selected as a parameter in designing the emission test conditions. In many European countries the minimum floor area of a room is 7 m^2, the room height 2.4–2.5 m and the air exchange rate 0.5 h^{-1}. This is considered to be a model room /15/.

The relationship between the airflow rate, test specimen area, loading factor and air exchange rate is /4/:

$$q = \frac{Q}{A_{ts} \cdot x} = \frac{n}{L} \tag{1}$$

where

q = area specific airflow rate	[m³ h^{-1} m^{-2}]
Q = airflow rate	[m³ h^{-1}]
A_{ts} = area of one test specimen	[m²]
x = number of test specimens	
n= air exchange rate	[h^{-1}]
L = loading factor	[m² m^{-3}]

Using the equation above, the loading factors and area specific airflow rates in a model room are given in Table 3.

Table 3. Examples of area specific airflow rates in a model room /4/.

Model room 17 m^3, n = 0.5 h^{-1} Surface area, A		Loading factor L [m² m^{-3}]	Area specific air flow rate, q m^3/(m^2 h) or n/L
Floor/ceiling	7 m²	0.41	1.2
Wall	24 m²	1.41	0.4
Door	2 m²	0.12	4.2
Window frames	0.2 m²	0.012	42
Sealants	0.2 m²	0.012	42

When using diffusor-technique for the sensory evaluation of the chamber air, the airflow rate coming out from the diffusor is recommended to be 0.9 l/s (3.24 m³ h^{-1}) /4/. This is to ensure that even when taking a deep breath the test person only breaths the air coming out from the chamber and the chamber air is not diluted with the surrounding air. This airflow is higher than the airflow rate traditionally used for emission testing in small-scale test chambers, i.e. chambers smaller than 1–2 m³, in which the air exchange rates of 0.5 h^{-1} or 1 h^{-1} are used.

When the supply airflow rate in the chamber is set at 0.9 l/s for sensory assessment, specimen areas required for different types of materials, obtained using Equation 1 and corresponding to an air change rate of 2 h^{-1}, are shown in Table 4 /4/. Air change rate 2 h^{-1} is selected because air change rate 1 h^{-1} would result in too large test specimen areas for e.g. wall materials to be inserted is a small test chamber /2/.

Table 4. Test specimen areas for sensory testing /4/.

	Air change rate 2 h^{-1}		
	Model room	Test chamber	
Material type	Area specific flow rate q=n/L [$m^3/(m^2 h)$]	Supply air flow rate, Q, [l/s]	Test specimen area, [m^2]
Floor/ceiling	4.76	0.9	0.68
Wall	1.42	0.9	2.28
Door	16.7	0.9	0.19
Sealats	167	0.9	0.019
Window frames	167	0.9	0.019

When using small, 50–200 litre chambers for sensory assessment of building materials the test specimen area of wall and floor/ceiling material required, even with air change rate 2 h^{-1}, is relatively high compared to the chamber volume. Required loading factors are in practice possible only for thin materials.

For the time being the sensory assessment of building materials in, e.g. the Finnish building material classification, is made using small chambers with supply air and test specimen target areas given in Table 5. A frequently encountered problem is that the tested material is so thick that the required test specimen area in the chamber can not be reached. To overcome the problem a 5-m^3 chamber was built at VTT Building and Transport. The purpose was to set up testing conditions, which can be used for both chemical testing and sensory assessment for a broad variety of building materials and even for furniture. The basic idea was that sensory assessment is made for the same test specimen and under same test conditions that were used for the chemical measurements.

Materials considered most suitable for chemical emission test chambers are polished stainless steel and glass /13/. The best material for sensory assessment chambers is glass. As glass was not considered a practical material to build a 5-m^3 chamber, four types of stainless steel plates and anodised aluminium were tested for their chemical emission and sensory properties. When regarding chemical emissions, all tested materials were low emitting and hence suitable for chemical emission testing. More variety was observed in the sensory assessment values as shown in Table 5. Electropolished stainless steel was assessed as most acceptable of the tested materials and selected as the 5-m^3 chamber material. Sorption characteristics of the materials were not tested.

Table 5. Sensory evaluation of four different stainless steel samples and anodised aluminium as potential emission test chamber materials.

Material	Without baking		After baking at 250 °C	
	Acceptability	Odour description	Acceptability	Odour description
Steel AISI 304, untreated	+0.24	Metallic	+0.86	Nearly odourless
Steel AISI 316, untreated	+0.71	Acceptable	+0.93	Nearly odourless
Steel AISI 316, mechanically polished	+0.65	Metallic	+0.95	Odourless
Steel AISI 316, electropolished	+0.81	Metallic	+1.0	Odourless
Anodised aluminium	+0.69	Acidic	-0.06	Pungent, acetic acid

5.1 Big chamber

In this project an electropolished stainless steel chamber of 5 m³ was built (width 120 cm, height 180 cm, depth 230 cm), Figure 4. The chamber was designed to enable both chemical measurements and sensory assessment to be performed using the test conditions traditionally used for chemical testing, i.e. material loading shown in Table 2 and air exchange of 0.5 h^{-1}. Instead of a diffusor, a hood is used in the sensory assessment. The hood is used because with the 5-m³ chamber having air exchange rate of 0.5 h^{-1} the supply air flow rate is 0.7 l/s instead of 0.9 l/s required for the diffusor.

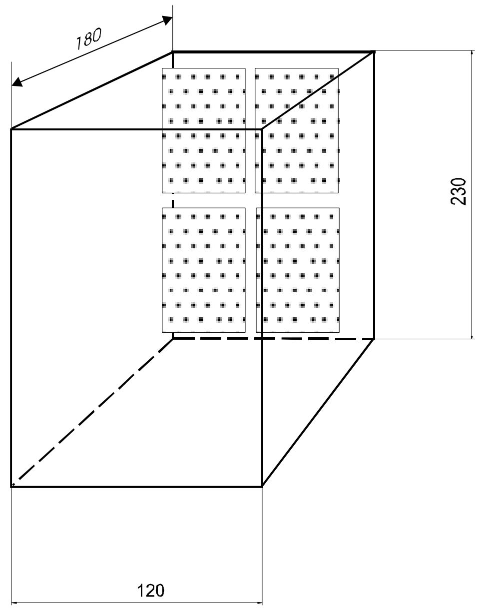

Figure 4. 5-m³ stainless steel chamber for emission testing.

6. Test arrangements

To compare the performance characteristics of the 5-m³ chamber with the conventional chambers six different materials were tested both in 1-m³ chamber, sensory assessment chamber and in the 5-m³ chamber. Illustration of the test procedure is shown in Figure 5. The sensory assessment chamber used for the comparison was a 100-litre aluminium chamber, which was operated according to the principles given in Nordtest method NT Build 482 /4/, i.e. using loading factors and air flow rates given in Table 3. The 1-m³ chamber and the 5-m³ chamber were operated with air change rate of 0.5 h^{-1} and loading factor of 0.4 m²/m³ for flooring materials and 1.4 m²/m³ for wall material.

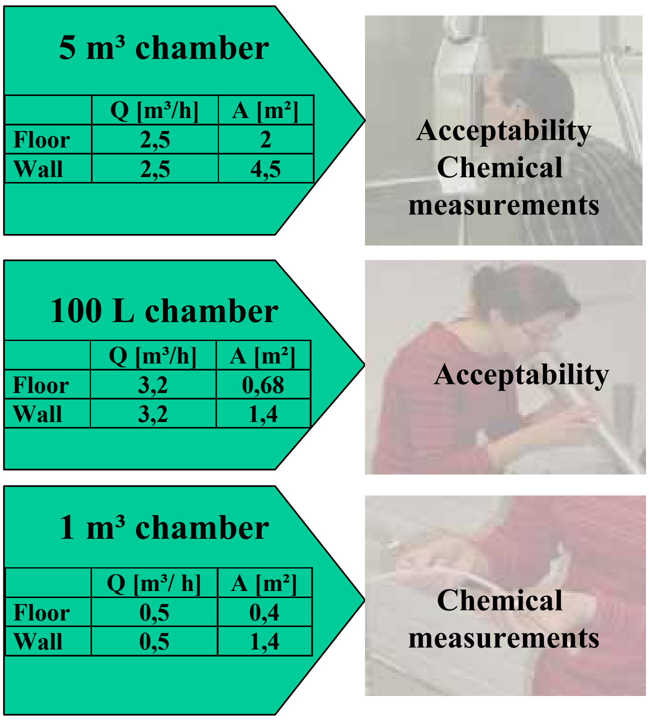

Figure 5. Test procedure to validate the sensory and chemical measurements made by the 5-m³ chamber.

The tested materials, selected to represent different odour characteristics, were:

- Linoleum
- PVC
- Pine floor boards, untreated, 26x138x2000 mm
- Water-based paint on gypsum board
- Parquet, lacquered oak, 15x200x2423 mm
- Heat-treated pine, floor board 26*68 mm.

All the materials were purchased from retailers. Test specimens from linoleum and PVC were made by covering the reverse side of the material with aluminium foil and low emitting aluminium tape. Pine floorboards and parquet were joined together with tongue-and-groove joint without glue. Reverse side of these test specimens was covered with aluminium foil. The gypsum board was roller-painted in laboratory using water-based paint. Reverse, non-painted side of the board was covered with aluminium foil. Heat-treated pine was tested as separate boards with one side covered with aluminium foil. Emission tests and sensory assessment were performed for test specimens aged 3 days and 4 weeks. Right after the test specimens were prepared they were placed in the emission test chamber except the painted gypsum board. The gypsum board was painted twice and, after the second layer was applied, the paint was allowed to dry overnight in normal room conditions before the specimens were placed into the chamber for the first measurement.

The area specific airflow rates during the tests are shown in Table 6.

Table 6. Area specific air flow rates in different chambers during the tests.

Material	Area specific air flow rate, $m^3/(m^2\,h)$		
	Sensory assessment chamber	1 m^3 chamber	5 m^3 chamber
PVC	4.6	1.2	1.0
Linoleum	4.8	1.2	1.0
Parquet	4.7	1.1	1.0
Pinewood flooring	4.6	1.2	1.1
Heat-treated pine	4.6	1.2	1.0
Painted gypsum board	2.2	0.4	0.5

After the 3-day measurements the test specimens were removed from the chambers and stored in a climatised room in temperature of 23 ± 2 °C and relative humidity of 50 ± 5 %. For the second measuring point at the age of 4 weeks (28 days) the test specimens were closed into the chambers three days before the actual time of chemical sampling/sensory evaluation.

7. Chemical emissions

The performance characteristics of the 5-m³ chamber on chemical emission testing were evaluated by comparing the emission test results with those obtained using 1-m³ chamber. Chemical emissions included volatile organic compounds, (VOC), ammonia and formaldehyde. VOCs were sampled on Tenax TA® adsorbent and analysed with gas chromatograph after thermal desorption. The chromatograph is equipped with two capillary columns and a mass spectrometer (MS) and a flame ionisation detector (FID). Single compounds were identified from the MS total ion chromatogram using a commercial spectrum-library. FID response was used to quantify the compounds as toluene equivalents. TVOC, Total volatile organic compounds, was calculated from the FID total area between hexane - hexadecane (these compounds included) as toluene equivalents.

Ammonia and formaldehyde were absorbed in dilute sulphuric acid using impinger technique. Ammonia was analysed using ammonia-specific electrode. Formaldehyde was analysed spectrophotometrically with acetylacetone-method. The results of the chemical emission tests are summarised in Table 7.

Table 7. The specific emission rates of TVOC (total volatile organic compounds), ammonia and formaldehyde measured from the six test materials using 5-m³ and 1-m³ chamber.

Material	TVOC, µg/(m²h)			
	3 days		4 weeks	
	1 m³	5 m³	1 m³	5 m³
PVC	82	84	42	39
Linoleum	185	193	20	52
Parquet	132	128	133	86
Pinewood	1180	1110	1620	856
Painted gypsum board	103	98	15	14
Heat-treated pine	113	191	102	137
	Ammonia, µg/(m²h)			
	3 days		4 weeks	
	1 m³	5 m³	1 m³	5 m³
PVC	<5	<5	<5	<5
Linoleum	<5	<5	<5	<5
Parquet	<5	<5	<5	<5
Pinewood	<5	<5	<5	<5
Painted gypsum board	67	89	<5	<5
Heat-treated pine	<5	<5	<5	<5
	Formaldehyde, µg/(m²h)			
	3 days		4 weeks	
	1 m³	5 m³	1 m³	5 m³
PVC	<5	<5	<5	<5
Linoleum	8	7	<5	<5
Parquet	8	8	7	10
Pinewood	9	10	6	7
Painted gypsum board	7	8	<5	<5
Heat-treated pine	<5	<5	5	<5

The emissions from PVC, linoleum and painted gypsum board were in good agreement measured in 1-m³ and 5-m³ chambers both after 3 days and 4 weeks. Wood based products showed more diversity, especially the pinewood, which showed increasing emissions in the 1-m³ chamber and decreasing emissions in the 5-m³ chamber. The emission measurements for the pinewood after 4 weeks were repeated twice to confirm the TVOC emission values reported in Table 7.

After 3 days ammonia was only detected in the emissions from painted gypsum board with emission values of 67 µg/(m²h) and 89 µg/(m²h) in 1-m³ and 5m³ chamber, respectively. The amount of wet paint applied on the gypsum board was 300 g/m² in the 1-m³ chamber and 356 g/m² in the big chamber. The relation between ammonia emission and amount of wet paint applied was 0.22 µg/(g h) for the 1-m³ chamber and 0.25 µg/(g h) for the 5-m³ chamber. After 4 weeks ammonia emission from the tested materials was below detection limit.

Formaldehyde emissions from the tested materials were low and in good agreement between the two chambers at both measuring points.

TVOC is a measure of the total level of VOCs emitting from the material. In the following the emissions measured from different materials are divided in chemical groups, e.g. alcohols, aldehydes and acids to overview the differences between the two chambers. The specific emission rates of single identified VOCs in toluene equivalents are given in Appendix A.

The most abundant compound groups emitting from the PVC are shown in Figure 6. The main compounds emitting from PVC were alcohols (2-ethyl-1-hexanol, benzyl alcohol and phenol). In general the specific emission rates of single VOCs were low and the differences between the two chambers were very small.

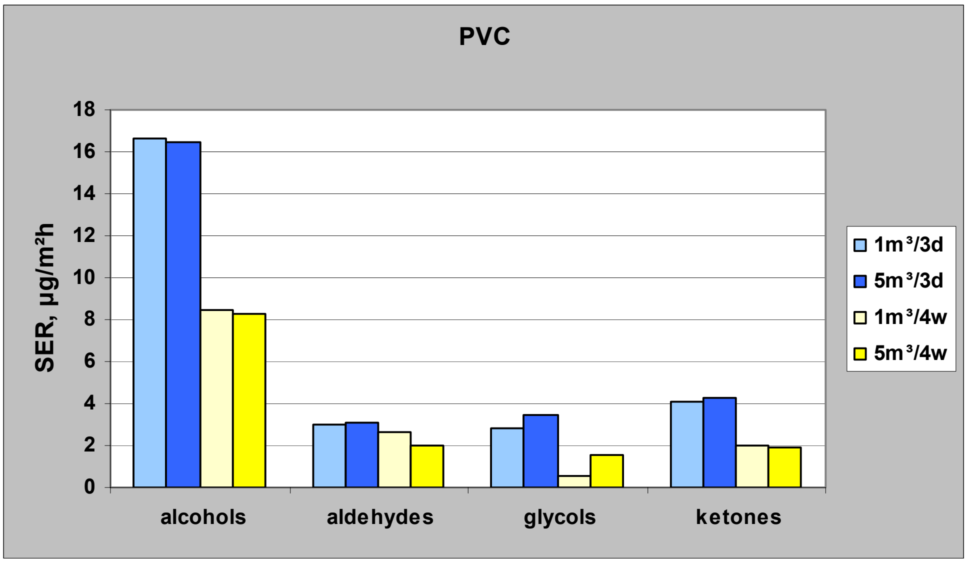

Figure 6. VOC emissions from PVC after 3 days and 4 weeks given as chemical groups and measured using 1-m³ and 5-m³ chambers. SER is given in toluene equivalents.

Typical VOC emissions from linoleum are aldehydes and acids (Figure 7). After three days the linoleum emitted mostly hexanoic acid, propanoic acid and hexanal. In the group of glycols the main compound was 2-butoxyethanol and in the group of ketones 1-methyl-2-pyrrolidinone. The differences in the SERs of single compounds were smaller after 3 days compared to the situation after 4 weeks. After 4 weeks slightly higher emissions were measured from the 5-m³ chamber. This may partly be explained by the few small cracks visually observed on the material surface after the measurements. They may have resulted from handling of the 5-m³ chamber test specimen, i.e. moving it to and from the chamber between the two measurements. It may also indicate the inhomogeneity of the material.

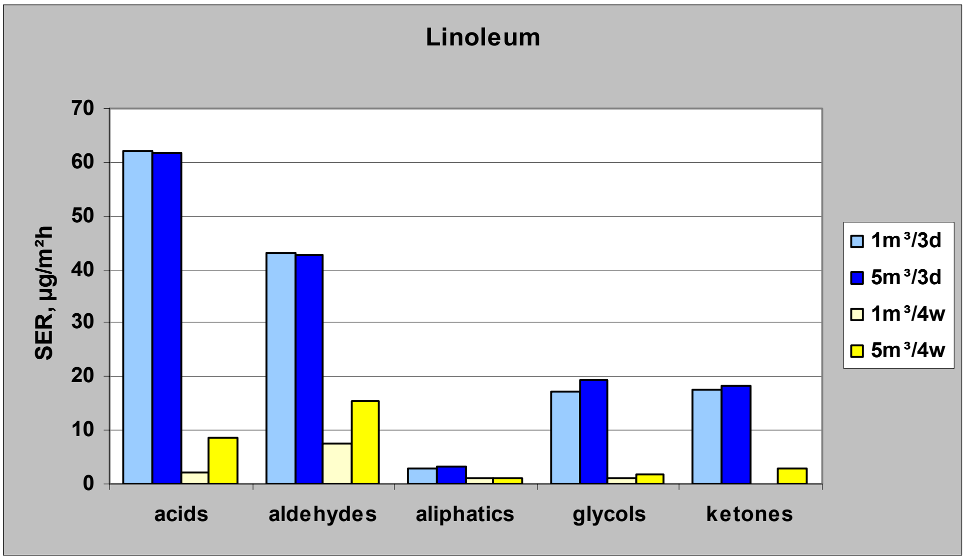

Figure 7. VOC emissions from linoleum after 3 days and 4 weeks given as chemical groups and measured using 1-m³ and 5-m³ chambers. SER is given in toluene equivalents.

The parquet emitted small amounts of aldehydes, mainly hexanal and pentanal, alkylbenzenes, methylcyclohexane and diphenylmethanone. Methylcyclohexane was detected in the emissions only after three days and it most probably originated from the plastic cover that was used in the retail package. The main components in the emissions were terpenes, especially α-pinene and Δ3-carene. The emission levels of chemical groups are shown in Figure 8. The TVOC level measured from the parquet in 1-m³ chamber after 3 days and 4 weeks was 132 µg/(m²h) and 133 µg/(m²h), respectively. In the 5-m³ chamber the TVOC emission decreased from 128 µg/(m²h) after 3 days to 86 µg/(m²h) after 4 weeks. As shown in Figure 8 the emissions of terpenes and aldehydes have increased during the conditioning of the test specimen. The main source for terpenes and aldehydes is the wooden underlayer of the parquet. The test specimens were prepared pushing the joints together and tightening the structure with aluminium tape striped over the bottom of the specimen. This may have resulted in slight, not visually remarkable opening of the joints during the test resulting in increased terpene emissions. Increasing humidity also increases the emissions of terpenes from wooden products. Also this phenomenon may have contributed to the observed increase of terpene emissions.

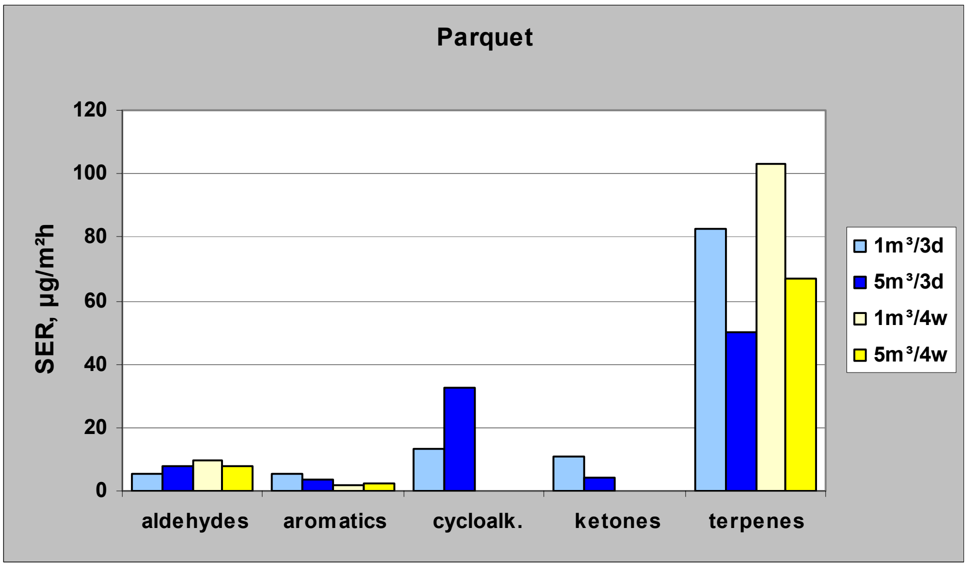

Figure 8. VOC emissions from parquet after 3 days and 4 weeks given as chemical groups and measured using 1-m³ and 5-m³ chambers. SER is given in toluene equivalents.

The test specimen from the pinewood floor planks was made by pushing the joints together without glue. The untreated pinewood floor planks emitted small amounts of pentanal and hexanal, aromatic hydrocarbons (e.g. cymene), methylcyclohexane and high amounts of terpenes (Figure 9). The main monoterpenes in the emissions were α- and β-pinene, Δ3-carene and limonene. As with the parquet methylcyclohexane, detected after 3 days, is suspected to originate from the plastic retail package.

The emissions from the pinewood after 3 days were on the same level in the 1-m³ and 5-m³ chambers. After 4 weeks the terpene (and hence also TVOC) emission measured from the 1 m³ chamber were increased by 40 %. From the single compounds the emission of α-pinene had increased by 26 % (from 810 to 1020 µg/(m²h) and the emission of β-pinene, Δ3-carene and limonene, which after 3 days had SERs of 83, 134 and 253 µg/(m²h), respectively, had increased by 70–80 %. The increase of the emissions from the 1-m³ chamber specimen was confirmed by repeated measurements. There were no visible differences between the tested specimens, e.g. the number of knots/area unit was almost equal in both 1-m³ and 5-m³ chamber specimens. The climatic conditions during the testing and conditioning were also identical for both test specimens. Most obvious reasons for the measured differences in the emissions are the very inhomogeneous nature of untreated wood plank samples and the effect of humidity on the emissions from wooden materials.

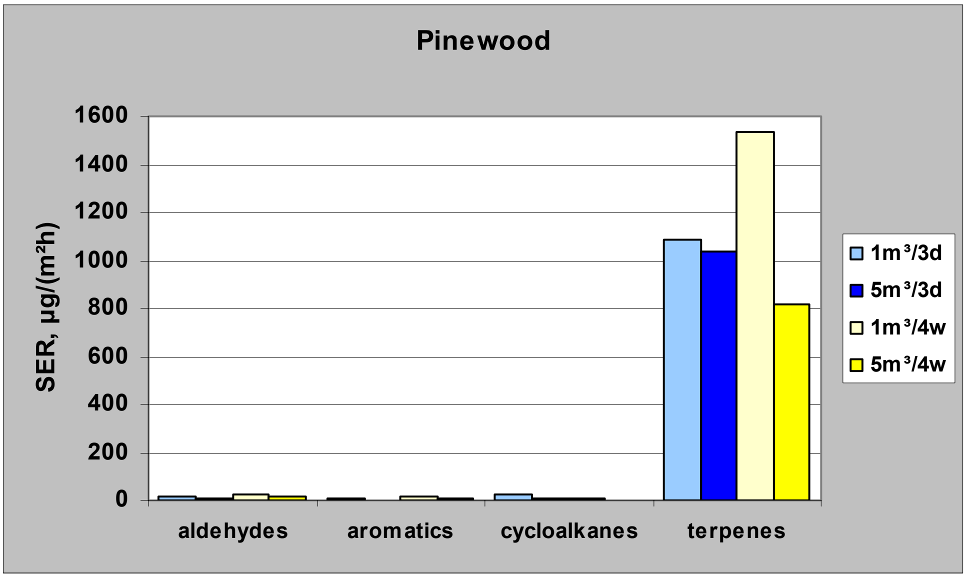

Figure 9. VOC emissions from untreated pinewood floor planks after 3 days and 4 weeks given as chemical groups and measured using 1-m³ and 5-m³ chambers. SER is given in toluene equivalents.

The main VOC compounds emitting from latex-painted gypsum board were aliphatic hydrocarbons (1-dodecene), esters (butyl acetate) and ethers (dibutyl ether. Emission results from 1-m³ and 5-m³ chambers were in good agreement as shown in Figure 10.

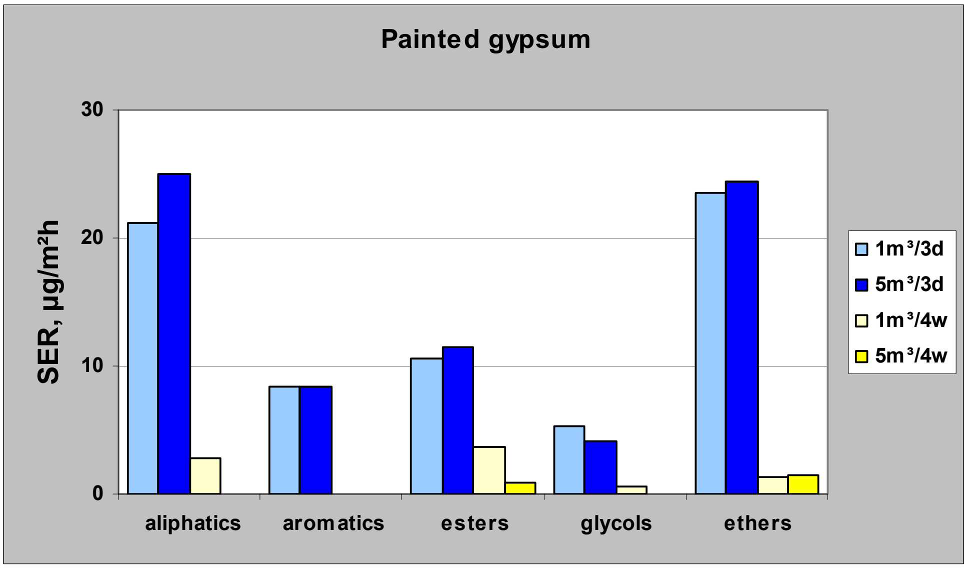

Figure 10. Emissions of VOCs from latex-painted gypsum board after 3 days and 4 weeks given as chemical groups and measured using 1 m³ and 5 m³ chambers. SER is given in toluene equivalents.

Heat-treated pinewood flooring material emitted mainly aldehydes and acids (Figure 11). The most abundant acids were acetic acid and hexanoic acid, and the most abundant aldehydes were hexanal, pentanal and furfural. The emission results measured using the different chambers were in good agreement. The most important factor causing slight differences into the results is most probably the inhomogeneity of the tested material.

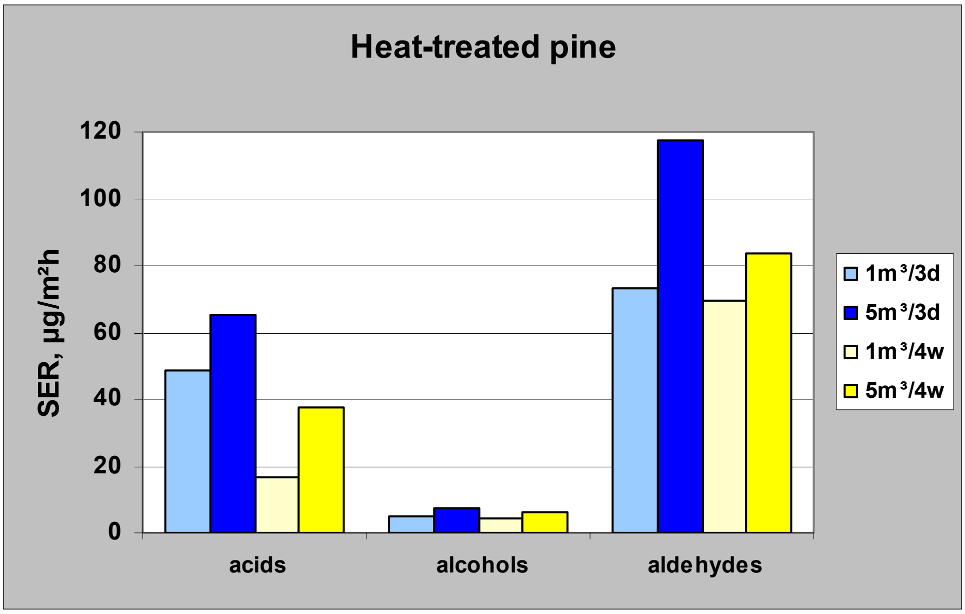

Figure 11. VOC emissions from heat-treated pinewood for interior use after 3 days and 4 weeks given as chemical groups and measured using 1-m³ and 5-m³ chambers. SER is given in toluene equivalents.

8. Sensory evaluation

Sensory characteristics of the 5 m^3 chamber were compared with 100-litre chamber made of anodised aluminium (referred to as 100-litre Al-chamber) equipped with a diffusor. In the small chamber the target loading was 0.68 m^2 for flooring materials and 2.28 m^2 for the wall material (painted gypsum). As the gypsum board (12.5 mm thick) was painted only from one side the test specimen was prepared by joining two boards together with aluminium tape with the unpainted sides facing inside. Five units of 2.5 cm thick test pieces with total surface area of 1.4 m^2 were put in the 100-litre chamber in which the width of the sample section is 30 cm, i.e. for the wall material the target surface area was not reached. The area specific flow rate was not adjusted accordingly, but maintained at 0.9 l/s. In the 5-m^3 chamber the model room loading was used resulting to the target test specimen areas of 1.8 m^2 for flooring materials and 6.4 m^2 for wall materials. In the 5-m^3 chamber the flooring materials were placed on the bottom of the chamber and the painted gypsum was placed against the walls with one test piece on the bottom of the chamber. In the Al-chamber the test specimen were placed in an upright position with the long side parallel to the airflow direction.

The sensory evaluation was made according to the instructions given in the Finnish Classification of Building Materials: Protocol for Chemical and Sensory Testing of Building Materials, which follows the general principles used internationally with untrained panels. According to the protocol the panellist is asked to imagine that he/she in the working environment would be exposed to the air similar to that coming out of the chamber. The evaluation is made using the acceptability scale -1 (clearly unacceptable) ... +1 (clearly acceptable) with +0.1 corresponding to just acceptable and -0.1 to just unacceptable, Figure 12 /2/:

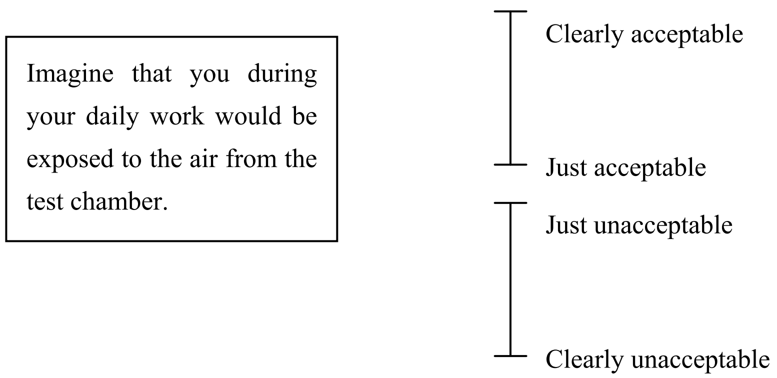

Figure 12. Continuous acceptability scale used for sensory evaluation of building materials /2/.

An untrained panel of 7–12 persons was used in each assessment session. The panellists were personnel of VTT and all of them were already familiar with the test method used and no specific training was considered necessary. During each of the assessment session the panellists evaluated the exhaust air from the 100-litre Al-chamber and the 5-m^3 chamber, which contained test specimens made of the same material, e.g. PVC. They were given the sensory assessment form and asked to assess the air from each of the two chambers in random order and to fill in separate forms for each chamber. Each panellist made two successive assessments from both chambers with a small, 1- to 2-minute break between assessments. As the main focus was to compare the two chambers (100-litre Al-chamber and 5-m^3 chamber) the panellists were not asked to evaluate an empty chamber. During each session only one material at certain age was to be evaluated. This resulted in total 12 separate assessment sessions as six materials at two age points were evaluated.

In the sensory assessment form the odour of the chamber air may be described using given alternatives. The present given alternatives in the form can be divided into three categories: degree of acceptance (pleasant, good, acceptable, satisfactory, unpleasant, unbearable), easily recognised odour types (woody, metallic, sweet, odourless) and others, even more subject to personal interpretation (fresh, humid, dry, heavy, stuffy, pungent). Each panellist may choose as many descriptive alternatives as needed to describe the sensory sensation caused by the odour of the tested material.

It was impossible to use the same group of voluntary panellists for all the consecutive assessment sessions. This means that for the materials the same group of panellists could not be used to perform the assessment after 3 days and 4 weeks. In total 37 different panellists attended the 12 assessment sessions arranged during the time interval of September – December 2002. 19 of them attended only one session and seven panellists attended in more than six sessions. The panellists were not selected according to e.g. gender or smoking habits.

9. Sensory evaluation results

9.1 Mean acceptability

Summary of the acceptability values determined using 100-litre Al-chamber and 5-m³ chamber are shown in Figure 13. Each bar represents the mean value of reported acceptability values and the error bar gives the 95 % confidence level of the mean value.

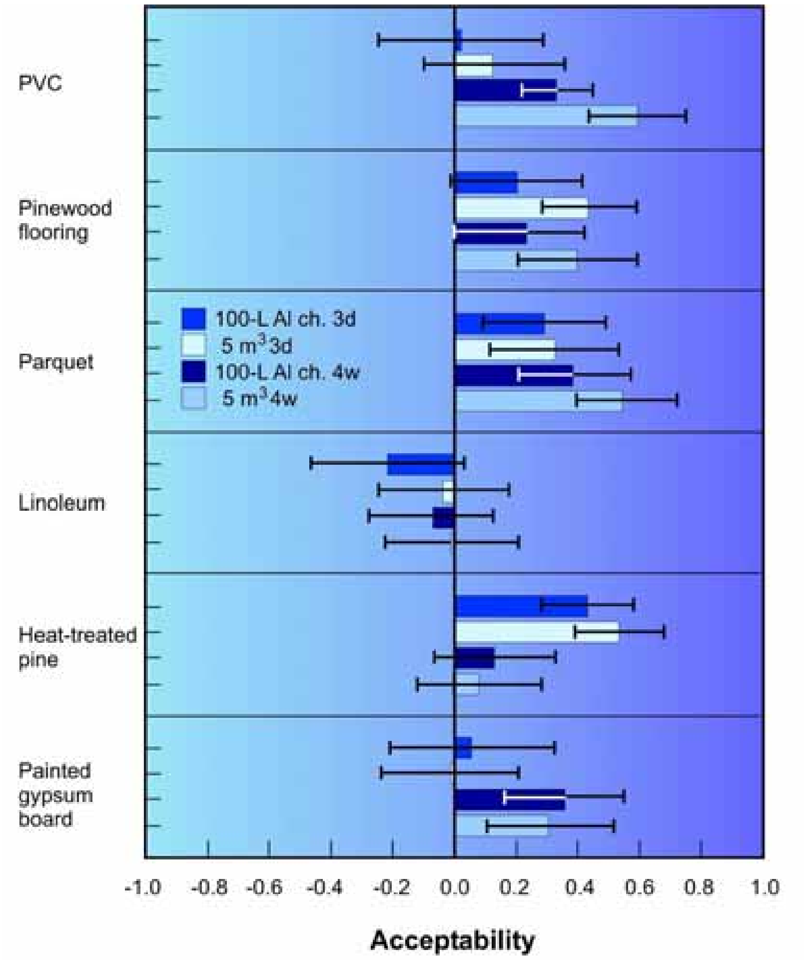

Figure 13. Sensory evaluation of tested materials using 100-litre Al-chamber and 5-m³ chamber.

The number of panellists in each session was:

Material	Number of panellists	
	After 3 days	After 4 weeks
PVC	10	10
Linoleum	7	10
Parquet	12	10
Pinewood	10	8
Painted gypsum board	10	8
Heat-treated pine	11	8

In most cases the mean acceptability value was slightly higher when tested using the 5-m³ chamber compared to the small chamber. The differences in the acceptability values between the chambers are shown in Figure 14. Highest differences were obtained for PVC after 4 weeks and for linoleum and pinewood after 3 days. Due to the relatively small differences, the decision of acceptance in the Finnish M 1 classification will be the same in all cases after the sensory tests made in either the small or large chamber.

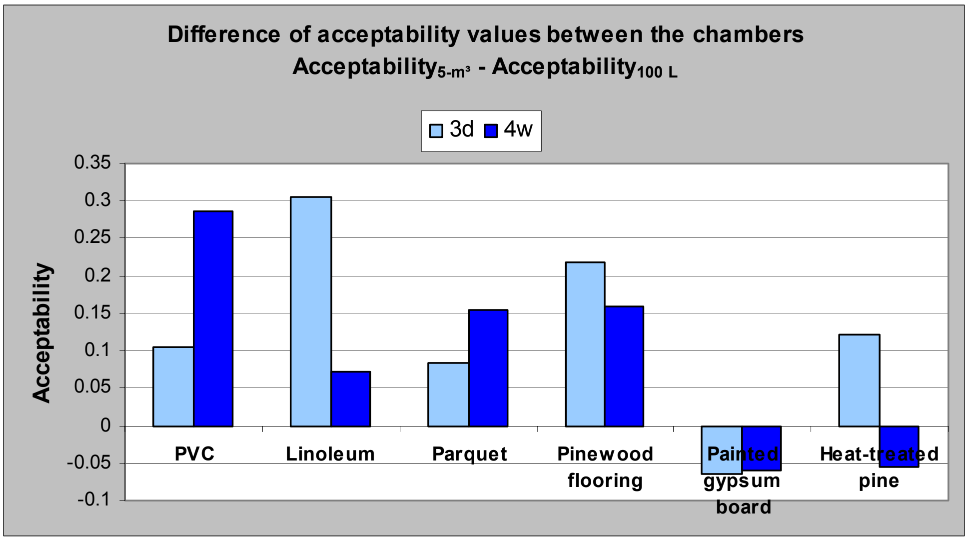

Figure 14. Difference of the mean acceptability values obtained using 5-m³ chamber and 100-L Al-chamber. The difference is positive for those materials for which the mean acceptability value for 5-m³ chamber was higher than for the 100-L chamber.

The PVC was evaluated as more acceptable when assessed from the 5-m³ chamber compared to the Al-chamber both after 3 days and 4 weeks. The odour of the PVC was commented to be more realistic in the big chamber compared to the odour in the small chamber and it gave an idea of a real space with new PVC-flooring.

The odour of linoleum is very characteristic. The sensory assessment values for linoleum using acceptability scale are generally quite low and e.g. the average of 10 linoleum flooring materials assessed at VTT after 4 weeks is 0.13. Also in this test the material was assessed weakly not acceptable after 3 days, the values being a little lower for 100-liter Al-chamber than for the big chamber. After 4 weeks the difference between the two chambers had decreased compared to previous assessment.

The parquet was assessed as acceptable and the mean acceptability values obtained for the two chambers differed by 0.1–0.2 acceptability units: the air from the 5-m³ chamber was considered slightly more acceptable.

For the pinewood the panellists evaluated the 5-m³ chamber air as more acceptable than the Al-chamber air both after 3 days and 4 weeks. In the 5-m³ chamber the pinewood was also evaluated by the walk-in -method. Compared to the acceptability values assessed using the hood, the air inside the chamber was considered slightly more acceptable the mean values being 0.50 from the hood and 0.66 assessed by being inside the chamber.

The amount of wet paint applied on the gypsum board was 356 g/m² in the 5-m³ chamber and 368 g/m² in the Al-chamber. The area specific airflow rate in the Al-chamber was 2.2 m³/(m²h) instead of 1.4 m³/(m²h) required by the protocol /2/. The airflow was maintained at 0.9 l/s. In spite of this the mean acceptability values assessed from the 100-L chamber were only slightly higher than the values obtained from the 5-m³ chamber. The result is in accordance with the observations made by Sakr et al. /16/. They found that increased dilution by a certain factor improves perceived air quality more than a similar reduction in the area of the air pollution source.

Heat-treated pine was the only material, which was assessed as less acceptable after 4 weeks than after 3 days. Also the chemical emissions increased during that time. This is most probably due to the increased humidity of the material during conditioning.

9.2 Odour descriptions

The odour descriptions given by the panellists for materials aged 4 weeks as percentage of the number of panel members are shown in Table 8.

Table 8. Odour descriptions given by the panellists for materials aged 4 weeks. The number indicates the percentage of panel members attending the corresponding assessment session.

	Percent of panellists, %											
	PVC		Linoleum		Parquet		Pine		Painted gypsum board		Heat-treated pine	
Odour description	5 m^3	100-L	5 m^3	100-L	5 m^3	100-L	5 m^3	100-L	5 m^3	100-L	5 m^3	100-L
pleasant					22							25
good					33	22			25	38		
satisfactory	40	50	30	30	33	78	88	67	38	25	50	63
unpleasant			30	50							25	25
unbearable												
woody	50	50	20	30	67	67	88	67	38	38	100	75
metallic		20				22		22				
sweet	30	30	20	20	22	33	25	44	50	50		38
odourless												
fresh						22			25			
humid	40	30				22						
dry	40	30		40	33	33	25		25	25		25
heavy		30				22						
stuffy	20		40	50		22		22			75	25
pungent			20	40				22				

Most of the materials were primarily described as satisfactory; linoleum and heat-treated pine also as unpleasant. Woody and sweet were also frequently used descriptions for all materials. Woody was a typical description also after 3 days for the odour of all materials except painted gypsum board. In general the differences in the odour descriptions between the chambers were small and the odour descriptions followed the pattern of acceptability evaluations.

In addition to acceptability evaluation and odour descriptions the panellists were also asked what material they thought there was in the chambers. PVC was recognised by two panellists out of ten when rest suggested wooden material. The odour of linoleum is very characteristic and three panellists out of seven recognised the material by odour. The rest of the panellists thought it was some wooden material. Wood based materials were identified by all panellists. Painted gypsum board was also ranked as wooden material by most of the panellists.

At the moment odour descriptions are not utilised in any classification systems. Odour descriptions could be used as an additional tool in evaluating the indoor air impact of materials. Using material orientated descriptions together with the acceptability evaluation the type of annoyance or off-odour of a material can be traced.

9.3 Odour descriptions versus VOCs

In connection with the 5-m³ chamber testing the odour descriptions were also dealt with. As the data from these tests was very limited we decided to use larger database /11/ to test whether there was a correlation between the odour descriptions and volatile organic compounds analysed in the emissions. Results are shown in Table 9.

Table 9. Single VOCs correlating with given odour descriptions.

Odour description	Compound	Pearson Correlation	Sig. (2-tailed)	Frequency of occurance
Fresh	α-pinene Limonene	0.68 0.66	0.01 0.04	27 % 20 %
Metallic	Cyclotetrasiloxane, octamethyl- Ethanol, 2-(2-butoxyethoxy)-	0.97 0.58	0.00 0.01	21 % 24 %
Pungent	Terpinolene Limonene Furfural Acetic acid Decanal Camphene	0.66 0.63 0.53 0.53 0.50 0.49	0.00 0.00 0.00 0.00 0.00 0.01	18 % 25 % 20 % 21 % 60 % 22 %
Woody	Hexanal	0.50	0.00	39 %
Good	Benzoic acid	0.45	0.02	23 %
Heavy	Acetic acid Terpinolene	0.53 0.48	0.01 0.02	17 % 17 %
Stuffy	1-Hexanol, 2-ethyl-	0.46	0.01	21 %

Of these compounds terpenes, α-pinene and limonene, typical compounds detected in the emissions of wood and wood based materials, were recognised in all homes where inhabitants did not have any indoor air related symptoms and who reported fresh and pleasant indoor air quality /17/. When the indoor air was described pungent and unpleasant, the dominant compounds in most cases were aldehydes and carboxylic acids. Also terpenes were recognised in these cases, however, the concentrations were very low. When reporting stuffy air and weekly reported bronchial symptoms, one of the most often recognised compounds was 2-ethyl-1-hexanol, a compound most often analysed in e.g. adhesives and PVC flooring materials, especially as a result of degradation of the material. These indoor air effects of the compounds have been reviewed based on the results obtained in a case-control study of indoor air related health problems. In this national survey correlation between diagnosed health effects and measured indoor air chemical data have been studied /17/.

9.4 Difference between chambers

For the tested materials the differences of the arithmetic mean acceptability values obtained using two different chambers are relatively small. With the current M1 acceptability limit value the selection of the chamber would not have affected the labelling of the materials. Sensory evaluation is based on the subjective judgement of panellists and there is always more or less scattering in the assessed values as shown in Figure 15 in which the two acceptability values given by each panellist are shown for materials after 3 days and 4 weeks.

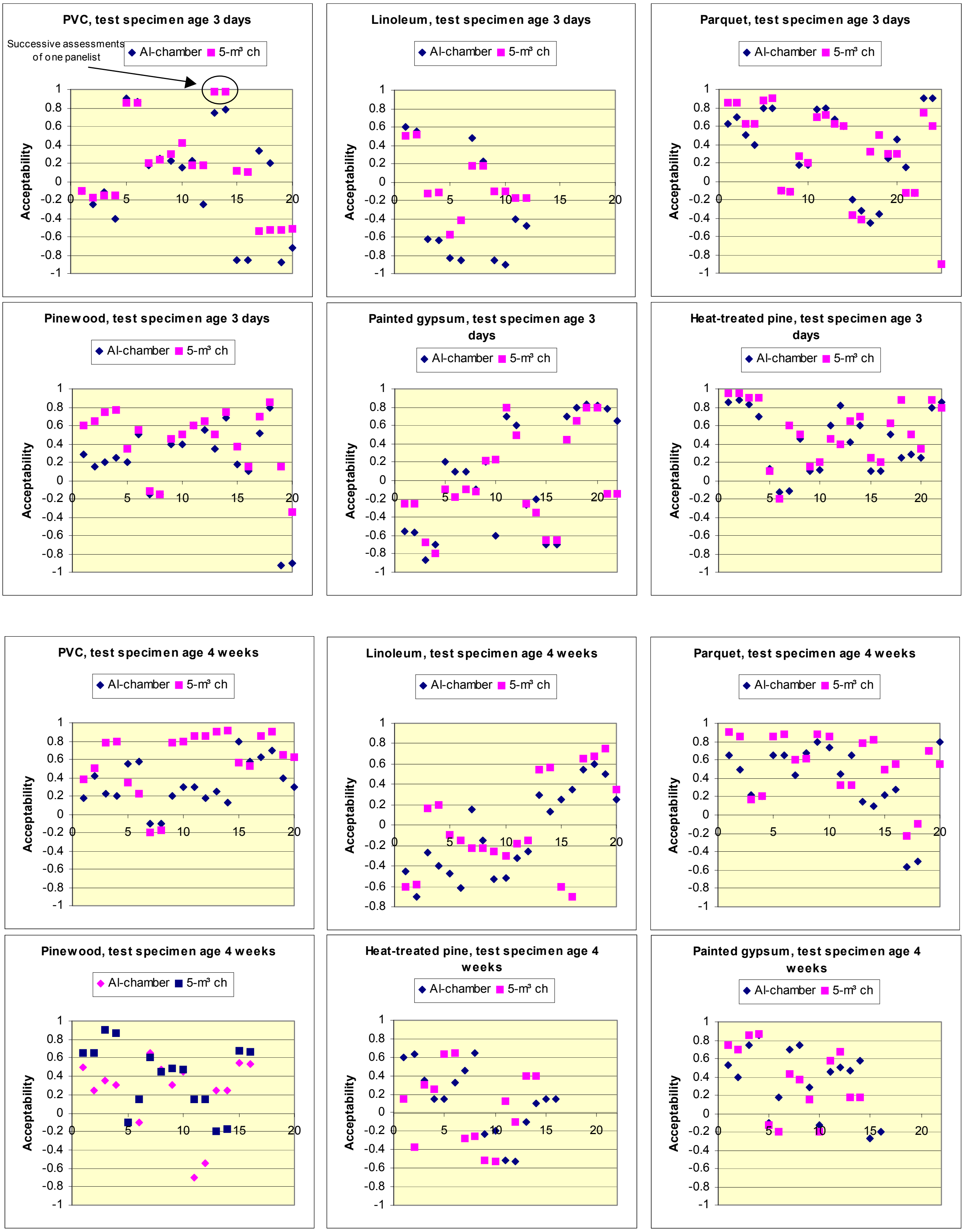

Figure 15. Scattering of single acceptability evaluations for tested materials after 3 days and 4 weeks.

To test whether there is statistically significant difference between the mean acceptability values obtained using the 1-m³ and 5-m³ chambers Wilcoxon signed ranks test (SPSS version 11.0) for the paired acceptability data was made. The results are shown in Table 10. There is a statistically significant difference in the acceptability mean values between the two chambers in case of PVC after 4 weeks and pinewood after 3 days. For the heat-treated pine p-value after 3 days was 0.059 which can be considered as nearly statistically significant.

Table 10. Wilcoxon signed ranks test for each panellist's paired acceptability evaluations from 100-L Al-chamber and the 5-m³ stainless steel chamber.

	Wilcoxon signed ranks test, p-value	
	3 days	4 weeks
PVC	0.093	0.047*
Linoleum	0.116	0.241
Parquet	0.260	0.093
Pinewood	0.005**	0.123
Painted gypsum	0.953	0.575
Heat-treated pine	0.059	0.735

* $p<0.05$

** $p<0.01$

1) Based on positive ranks of the test variable Acc_{5m^3} - $Acc_{100\,L}$,

Acc = mean acceptability of two successive values of each panellist.

10. Summary

Chemical emission values determined after 3 days were in good agreement between the 1-m³ chamber and the 5-m³ chamber for all materials, except for the heat-treated pine, which showed higher emissions in the big chamber compared to the small chamber. For the pinewood in the 1-m³ chamber the emissions after 3 days were 15 % higher than the emissions in the 5-m³ chamber. For other materials the difference in the TVOC values was 2–4 %. The differences characterize the homogeneity of the materials: materials of natural origin, as wood, are much more inhomogeneous than synthetically manufactured materials.

After 4 weeks the PVC and painted gypsum board test specimens showed 8–9 % smaller emission values in the big chamber compared to the 1-m³ chamber. For parquet and pinewood the difference was 55–89 %. Heat-treated pine and linoleum test specimens had higher emissions in the big chamber (26 % and 61 %, respectively). The relative differences for some materials are high due to the low overall emission levels shown in Figure 16. The emission behaviour of the untreated pinewood planks clearly demonstrates the inhomogeneous nature of natural wooden materials. Results of ammonia and formaldehyde emission were in good agreement between the two chambers for all tested materials.

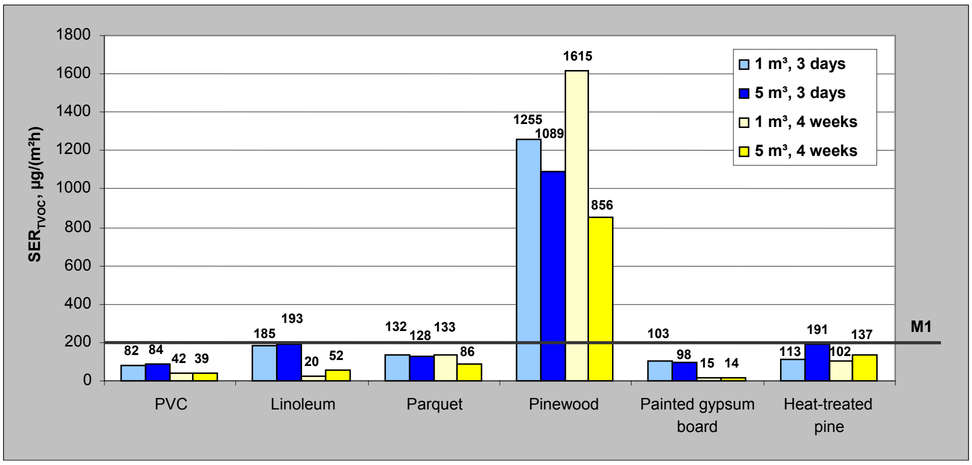

Figure 16. TVOC emission (SER_{TVOC}) of the tested materials in 1 m³ chamber and 5-m³ chamber measured after 3 days and 4 weeks. M1 is the emission limit value (200 µg/(m²h) after 4 weeks) of the best material group in the Finnish material labelling system.

Sensory evaluation of the tested materials was made using acceptability scale and untrained panel. The results are shown in Figure 17 together with the Finnish M1 classification limit for sensory evaluation. The highest difference between the mean acceptability values between the two chambers was 0.3 acceptability units assessed for PVC after 4 weeks. For 4 of the tested materials the odour was considered slightly more acceptable when assessed from the 5-m³ chamber compared to the assessment made from the 100-liter Al-chamber. Painted gypsum board and heat-treated pine (after 4 weeks) were considered slightly less acceptable when assessed from the 5-m³ chamber compared to the 1-m³ chamber.

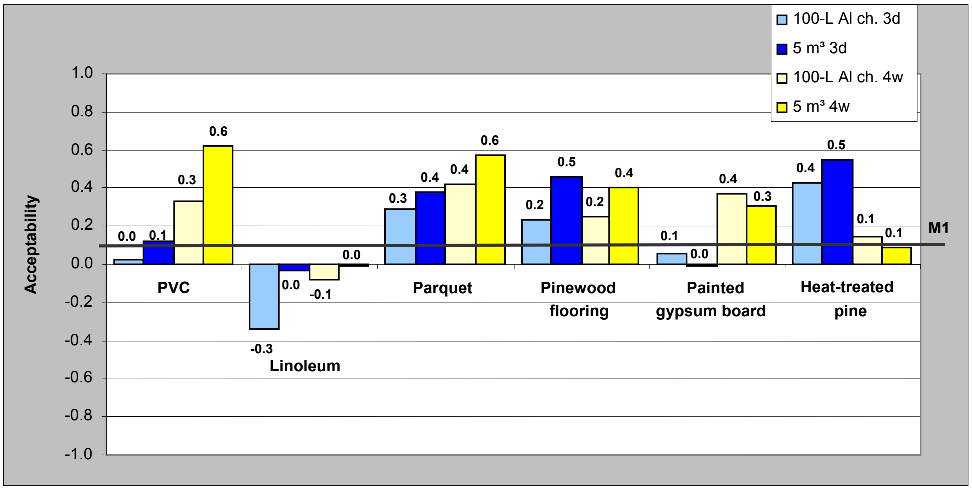

Figure 17. The arithmetic mean acceptability values of the tested material assessed after 3 days and 4 weeks using 100-liter aluminium chamber and 5-m³ stainless steel chamber. M1 refers to the acceptability limit value used in the Finnish material labelling system.

In the Finnish building material classification the requirement for the best material group M1 TVOC emission is 200 µg/(m²h). The limit value for the sensory acceptability is 0.1 acceptability units /20/. For the tested materials the selection of chamber size would not have affected the labelling of the materials.

11. Calculations of the reliability of sensory tests and its use in the labelling of the building materials

The risk connected with the use of small, untrained panels for sensory evaluations can be calculated using the procedure described in standard books of statistics. These risk calculations are based on the use of well-known t-distribution. In the Finnish emission labelling system the risk of making a false decision of 10 % has been chosen and the risk is equal to both parties. Based on numerous measurements carried out in Denmark and Finland, the standard deviation in these sensory tests is lower than 0.6 acceptability units when using acceptability scale from -1 to +1. This means that the accuracy of the mean acceptability is about 0.2 acceptability units when the size of the panel is 15 members, and about 0.4 if the size of the panel is only 5 members. The calculation procedure of the probable error of sensory assessment and the factors affecting it are described in this section.

11.1 Calculation of the probable error

In the calculation of the reliability and the accuracy of the sensory assessment result of an untrained panel the t-distribution may be used. The sufficient previous assumption for it is that the human sensory perceptions are normally distributed. The reliability and accuracy of the t-distribution are handled and presented in many common handbooks of statistics. The use of the t-distribution gives a possibility to use quite small samples with known reliability and accuracy.

The probable error dx may be calculated from the following equation

$$dx = \pm t_{p(n-1)}\, s / \sqrt{n} \qquad (2)$$

where s is the standard deviation of the sample

n is the size of the sample (the size of the panel)

$t_{p(n-1)}$ is t-factor, which is a function of the degrees of freedom (n-1) and the selected risk of making right conclusions

This function is a useful tool and typical for t-distribution. t-factors have been calculated and presented in statistical tables in standard books of statistics. The t-factors have been calculated both for one tailed and two tailed studies. Here the one tailed consideration is selected and reasonable, because we are not interested in the worst cases with very low acceptability values or the best cases with very high positive acceptability values.

In the next Figure the effect of the chosen risk, here expressed as the risk of making a wrong labelling decision, is illustrated. The coefficient k on the y-axis in the Figure 18 is the coefficient of the normal distribution standard deviation (s) in the equation 2.

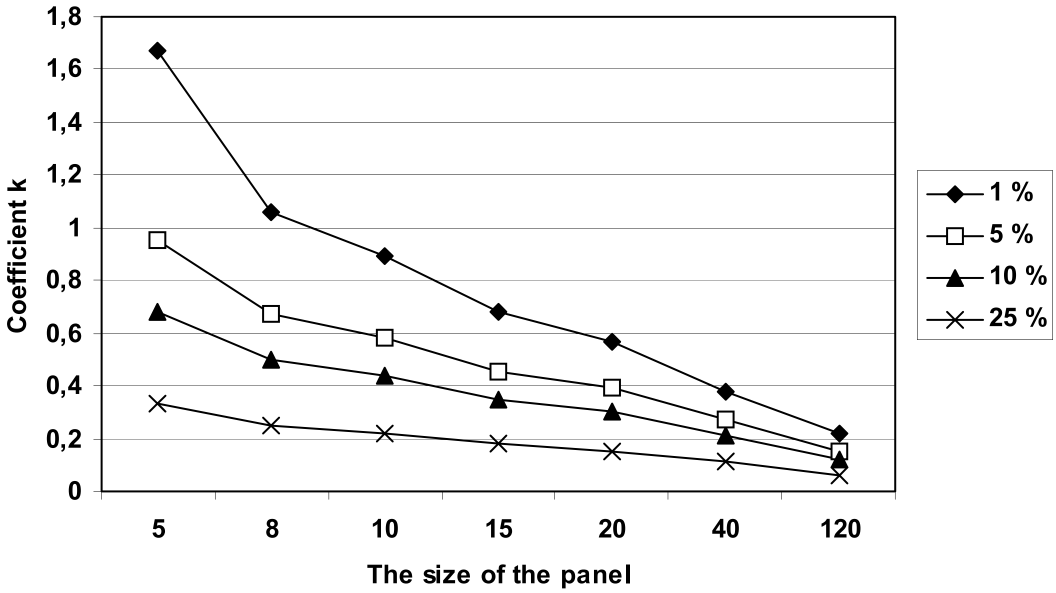

*Figure 18. The dependence of the coefficient k (in y-axis) from the size of the sample size **n** (in the x-axis, axis not linear) and the calculated risk of making a wrong labelling decision (acceptance or rejection). The coefficient k has been calculated using four different risks: 1%, 5 %, 10 % and 25 %.*

From the Figure 18 one may see that the coefficient k is very strongly dependent on the selected level of risk. If the risk of 10 % to make a wrong decision is accepted the coefficient k with the sample size of 15 is below 0.4. With the risk level of 1 % the same coefficient (representing the accuracy) will require bigger sample than 40, i.e. a sensory panel of more than 40 members will be needed.

The risk is symmetrical. The risk that an acceptable product will not be granted a label is equal to the risk that an unacceptable product will be labelled. The risk level is the same for both the producer of the product and the labelling body.

11.2 The standard deviation is known

According to the equation 2 the key factor for the accuracy and reliability of the sensory tests made by an untrained panel is the standard deviation of the odour sensations and acceptance of the measured odour. In the literature there exist results from large series of measurements with untrained panels made in Denmark. In these published results the standard deviation is from 0.4 to 0.6, with lowest values typically in both ends of the acceptability scale, where the judgements are naturally easier and more clearly positive or negative, see Figure 19.

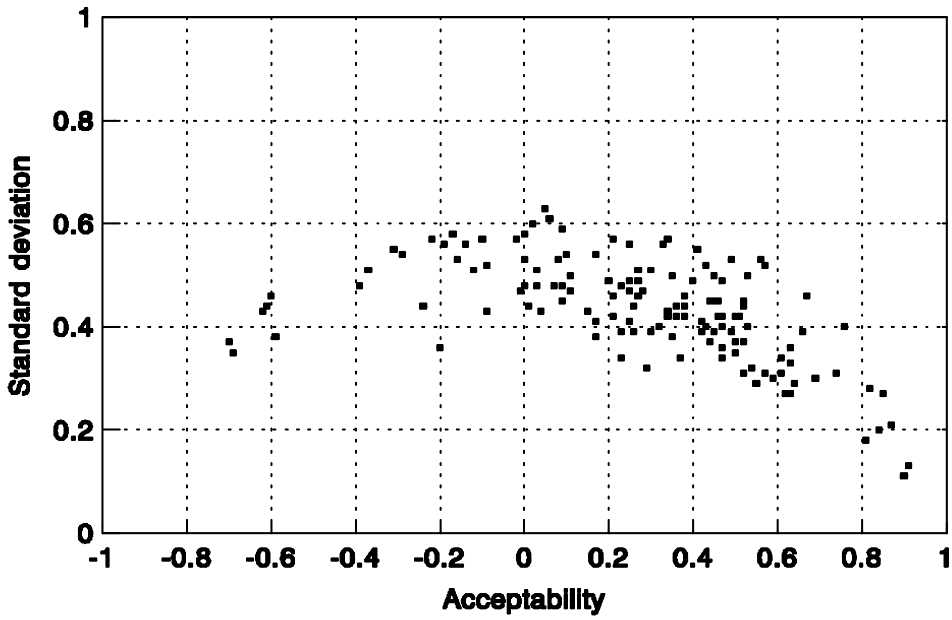

Figure 19. Standard deviation on acceptability votes as a function of the mean acceptability vote with a naive panel according to the Danish results /18/.

Similar results with standard deviation from 0.4 to 0.6, have been also reached in sensory tests in Finland when using untrained panels. In the following two pictures (Figures 20–21) standard deviation as a function of the acceptability from the sensory assessments performed in the HVAC -laboratory of Helsinki Technical University /19/ and at VTT /11/ are presented.

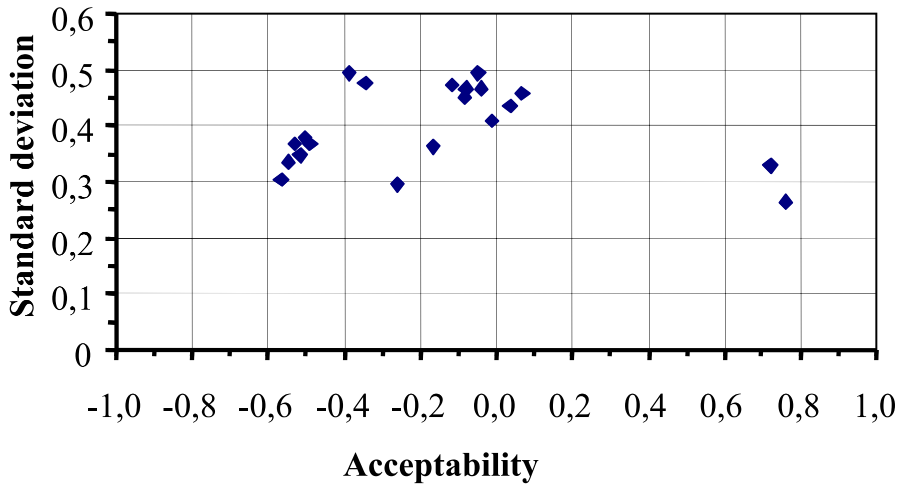

Figure 20. Standard deviation of sensory assessment tests performed in HUT /19/ with untrained panel.

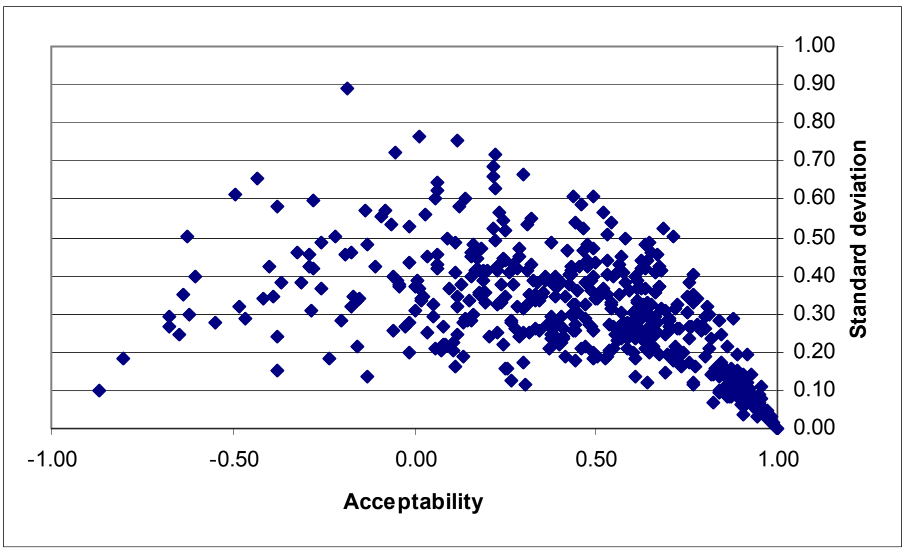

Figure 21. Standard deviation of the acceptability evaluations of 485 building materials tested at VTT /11/.

From all the results presented above, the estimate 0.6 can be selected as a representative and secure higher estimate for the standard deviation. It is also used in the calculations in the Finnish emission classification.

Using the equation 2 of t-distribution and the calculated values of standard deviation **s** and the coefficient **k**, the accuracy (the probable error) of the sensory tests with untrained panel may be calculated, Table 11.

Table 11. Calculated probable error as a function of the size of the panel, for 2 different standard deviations of 0. 4 and 0.6 when using acceptability scale from -1 to +1 in the sensory tests with untrained panels.

Size of the untrained panel	**Probable error**	
	Standard deviation 0.4	Standard deviation 0.6
5	0.27	0.40
10	0.17	0.25
15	0.14	0.22
20	0.11	0.17

The values in the Table 11 for the standard deviation 0.6 will give quite a realistic picture about the accuracy or probable error of the sensory acceptance procedure with untrained panels used in the Finnish emission classification.

The standard deviation **s** seems to be very constant, but of course the coefficient **k** may be selected higher or lower depending on the chosen risk or panel size. For example with a risk of 1 % instead of chosen 10 % the probable error 0.40 requires the panel size of 15 and similarly the probable error 0.22 requires panel size of 50–60.

To avoid unnecessary testing costs the risk level of 10 % to make wrong labelling decision has been selected in the Finnish classification system. It is in good harmony with the accuracy of the chemical tests, ± 20 %. Very important is also that the risk is symmetrical and hence equal to both parts in the classification process.

In the scientific research, where the "real" right values are searched, this risk factors required must of course be lower. This means naturally, that the size of the panel must be much bigger than in the classification.

11.3 Application: Procedure of sensory evaluation in the Finnish emission classification

In the Finnish emission classification the sensory tests are carried out by naive sensory panels using normal -1 ...– +1 acceptability scale. The sensory testing of material emissions is a complementary method to chemical testing in detection of emissions, as the sensitivity of human nose is in many cases better than instrumental methods.

Sensory characterisation of material emissions is carried out in the measuring chamber using a two-phase sensory test. The sensory assessments are commenced with a naive untrained sensory panel of at least five members. The mean acceptability value is then calculated. If the mean acceptability value of the 5-membered panel for a product is $\geq +0.4$, the product is classified M1 without any further testing. If the mean acceptability value is ≤ 0.4, the product will belong to class M3 and no further sensory evaluation will be required. If the mean acceptability of a 5-membered panel is between -0.4 and +0.4, the sensory evaluation must be repeated using a new panel of ten more naive subjects, other than those used in the first sensory panel. The mean acceptability value is then calculated as the mean of all 15 assessments and this mean value is used to classify the product together with the results of the chemical measurements.

The probable error of the sensory tests with these small two step panels (5/15) has been calculated using the assumption of T-distribution of votes and examining here only one-sided deviations with a risk of 10 %. The estimated error can be calculated basing on the knowledge that the standard deviation of the untrained sensory panels in this kind of tests has shown to be quite constantly in the range of 0.4–0.6 in the acceptability scale from -1 to +1. After these calculations the probable error is shown to be of the magnitude 0.2 in the acceptability scale from -1 to +1 with the calculated risk of 10 % of wrong conclusions in the whole testing procedure.

11.4 Demonstration on the reliability of the error calculations

11.4.1 Calculations with the measurement data of HUT / 19/

The calculated risks and small possibilities to make wrong decision can be demonstrated also by following calculations. In these calculations the sensory result of a large panel of 35 members has been set as the basic value to which the results of smaller panels of 5, 10 or 15 members stochastically selected from the large panel have been compared. The mean acceptability values of 12 panels (5, 10 or 15 members) selected stochastically from the main group are presented in the following Figures. The limits of accuracy are calculated here using the equation 2 and the standard distributions calculated for the original assessment data (not the same as used in classification tests).

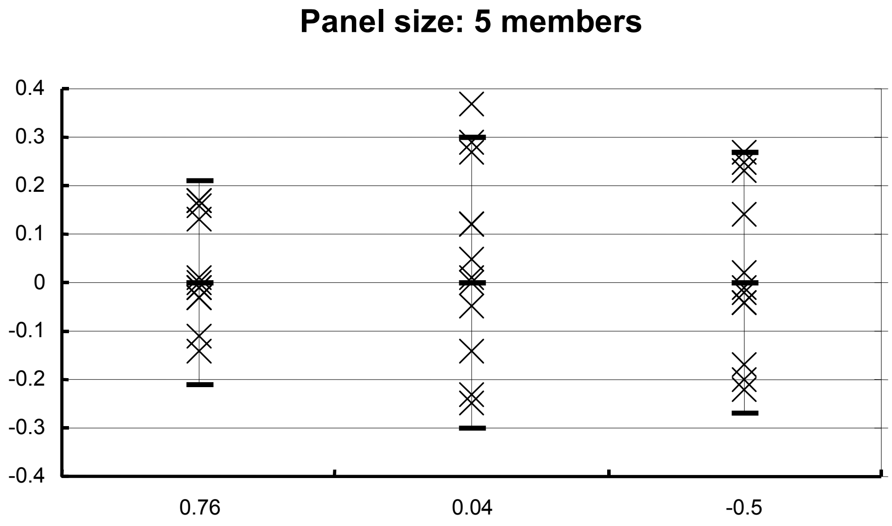

Figure 22. The 36 crosses show the difference of the calculated mean values from stochastically selected 36 panels of 5 persons compared with the mean value of a larger panel. Calculations are made in 3 different levels of sensory load, where the acceptability in the sensory tests were 0.76, 0.04 and -0.5.The short lines show the calculated probable error calculated according to the equation 2. Standard distributions are calculated from original measurement data.

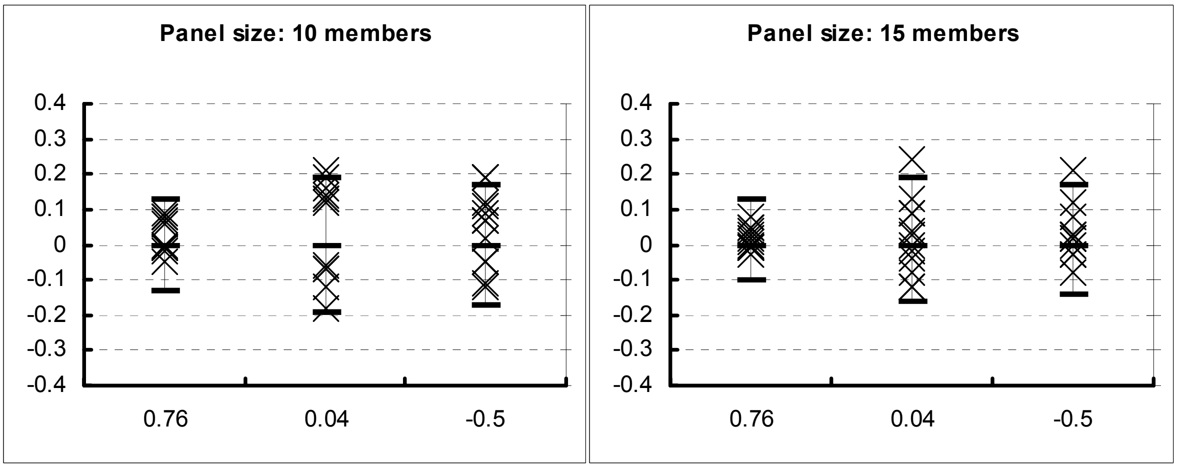

Figure 23. The 36 crosses show the differences from the calculated mean values from stochastically selected 36 panels of 10 (15) persons compared with the mean value of a larger panel. Calculations are made in 3 different measured level of sensory load, where the acceptability in the sensory tests was 0.76, 0.04 and -0.5. The short lines show the calculated probable error.

From the Figures 22 and 23 one may easily see that the calculations of the risk of false decision when using only small 5, 10 and 15 panel members are reliable. Only in four cases the results with smaller panels (total number 36 + 36 + 36= 108) would have given reason to a wrong decision, the error will be then larger than calculated limit and outside the corresponding lines in pictures. Maximum allowed number of the cases according to the theory would have been 10 % of 108 or 11 cases.

When using the standard deviation of 0.6 instead of the standard deviation calculated for the measurement data, as done in the Finnish classification system, only one case would have been outside the calculated and expected limits (0.4 in panels of 5 members, 0.25 in panels of 10 members and 0.22 in panels of 15 members).

11.4.2 Calculations with the measurement data of VTT

Similar calculations as presented above were also made using the results from a sensory test of a building material performed at VTT. The mean acceptability of the panel of 30 members was -0.01 with standard deviation of 0.37. The results of this sensory assessment were studied by randomly selecting 60 smaller panels out of the original 30-membered panel. The small panels consisted of 5, 10 and 15 members, 20 different combinations of each panel size.

The mean acceptability values from the 20 panels consisting of 5 members varied from -0.32 to + 0.21. These results were well between the limits of the acceptable values of -0.39 to -0.41, calculated with the presented method.

Similarly the results from the 20 panels of 10 members varied from -0.12 to +0.15, which was well between the accepted limits of -0.26 to +0.24.

The mean acceptability values from the 20 panels of 15 members varied from -0.10 to +0.16, which was well between the calculated and accepted limits of -0.23 to +0.21. Because the mean acceptability of the tested material was in the range of -0.4 and +0.4 the labelling decision would have been based on the results of a panel of at least 15 members. In this case only one combination of 15-membered panels would have resulted in a false labelling decision. The calculated 10 % risk of faulty decision seems to be in line with the theory.

12. Conclusions and recommendations

- The results of this project as well as the experiences of the Finnish M1 classification will certify that the independent use of chemical and sensory tests gives the best and solid background for the assessment of harmful emissions from building materials. No clear evidence has been found of the correlation between the results of the chemical and sensory tests.

- The most practical type of sensory tests for the labelling purposes is to use an untrained panel and acceptability scale. This method has relatively small costs and it is reliable enough for material labelling purposes.

- There may be a large variation in the sensory assessment values between panel members. This may result in quite high standard deviation of the assessment data, 0.4 to 0.6 acceptability units when using acceptability scale of -1 to +1. The use of the presented statistical calculations shows that the risk to make a wrong labelling decision may however be known and accepted.

- Calculations and experiences, presented in this paper show, that the stepwise use of small, untrained panels of 5/15 members and acceptability scale give results reliable enough for the labelling purposes. The risk to make wrong labelling decisions (accepted/not accepted) is small and acceptable, 10 %, and it is also equal for both parties.

- The results of the tested materials show that the 5-m^3 chamber designed for both chemical and sensory testing of building materials is well suited for labelling purposes when the mean of the acceptability value is used as the labelling criterion. The differences in the chemical measurements between the tested chambers were mostly due to the inhomogeneous nature of the tested materials. There were slight differences in the sensory acceptability of the chamber air odour in favour of the 5-m^3 chamber. This most probably reflects the difference between the assessing devices and systems of the two chambers. Compared to the diffusor the hood enables free breathing of the odour in a similar manner as if one was inside the chamber or a room. However the classification decisions (accepted/not accepted) due to the sensory tests was shown be the same in both chambers.

- The comparison results show, that bulky materials, which can not be tested following the established procedures of sensory testing with small emission chambers, should and can be tested enough reliable in bigger, in this studies 5 m^3, chambers using the test conditions of chemical measurements.

- For some materials the nature of the odour may divide panel members' opinions in two clearly different groups. In the cases where acceptability values are pooled at both endpoints of the used acceptability scale the arithmetic mean value poorly represents both groups. In the future tests it may be necessary to note and register the normality of the distribution of the votes.

13. Further research needs

1. Basic assumptions concerning the relationship between sensory and chemical assessment evaluations of building materials performed in laboratory and the measured and indoor air quality evaluated sensory terms in actual building environment must be analyzed and proved with comparative studies in full scale buildings.

2. General quality assurance methods of sensory testing for labelling purposes must be developed. The statistical calculations of the reliability of the sensory tests, specially the effect of the panel size must be studied more thoroughly.

3. The effect of air velocity at sniffing port, sniffing port design and other related factors on the sensory testing of building materials must be scientifically studied thoroughly and recommended methods also standardized.

4. The usability of odour descriptions as validation criteria in the sensory tests of building materials must be studied more thoroughly. Possible essential differences and the reasons for these differences between the individuals must be analyzed.

5. The role of irritation on the sensory sensation and evaluation of the building materials must be studied.

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Appendix A: Specific emission rates of single identified volatile organic compounds

Table 1. Specific emission rates of single VOCs (in toluene equivalents) from the tested PVC flooring material.

			PVC			
CLASS	COMPOUND	CAS	SER, μg/(m²h)			
			1 m³/3d	5 m³/3d	1m³/4w	5 m³/4w
alcohol	1-Hexanol, 2-ethyl-	000104-76-7	10	9	5	5
alcohol	Benzyl alcohol	000100-51-6	4	5	2	2
alcohol	Phenol	000108-95-2	3	3	2	1
aldehyde	Benzaldehyde	000100-52-7	3	3	3	2
glycol/glycolether	Ethanol, 2-(2-butoxyethoxy)-	000112-34-5	2	2	1	2
glycol/glycolether	Ethanol, 2-butoxy-	000111-76-2	1	1		
ketone	2-Hexanone, 5-methyl-5-phenyl	014128-61-1	2	2	1	1
ketone	2-Pentanone, 4-methyl-4-phenyl-	007403-42-1	2	2	1	1
	TVOC		82	84	42	39

Table 2. Specific emission rates of single VOCs (in toluene equivalents) from the tested linoleum.

CLASS	COMPOUND	CAS	**Linoleum**			
			SER, µg/(m²h)			
			1m³/3d	5m³/3d	1m³/4w	5m³/4w
acid	Acetic acid	000064-19-7	5	1		3
acid	Benzoic acid	000065-85-0	6	5	2	3
acid	Butanoic acid	000107-92-6	5	5		
acid	Heptanoic acid	000111-14-8	3	5		
acid	Hexanoic acid	000142-62-1	19	26		3
acid	Hexanoic acid, 2-ethyl-	000149-57-5	1	1		
acid	Octanoic acid	000124-07-2	1	1		
acid	Pentanoic acid	000109-52-4	7	5		
acid	Propanoic acid	000079-09-4	14	12		
alcohol	1-Penten-3-ol	000616-25-1	2	2		
aldehyde	2-Furancarboxaldehyde	000098-01-1	1	1		
aldehyde	2-Heptenal, (E)-	018829-55-5	2	2		
aldehyde	2-Pentenal, (E)-	001576-87-0	1	1		
aldehyde	2-Tridecenal, (Z)-	071277-06-0	1	2		
aldehyde	Benzaldehyde	000100-52-7	2	2	1	1
aldehyde	Butanal, 3-methyl-	000590-86-3	5	5		
aldehyde	Decanal	000112-31-2	1	2		
aldehyde	Heptanal	000111-71-7	1	1		1
aldehyde	Hexanal	000066-25-1	25	23	7	12
aldehyde	Nonanal	000124-19-6	3	3		
aldehyde	Octanal	000124-13-0				2
aliph. hydrocarbon	Hexadecane	000544-76-3	2	2	1	1
aliph. hydrocarbon	Pentadecane	000629-62-9	1	1		
cycloalkane	Cyclooctane	000292-64-8	1	1		
ether	Furan, 2-ethyl-	003208-16-0	2	2		
glycol/glycolether	Ethanol, 2-(2-butoxyethoxy)-	000112-34-5	1			
glycol/glycolether	Ethanol, 2-(2-ethoxyethoxy)-	000111-90-0	6	9		
glycol/glycolether	Ethanol, 2-butoxy-	000111-76-2	10	10	1	2
ketone	2(5H)-Furanone, 5-ethyl-	002407-43-4	2	4		
ketone	2-Pyrrolidinone, 1-methyl-	000872-50-4	15	15		3
	TVOC		185	193	20	52

Table 3. Specific emission rates of single VOCs (in toluene equivalents) from the tested parquet.

CLASS	COMPOUND	CAS	**Parquet**			
			SER, µg/(m²h)			
			1m³/3d	5m³/3d	1m³/4w	5m³/4w
aldehyde	2-Pentenal	002100-17-6	1	3	3	1
aldehyde	Benzaldehyde	000100-52-7	1	1		1
aldehyde	Hexanal	000066-25-1	3	3	6	5
arom. hydrocarbon	Benzene, dimethyl	001330-20-7	1	1		
arom. hydrocarbon	Benzene, 1-methyl-2-(1-methylethyl)-	000527-84-4	1		2	1
arom. hydrocarbon	Benzene, 1-methyl-4-(1-methylethyl)-	000099-87-6	3	1		1
arom. hydrocarbon	Benzene, methyl-	000108-88-3	1	2		
cycloalkane	Cyclohexane, methyl-	000108-87-2	14	33		
ester	Aceic acid, methyl ester	000079-20-9				2
ketone	Methanone, diphenyl-	000119-61-9	11	4		
terpene	2-beta-Pinene	000127-91-3	2	3	1	4
terpene	alpha-Pinene	000080-56-8	57	32	77	42
terpene	Camphene	000079-92-5	3	1	2	
terpene	delta-3-Carene	013466-78-9	18	12	20	20
terpene	dl-Limonene	000138-86-3	2	1	3	1
terpene	Terpinolene	000586-62-9	1	1		
	TVOC		132	128	133	86

Table 4. Specific emission rates of single VOCs (in toluene equivalents) from the tested pinewood planks.

CLASS	COMPOUND	CAS	**Pinewood**			
			SER, µg/(m²h)			
			1m³/3d	5m³/3d	1m³/4w	5m³/4w
acid	Acetic acid	000064-19-7				1
acid	Benzoic acid	000065-85-0				2
alcohol	1-Pentanol	000071-41-0	4		3	2
aldehyde	Benzaldehyde	000100-52-7	2	2	2	3
aldehyde	Decanal	000112-31-2	3	3	1	
aldehyde	Hexanal	000066-25-1	10	7	13	7
aldehyde	Pentanal	000110-62-3			5	3
arom. hydrocarbon	Benzene, 1-methyl-4-(1-methylethyl)-	000099-87-6	5	1	9	5
arom. hydrocarbon	Benzene, methyl (1-methylethenyl)-	026444-18-8			3	3
arom. hydrocarbon	Benzene, methyl-	000108-88-3	4	2	5	2
cycloalkane	1,3,5-Cycloheptatriene, 3,7,7-trimethyl-	003479-89-8			8	1
cycloalkane	Cyclohexane, methyl-	000108-87-2	24	10		
cycloalkane	Tricyclene	000508-32-7	2	1	3	
ketone	2-Propanone	000067-64-1	22	15		8
terpene	2-beta-Pinene	000127-91-3	83	145	140	105
terpene	alpha-Fenchene	000471-84-1		1	2	2
terpene	alpha-Phellandrene	000099-83-2			4	1
terpene	alpha-Pinene	000080-56-8	810	740	1021	576
terpene	Verbenone	000080-57-9			4	2
terpene	beta-Myrcene	000123-35-3	4	10	12	7
terpene	Camphene	000079-92-5	11	12	19	13
terpene	delta-3-Carene	013466-78-9	134	78	253	62
terpene	dl-Limonene	000138-86-3	37	45	69	40
terpene	gamma-Terpinene	000099-85-4		1	1	1
terpene	Pinocarvone	016812-40-1			4	2
terpene	Terpinolene	000586-62-9	8	6	6	3
	TVOC		1183	1107	1615	856

Table 5. Specific emission rates of single VOCs (in toluene equivalents) from the painted gypsum board.

CLASS	COMPOUND	CAS	Painted gypsum board			
			SER, µg/(m²h)			
			1m³/3d	5m³/3d	1m³/4w	5m³/4w
alcohol	1-Butanol	000071-36-3	4	4	2	2
aldehyde	Benzaldehyde	000100-52-7	3	3	1	1
aliph. hydrocarbon	1-Dodecene	000112-41-4	21	25	3	
arom. hydrocarbon	Benzene, (1-methylethyl)-	000098-82-8	2	2		
arom. hydrocarbon	Benzene, dimethyl-	001330-20-7	3	3		
arom. hydrocarbon	Benzene, ethyl-	000100-41-4	2	2		
arom. hydrocarbon	Benzene, propyl-	000103-65-1	1	1		
cycloalkane	Cyclohexane, methyl-	000108-87-2	2			
ester	Acetic acid, butyl ester	000123-86-4	3	3		
ester	Butanoic acid, butyl ester	000109-21-7	1	2		
ester	Ethanol, 2-(2-butoxyethoxy)-, acetate	000124-17-4			4	
ester	Propanoic acid, butyl ester	000590-01-2	6	6		1
glycol/glycolether	1,2-Propanediol	000057-55-6	4	4		
ether	Butane, 1,1'-oxybis-	000142-96-1	24	24	1	1
glycol/glycolether	Ethanol, 2-(2-butoxyethoxy)-	000112-34-5			1	
glycol/glycolether	Ethanol, 2-(2-ethoxyethoxy)-	000111-90-0	1			
	TVOC		103	98	15	14

Table 6. Specific emission rates of single VOCs (in toluene equivalents) from the heat-treated pine.

CLASS	COMPOUND	CAS	Heat-treated pine			
			SER, µg/(m²h)			
			1m³/3d	5m³/3d	1m³/4w	5m³/4w
acid	Acetic acid	000064-19-7	26	21		7
acid	Benzoic acid	000065-85-0	6	4	3	3
acid	Hexanoic acid	000142-62-1	17	37	14	25
acid	Pentanoic acid	000109-52-4		4		3
alcohol	1-Pentanol	000071-41-0	5	7	4	6
aldehyde	2-Decenal, (E)-	003913-81-3				1
aldehyde	2-Furancarboxaldehyde	000098-01-1	9	7	6	6
aldehyde	2-Hexenal, (E)-	006728-26-3		3		
aldehyde	2-Octenal	002363-89-5				1
aldehyde	Benzaldehyde	000100-52-7				1
aldehyde	Decanal	000112-31-2			1	1
aldehyde	Heptanal	000111-71-7		2	1	1
aldehyde	Hexanal	000066-25-1	47	78	46	53
aldehyde	Nonanal	000124-19-6	4	6	3	5
aldehyde	Octanal	000124-13-0	4	6	3	5
aldehyde	Pentanal	000110-62-3	10	16	9	11
ketone	1,3-Isobenzofurandione	000085-44-9		1		
ketone	2(3H)-Furanone, 5-ethyldihydro-	000695-06-7		1		1
ketone	2-Heptanone	000110-43-0	2	2	1	1
	TVOC		113	191	102	137

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Title
Sensory evaluation method of building materials for labelling purposes

Abstract
It has been shown that odour is an important factor of material emissions and the odour of a product can very seldom be predicted by the chemical emissions. A full size chamber of 5 m^3 equipped with a sniffing hood was built to enable both chemical measurements and sensory assessment to be performed using the test conditions of chemical testing. To compare the performance characteristics of the new 5-m^3 chamber with the conventional chambers six different materials were tested both in 1-m^3 chamber, sensory assessment chamber and in the 5-m^3 chamber. The sensory assessment chamber used for the comparison was a 100-litre aluminium chamber, which was operated according to the principles given in Nordtest method NT Build 482 (diffusor). Statistical studies were performed to verify the panel size required for sensory tests for labelling purposes. Chemical and sensory test results obtained with different chambers were in good agreement. Comparing the results with the Finnish building material classification the chamber size would not have affected the labelling decision the materials. Statistical calculations presented here show that for labelling purposes reliable sensory acceptability evaluations can be performed using a relative small naive, untrained panel. When accepting uncertainty of 0.4 on the acceptability scale and a symmetric risk of 10 %, a panel of 5 members can be used. In those cases when the mean acceptability is near the labelling limit value, a bigger panel with 15 members is needed to ensure uncertainty of 0.2 acceptability units and 10 % risk level of making a wrong decision.

Keywords
indoor air quality, emission chamber, sensory evaluation, building materials, labelling systems, chemical emissions, emission measurement, low emitting products

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It has been shown that odour is an important factor of material emissions and the odour of a product can very seldom be predicted by the chemical emissions. A full size chamber of 5 m^3 equipped with a sniffing hood was built to enable both chemical measurements and sensory assessment to be performed using the test conditions of chemical testing. To compare the performance characteristics of the new 5-m^3 chamber with the conventional chambers six different materials were tested both in 1-m^3 chamber, sensory assessment chamber and in the 5-m^3 chamber. The sensory assessment chamber used for the comparison was a 100-litre aluminium chamber, which was operated according to the principles given in Nordtest method NT Build 482 (diffusor). Statistical studies were performed to verify the panel size required for sensory tests for labelling purposes. Chemical and sensory test results obtained with different chambers were in good agreement. Comparing the results with the Finnish building material classification the chamber size would not have affected the labelling decision the materials. Statistical calculations presented here show that for labelling purposes reliable sensory acceptability evaluations can be performed using a relative small naive, untrained panel. When accepting uncertainty of 0.4 on the acceptability scale and a symmetric risk of 10 %, a panel of 5 members can be used. In those cases when the mean acceptability is near the labelling limit value, a bigger panel with 15 members is needed to ensure uncertainty of 0.2 acceptability units and 10 % risk level of making a wrong decision.

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