

VOC and carbonyl emissions from carpets: A comparative study using four types of environmental chambers

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Abstract

Emissions of Volatile Organic Compounds (VOCs) and carbonyls from carpets of different type (wool, synthetic) over a time period of three days at 23 °C, at 45% relative humidity, 0.5 air change rate and a loading factor of 0.4 m² m⁻³ were measured. The experiments were carried out at four different environmental chambers (volumes of 0.02/0.28/0.45/30 m³). For TVOCs, maximum concentrations up to 2300 µg m⁻³ (for carpet with synthetic backing) were found. Aromatic compounds e.g. benzene, toluene, the xylenes and styrene are emitted in relatively low concentrations, while for 4-phenylcyclohexene and 2, 2-butoxyethoxy-ethanol concentrations up to 170 and 320 µg m⁻³, respectively, were measured. In all experiments, emission rates reached the maximum value within few hours from the beginning of the experiment.

The emission rates of TVOCs from the same type of carpet measured with various types of chambers (0.02/0.28/0.45/30 m³), exhibited differences of up to 75%.

Chamber concentrations of carbonyls (formaldehyde, acetaldehyde, acetone and propanale) are of a few µg m⁻³. Acetone and formaldehyde reach concentrations up to 15 and 10 µg m⁻³, respectively.

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1. Introduction

Emissions of volatile organic compounds (VOCs) from household materials and building products used indoors constitute an important parameter for the impact of chemical substances on indoor air quality (IAQ) [1–3]. VOCs are widely used in many household products such as paints, varnishes, waxes, solvents, detergents and can also be emitted by the use of other products, such as printers, photocopiers, etc. [4]. As VOCs are classified organic compounds that have boiling point between 50 and 260 °C [5]. These compounds may cause various health effects like eye, nose and throat irritation, headaches, loss of coordination, nausea, damage to liver, kidney and central nervous system, etc. [6–8].

Emissions of VOCs by flooring materials have attracted special interest because usually flooring materials (e.g. carpets)

occupy large areas and consist of layers made of different materials. In the past, many experiments have taken place to study the emissions of VOCs from carpets. In a study of Wilke et al. [1], 14 types of carpets were examined and it was shown that emission factors may vary significantly, depending on the type of carpet. Thus, they reported values (for $t=24$ h) ranging from around 100–5500 µg m⁻² h⁻¹. The highest value was exhibited by a carpet made of woven natural fibres with embossed styrene–butadiene foam as backing material. In other studies, emission rates with big variations were found, i.e. from 5.9 to 56223 µg m⁻² h⁻¹ [9].

Until now, no guideline exists at European level that regulates the maximum permissible emissions of total or individual VOCs from carpets. There are some labelling schemes in some countries, mainly the North European ones, but all of them are on a voluntary basis, and usually country-specific. The duration of these tests may vary from few days to 6 months. The Swedish National Flooring Trade Association and the Swedish National Testing and Research Institute in their “Trade Standard: Measurement of Chemical Emission from Flooring Materi-

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als” have specified a method to measure the emissions of VOCs from flooring materials that has been in use for over a decade. The most known European labelling scheme for carpets remains the “GUT” (Gemeinschaft umweltfreundlicher Teppichboden—Association for Environmentally Friendly Carpets), which appeared in the market in 1990 [10]. In order for a carpet to be labelled by GUT, it is necessary that, after 3 days of testing, the chamber concentrations of TVOCs are below $300 \mu\text{g m}^{-3}$ (as concentration in the test chamber), the total semi-volatile organic compounds (TSVOCs) are below $30 \mu\text{g m}^{-3}$, formaldehyde is below $10 \mu\text{g m}^{-3}$, unknown VOCs are below $100 \mu\text{g m}^{-3}$ and that there are no vinylchloride or vinylacetate emissions.

In the United States, the Carpet and Rug Institute adopted in 1992 the so-called CRI’s Indoor Air Quality Carpet Testing Program, which in order to help consumers to identify low-emitting carpets, has established some limits for the maximum allowable emissions. These limits (called “Green Label”) included TVOCs ($500 \mu\text{g m}^{-2} \text{h}^{-1}$); 4-phenylcyclohexene (4-PCH; $50 \mu\text{g m}^{-2} \text{h}^{-1}$); formaldehyde ($50 \mu\text{g m}^{-2} \text{h}^{-1}$) and styrene ($400 \mu\text{g m}^{-2} \text{h}^{-1}$). The last years, the CRI went one step further and introduced the “Green Label PLUS”, which is now used to identify the truly low-emitting products. The latter label includes more target chemicals, and lower maximum permissible limits (acetaldehyde: $4.5 \mu\text{g m}^{-3}$; benzene $30 \mu\text{g m}^{-3}$; formaldehyde $16 \mu\text{g m}^{-3}$; 4-PCH: $2.5 \mu\text{g m}^{-3}$; toluene $150 \mu\text{g m}^{-3}$; styrene: $220 \mu\text{g m}^{-3}$) [11–13].

The European Commission has highlighted since many years [14] the need for the introduction of a mandatory, generally applicable and validated procedure for the evaluation of all types of building materials for all purposes, with respect to their VOC emissions.

In this study, four types of carpets, made by one of the most known Italian manufacturers and not carrying any eco-label, were purchased and tested for the emissions of VOCs during 3-day exposure experiments (in analogy with the GUT testing procedure), using environmental chambers of different volumes and conditions simulating a “real world setting”. For the selection of the carpets, the criteria were that the different purchased carpets were made of different materials and that they were “presentable” (exactly as a normal family would select) and the main objectives of this study were (a) to evaluate the emissions of VOCs from carpets; (b) to examine the ability of this test to be used as a fast screening procedure and its reproducibility when different types of chambers are used and (c) to compare the emissions with the already existing labelling schemes.

2. Materials and methods

2.1. Chambers

Three small (20, 280 and 450 lt) and a big walk-in-type (30 m^3 -INDOORTRON) environmental chambers were used for the purposes of this study. Two were made of glass (20 and 450 lt) and two made of stainless steel (280 lt and 30 m^3). To avoid sink effects on interior surfaces, the material used for the construction of the chamber has to be non-adsorbent, chemically inert

and with a smooth surface [9]. The chambers were operating at 0.5 ach (air changes per hour), at 23°C , while maintaining the relative humidity at 45% (+5%). These parameters are typically used in experiments that involve environmental chambers as they simulate typical average indoor air conditions. The chamber’s loading factor was kept constant in all experiments ($0.4 \text{ m}^2 \text{ m}^{-3}$).

2.2. Carpets

Wool, synthetic and mixed-type carpets were used in this study. All carpets were new, ordered directly to the manufacturer and after purchase were wrapped in aluminium foil, stored in a laboratory with constant temperature (21°C) and were tested within 1 month from supply. The carpets used had the following characteristics:

- Carpet 1 (Cp-1): Fibers by 100% polyamide and 100% synthetic backing (unknown composition; not Styrene-Butadiene-Rubber; SBR).
- Carpet 2 (Cp-2): Fibers by 80% wool, 10% polyamide and 10% polypropylene and 100% synthetic backing (SBR).
- Carpet 3 (Cp-3): Fibers by 100% wool and 100% synthetic backing (SBR).
- Carpet 4 (Cp-4): Fibers by 100% polyamide and 100% synthetic backing (SBR).

The backing is the material comprising the back or underside of a carpet. In some cases there is primary and secondary backing. Primary backing is what is seen between the fibres and secondary is the underside of the carpet.

All carpets were examined in the three small chambers and two of them (namely, Cp-2 and Cp-4) were examined also at the INDOORTRON facility (30 m^3).

2.3. Methodology

Air sampling from the chambers for the occurrence of VOCs and aldehydes has been described elsewhere [15]. Briefly, for VOCs, 1 L of air was pumped (sampling rate: 100 mL min^{-1}) by TENAX TA tubes (SUPELCO) and analysis was made by thermal desorption (Perkin-Elmer ATD 400 equipped with a TENAX TA cool trap of 100 mg) and GC/MSD (GC: HP 5890 Series II, MSD: HP 5972). For carbonyl compounds, sampling of 10 L (sampling rate: 1 L min^{-1}) of air was conducted by Sep-Pak DNPH-Silica cartridges and after derivatization with acetonitrile, analysis is done by HPLC-UV (360 nm). Air exchange rates were determined by using the tracer gas SF_6 technique according to ASTM E 741-93 standard method. Determination of SF_6 was performed by an automated gas-chromatograph coupled to electron capture detector (Lagus Applied Technology Autotrac 101). Sampling for carbonyl compounds was not applied at the small chamber (0.020 m^3), due to the fact that the air sampling of 10 L would require half of the total air of the chamber.

Sampling for VOCs and CCs was conducted after 24 and 72 h. Especially for the characterisation of the emission rates of TVOCs, a significant number of samples were collected in order to follow the peak values, mainly within the first hours of

the experiment. Samples of filtered air, chamber blanks and field blanks were collected prior to all experiments for quality control reasons. Background concentrations of VOCs, CCs and TVOCs found in these samples were then subtracted from concentrations of the real samples.

3. Results and discussion

3.1. Emissions of VOCs

Table 1 summarizes the emissions of individual VOCs from all carpets at the various chambers after 24 and 72 h. Benzene and toluene were found to be released from all carpets in concentrations varying from ND (not detected) to $4.6 \mu\text{g m}^{-3}$ (Cp-2/24 h/0.28 m³), and from ND to $8.6 \mu\text{g m}^{-3}$ (Cp-4/24 h/0.02 m³), respectively. Ethylbenzene, xylenes and styrene were detected only in few cases, in relatively low concentrations. The highest concentration of styrene ($11 \mu\text{g m}^{-3}$) was by Cp-2 (at $T=24 \text{ h/INDOORTRON}$) and it was the highest concentration among all BTEXS measured, during all experiments.

The VOC that was detected in high concentrations in all experiments from the Cp-2; -3; -4 was the 4-PCH. After the 72 h all three carpets were still emitting 4-PCH; its chamber concentrations after 72 h were similar to the ones of the 24 h indicating its long lasting emission behavior. The highest air concentration of 4-PCH was $140 \mu\text{g m}^{-3}$, detected at the INDOORTRON experiment of Cp-2, after the 24 h of exposure. 4-PCH was found to be the individual VOC with the highest emission rates from two out of the four carpets, examined by Little et al. [16], and at a third carpet it was again among the most prominent VOCs. 4-PCH is considered to be a common semivolatile organic contaminant found in the built environment. In two reported studies [17], once, it was one of the 12 most frequently occurring volatile organic chemicals (VOCs) emitted by 19 carpets backed by SBR latex and in the second, it was the most abundant of 10 VOCs found in headspace emissions from carpet made of nylon with a laminated fabric backing. 4-PCH is also the major odorant VOC associated with new carpets and is commonly found with styrene and 4-vinylcyclohexene, a butadiene dimer. The SBR latex adhesive for binding carpets' secondary backing is generally considered as the primary source of 4-PCH. Air concentrations of 4-PCH measured in buildings after the installation of new carpets ranged from 2 to $17 \mu\text{g m}^{-3}$ [17].

Another VOC detected in high concentrations from the Cp-2 in all chambers was the 2,2-butoxyethoxy-ethanol (2,2-BEE). Like 4-PCH, 2,2-BEE was also quite persistent and its chamber concentrations after 72 h were similar to those of 24 h. 2,2-BEE is said to be one of the major VOCs emitted from latex paint [18,19] and has been reported to be present in emissions from carpets in concentrations of $224.8 \mu\text{g m}^{-3}$ (after 1 h of exposure) [20].

3.2. Emissions of carbonyl compounds

Table 2 summarizes the chamber concentrations of some carbonyl compounds (formaldehyde, acetaldehyde, acetone and

Table 1
Chamber concentrations of individual VOCs after 24 and 72 h (concentration in $\mu\text{g m}^{-3}$)

Time (h)	Benzene			Toluene			Ethylbenzene			Xylenes			Styrene			4-PCH			2,2-BEE				
	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³	30 m ³	0.45 m ³	0.02 m ³		
Cp-1	24	1.6	1.7	0.07	2.1	2.3	0.73	ND	0.16	ND	0.76	ND	ND	0.92	ND	ND	ND	ND	ND	ND	ND	ND	
	72	ND	ND	0.23	2.1	1.8	0.27	ND	0.14	ND	0.61	ND	ND	0.78	ND	ND	ND	ND	ND	ND	ND	ND	
	24	4.4	4.6	3.7	1.2	0.8	1.7	0.79	2.7	ND	1.2	0.88	11	ND	9.0	140	71	59	23	320	11	21	29
Cp-2	72	3.9	3.7	1.5	1.2	2.4	3.0	3.0	ND	1.3	0.95	2.0	ND	7.2	2.4	110	71	37	15	270	1.0	12	26
	24	4.4	4.6	3.7	1.2	0.8	1.7	0.79	2.7	ND	1.2	0.88	11	ND	9.0	140	71	59	23	320	11	21	29
	72	3.9	3.7	1.5	1.2	2.4	3.0	3.0	ND	1.3	0.95	2.0	ND	7.2	2.4	110	71	37	15	270	1.0	12	26
Cp-3	24	0.66	4.0	ND	2.0	2.4	3.6	3.6	ND	0.29	0.73	4.0	0.53	ND	ND	17	17	17	29	ND	ND	ND	ND
	72	0.97	ND	ND	0.97	2.0	4.4	4.4	ND	ND	ND	4.4	0.27	ND	ND	12	18	18	26	ND	ND	ND	ND
	24	0.75	0.32	0.56	1.9	0.75	0.45	8.6	8.6	ND	ND	ND	ND	ND	ND	22	32	40	32	ND	ND	ND	ND
Cp-4	72	0.37	ND	0.80	1.4	0.37	0.24	7.5	7.5	ND	ND	ND	ND	ND	ND	21	29	35	29	ND	ND	ND	ND

Table 2
Chamber concentrations of carbonyl compounds after 0, 24, 48 and 72 h (concentration in $\mu\text{g m}^{-3}$)

Time (h)	Formaldehyde				Acetaldehyde				Acetone				Propanale			
	0.45 m ³		0.28 m ³		0.45 m ³		0.28 m ³		0.45 m ³		0.28 m ³		0.45 m ³		0.28 m ³	
	INDOORTRON		INDOORTRON		INDOORTRON		INDOORTRON		INDOORTRON		INDOORTRON		INDOORTRON		INDOORTRON	
Cp-1																
24	8.3	13	4.0	3.4												
72	ND	ND	4.1	1.0												
Cp-2																
24	2.8	ND	14	ND	11	8.5	ND	4.0	ND	7.4	ND	3.2	ND	3.1	ND	ND
72	3.1	ND	7.7	ND	13	15	ND	ND	14	3.7	3.5	3.5	ND	ND	ND	ND
Cp-3																
24		15	2.8	3.7												
72		14	2.1	2.9												
Cp-4																
24	6.9	13	7.2	3.1	4.9	9.5	ND	12	ND	ND	2.6	2.6	2.2	2.2	3.3	3.3
72	2.8	3.9	1.1	2.8	3.5	8.5	ND	6.6	ND	ND	2.3	2.3	ND	ND	2.8	2.8

propanale) from carpets at two small chambers (0.28 m³ and 0.45 m³) and at the INDOORTRON. Highest concentration of formaldehyde (24 $\mu\text{g m}^{-3}$) was observed by Cp-2, but Cp-3 exhibited the highest concentrations of HCHO after the 72 h (14 $\mu\text{g m}^{-3}$). Formaldehyde is likely to result from the release of unreacted formaldehyde from the glue mixture that bonds together the fibers with the backing or other materials used for the production of the carpet. The impact of the studied carpets at the occurrence of formaldehyde indoors is considered low comparing to the air quality guideline of World Health Organization (WHO) (100 $\mu\text{g m}^{-3}$ for 30-min average concentration).

The chamber concentrations of acetaldehyde were higher for Cp-2 (14 $\mu\text{g m}^{-3}$), significantly higher than for other carpets (5.0 $\mu\text{g m}^{-3}$, 3.4 $\mu\text{g m}^{-3}$, 3.1 $\mu\text{g m}^{-3}$, for Cp-3; -1 and Cp-4, respectively). In a recent study in Japan [21], it was concluded that the presence of carpets is one of the major variables affecting the concentrations of formaldehyde and acetaldehyde indoors. Emissions of carbonyl compounds from carpets can increase significantly if there is ozone in the indoor air (secondary emissions, resulting from the reaction of ozone with unsaturated organic compounds [22–23]). Morrison and Nazaroff [22] reported that aldehydes emission rates from four carpets increased from 1 to 70 $\mu\text{g m}^{-2} \text{h}^{-1}$ (without ozone) to 60–800 $\mu\text{g m}^{-2} \text{h}^{-1}$ (with ozone).

3.3. Emissions of total volatile organic compounds (TVOCs)

The chamber concentrations of TVOCs are presented in Fig. 1. Cp-1 was the one with the lowest emissions, exhibiting a maximum value of 200 $\mu\text{g m}^{-3}$ (24 h/0.28 m³), and after the 72 h the emissions varied between 65 and 100 $\mu\text{g m}^{-3}$ at the various chambers. The emissions from the other three carpets were substantially higher, with maximum values to be 2100, 2300 and 2200 $\mu\text{g m}^{-3}$ for Cp-2; -3 and -4, respectively. Given the common backing but the different fibers of these three carpets, the big differences in chamber concentrations should be attributed to the ingredients of the backing. The concentrations of TVOCs (Fig. 1) reach a maximum value within some hours after the start of the exposure and then they decrease. In almost all cases this happened within the first 6 h. For Cp-1 and Cp-3, concentrations reached maximum values after 24 h and 12 h, respectively and one for Cp-3 (0.45 m³ chamber: max. value after 12 h). Little et al. [16] had also observed that maximum emission rates appear after 12 h, and are followed by a rapid decay. At the same study, the authors underlined the significance of the polymer backing material and characterized it as the dominant source for the emissions of VOCs by carpets.

The emissions of TVOCs (and also individual substances) are very often presented as emission rates, given in units of $\mu\text{g m}^{-2} \text{h}^{-1}$. Emission rates can be calculated by the formula [14]:

$$E = \left[\frac{dC}{dt} + n \times C \right] \times \frac{V_C}{A} \quad (1)$$

where E ($\mu\text{g m}^{-2} \text{h}^{-1}$) is the emission rate; C ($\mu\text{g m}^{-3}$) is the chamber concentration; A (m²) is the emitting surface area; V_C

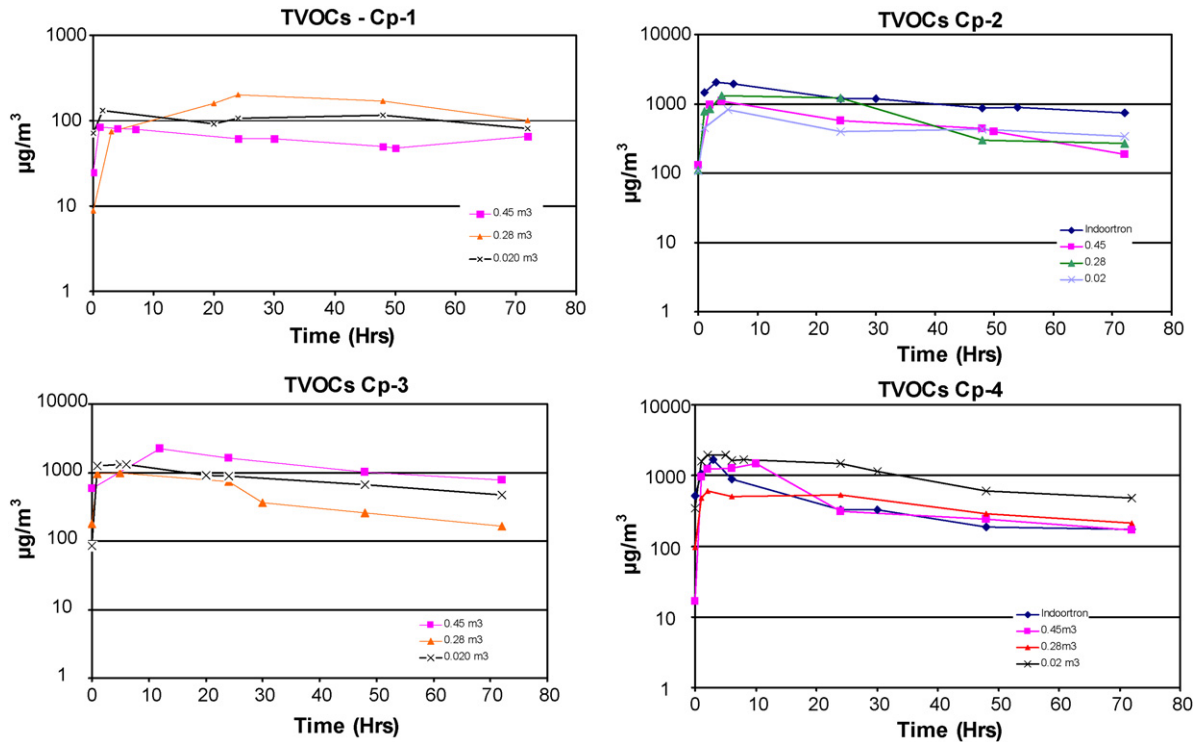


Fig. 1. Chamber concentrations of TVOCs plotted against time.

(m^3) is the chamber volume and n (h^{-1}) is the air change rate. In steady state conditions ($dC/dt \ll n \times C$), the formula (1) can be simplified to:

$$E = n \times C \times \frac{V_C}{A} \quad \text{or} \quad E = n \times \frac{C}{L} \quad (2)$$

where $L = A/V_C$ ($m^2 m^{-3}$) is the loading factor. By applying the formula (1), the emission rates were calculated for the present experiments and are presented in Fig. 2. Again, it can be seen in all experiments (except from the Cp1/0.28 m^3), that the emission rates are very high during the first hours and then are following a power decrease (equations are given in Table 4). Highest emission rate observed was $5500 \mu g m^{-2} h^{-1}$ for Cp-2/0.02 m^3 , followed by $5100 \mu g m^{-2} h^{-1}$ for Cp-4/0.02 m^3 .

Two approaches for air quality guidelines for the occurrence of TVOCs in an indoor environment have been proposed. The first one by Molhave [24] categorizes as follows: (concentration of TVOCs at the indoor air in $\mu g m^{-3}$):

- <200: comfort range.
- 200–3000: multifactorial exposure range.
- 3000–25000: discomfort range.
- >25000: toxic range.

The second approach, by Seifert [25] suggested that TVOCs concentrations should not exceed $300 \mu g m^{-3}$. Furthermore, he suggested that if this concentration was apportioned to different chemical classes, the following concentrations resulted: $100 \mu g m^{-3}$ for alkanes; $50 \mu g m^{-3}$ for aromatics; $30 \mu g m^{-3}$ for terpenes; $30 \mu g m^{-3}$ for halocarbons; $20 \mu g m^{-3}$

for esters; $20 \mu g m^{-3}$ for carbonyls (excluding formaldehyde) and $50 \mu g m^{-3}$ for other pollutants. He also suggested that no individual compound should exceed 50% of its class average value or the 10% of the measured TVOC value.

Comparing the emissions from carpets in the present study, and following the aforementioned clarifications, it can be seen that a new carpet can cause for some hours, just by itself, an unpleasant atmosphere.

3.4. Emissions tests in different chambers

The emission tests performed with the same carpet, under the same conditions but in different chambers, should ideally give similar results. In some cases in the present study, big differences in the emission behaviour of the carpets in different chambers were found. Concerning individual VOCs, very big differences have been observed for the Cp-2 for the concentrations of 4-PCH and 2,2-BEE, between the INDOORTRON and all the small chambers. For instance, the 2,2-BEE concentrations in INDOORTRON were 15–20 times higher than the average of the three smaller chambers, and for 4-PCH were 2–3 times higher. For the TVOCs, as mentioned, the pattern of emissions and the maximum values are usually very close, but some differences have also been observed. For example, for Cp-4, the concentrations of TVOCs at the INDOORTRON were almost identical to the ones found at the chamber of 0.45 m^3 , but quite lower than at the 0.02 m^3 and higher than those at the 0.28 m^3 . The parameters of temperature and humidity were kept constant and therefore are not expected to have a different impact on the experiments undertaken in different chambers. More efforts

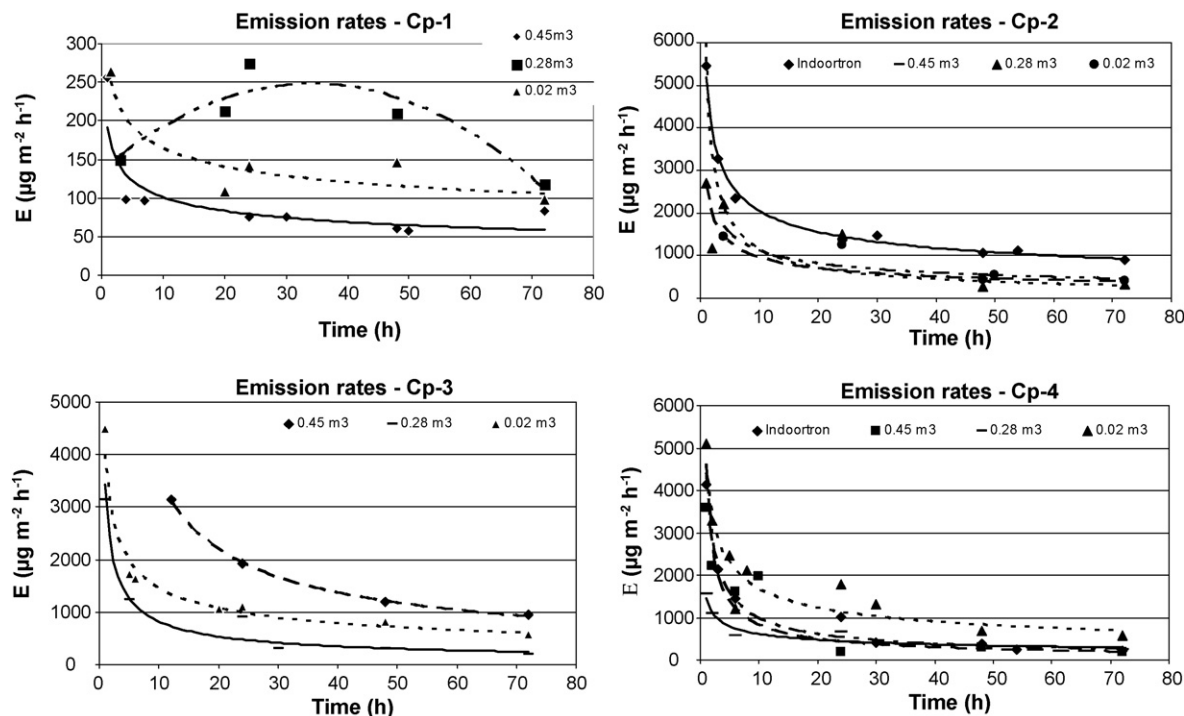


Fig. 2. Emission rates of the four carpets at the various chambers.

should be done in order to be able to understand the differences observed when different chambers are applied.

The big differences observed between different emissions tests of the same material, either in different chambers, or under different conditions or in different laboratories, is not something unusual. As a matter of fact, Windhoven and Oppl [26] reported differences of 10–15 times between the various results of round-robin tests (largest results higher than the lower results) and more than 40% relative standard deviation around the mean value.

3.5. Comparison with existing labelling schemes

Table 3 summarizes some features of the existing labelling schemes for building materials. As seen, most of the existing schemes include measurements and maximum permissible limits for the third day of exposure, and some of them require also a testing for specific compounds after the first 24 h (i.e. Emicode EC1; [10]). Comparing the results of this study with these limits, it is seen that Cp-1 would have been labeled by all schemes. Cp-2 exhibited chamber concentrations of TVOCs that in two cases exceeded the GUT value, something that was observed also in Cp-3 and in one case in Cp-4. Another GUT requirement that is not met by Cp-2 is the one that refers to all unknown/other VOCs that should not exceed $100 \mu\text{g m}^{-3}$. This threshold was once exceeded by 4-PCH and 2,2-BEE ($110 \mu\text{g m}^{-3}$ and $270 \mu\text{g m}^{-3}$, respectively). The formaldehyde values were within the acceptable limits except for Cp-3 that in the 0.28 m^3 experiment, the chamber concentration after 72 h was $14 \mu\text{g m}^{-3}$. The Emicode EC1 value of $50 \mu\text{g m}^{-3}$ after 24 h for formaldehyde and acetaldehyde was never exceeded. Concerning the requirements of labelling schemes that include measurements after 28 days, it can be assumed that they would be met by all carpets. These

requirements are similar to those of GUT (MI and Natureplus), but given that the concentrations are decreasing after the first hours, it is likely that the chamber concentrations after the 28 days will be below these values. A rough estimation can be done by extrapolating from the plots of Fig. 2. The results of this extrapolation are given in Table 4 for 10, 14 and 28 days. It can be seen that if the observed behaviour of the four studied carpets goes on until the 28 days, then there would still be exceedances of the maximum value of some labelling schemes. For example the emission rate value of $200 \mu\text{g m}^{-2} \text{h}^{-1}$ that is proposed by M1, LQAI and Natureplus would be exceeded four times. Furthermore, the value of $500 \mu\text{g m}^{-2} \text{h}^{-1}$, proposed by CRI for the 14 days, would also be reached once (Cp-2/ 30 m^3).

Until the end of 2003 the GUT label was including also other target-chemicals in its list. Among others, there were toluene, styrene and 4-PCH, compounds that are also listed by the American Green Label Plus. The latter labelling scheme requires measurement of the chamber concentrations after 14 days, and from the obtained results of the present study, the decisive parameter is likely to be 4-PCH. The Cp-2; -3 and -4 exhibited high chamber concentrations of this compound and the most interesting characteristic was its persistence. It can be seen that for Cp-2, in the emission test undertaken at the INDOORTRON, the chamber concentration at the 24 h was $140 \mu\text{g m}^{-3}$ and after the 72 h became $110 \mu\text{g m}^{-3}$, suggesting that it is highly possible that even after the 14 days, the concentration will still be in a level higher than the recommended by CRI.

All these differences and the labels that would be, or would not be given to the studied carpets suggest that the existence of a unique labelling scheme, at least at European level, will facilitate a lot similar studies at the future, and it will make it easier for both consumers and manufacturers to decide which

Table 3
Requirements by various labeling schemes for emissions (or test chamber concentrations) by building materials

	AgBB	CESAT	MI	LQAI	Natureplus	Blue Angel	Austrian Ecolabel	GUT	Emicode ECI
TVOC	3d: 10000 $\mu\text{g m}^{-3}$ 28d: 1000 $\mu\text{g m}^{-3}$	3d: 5000 $\mu\text{g m}^{-3}$ 28d: 200 $\mu\text{g m}^{-3}$	28d: 200 $\mu\text{g m}^{-2} \text{h}^{-1}$	3d: 5000 $\mu\text{g m}^{-2} \text{h}^{-1}$ 28d: 200 $\mu\text{g m}^{-2} \text{h}^{-1}$	28d: 200–300 $\mu\text{g m}^{-3}$	3d: 1200 $\mu\text{g m}^{-3}$ 28d: 360 $\mu\text{g m}^{-3}$	28d: 380 $\mu\text{g m}^{-2} \text{h}^{-1}$	3d: 300 $\mu\text{g m}^{-3}$	10d: 500 $\mu\text{g m}^{-3}$
HCHO	28d: 120 $\mu\text{g m}^{-3}$	28d: 10 $\mu\text{g m}^{-3}$	28d: 50 $\mu\text{g m}^{-3}$	28d: 10 $\mu\text{g m}^{-3}$	28d: 36 $\mu\text{g m}^{-3}$	28d: 60 $\mu\text{g m}^{-3}$	–	10 $\mu\text{g m}^{-3}$	1d: 50 $\mu\text{g m}^{-3\text{a}}$

^a Also acetaldehyde should not exceed the same chamber concentration.

Table 4
Predicted emission rates ($\mu\text{g m}^{-2} \text{h}^{-1}$) after 10, 14 and 28 days

	Chamber	Formula	10d	14d	28d
Cp-2	30 m^3	$y = 5191.8x - 0.4022$	573	500	379
	0.45 m^3	$y = 5399.8x - 0.6727$	135	108	68
	0.28 m^3	$y = 2700.9x - 0.4481$	271	233	171
	0.02 m^3	$y = 3123.7x - 0.4461$	232	199	146
	Average		303	260	191
Cp-3	0.45 m^3	$y = 16798x - 0.6788$	407	324	202
	0.28 m^3	$y = 3422.6x - 0.6193$	115	93.3	60.7
	0.02 m^3	$y = 4008.3x - 0.439$	361	312	230
	Average		294	243	164
Cp-4	30 m^3	$y = 4616.7x - 0.6706$	117	93.4	58.7
	0.45 m^3	$y = 4405.3x - 0.7224$	84.0	65.9	39.9
	0.28 m^3	$y = 1448.6x - 0.3713$	189	167	129
	0.02 m^3	$y = 4636.5x - 0.4413$	413	356	262
	Average		201	171	122

products are environmentally friendly and which are not. It is clear that the consumers cannot recognise more than one label, if possible, applicable to more than one product. Also, from the manufacturers' point of view, having their product labelled is a big investment in time and money, and only a Pan-European label would be convenient for them in terms of time, money and widening of their market.

4. Conclusions

Four new carpets made of different materials were investigated under real world setting conditions of temperature, humidity and air change rate using four environmental chambers for emissions of TVOCs, individual VOCs and low molecular weight carbonyls over a time period of 3 days. In all experiments, chamber concentrations reached the maximum value (up to 2300 $\mu\text{g m}^{-3}$) within few hours (6 h) from the beginning of the experiment.

4-phenylcyclohexene and 2,2-butoxyethoxy-ethanol were the main VOCs emitted, found at concentrations up to 170 and 320 $\mu\text{g m}^{-3}$, respectively. Aromatic compounds (BTEXS) and carbonyls (formaldehyde, acetaldehyde, acetone and propanale) are found at lower concentrations which tend to substantially decrease during the 3 day exposure period.

Comparing the chamber concentrations for TVOCs measured applying different chambers in the present study among the various chambers, differences up to 75% were estimated.

From the results of this study, it seems that the 3 days exposure represents an appropriate period for the fast screening and the evaluation of the overall emission behaviour of carpets, non affected by factors such as ageing and/or damage by usage. Three days is a period of time already applied by some existing labelling schemes, as well. On the basis of the results of the present study, it is concluded, that Cp-1 would be labelled by all schemes as low-emitting, whereas the Cp-2; -3 and -4 would fail to meet some of the requirements set by a number of these schemes. This variation underlines the need for the development and catholic acceptance of a single harmonised labelling

scheme, if possible not applicable just to carpets, but to a wider category of similar products.

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