What is behind TVOC in new buildings

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ABSTRACT
This study reports the attained indoor air quality in new buildings when using different M1-classified finishing materials and ventilation systems. It is practical to use the TVOC value as a reference in comparing material emissions, their effect on indoor air quality and in following the effect of different parameters on the indoor air quality. But is TVOC a relevant tool from the health point of view to be used in characterizing the indoor air as the single compounds contained in the TVOC value do have very different effects on the health and perceived indoor air quality? This study reports the TVOC and the single VOCs included in the TVOC value of 10 new apartments and evaluates the validity of TVOC in predicting the indoor air quality and comfort in new buildings.

INDEX TERMS
Air quality; IAQ assessment; VOC; TVOC; Guidelines new buildings

INTRODUCTION
The Classification of Indoor Climate, Construction and Finishing Materials was published in 1995 in Finland. The classification has three important parts aiming at good indoor climate: the target values of indoor climate, guidance for design and construction, and requirements for building products. Materials are classified according to TVOC emission, ammonia and formaldehyde emission and sensory evaluation. Materials for the Emission Class M1 label must fulfil the following requirements: TVOC emission is below 0.20 mg/m^2/h, formaldehyde emission below 0.05 mg/m^2/h, ammonia emission below 0.03 mg/m^2/h and the number of dissatisfied with the odour below 15%. Today more than 600 building materials have been granted the M1 label. By using a defined amount of M1 labelled materials, the S1 with a TVOC limit of 200 μg/m^3 or S2 of 300 μg/m^3 indoor air quality class should be reached. A question is, if TVOC is capable of describing well enough the indoor air quality, how it compares to the TVOC emission from materials (Saarela *et al.*, 2002a).

METHOD
The Finnish Classification of Indoor Climate 2000 evaluates the indoor air quality according to the TVOC value. From the point of view of health and comfort the concentration of single VOCs are more relevant factors in describing the indoor air quality. This study reports the single VOCs included in the TVOC value of 10 apartments in seven new buildings at the moment when they are completed but before the inhabitants have moved in. The development of the indoor air quality in terms of chemical compound groups is in this study reported from new residences and after 1 year of residency. The results are compared to the results of over two hundred randomly chosen residencies in Helsinki urban area (Saarela *et al.*, 2002b) and results of 26 reference buildings of the patients from a study of the Helsinki University Central Hospital, Department of Dermatology and Allergic diseases (Villberg *et al.*, 2002). The VOCc were collected to TENAX TA and analysed with a gas chromatograph equipped with FI/MS in toluene equivalents between C6 and C16.

RESULTS

Figure 1 shows that the TVOC is considerably higher in new spaces than the indoor design values of the Classification (Class S1 TVOC ≤ 200 µg/m^3 and Class S2 TVOC ≤ 300 µg/m^3) when using M1-classified materials. The main component stands for from 10 to 25% of the TVOC value in new dwellings (Figure 1). Xylenes and alpha-pinene occur in highest concentrations, 406 and 148 µg/m^3, respectively. The two following most abundant were other emissions deriving mainly from wood based materials (hexanal, carene, terpinene) or paints (1,2-propandiol, toluene, decane, 2-propanol, methyldecane, 2-(2-butoxyethoxy)ethanolacetate and 1-butanol).

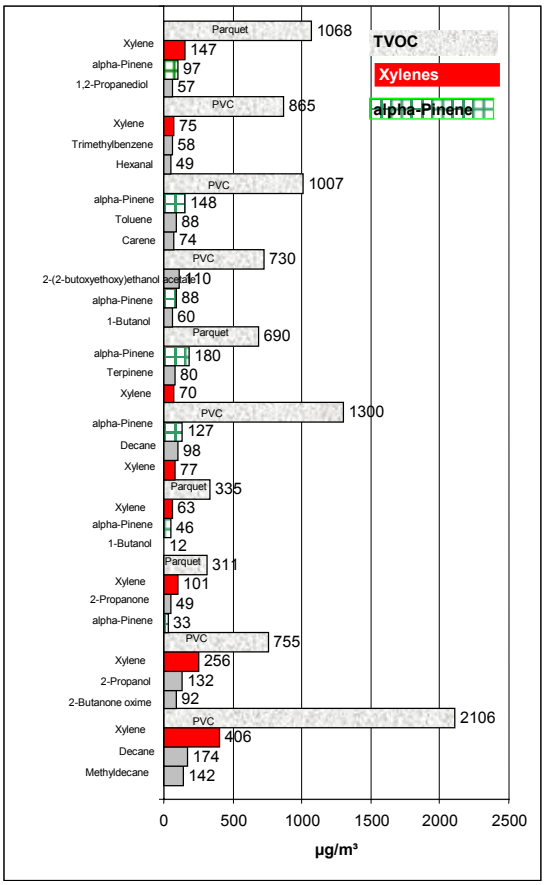

Figure 1 TVOC $_{FID}$ concentration and the concentration of the three main components of the TVOC value of new dwellings. The flooring material is given in the TVOC column.

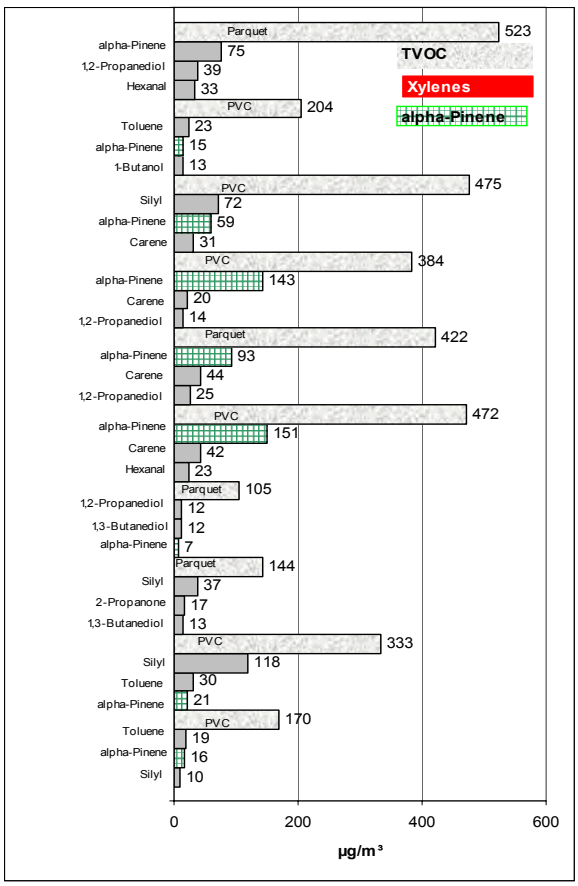

Figure 2 TVOC $_{FID}$ concentration and the concentration of the three main components of the TVOC value of 12-month-old dwellings.

Figure 2 shows that the concentrations of solvent type emissions as xylenes, aliphatics, cycloalkanes and glycols undergo the strongest decay during the first year in dwellings. These compounds are typical for paints, adhesives and sealants. Alpha-pinene does not decay as much as the solvent type VOCs or even rice during the first year of occupancy. The highest concentration of the three main components was 151 µg/m^3 of alpha-pinene after 1 year of occupancy. A detailed study of the decay and factors affecting the concentrations of chemicals such as ventilation, temperature, humidity and occupancy are given in (Jarnstrom and Saarela, 2003).

The three main components in Figures 1 and 2 occur as relatively low concentrations compared to the TVOC value. In order to give a picture of the potential concentration of the VOCs other than the three main components, Table 1 gives the number of all single VOCs occurring at different concentration levels.

Table 1 The number of single VOC contained in the TVOC value

New dwellings, number of single VOCs			12-month-old dwellings, number of single VOCs		
≥5 µg/m^2	≥2µg/m ^{2}	≥1µg/m ^{2} (=over detection limit)	≥5µg/m ^{2}	≥2 µg/m^2	≥1µg/m ^{2} (=over detection limit)
46	76	90	30	52	74
49	78	85	8	24	51
39	61	73	16	44	68
17	34	38	12	33	52
19	36	41	15	32	47
28	30	31	16	29	32
16	30	42	4	9	20
11	25	36	4	19	25
19	38	53	7	27	35
44	56	65	8	27	44

Figures 3 and 4 show the variation of indoor concentrations as 25th, 50th and 75th percentiles of VOC concentrations expressed as chemical groups in the 10 dwellings as new before occupants moving in and after 1 year of residency.

Table 2 shows the median values from box plots in Figures 3 and 4 of the chemical groups from the 10 dwellings as new and after 1 year of residency. The median values are compared to median values from a random choice of residents in Helsinki urban area from the EXPOLIS project (Saarela *et al.*, 2002b) and to the reference buildings of the Finnish Environmental Research program Indoor Air Quality Control Project (SYTTY IAQ) (Villberg *et al.*, 2003).

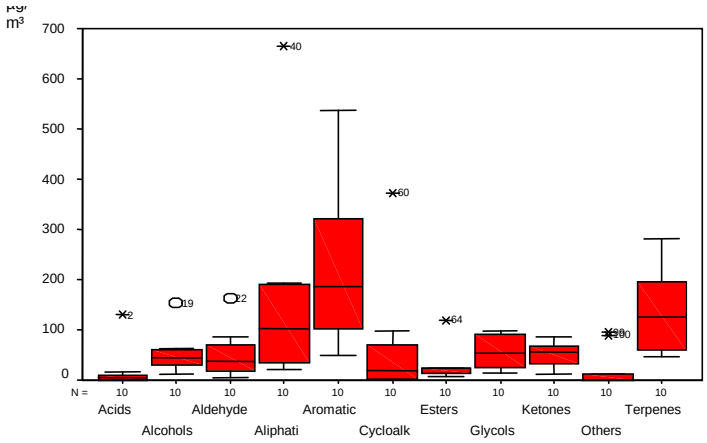

Figure 3 Box plots to illustrate the 25th, 50th and 75th percentiles of VOC concentrations as chemical groups in new dwellings.

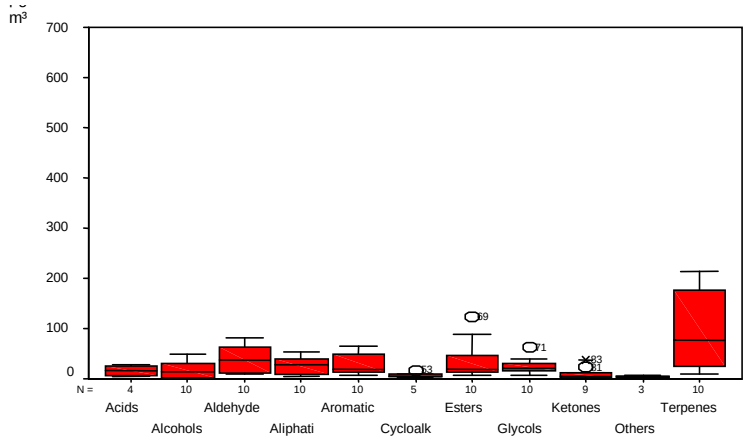

Figure 4 Box plots to illustrate the 25th, 50th and 75th percentiles of VOC concentrations as chemical groups in 12-month-old dwellings.

To give an illustration of the TVOC and VOC concentrations in new and 1-year occupied buildings, Table 2 compares the median values of chemical groups in Figures 2 and 3 to randomly chosen buildings.

In order to describe the health effect of chemical compound groups behind the TVOC value, a risk index was calculated according to ECA Report 18 (ECA) from the LCI values (lowest concentration of interest) according to equation:

$$R = \sum \frac{c_{i,g}}{LCI_{i,g}} \qquad (1)$$

where $c_{i,g}$ is the median concentration of the single chemical group and $LCI_{i,g}$ lowest concentration of interest, representing each chemical group. The risk index R shall be ≤1.

Table 2 Concentrations of VOCs (in toluene equivalents) as chemical groups in 10 new dwellings, in over 200 random choice urban dwellings (EXPOLIS) and 26 reference dwellings (SYTTY IAQ). *N* is the number of occurrences

	0 month		12 month		Change (%)	EXPOLIS		SYTTY IAQ	
	N	Median	*N*	Median		*N*	Median	*N*	Median
Acids	10	3.5	4	15.5	*343*	138	8.8	25	6.9
Alcohols	10	45.1	10	13.7	*-70*	199	12.7	23	32.0
Aldehydes	10	36.3	10	37.5	*3*	204	25.6	26	24.0
Aliphatic hydrocarbons	10	102.4	10	27.0	*–74*	204	20.4	26	27.9
Aromatic hydrocarbons	10	186.7	10	19.7	*–90*	204	35.5	26	25.5
Cycloalkanes	10	18.3	5	5.5	*–70*	95	5.0	15	2.6
Esters	10	22.6	10	19.8	*–12*	201	10.8	26	14.9
Ethers						6	2.7	4	2.1
Glycols	10	53.8	10	22.0	*–59*	131	4.6	23	5.3
Halocarbons						70	3.8	9	1.5
Ketones	10	55.5	9	5.4	*–90*	116	2.3	22	7.5
Others	10	0.0	3	4.1		11	5.1	9	4.4
Silyls						20	3.7	20	1.3
Terpenes	10	124.7	10	76.6	*–39*	204	30.6	26	44.7
TVOC	10	810		360			227		233
Risk index, R		1,7		1,30			0,74		0,95

DISCUSSION

The indoor air of new dwellings contains dozens of chemicals compounds from all major chemical compound groups. Aromatic hydrocarbons appear at the highest median concentrations and terpenes at slightly lower concentrations. The dominating single VOCs are the xylenes with the highest concentration 406 μg/m^3 and alpha-pinene 180 μg/m^3. Other single VOCs with concentration about 100 μg/m^3 are decane, methyldecane, 2-(2-butoxyethoxy)ethanolacetate and 2-propanol and 2-butanone oxime. Of these, 2-(2-butoxyethoxy)ethanolacetate showed emission over 100 μg/m^2/h also in the study of material emissions (Saarela *et al.*, 2002a) and is suspect for being neurotoxicant or other toxicant.

Within 12 months the median concentrations of aromatic compounds and ketones decay by 90% and the decay of terpene median concentration is 39%. The median levels of aromatics in 12 months old buildings were lower than the EXPOLIS or SYTTY IAQ medians, which are representing normal indoor air concentrations in randomly chosen dwellings with no reported complaints. The terpene median levels were even after 1 year of residency twice the levels in EXPOLIS and SYTTY IAQ. The lower decay of terpenes may depend on the slower diffusion process of terpenes from massive materials compared to the more rapid decay of aromatics some other typical groups such as paints, adhesives and sealants. The acids comprised mainly of acetic acid and pentanoic-, hexanoic- and octanoic acids (in three spaces). None of them exceeded a known harmful concentration limit.

The median concentrations of VOCs expressed as chemical groups were generally higher in new buildings, but after 1 year at the same level as in the EXPOLIS and SYTTY projects except the acids, aldehydes, esters and glycols, which were higher and were originating from the finishing works of new apartments. Respectively the TVOC values were higher in new dwellings exceeding the indoor air quality classes S1 and S2, but decayed nearly to the same level as in EXPOLIS and SYTTY.

None of the chemical group median values exceeded the LCI value used for the group but the sum $R = \Sigma$(group median/LCI) exceeded slightly the risk index 1 in the new apartments even after 12 moths of occupancy. The random choice of residences as used in EXPOLIS and SYTTY IAQ represents well normal building stock in Finland. In these groups the risk index was ≤1.

CONCLUSION

In the evaluation of the indoor air quality the Finnish Indoor Climate Classification uses TVOC values of three categories and gives limit values for carcinogens. The S2 class was in most cases reached within 1 year while the S1 class was normally not reached within a year.

The TVOC value consists of dozens of single VOCs exceeding the analytical detection limit. According to this study the prevailing component maximally covers one-third of the TVOC value and the three most abundant less than a half of the TVOC. Of the single VOCs the concentration of one chemical compound, 2-(2-butoxyethoxy)ethanolacetate, exceeded 100 μg/m^3. This compound is a possible toxicant.

None of the single chemical group median values exceeded the LCI value used for the group, but the group sum risk index $R = \Sigma$(group median/LCI) slightly exceeded 1 in the new apartments even after 12 months of occupancy. The random choice of residences as used in EXPOLIS and SYTTY IAQ represents well normal building stock in Finland. In these groups the risk index was ≤1.

According to this study, the TVOC value can be used as a simplified measure in describing the indoor air quality, but with high TVOC values there is a risk that single VOCs can appear in irritative and risky concentrations.

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