VOLATILE ORGANIC COMPOUNDS (VOC) IN THE SWEDISH HOUSING STOCK

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ABSTRACT

Measurements of VOC, formaldehyde, temperature, relative humidity, ventilation and inspections of humidity related problems were made in 178 randomly selected Swedish dwellings. More than one hundred single VOCs was identified with a mean concentration less than 25 μg/m^3. The concentration of 80% of the identified VOCs were less than 10 μg/m^3. One-family houses had a higher concentration of VOCs than multi family houses. Building period, type of ventilation system and indications of humidity related problems in the dwelling did not correlate with the concentration of VOCs to any larger extent. Relative humidity in indoor air were positively correlated to some VOCs, however, temperature and ventilation rate was not correlated to VOCs.

KEYWORDS: VOC, TVOC, ventilation system, residential, dampness, relative humidity, construction

INTRODUCTION

The main part of the done measurements of Volatile Organic Compounds (VOC) in non-industrial indoor air has included the "total" concentration of VOC, i.e. TVOC [2,14]. This means that there are limited data concerning single VOC-compounds (VOCs) in indoor air, particularly for dwellings. The purpose with the study was to estimate the concentration of single VOCs in the Swedish housing stock and to investigate the co-variation between single VOCs and different building related factors.

METHODS

Samples for VOC were taken in 178 randomly selected dwellings in Sweden, 85 single family houses and 93 apartments in multi family houses. VOCs were collected with a passive equipment for 30 days. The definition for VOC in the study was VOCs that could be adsorbed on Tenax TA^{TM} with a boiling point between +50°C and about 290°C. Adsorbed compounds were desorbed thermally to a GCMS-system (Shimadzu QP1000, equipped with a Chrompac Thermal Desorption Device). Results were reported in n-decane equivalents with a lower detection limit of 1 μg/m^3. Indications of dampness related problems in the dwellings were investigated and reported by inspectors. Five different indications were used: Condensation on inside of window panes, humidity problem in bathroom, humidity problem in basement, humidity problem in dwelling, mould odor in the dwelling. Two indexes were calculated:

DAMP1: at least one of the four indications (condensation excluded), DAMP2: at least one of the three indications (condensation and humidity problems in basement excluded). Statistical analysis of differences in mean concentration of VOCs between different building environments were made by ANOVA.

RESULTS

The mean concentration of TVOC and formaldehyde was 350 μg/m^3 (85-1050 μg/m^3) and 12 μg/m^3 (0-62 μg/m^3) respectively in the 178 dwellings, see also [12]. About 120 single VOCs could be identified in the indoor air of the dwellings. Of these there were 27 VOCs with a mean concentration above 10 μg/m^3, i.e. about 80% of the identified compounds had a mean concentration less than 10 μg/m^3. About half part of the 27 VOCs could be identified in more then 25 dwellings, see Table 1.

Table 1. Volatile Organic Compounds (VOC) with a mean air concentration above 10 μg/m^3 identified in 178 randomly selected Swedish dwellings, (85 single family houses and 93 apartments in multi family houses).

VOC	n[1)]	Proportion[2)] (%)	Min. (μg/m^3)	Max. (μg/m^3)	Mean (μg/m^3)	Std. Dev.
Metoxyetoxyetanol	1	0.6	56.0	56.0	**56.0**	
SI[3]	5	2.8	13.0	44.0	**27.0**	11.6
limonene	143	80.3	3.0	189.0	**25.5**	29.7
alkane C11	123	69.1	3.0	67.0	**22.8**	14.7
trichloroethylene	1	0.6	20.0	20.0	**20.0**	
aromatic C10	4	2.2	5.0	30.0	**18.8**	12.7
glykolether	2	1.1	4.0	33.0	**18.5**	20.5
aromatic C9	49	27.5	3.0	112.0	**18.2**	23.0
tetrahydrofurane	2	1.1	4.0	31.0	**17.5**	19.1
aromatic C8	80	44.9	3.0	211.0	**17.0**	29.2
alkane C8	4	2.2	4.0	44.0	**16.0**	18.9
n-decane	165	92.7	3.0	148.0	**13.9**	14.5
butoxypropanol	29	16.3	3.0	38.0	**13.0**	8.8
alkane C10	55	30.9	3.0	78.0	**12.2**	13.3
alkane C12	115	64.6	3.0	47.0	**11.9**	7.6
n-undecane	147	82.6	3.0	72.0	**11.7**	12.2
alkane C7	25	14.0	3.0	33.0	**11.6**	9.8
toluene	167	93.8	3.0	126.0	**11.2**	12.6
Isopropylformiate	1	0.6	11.0	11.0	**11.0**	
n-dodekane	160	89.9	3.0	48.0	**10.8**	7.7
alkane C6	3	1.7	3.0	24.0	**10.7**	11.6
n-tetradekane	3	1.7	7.0	13.0	**10.3**	3.1
butoxyetoxyetanol	36	20.2	3.0	110.0	**10.2**	17.4
n-nonanal	157	88.2	3.0	31.0	**10.2**	5.5
methyl pyrrolidinone	2		4.0	16.0	**10.0**	8.5
propoxyetanol	1	0.6	10.0	10.0	**10.0**	
formaldehyde	177	99.4	0.0	62.0	**12.3**	8.1

1) Number of dwellings where the VOC-compound could be identified
2) Proportion of the 178 dwellings where the VOC-compound could be identified
3) Sum of hexamethyl cyclotrisiloxane and octamethyl cyclotetrasiloxane

Identified VOC-compounds were summed up to different chemical groups. The concentration of different groups of VOCs is presented in Table 2.

Table 2. Mean concentration of different chemical groups for VOCs including TVOC in 178 randomly selected Swedish dwellings.

Chemical group(s)	Valid N	Min. (µg/m³)	Max. (µg/m³)	Median (µg/m³)	Mean (µg/m³)	Std. Dev.
TVOC	178	85.0	1050.0	318	**351**	181.0
alkanes/alkenes/cykloalkanes	176	3.0	484.0	70	**80**	66.5
terpenes/aromatics	172	3.0	442.0	29	**51**	57.8
aldehydes	163	3.0	56.0	19	**20**	12.4
alcoholes	99	3.0	29.0	6	**7**	4.9
ketones	91	3.0	116.0	9	**13**	16.1

VOCs in indoor air and building related factors

A comparison was made between the air-concentration of single VOCs in single family houses and multi family houses. 17 VOCs showed a higher mean concentration in single family houses. However, the difference was significant only in 6 cases. The TVOC-concentration was also significantly higher in single family houses compared to multi family houses, see Table 3.

The comparison between dwellings built before and after 1973 showed no significant difference for single VOCs. However, the mean concentration of alkanes/alkenes were significant higher in dwellings built before 1973. (92/71 µg/m³).

The mean concentration of single VOCs ws higher in naturally ventilated dwellings in 20 cases. However, the result was significant only for n-nonanal and n-undecane. Furthermore, the concentration of TVOC (401/317 µg/m³) an aldehydes (32/18 µg/m³) were significantly higher in the naturally ventilated dwellings.

Thus, the investigation showed that the type of building was the most important building factor for VOC in indoor air a stratified analysis was made for building period and type of ventilation system in respect of type of building. However, the analysis showed the same results as earlier.

The mean concentration of a VOC was compared between dwellings with and without indications of humidity problems indoors. The analysis showed that the mean concentration of 18 VOCs were higher in dwellings with reported condensation on window panes. However, the result was significant only for butoxyetoxyetanol, (21.9/6.9 µg/m³). The mean concentration for individual VOCs was also higher in dwellings with reported humidity problems in bathroom in 14 cases but significant only for n-tridecane, alkene C12 and alkane C7. In dwellings with reported humidity problems in the basement the mean concentr tion of individual VOCs was higher in 12 cases, however, significantly higher only for n-undecane (21.1/11.4 µg/m³) and n-nonane (14.4/7.0 µg/m³). In dwellings with the criteria of DAMP1 fulfilled the mean concentration of 14 VOCs was higher compared to dwellings without DAMP1 fulfilled. However, no result was significant. Furthermore, 12 VOCs had a higher mean concentration where DAMP2 was fulfilled but the differences were only significant for n-tridecane. alken (unidentified) and alkane C7.

Finally, the correlation between the concentration of VOCs, relative humidity in indoor air, ventilation rate, and indoor temperature was calculated. Since both relative humidity, ventilation rate and temperature is different in single family houses compared to multi family houses the analysis have been adjusted for type of building. The analysis include individual VOCs which could be identified in more than 20% of the 178 dwellings. Relative humidity in indoor air was significantly positively correlated to the concentration of seven VOC-compounds (formaldehyde, n-decane, limonene, alkane C12, n-hexanal, n-tridecane, alkane C10). Indoor temperature was significant positively correlated to toluen and aromat C8. Ventilation rate expressed as l/s, m^2 showed no significant correlation with VOC. However, ventilation rate expressed as l/s, person was negatively correlated to TVOC and the concentration of hexanal.

Table 3. Co-variation between the mean concentration of single VOCs and building related factors.

VOC	Type of Building 1) (µg/m^3)	Building period 2) (µg/m^3)	Ventilation system 3) (µg/m^3)	DAMP1 4) (µg/m^3)	DAMP2 5) (µg/m^3)
formaldehyde	**15.8/9.1 *****	11.0/13.2 ns	12.5/12.2 ns	11.8/13.2ns	12.9/12.0 ns
toluene	**13.9/8.7 ****	11.5/11.0 ns	11.9/10.8 ns	11.7/12.6 ns	10.9/11.3 ns
n-decane	**16.8/11.3 ***	15.8/12.4 ns	16.2/12.3 ns	16.5/13.9 ns	11.1/14.1 ns
n-dodecane	12.0/9.8 ns	10.9/10.7 ns	11.9/10.1 ns	12.0/11.3 ns	10.9/10.7 ns
n-nonanal	10.4/10.0 ns	10.4/10.0 ns	**11.8/9.2 ****	11.2/10.1 ns	11.5/10.0 ns
n-undecane	**14.9/8.6 ****	13.5/10.4 ns	**15.3/9.4 ****	15.9/11.4 ns	11.0/11.5 ns
limonene	23.5/27.6 ns	27.3/24.3 ns	27.2/24.3 ns	20.9/30.0 ns	22.8/26.3 ns
alkane C11	21.7/23.7 ns	23.6/22.1 ns	24.9/21.4 ns	26.7/20.9 ns	23.6/22.5 ns
alkane C12	11.4/12.3 ns	12.3/11.6 ns	11.8/12.0 ns	11.1/11.4 ns	11.6/11.9 ns
n-hexanal	**6.2/4.5 ****	5.5/5.6 ns	5.7/5.4 ns	5.4/5.6 ns	5.7/5.4 ns
n-decanal	8.0/9.5 ns	9.7/8.1 ns	9.3/8.4 ns	8.6/8.6 ns	7.6/8.9 ns
n-tridecane	7.4/5.1 ns	5.1/7.3 ns	5.5/7.0 ns	9.3/6.2 ns	**11.7/5.6 ***
aromatic C8	**26.4/8.0 ****	16.8/17.2 ns	20.5/13.8 ns	26.5/17.0 ns	30.9/14.8 ns
alkene C12	7.9/9.8 ns	9.3/8.4 ns	8.4/9.3 ns	11.3/8.1 ns	**12.0/8.1 ***
n-nonane	9.0/6.5 ns	8.8/7.0 ns	9.2/6.6 ns	12.2/7.1 ns	8.1/8.2 ns
a-pinene	6.8/4.8 ns	5.4/6.8 ns	5.6/6.7 ns	4.9/5.9 ns	5.6/5.6 ns
alkane C10	16.0/9.2 ns	14.4/9.9 ns	15.0/9.8 ns	18.2/12.1 ns	13.5/12.2 ns
alkane C13	7.8/9.1 ns	9.3/7.9 ns	7.9/9.1 ns	6.6/9.0 ns	5.3/8.8 ns
aromatic C9	22.8/10.3 ns	22.6/14.7 ns	20.7/15.2 ns	25.5/19.3 ns	20.1/18.2 ns
2-ethylhexanol	5.0/5.2 ns	4.5/5.2 ns	5.0/5.1 ns	4.9/5.2 ns	5.1/5.1 ns
Δ-3-carene	8.5/5.0 ns	8.6/7.0 ns	5.8/8.4 ns	5.5/7.4 ns	6.0/7.1 ns
buthylacetate	6.0/4.6 ns	6.1/5.2 ns	6.1/5.0 ns	4.4/6.2 ns	4.5/5.9 ns
butoxyetoxyetanol	5.8/14.6 ns	16.4/7.1 ns	14.1/7.4 ns	8.1/7.0 ns	8.8/10.5 ns
butoxypropanol	14.4/10.4 ns	15.0/11.9 ns	16.8/10.4 ns	15.3/13.6 ns	19.5/12.4 ns
alcohol. unidentified	3.8/4.5 ns	4.6/4.1 ns	4.6/3.9 ns	3.0/4.0 ns	3.0/4.3 ns
n-butanol	4.¼.2 ns	4.3/4.1 ns	4.3/4.0 ns	5.0/4.0 ns	4.0/4.2 ns
alkane C7	12.9/9.8 ns	12.9/10.3 ns	13.1/10.3 ns	17.6/10.5 ns	**24.5/10.5 ***
TVOC	**388/317 ****	378/331 ns	**401/317 ****	363/359 ns	330/352 ns

*=p<0.05. **=p<0.01 ***=p<0.001, ns=no significant. 1) Single family houses (n=85)/multi family houses (n=95). 2) Buildings erected before 1973/Buildings erected after 1973. 3) Naturally ventilation/mechanical ventilation. 4) Criteria for DAMP1 fulfilled/Criteria for DAMP1 not fulfilled. 5) Criteria for DAMP2 fulfilled/Criteria for DAMP2 not fulfilled.

DISCUSSION

Different investigations have identified several hu dred different VOC-compounds in non-industrial indoor air. An American database showed hat the concentration for nearly 50% of 66 identified VOC-compounds were 0.4-4 μg/m^3, [11]. [6] reported that the mean concentration for single VOCs was less than 50 μg/m^3 and most of the VOCs showed a concentration less than 5 μg/m^3. Furthermore, several investigations have shown concentrations less than 10 μg/m^3. [4,7,9,10]. Thus, the results presented in this investigation is in agreement with other studies even if comparisons is difficult because of differences in sampling methods, analysis methods, different environments, etc.

The analysis showed that type of building was the most important building related factor for concentration of VOCs indoors. The results showed that the concentration often were higher in single family houses. One possible explanation for this is that the ventilation rate is lover in single family houses in Sweden compared with multi family houses [3]. On the other hand very few compounds were negatively correlated to he ventilation rate in the dwellings.

The finding of higher concentrations of VOCs in buildings with naturally ventilation maybe could be explained by lover ventilation in buildings with such ventilation system. Andersson et al. [3] showed that the ventilation rate is significant lower in buildings with naturally ventilation system compared to mechanical systems. However, such a finding could not be confirmed in the analysis or type of ventilation system in Table 3 as the results were only significant in two cases. The finding of a higher concentration of VOCs in dwellings with reported condensation on window panes maybe also is a result of low ventilation rate.

There was a positive correlation between relative humidity in indoor air and the concentration of some VOCs. This is in agreement with other studies. Andersen et al. [1] found that the emission of formaldehyde from chipboard increased when the relative humidity increased from 30 to 70% RH.

There are findings that the alcohols 2-ethyl hexanol and n-butanol can be associated to humidity proble s indoors. e.g. emissions from degradated PVC-carpets and adhesives on concrete floors [5,8]. There were no such findings in this study. It should be observed that reported moisture problems were based statements from inspectors and that no real moisture measurements were done in constructions. Unfortunately, there were no information on used carpets (eg. PVC) or used adhesives.

CONCLUSIONS

- More than 100 single VOC-compounds in concentrations exceeding 1 μg/m^3 could be identified in 178 randomly selected Swedish dwellings. Of these, 27 VOC could be identified in more than 25 dwellings.
- The mean concentration of identified single VOCs was less than 25 μg/m^3 and about 80 % of identified VOCs showed a concentration less than 10 μg/m^3.
- The concentration of individual VOCs was in many cases higher in single family houses compared to multi family houses. Building period and type of ventilation system was associated to VOC in a lesser degree.
- Humidity related problems could be associated to VOC in a few cases.

- Relative humidity in indoor air was positively correlated to a handful of VOCs. Temperature indoors and ventilation rate was not correlated to VOC.

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