Material emissions in new buildings

H. Jarnstrom[*], K. Saarela

VTT Building and Transport, P.O. Box 1804, FIN-02044 VTT, Finland

ABSTRACT
A 3-year research project was established in 1999 to create numerical reference data for material emissions during the time of construction and during the first year after the building has been taken into use. A total of nine measurement sites, representing the present construction practice in Finland, were chosen for investigation. Material emission measurements for surfaces, using the field and laboratory cell (FLEC) technique, were performed in the newly finished and 6- and 12-month-old buildings according to a specified schedule. The emission rates for Volatile Organic Compounds (VOCs), formaldehyde and ammonia as well as the humidity of the construction were measured. The results are compared to the material emission rate target values, defined in the Finnish 'Classification of Indoor Climate 2000', and are discussed.

INDEX TERMS
Material emissions; New buildings; VOC; Formaldehyde; Ammonia

INTRODUCTION
The Finnish building material classification gives emission limits for VOCs (TVOC), formaldehyde and ammonia (FiSIAQ, 2001), which are suspected to be responsible for health effects or indicators of material degradation. This 3-year study was established to investigate how the limits for material emissions defined in the classification can be reached in new, residential buildings, which are built with today's good building practice, including structure humidity control, and in which low emitting, classified materials are used. The objective is to create reference data for material emissions in newly finished buildings and this data can be used as a part of the quality control in today's building practice and in the identification of material/moisture-based problems in suspected cases.

METHODS
Measurement Sites
The measurement sites were chosen in collaboration with three different construction partners. Emission measurements were performed in six apartment buildings (site built and manufactured). Four buildings have a mechanical exhaust ventilation (sites 1, 2, 4 and 7) and two a mechanical supply and exhaust ventilation (sites 5 and 6). Five of the buildings are located in the Helsinki area and one in the city of Turku. The time taken for construction of the buildings was 12–15 months during the years 1999–2002. The follow-up measurements were performed every time at the same sites at all building stages. The TVOC, ammonia and formaldehyde emissions were determined for all surfaces in the newly finished and in the 6- and 12-month-old, inhabited building. The structure ages in the newly finished buildings were as follows: for the floor covering 8–22 weeks, the ceiling structure 17–27 weeks and for the wall structure 11–26 weeks.

[*] Corresponding author. E-mail: helena.jarnstrom@vtt.fi

Materials

At all measurement sites, low emitting, M1-classified materials (www.rts.fi) were used. That is, the laboratory tests performed for a 4-week old sample gives a TVOC-, ammonia- and formaldehyde emission lower than 200, 30 and 50 $\mu g/m^2$ h, respectively. At eight measurement sites the walls were finished with screed and painted. Wallpaper was laid on the screed at site 4. Ceiling structures were finished with screed. The floor structure was finished with fine screed (dispersal 2–5 mm) in the site built houses and with gross screed (dispersal 10–30 mm) in the case of manufactured houses. Different types of PVC materials (PVC 1–6), adhesives (adhesive 1–4) and parquets (Parquet 1–2) were used as floor covering materials. At site 7, apartment 2, no adhesive was used in the installation of the floor covering material. Table 2 summarizes the floor structure and floor covering materials as well as the time of construction.

Table 2 Measurement sites (OSCC = on site built concrete cast, MCCS = manufactured, cored concrete slab, ME = mechanical exhaust, MES = mechanical exhaust and supply system)

Site	Structure	Floor covering material	Air exchange system	Time of construction (heating on)
Site 1, 2nd floor	OSCC	Parquet 1	ME	December 1999–August 2000
Site 1, 4th floor	OSCC	PVC 1, adhesive 1		
Site 1, 5th floor	OSCC	PVC 2, adhesive 2		
Site 2, 6th floor	MCCS	PVC 3, adhesive 1	ME	June 2000–February 2001
Site 4, 3rd floor	OSCC	PVC 4, adhesive 3	ME	November 2000–June 2001
Site 5, 2nd floor	MCCS	Parquet 2	MES	January 2001–July 2001
Site 6, 1st floor	MCCS	Parquet 2	MES	May 2001–December 2001
Site 7, 2nd floor	MCCS	PVC 5, adhesive 4	ME	June 2001–December 2001
Site 7, 3rd floor	MCCS	PVC 6, no adhesive	ME	June 2001–December 2001

Sampling and analysis

Field measurements for material emissions of structures were performed using the Field and Laboratory Cell (FLEC) technique (CEN, 1999). The humidity of the structure was determined with a Vaisala® HMP44 moisture detector according to the instructions given by the Finnish Building Foundation (RTS, 1998). The indoor air temperature and relative humidity were registered using a Vaisala® HMP41 moisture detector and the air exchange rate for the facility was determined simultaneously with an Alnor AXD-530 meter.

The total amount of VOCs was determined by sampling 2–5 l of air on Tenax TA adsorbent and analyses with GC-MSD/FID after thermal desorption. The TVOC was calculated as toluene equivalents from the total integrated FID signal between hexane and hexadecane. The sampling of ammonia and formaldehyde was performed on a 0.005 M sulfuric acid solution. The ammonia concentration was determined with an ion-selective electrode and the analysis of formaldehyde was done with the spectrometric acetyl-acetone method.

RESULTS

The humidity of the floor structure decreased from a level of >90% to the level 60–80% in 18–20 months after the structure was finished and the building was heated at >15°C. The 80% structure humidity was measured at sites 4 and 7 in the 12-month follow-up measurement.

The highest TVOC emissions in the newly finished building were measured from the ceiling structure (sites 1, 2, 4 and 7) and from some of the PVC materials used as floor coverings (sites 2 and 4, PVC 3 and 4). These emissions clearly exceeded the M1-class limit of 200 μg/m^2 h (FiSIAQ, 2000). Nearly M1-class TVOC emissions from all surfaces were measured at sites 5 and 6 where a mechanical supply air system was installed. The clearly lowest indoor air TVOC concentration was also measured at these sites (Jarnstrom and Saarela, 2003). The TVOC emission for the painted walls (concrete/gypsum board) were within the M1-class target value when the structure was over 10 weeks old. At site 4 a ~500 μg/m^2 h TVOC emission was measured from the wall structure which was finished with wall paper. The TVOC emission for all surfaces decreased in 6–12 months to the M1-class level at all measurement sites. The TVOC emissions for the 0–12 month-old buildings are summarized in Figure 1.

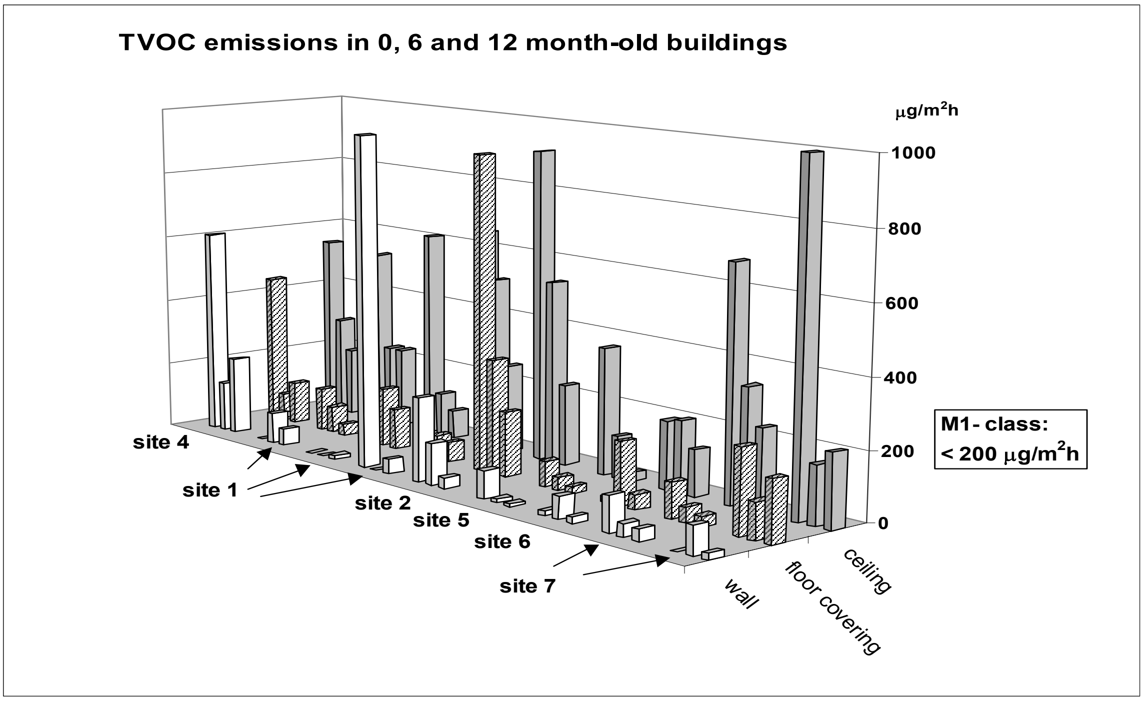

Figure 1 TVOC emissions in 0-, 6- and 12-month-old buildings. The three columns for sites 2–7 represent the 0, 6 and 12 month results.

The highest ammonia emissions in new buildings were measured from the ceiling structure. These emissions were on the level 20–60 μg/m^2 h and generally over the M1-class limit of 30 μg/m^2 h.. The ammonia emission measured from the different floor covering materials and painted wall structure (concrete/ gypsum board) was 15 μg/m^2 h or lower. Clearly higher ammonia emissions, 40–60 μg/m^2 h were measured from the wall structure which was finished with wall paper. The ammonia emission for the ceiling structure increased during the 6–12 month follow-up measurements, which were performed during the summer period. The indoor air relative humidity was 50% or higher at these measurement points. The indoor air ammonia concentration was also elevated and was found to correlate with the indoor air relative humidity (Jarnstrom and Saarela, 2003). The ammonia emissions measured from the other surfaces showed no significant increase during the follow-up measurements.

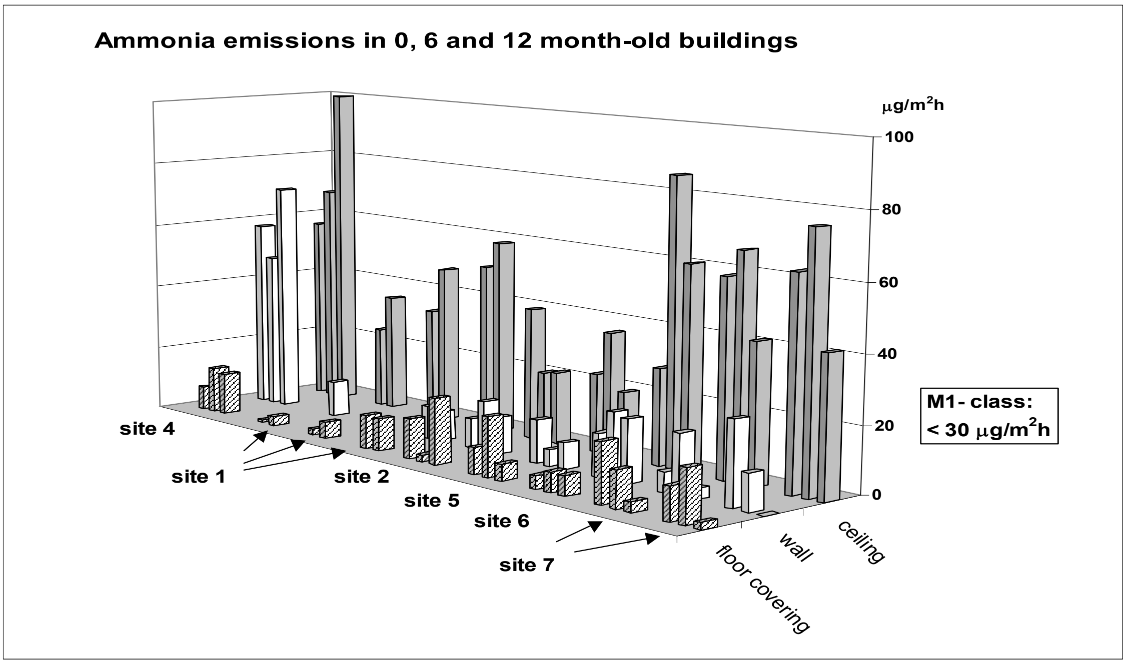

Figure 2 Ammonia emissions in 0-, 6- and 12-month-old buildings. The three columns for site 2–7 represent the 0, 6 and 12 month results. The two columns for site 1 represent the 6 and 12 month results.

The highest formaldehyde emissions, which were on the level 20–60 μg/m^{2}h in the newly finished buildings, were measured from the ceiling structure and from the wall structure, which was finished with wall paper. The lowest formaldehyde emission of 20 μg/m^2 h from the ceiling structure was measured at sites 5 and 6, where a mechanical supply air system was used, during all follow-up measurements. At these sites the indoor air formaldehyde concentration remained on a low level in comparison to the other measurement sites (Jarnstrom and Saarela, 2003). The formaldehyde emissions at the measurement sites with only a mechanical exhaust system showed greater variations during the 12 month measurement period. The highest formaldehyde emission of 100 μg/m^2 h was measured at site 7, apartment 1 during the 6-month follow-up measurement in May 2002. The relative humidity at this point was 38%. The M1-class target value of 30 μg/m^2 h was reached for the ceiling structure in the 12 month follow-up measurement at all sites except at site 4, where it was slightly exceeded (FiSIAQ, 2001). The formaldehyde emisison for the wall structure, which was finished with wall paper also remained on the level of 40 μg/m^2 h during the follow-up measurements. The formaldehyde emissions from the painted wall structure (concrete/gypsum board) and the different floor covering materials remained on the low level of <15 μg/m^2 h during the measurement period of 12 months.

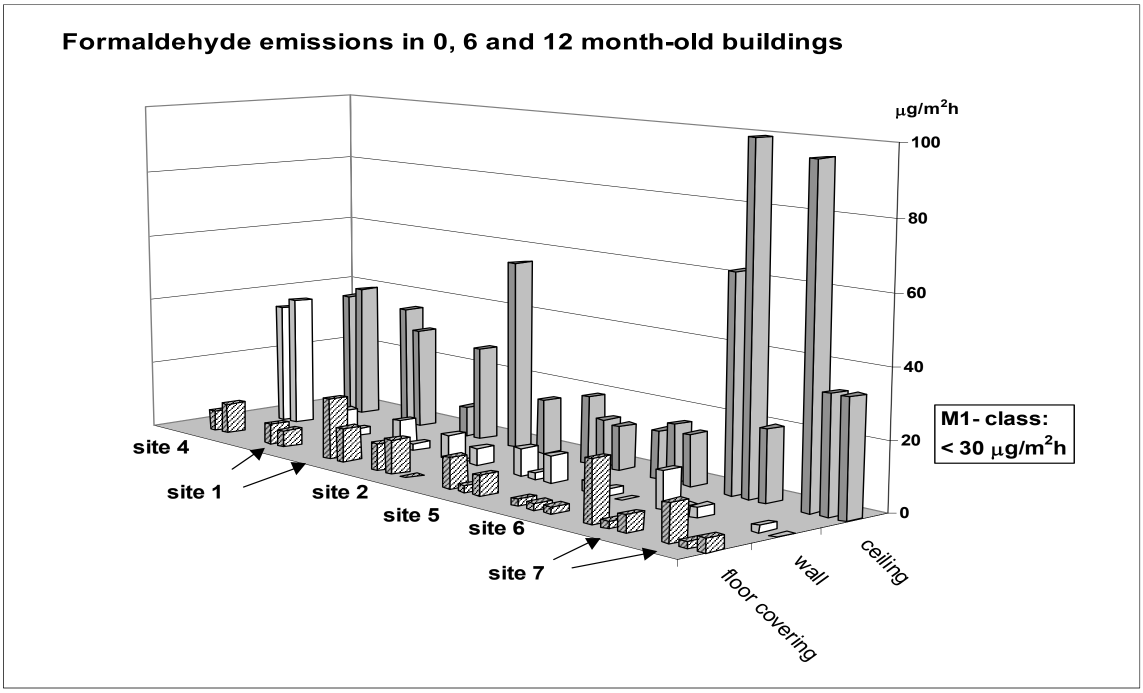

Figure 3 Formaldehyde emissions in 0-, 6- and 12-month-old buildings. The three columns for site 2–7 represent the 0, 6 and 12 month results. The two columns for sites 1 and 4 represent the 6 and 12 month results.

DISCUSSION

The results obtained during this project give a good overview of what emission levels are achieved in real buildings when using different low-emitting, classified building materials. It was concluded that very different emissions levels are measured from low-emitting, classified surface materials in new buildings. For example, the TVOC emissions of different M1-classified PVC materials can exceed the M1-class target value (FiSIAQ) by a factor of five in the newly finished building. The higher emission is a result of the permeability of the material to the compounds originating from the underlying structure. Clearly higher, M1-class exceeding emissions were also measured from the wall structure, which was finished with wallpaper, in comparison to painted walls.

The TVOC emissions of the floor covering materials and other surfaces as well decreased steadily during the first year to the M1-class level (FiSIAQ). The emission of the uncovered floor structure emission results during the 12 month follow-up measurements for site 1 have been reported earlier (Jarnstrom and Saarela, 2002). The same measurement of the uncovered floor structure (1 and 3 days after opening the floor covering) was performed at the other sites presented here and similar results as earlier were obtained, i.e. relatively high TVOC and ammonia emissions were measured from the floor structure under some PVC materials (site 7, PVC 5 and 6) whereas the emission measured from the floor covering itself was very low. These results further implied a great variety in the permeability of the floor covering materials for the compounds under investigation. Furthermore, no difference in the level of TVOC or ammonia emissions were observed between the measurement results under PVCs 5 and 6 at site 7 and this observation was of special note since no adhesive was used in the installation of PVC 6. The ammonia and formaldehyde emissions measured from the ceiling structure was relatively high in comparison to the other surfaces and it is to be noted that the emissions increased at some of the measurement sites during the 6–12 month follow-up measurements. The M1-class target value for ammonia emission was not achieved at all sites during the first year whereas the formaldehyde emissions reached the M1 target value (FiSIAQ). The ceiling structure was finished with a porous screed layer, which presumably has good adsorption properties for the indoor air compounds under investigation and this effect could result in the dynamic emission state observed for the ceiling structure in the new buildings during the first year. The increase in the ammonia and formaldehyde emissions correlated to some extent with the increase in indoor air relative humidity and the result was seen as elevated indoor air concentrations. The indoor air concentration measurement results are published in a separate conference paper (Jarnstrom and Saarela, 2003). No significant effect of the higher structure humidity at sites 4 and 7, in comparison to the other measurement sites, on the emission results was observed.

CONCLUSIONS AND IMPLICATIONS

Building designers and constructors can use the knowledge gained during this project to develop their building practice in the course of producing buildings with high indoor air quality. The applicability for material suppliers is to develop long-term resistant, low emitting surface materials. In addition, the on site reference data can be utilized in the identification of material/moisture-based problems in suspected cases.

ACKNOWLEDGEMENTS

This project is part of the national Healthy Building-project 'Verification, Source Apportionment and Remediaton of an Indoor Air Problem' and it is partly financed by the Finnish National Technology Agency (TEKES).

REFERENCES

FiSIAQ (2001). *Classification of Indoor Climate 2000*. Espoo: Finnish Society of Indoor Air Quality and Climate.

RTS (1998). *RT Building Information File 14-10675: Determination of the Humidity of Structures*. Helsinki: The Finnish Building Information Foundation, www.rts.fi

CEN (1999). *ENV 13419-2, Building Products. Determination of the Emission of Volatile Organic Compounds. Part 2: Emission Test Cell Method*. Bruxelles: European Committee for Standardisation.

Jarnstrom, H. and Saarela, K. (2002). The material emissions and indoor air quality in new buildings. *Proceedings of Indoor Air 2002.*

Jarnstrom, H. and Saarela, K. (2003). The development of indoor air quality in new buildings. *Proceedings of Healthy Buildings 2003.*