The development of indoor air quality during the first year in new, residential buildings

H. Jarnstrom* and 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 indoor air quality follow-up in new buildings. A total of 12 measurement sites, representing the present construction practice in Finland, were chosen for investigation. Low-emitting surface materials according to the 'Finnish Classification of Building Materials' were used at all sites. The indoor air VOCs, formaldehyde and ammonia concentration as well as the temperature, relative humidity and the air exchange rate were defined for the newly finished building. The measurements were repeated after 6 and 12 months. The effect of the different building types, building materials and external conditions on indoor air concentrations are summarized along with the questionnaire results given to the inhabitants on the indoor air quality experienced, living environment and health effects. As a conclusion, justification aspects for indoor air concentration target values, defined in the Finnish 'Classification of Indoor Climate 2000' are discussed.

INDEX TERMS
IAQ; New buildings; VOC; Formaldehyde; Ammonia

INTRODUCTION
In order to improve the quality of indoor air the Finnish classification of indoor climate was developed (FiSIAQ, 2001). The classification gives target values for indoor air concentrations of VOCs (TVOC), formaldehyde and ammonia, which have to some part been considered to be responsible for health effects among inhabitants or indicator compounds for structure degradation. This study investigated how the limits for indoor air concentrations defined in the classification can be reached in 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 indoor air quality for newly finished buildings, which 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. Indoor air measurements were performed in seven apartment buildings (site built and manufactured) and in one (site built) 2-family house. Five buildings have a mechanical exhaust ventilation and three a mechanical supply and exhaust ventilation. Seven of the buildings are located in the Helsinki area and one in the city of Turku. The time of construction for the buildings was 12–15 months during the years 1999–2002.

The follow-up measurements were performed every time in the same room (usually the bedroom) and at the same site at all building stages. A survey among the inhabitants on their background, living environment and possible building related symptoms was performed at all sites after the 12-month follow-up measurement.

*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 seven 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 (PVC 1-6) materials and parquets (Parquet 1–4) were used as floor covering materials. Table 1 summarizes the building structure type and floor covering materials as well as the type of air exchange system.

Table 1 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 3, 2nd floor	OSCC	Parquet 1	ME	June 2000–March 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		
Site 8, 2nd floor	OSCC	Parquet 3	MES	October 2001–June 2002
Site 8, 3rd floor	OSCC	Parquet 4		

Sampling and analysis

Indoor air sampling was performed in the closed room at approximately 1.40 m above the floor level. No additional ventilation through doors or windows was done 24 h prior to the measurement. The temperature and relative humidity were registered using a Vaisala® HMP41 moisture detector during the 1 hour measurement period. 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 a ion-selective electrode and the analysis of formaldehyde was done with the spectrometric acetyl-acetone method.

RESULTS

The TVOC concentration in the newly finished buildings varied between 310–2100 μg/m^3 (Figure 1). The highest concentration of TVOC was measured in one of the apartments at site 7 and this was explained by a preceding 'bake out' period (the apartment was heated at 30 – 35°C for 2 weeks) which was performed in the newly finished apartment after a water leakage. In general, the TVOC concentration was above the S3- class limit of 600 μg/m^3 in the newly finished buildings (FiSIAQ, 2001). The parameter that most affected the TVOC concentration at this point was the type of ventilation: at sites 5, 6 and 8, where a mechanical supply and exhaust ventilation system was used, the lowest TVOC concentrations of 310–620 μg/m^3 were measured. The single VOC concentrations in the newly finished buildings are reported for in a separate conference paper (Saarela *et al*., 2003).

The TVOC concentration decreased in 6 months to a <600 μg/m^3 level at all sites except at site 2, where the TVOC concentration reached a level of 1000 μg/m^3. The increase in the total amount of VOCs was explained with the increase in the concentrations of the single VOCs

α-Pinene and δ-carene, which were concluded to originate from a newly installed wooden furniture (bookcase). In six apartments (site 1, 4, 5, 7 and 8) the TVOC concentration reached a low level of 200 μg/m^3 during the first 6 months. The effect of the 'bake out' period in one of the apartments at site 7 could be seen in the low TVOC concentration during the follow-up measurements. No significant change was seen between the 6- and 12-month results except at site 4 where the TVOC concentration level rose by the increase in the single VOCs. The air exchange was not functioning normally prior to the measurement since the fresh air supply was restricted and this most likely affected the results.

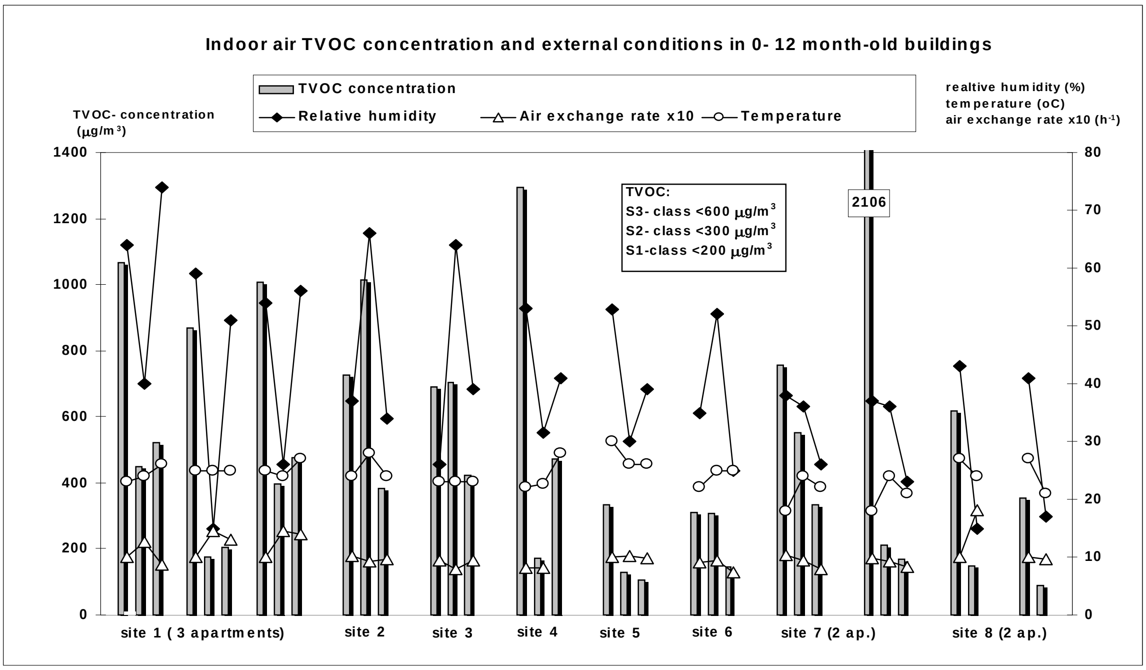

Figure 1 Indoor air TVOC concentration and external conditions in 0–12 month old buildings (the three columns represent the TVOC concentration in the 0, 6 and 12 month old building at sites 1–7. At site 8 the TVOC concentration for the 0 and 6 month old building is shown).

The air exchange rates at the measurement sites varied between 0.73-1.81 h^{-1} during the first year and these were above the required value of 0.5 h^{-1} in residential buildings (Ministry of the Environment, 1987). The variations in the air exchange rates could to some extent explain the differences in the TVOC concentrations measured. No correlation between the change in the relative humidity and the TVOC concentration was observed. The use of different building materials was also of less importance regarding the TVOC concentration during the first year; low TVOC concentrations were measured at sites with different structure types (on site built concrete cast/ manufactured cored concrete slab structure), different floor covering materials (PVC/ parquet) as well as different air exchange systems (mechanical exhaust only/exhaust and supply system).

The indoor air ammonia concentrations were 20–60 μg/m^3 in the newly finished buildings (Figure 2). The lowest ammonia concentrations were measured at sites 2, 3 and 7, which differed in building structure and floor covering materials (on site built, concrete cast/ manufactured, cored concrete slab structure, parquet/PVC 3,5/6) and air exchange system. These sites were finished in winter.

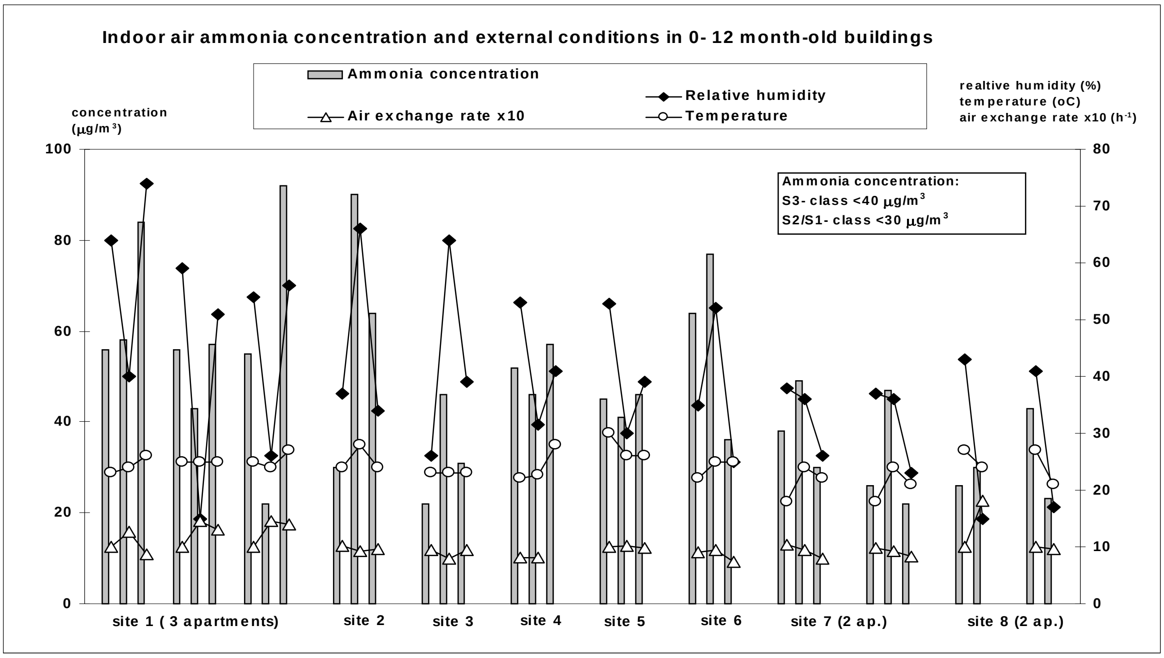

Figure 2 Indoor air ammonia concentration and external conditions in 0–12 month- old buildings (the three columns represent the ammonia concentration in the 0, 6 and 12 month old building at sites 1–7. At site 8 the ammonia concentration for the 0 and 6 month old building is shown).

The ammonia concentration levels changed during the first year and the variations correlated with seasonal variations, i.e. the changes in the relative humidity. The relatively high concentrations of 60–90 μg/m^3 were measured in the 6–12 month old buildings during the summer, which is clearly above the S3-level of 40 μg/m^3 (FiSIAQ, 2001). The relative humidity was at this point 50% or higher. In the winter the relative humidity was below 40% and the ammonia concentrations measured were on the level 20–50 μg/m^3. No difference between the different air exchange systems used on the ammonia concentration was observed. The use of different building materials had no significant effect on the ammonia concentration during the first year.

The indoor air formaldehyde concentration was 13–37 μg/m^3 in the newly finished buildings (Figure 3). Seasonal changes were observed during the follow-up measurements at the sites where a mechanical exhaust ventilation system was used. In general, higher formaldehyde concentrations were measured in summer time when the relative humidity was 50% or higher. However, the formaldehyde concentration did not significantly exceed the S2-class level of 50 μg/m^3 during the first year at any measurement site (FiSIAQ, 2001).

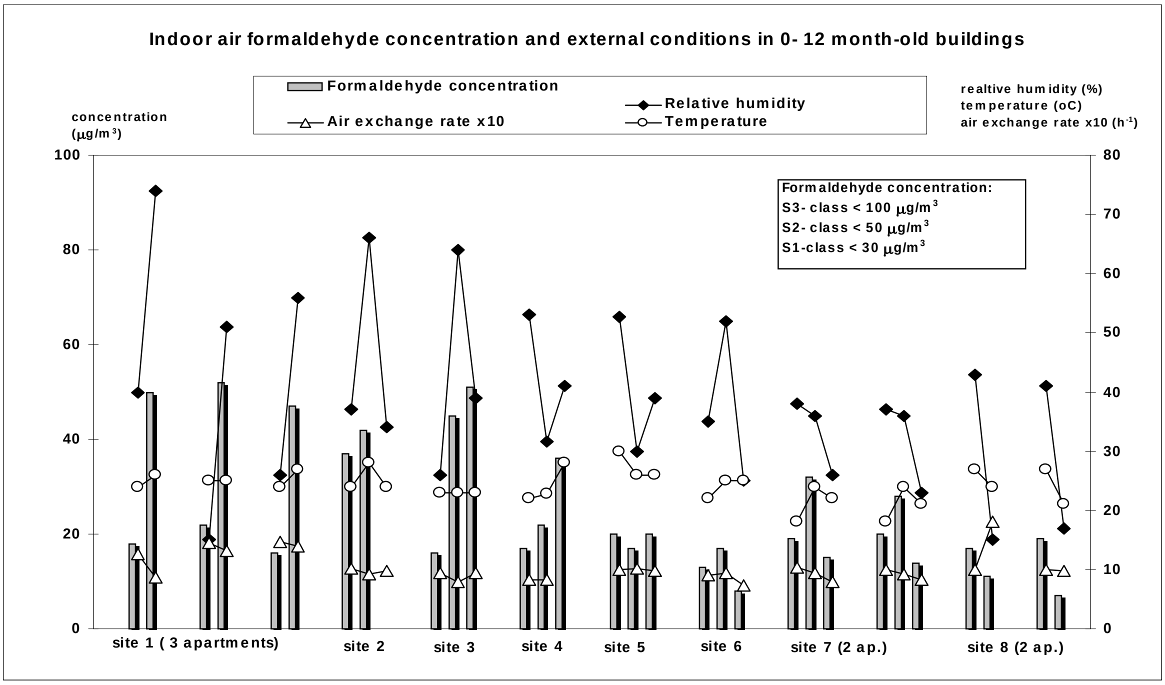

Figure 3 Indoor air formaldehyde concentration and external conditions in 0–12 month old buildings (the three columns represent the formaldehyde concentration in the 0, 6 and 12 month old building at sites 3–7 , at site 1 the 6 and 12 month results are shown and at site 2 and 8 the 0 and 6 month results are shown).

The survey performed among the inhabitants showed that there were no complaints on indoor air quality regarding building related symptoms during the first year. The age range of the inhabitants was distributed evenly from 4 years to >60 years (a total of 20 inhabitants) and all of them had been living in the apartments for the 12 month measurement period. No smoking inside or pets were reported or observed during the follow-up measurements. The apartments were vacuum cleaned and washed once a week on average.

DISCUSSION

In this study it was concluded that the target values for indoor air concentrations, defined in the Finnish 'Classification of Indoor air Climate', were not reached during the first year in new, residential buildings, in which classified, low-emitting building materials were used. From the follow-up measurements it could be concluded that, in general, the S3-class limit of 40 μg/m^3 for indoor air ammonia concentration was exceeded in new buildings during the first year. The TVOC and formaldehyde concentrations reached, in general, the S2/ S3 class values in 0–6 months (FiSIAQ, 2001). No complaints on indoor air quality were, however, registered in the survey performed among the inhabitants.

The results indicated that external conditions significantly affect the indoor air concentration levels in new buildings. The ammonia and formaldehyde concentrations correlated with the seasonal changes in the relative humidity whereas the air exchange rate mostly affected the TVOC concentration during the first year. The activities of the inhabitants also contribute to the concentration levels in the inhabited buildings and this should be noted for when indoor air measurement results are evaluated. Especially, their contribution to the functioning of the air exchange system is of importance and, therefore, this should always be checked and reported for when the indoor air concentrations are determined.

The results for the emission measurements performed at the sites presented here are reported for in another conference paper (Jarnstrom and Saarela, 2003).

CONCLUSIONS AND IMPLICATIONS

The indoor air data presented here were collected to form a reference database, which serves as a tool for indoor air quality follow-up in quality control as well as in suspected indoor air problem cases. 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.

ACKNOWLEDGEMENTS

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