Measurements of aldehydes and VOCs in a newly constructed, multi-family residential building using passive methods

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ABSTRACT

Unique means to evaluate IAQ with passive sampling devices are described in this paper. They are simple, silent and require less equipment. Field measurements in a newly constructed, multi-family residential building were conducted with these means and the results show the effect of ventilation, occupancy and interior finishing on IAQ. Indoor air concentration, emission rates from indoor surfaces and ventilation rate were measured by passive sampling methods. The ADSEC method was used for emission measurements. The PFT method was used for measurement of the ventilation rate. It was proved that the methods were effective in measuring IAQ. It was found that both indoor air concentration and emission rate were low in the room with a mechanical ventilation system. In some cases, indoor concentrations without a ventilation system were above the Japanese guidelines. Indoor concentration was generally lower in the occupied room than that of the empty room. Some chemicals, which were not detected in the empty room were detected in the occupied room.

INDEX TERMS

IAQ assessment; Measurement technique; Passive sampler; Aldehydes; VOC

INTRODUCTION

In order to determine the causes of indoor pollution, emission from building materials and material brought in by occupants as well as indoor air concentration should be investigated. Measuring the whole set of indoor air concentrations, emission rates and ventilation rates in the field have not been common among the previous researchers because it is very cumbersome. An active sampling method to measure all these items requires a large amount of equipment, and the sampling noise is a problem in occupied places. A simple and silent method is needed in field measurements, and passive methods were developed as a solution to satisfy these requirements.

Field measurements in a newly constructed, multi-family residential building by using passive methods were conducted in the summer of 2002. The building was located in Tokyo, Japan. DSD-DNPH diffusive sampler and diffusive sampler VOC-SD were used for measurements of indoor air concentrations. The ADSEC method (Akutsu *et al*., 2000; Matsumoto *et al*., 2002) was used for emissions. The PFT method (Dietz *et al*., 1986; Fisk *et al*., 1993) was used for measuring the ventilation rate. For comparison, measurements of indoor air concentration using the active sampling method and emission rate with FLEC (Wolkoff *et al*., 1991) were conducted simultaneously. Interviews with occupants on their lifestyles were also carried out. Four residences with different conditions for ventilation, occupancy and building materials were compared to examine their influence on IAQ.

METHODS

Indoor aldehydes and VOCs concentrations, emission rates from building materials and ventilation rates were measured in a newly constructed, multi-family residential building. Four residences were selected with different conditions for ventilation, occupancy and

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building materials. The conditions of residences are shown in Table 1. The floor plan of the residence (all residences had the same floor plan) with measurement points and locations of tracer gas sources are shown in Figure 1. Measurements were conducted in the living room (LR) and bedroom 2 (BR) of each residence. In addition, outdoor air was sampled outside in the balcony. Active air samplings in bedroom 2 were also conducted except for residence 302. Emission rate measurement with FLEC was carried out in bedroom 2 of residence 202. The parameters of the passive measurement methods are described in Table 2, sampling conditions of the active sampling method are shown in Table 3 and measurement conditions of FLEC are shown in Table 4. The emission rates were measured on the floor, wall and ceiling. Only the floor was measured in residence 302 to avoid disturbing the occupants. Aldehydes were analysed with HPLC. VOC-SD and Tenax TA were analysed with GC/MS after solvent desorption and thermal desorption, respectively.

Table 1 The conditions of residences

Residence no.		103[a]	202	302	303
Conditions	Mechanical ventilation system	No	Yes	Yes	No
	Occupancy	No	No	Yes	No

[a]Low emission floor materials were used for bedroom 2 in residence 103.

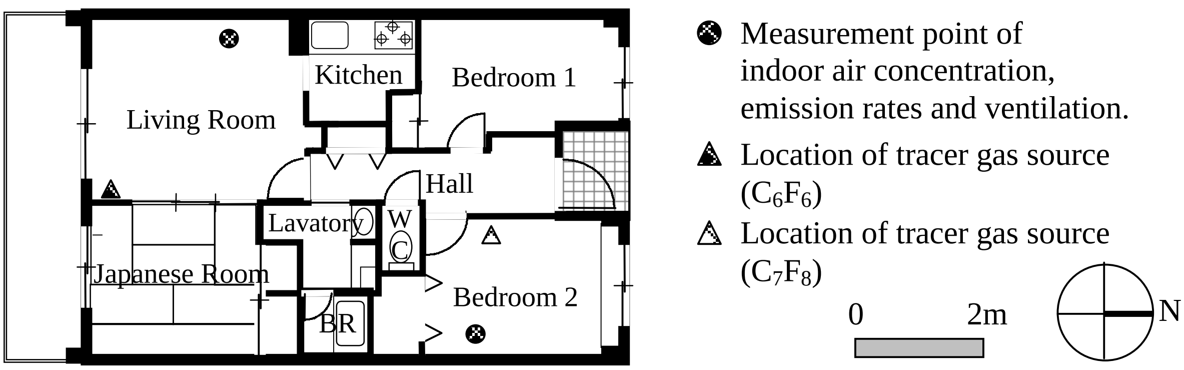


Figure 1 The plan of the residence.

Table 2 Passive measurement methods

Measurement items		Methods
Temperature and relative humidity		Thermo recorder
Ventilation rate		PFT method Diffusive sampler VOC-SD (24 h)
Indoor air concentration	Aldehydes	DSD-DNPH diffusive sampler (24 h)
	VOCs	Diffusive sampler VOC-SD (24 h)
Emission rates	Aldehydes	Carbonyl-ADSEC with DSD-DNPH diffusive sampler
	VOCs	VOC-ADSEC with diffusive sampler VOC-SD
Interview about lifestyle		Interview sheets

Table 3 Sampling conditions of active sampling

Chemicals	Aldehydes	VOCs
Sampling tube	Sep-Pak DNPH-silica cartridge	Tenax TA
Sampled air volume (l/min)	0.89	0.10
Sampling period (min)	30	32
Total volume (l)	27	3.2

Table 4 Measurement conditions of FLEC

Chemicals	Aldehydes	VOCs
Sampling tube	Sep-Pak DNPH-silica cartridge	Tenax TA
Airflow rate (l/min)	400	400
Relative humidity (%RH)	50	50
Sampled air volume (l/min)	0.30	0.10
Sampling period (min)	33	32
Total volume (l)	10	3.2

RESULTS AND DISCUSSION

Indoor Air Concentrations

The results of air concentrations in all residences are shown in Figures 2 and 3 for aldehydes and VOCs, respectively. Formaldehyde and acetaldehyde were selected from aldehydes, and toluene and xylenes from VOCs. The mean temperature in each room was almost equal to 30.1±1.2˚C. The indoor air concentrations of residences 202 and 302 were lower than those of 103 and 303 for all chemicals. Residences 202 and 302 were equipped with a 24 h mechanical ventilation system, which kept the indoor concentration lower. Because residence 302 was occupied and well-ventilated, the concentrations were lower. Measured values in some of the empty rooms in 103 and 303, which were not equipped with a ventilation system were over the Japanese guidelines for formaldehyde, acetaldehyde and toluene.

p-Dichlorobenzene and benzene were detected only in 302. It was estimated that these chemicals were emitted from products brought in by occupants. The results obtained by active sampling and passive sampling showed a similar tendency for both aldehydes and VOCs. Ventilation before and after moving-in was found to be important to maintain low concentrations.

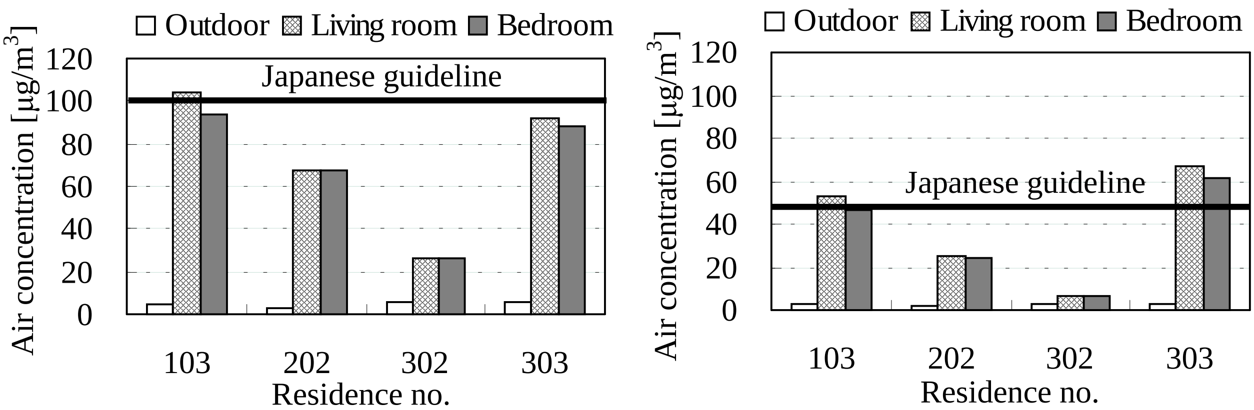


Figure 2 Results of air concentrations for aldehydes (left: formaldehyde, right: acetaldehyde).

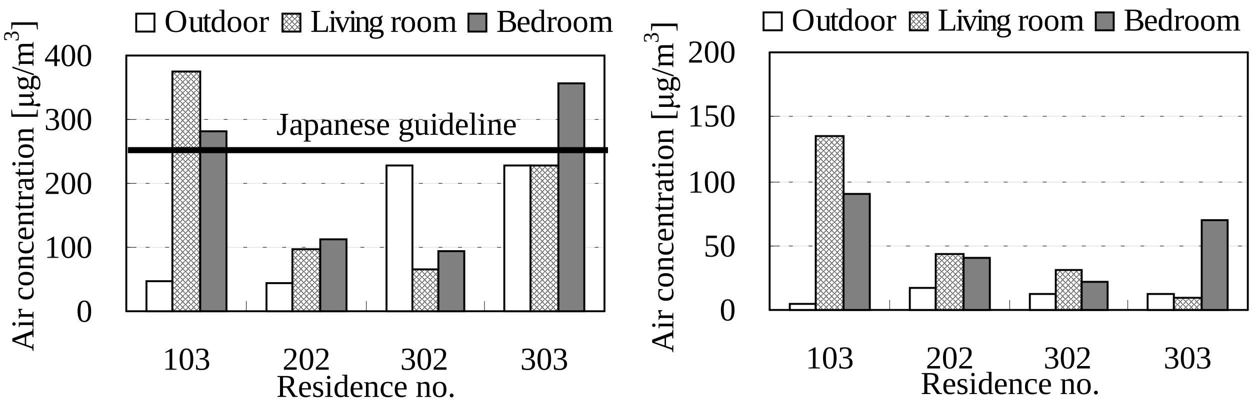


Figure 3 Results of air concentrations for VOCs (left: toluene, right: xylenes).

Emission Rates from Floor, Wall and Ceiling

The emission rate of ADSEC was calculated as the emission amount per unit area and time (Akutsu *et al.*, 2000). The results of formaldehyde and acetaldehyde emission rates from building materials in all residences are shown in Figure 4 and those for toluene and xylenes in Figure 5. These results are the mean of double samplings. The difference among floor, wall, and ceiling was small. Floor emission rates of BR were lower than that of LR in 103, and the effect of using low emission material was confirmed. VOC emission rates were high in 302. It was suspected that products brought in by occupants, such as wax, emitted VOCs and resulted in a high emission rate. Though the emission rate from building materials may decrease as time goes on, indoor concentration may rise again due to products brought in by occupants.

Comparisons of measured values between ADSEC and FLEC are shown in Figure 6 for formaldehyde and toluene. Formaldehyde emission rates measured by FLEC were higher than those by ADSEC, while toluene was higher with ADSEC than FLEC, except for wall emissions. Although the materials of wall and ceiling were the same, the values for wall emissions by FLEC were high for both chemicals. It is suspected that some of the ambient air was collected through a space between the wall surface and the FLEC cell.

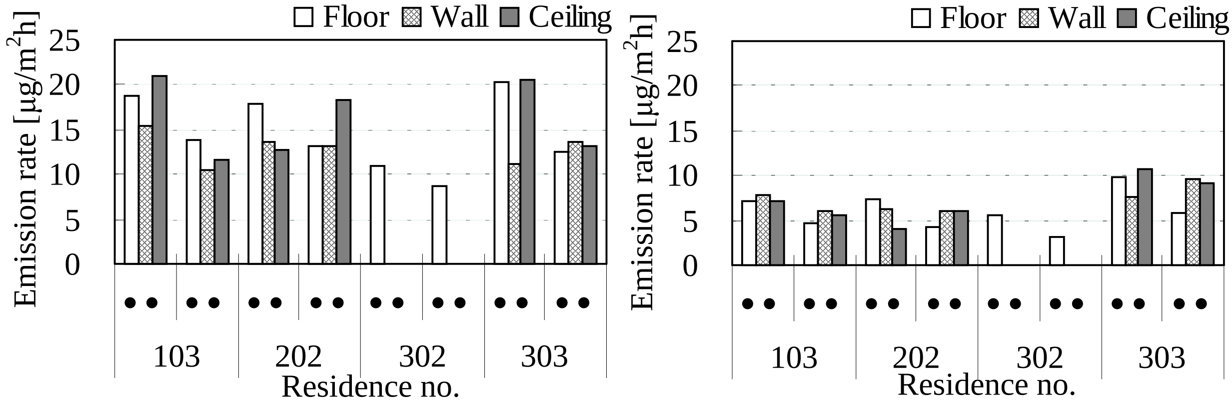


Figure 4 Results of emission rates for aldehydes (left: formaldehyde, right: acetaldehyde).

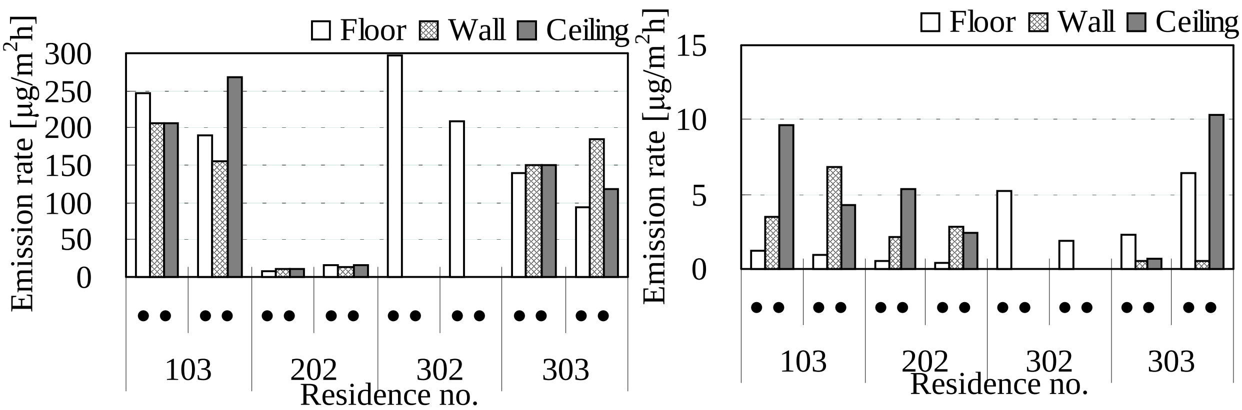


Figure 5 Results of emission rates for VOCs (left: toluene, right: xylenes).

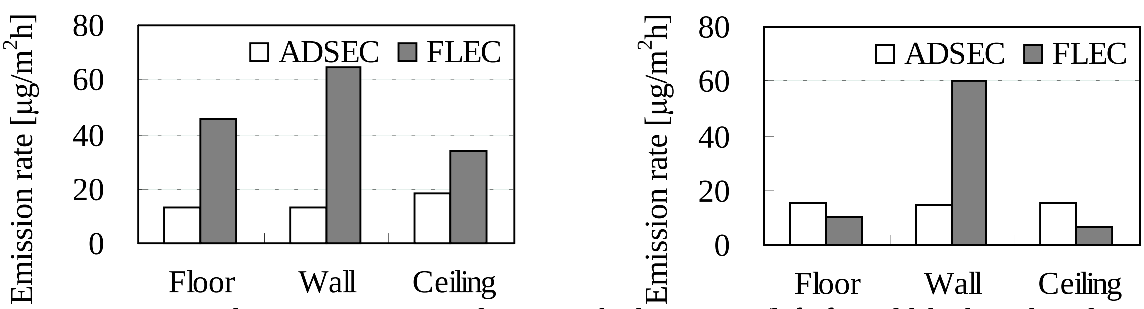
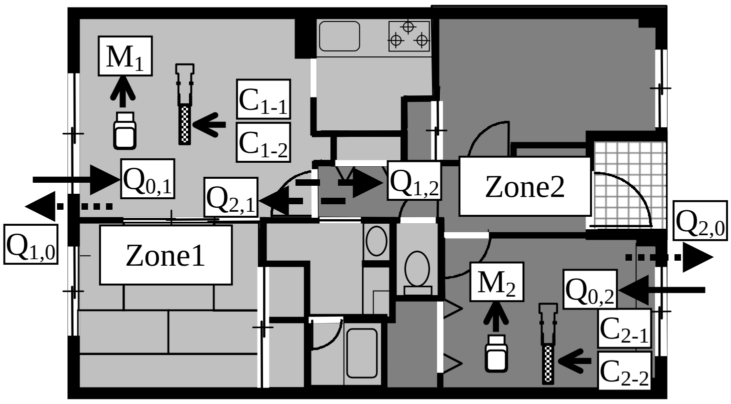


Figure 6 Comparisons between ADSEC and FLEC in bedroom 202 (left: formaldehyde, right: toluene).

Ventilation Rate

To calculate the air mass flow, each residence was divided into two zones as illustrated in Figure 7. The air mass flows were calculated based on the Eqns given in Figure 7. Ventilation rates were determined using these air mass flows and zone volumes. The results are shown in Table 5. The ventilation rates in Zone 1 were larger than those in Zone 2 in spite of the same design value of 0.5[1/h] in all residences. The ventilation rate in 303 was larger than that in 103, though neither had a mechanical ventilation system. The cause was assumed to be the difference in the stories in which the residences were located. That is, there was more breeze on the 2nd floor than on the ground floor. $Q_{0,1}$ was larger than $Q_{1,0}$, $Q_{1,2}$ was larger than $Q_{2,1}$ and $Q_{2,0}$ was larger than $Q_{0,2}$ in all residences. Therefore, it was found that the air flowed from Zone 1 to Zone 2 due to the south wind. The sampler in 302 hardly collected any tracer gas due to much ventilation by residents. Setting more tracer gas sources might prevent this problem.



Zone1

$$Q_{2,1}C_{2\text{-}2} - Q_{1,0}C_{1\text{-}2} - Q_{1,2}C_{1\text{-}2} = 0$$
$$Q_{2,1}C_{2\text{-}1} - Q_{1,0}C_{1\text{-}1} - Q_{1,2}C_{1\text{-}1} = -M_1$$

Zone2

$$Q_{1,2}C_{1\text{-}2} - Q_{2,0}C_{2\text{-}2} - Q_{2,1}C_{2\text{-}2} = -M_2$$
$$Q_{1,2}C_{1\text{-}1} - Q_{2,0}C_{2\text{-}1} - Q_{2,1}C_{2\text{-}1} = 0$$

$$Q_{0,1} = Q_{1,0} + Q_{1,2} - Q_{2,1}$$
$$Q_{0,2} = Q_{2,0} + Q_{2,1} - Q_{1,2}$$

Figure 7 Outline view about calculation of air mass flow.

Table 5 Results of air mass flows and ventilation rates

Residence	Air mass flow (m^3/h)						Ventilation rate (1/h)	
no.	$Q_{1,0}$	$Q_{0,1}$	$Q_{1,2}$	$Q_{2,1}$	$Q_{2,0}$	$Q_{0,2}$	Zone 1	Zone 2
103	11.9	21.6	23.2	13.5	4.1	–5.6	0.3	0.1
202	51.0	57.6	17.5	10.8	14.9	8.3	0.8	0.1
302	–	–	2268.6	0.0	3297.8	1029.0	–	16.0
303	26.0	47.2	22.6	1.3	4.5	16.8	0.6	0.3

Prediction of Indoor Air Concentration

Measured indoor concentrations were compared with the predicted values. The predicted values were calculated by simultaneous Eqns (1) and (2).

$$M_1 + C_0Q_{0,1} - C_1Q_{1,0} + C_2Q_{2,1} - C_1Q_{1,2} = 0 \quad (1)$$
$$M_2 + C_0Q_{0,2} - C_2Q_{2,0} + C_1Q_{1,2} - C_2Q_{2,1} = 0 \quad (2)$$

where M_n is the total emission amount of floor, wall and ceiling in Zone n, C_0 is the measured outdoor air concentration, C_n is the predicted indoor air concentration in Zone n, $Q_{n,m}$ is air mass flow from Zone n to Zone m. The subscript of 0 describes the outdoor.

Results in residence 202, which had a 0.5[1/h] mechanical ventilation system, are shown in Figure 8. Both values were almost the same. The measured values were slightly higher than the predicted value in Zone 1. This showed that chemicals were emitted not only from floor, wall and ceiling but also from doors and closets. On the other hand, the predicted values were higher than the measured in Zone 2. The measured ventilation rate in Zone 2 is suspected to be lower than actual, as the values were generally lower than that in Zone 1.

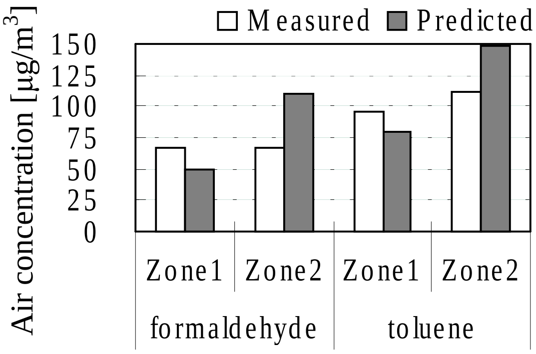


Figure 8 Comparison of measured and predicted values.

CONCLUSION

1. The mechanical ventilation system was confirmed to help in lowering indoor air concentration of aldehydes and VOCs.
2. The indoor air concentration of aldehydes and VOCs was generally lower in occupied rooms than in empty rooms. On the other hand, pollution by coatings caused high emission rates from the floor.
3. For indoor air concentrations, measured values almost corresponded to values predicted from emission rates and ventilation rates.
4. The efficiency end effectiveness of passive methods were confirmed by these field measurements.

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