Study on measurement of formaldehyde emitted from medium density fibreboards and televisions under simulated room conditions

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ABSTRACT

In order to measure the emission rate of chemical compounds from materials under actual room conditions, a full-scale test chamber (20 m^3) was developed. The test chamber was made from stainless steel, and the surface of the test chamber was electro-polished. Ventilation systems used were: blow off over the whole floor surface, and surface suction over the whole ceiling. A chemical substances removal filter filled up with activated carbon was installed in the supply line. The air change rates were 0.5 and 1 h^{-1}. Temperature and air humidity in the test chamber were controlled to 23 or 28±0.5°C and 50±5%. In this paper, the emission phenomena of chemical compounds released from Medium Density Fibreboard (MDF) and Television materials were studied. The effects of temperature and sample area within the test chamber on the mean emission rate were examined for different materials.

INDEX TERMS

Full-scale chamber; Emission rate; Air change rate; Sample area

INTRODUCTION

Emissions of chemical substances from building materials and products are often measured with a method that uses a complete mixing type chamber specified under ASTM, ECA and ENV for building materials placed in a test chamber (ECA-IAQ, 1989, 1991; ASTM, 1997; ENV 13419-1, 1999). Many small-scale test chambers developed to measure the emission rates from building materials and products are based on these standards (Tanabe *et al.*, 2000; Knudsen *et al.*, 1998). However, the gradients of the concentrations of chemical substance in the test chamber are different form the concentrations at the surface of the material in the actual room, and a difference in scale of the material emission area may lead to a difference between the measured emission rate in a small-scale test chamber and the actual emission rate in an actual room (Claus Topp *et al.*, 1997; Murakami *et al.*, 2002). Zhang and Shaw (1997) had developed a full-scale stainless steel test chamber (55 m^3) with an HVAC system that simulates realistic room conditions. In order to clarify the emission characteristics of building materials and products under actual room conditions, the authors developed a full-scale test chamber that is equipped with an HVAC system with chemical substance filtration and

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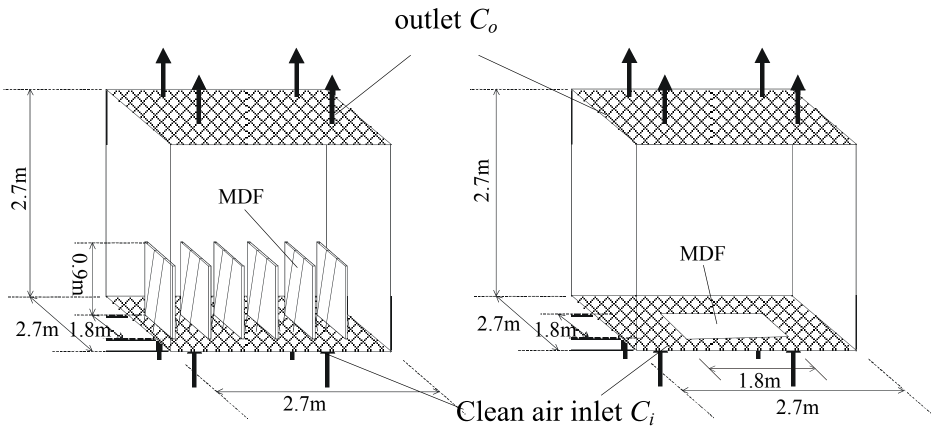
ambient temperature, humidity, and air change rate control. In this paper, the emission characteristics of Medium Density Fibreboard (MDF) and one television set are reported under actual ambient conditions using a full-scale type chamber, and the correlation between emission rates in the small-scale type test chamber and in a full-scale type test chamber is investigated.

METHODS

The full-scale stainless steel test chamber that the authors developed is shown in Figure 1. The ventilation system includes blow off over the whole floor surface and surface suction over the whole ceiling. The clean air supply system incorporates coarse, medium, and high efficiency particulate air filters (HEPA). The internal surfaces of the chamber and ventilation duct are constructed of electro-polished stainless steel to minimize surface adsorption. The air change rate can be changed from 0.5 to 130 h^{-1} to meet a variety of research needs. Extensive ventilation and high-temperature washing at 50°C were performed before the experiment to decrease the background concentrations in the test system. The background concentrations were below 13 μg/m^3 for HCHO, 36 μg/m^3 for toluene, and 47 μg/m^3 for TVOC when the air change rate was 0.5 h^{-1}. An ultrasonic gas flow meter was set to record and monitor the amount of ventilation.



(1-1) Case1 to 4 (1-2) Case5, 6

Figure 1 Full-scale test chamber.

Test 1: Emission test for MDF: Test samples of MDF of known age were piled up, wrapped in polyethylene bags, and not opened until just before the experiment. The size of each sample was 0.9 × 1.8 m, and the thickness was 2.7 mm. Before the measurement, the test chamber was first conditioned and maintained at 23 or 28 ± 0.5°C and 50 ± 5% RH, and the samples were stored in this condition for about 33 days. After ageing, air samples were taken from the air inlet, the room, and the outlet of the chamber with a DNPH cartridge and Tenax TA (0.2 l/min., 20 l) at 48 and 72 h. These chemical substances were analysed quantitatively by HPLC and TDS/GC/MS. The concentrations were measured twice and the average is shown in this paper. The emission test for MDF was carried out using three parameters: air temperature, air change rate and sample area. The experimental conditions are shown in Table 1.

Table 1 Tested case of MDF (50 ± 5% RH)

Case no.	Temperature (°C)	Air change rate n (h^{-1})	Ventilation amount/area Q/A (m/h)	Number of sheets
1		0.5	0.38	8
2		1	0.76	
3	23	0.5	0.76	4
4	28	1	1.52	
5		0.5	3.04	2
6		1	6.08	

Test 2: Emission test for television materials: A commercial TV with the power switched on was set in the test chamber at 23°C and 50% RH when the air change rate was 1 h^{-1}. The chemical substances emitted from TV were measured after ageing for 48 h. Air samples were taken from the air inlet, the room and the outlet of the chamber with Tenax TA (0.2 l/min, 200 l).

Formaldehyde concentration from the MDF in the full-scale test chamber: When the indoor air is assumed to be in a perfect mixed state, the emission rate *flux* (mg/h/m^2) is calculated from the concentration difference between the inlet and the outlet of the test chamber ($C_o - C_i$) (mg/m^3), the amount of ventilation in the test chamber Q (m^3/h), and the surface area of the test building material A (m^2) (Hoetjer and Koerts, 1986).

$$\text{flux} = (C_o - C_i) \cdot Q / A \qquad (1)$$

and *flux* (mg/h/m^2) can be expressed by formula (2).

$$\text{flux} = \alpha_m (C_s - C) \qquad (2)$$

where α_m (m/h) is the mass transfer coefficient, C_s (mg/m^3) is the vapour phase concentration in equilibrium with the solid phase concentration in the test material, and C (= $C_o - C_i$) (mg/m^3) is the concentration of the test chamber in the steady state. From Eqns (1) and (2), C and Q/A have a relationship expressed by the following formula:

$$\frac{1}{C} = \frac{1}{C_s} + \frac{1}{\alpha_m C_s} \frac{Q}{A} \qquad (3)$$

and the mass transfer resistance $1/\alpha_m$ can be expressed by formula (4):

$$\frac{1}{\alpha_m} = \frac{1}{\alpha_g} + \frac{1}{\alpha_o} \qquad (4)$$

where $1/\alpha_g$ is the mass resistance of the material, and $1/\alpha_o$ is the mass resistance of the air in (1/(m/h)).

RESULTS

Formaldehyde Emitted from the MDF

Five main chemical substances were detected. They were formaldehyde, acetaldehyde, acetone, 2-butanone and valeraldehyde. The average concentration of chemical substances was below 10 µg/m^3 except formaldehyde. The results of the concentration and emission rate of formaldehyde emitted from the MDF are shown in Figure 2. The formaldehyde concentration decreases with increasing *Q*/*A* (amount of ventilation *Q* / sample area *A* (m/h)). When (*Q*/*A)* is about 0.76 (m/h), the formaldehyde concentration increases in spite of the emission area *A* being decreased by half because the amount of ventilation *Q* is decreased. The emission rate of formaldehyde emitted from the MDF increased about 20–40% in the experiment when the temperature increased from 23 to 28°C.

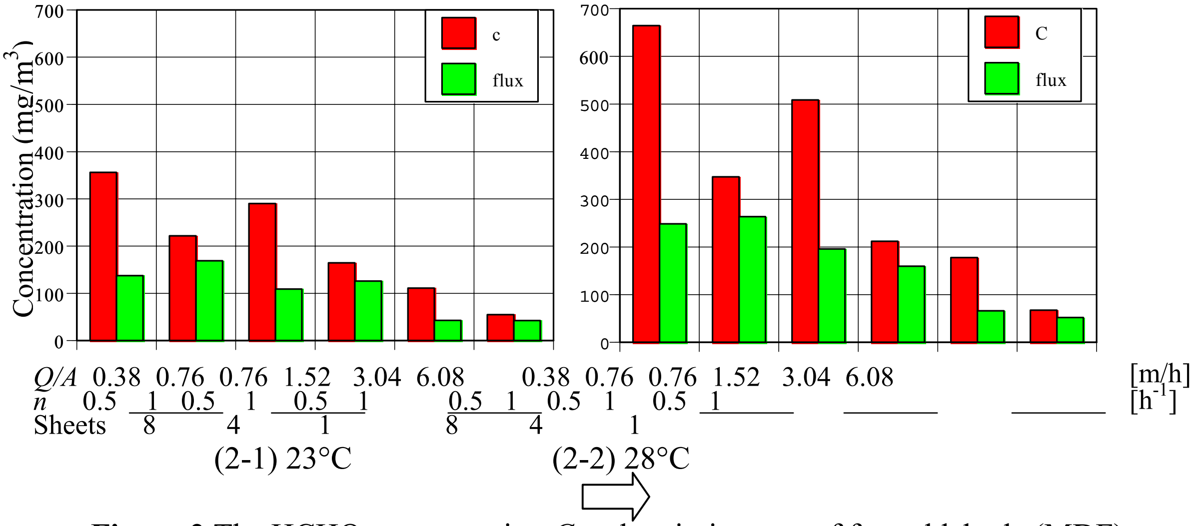


Figure 2 The HCHO concentration *C* and emission rate of formaldehyde (MDF).

Based on formula (3) derived from the mass balance, the relationship between the formaldehyde concentration *C* and the (amount of ventilation *Q*/sample area *A* (m/h)) for different scale test chambers is shown in Figure 3 in the steady state. A straight line is obtained by curve fitting for the two parameters *C* and (*Q*/*A*). The formaldehyde concentration C_s in the surface of the test material is 0.54 mg/m^3 at 23°C and 0.76 mg/m^3 at 28°C. The formaldehyde average mass transfer coefficient α_m is 0.71 m/h at 23°C and 0.84 m/h at 28°C. The equivalent heat transfer coefficient α_c is 0.24 W/m^2/K at 23°C and 0.28 W/m^2/K at 28°C according to the Lewis relation for the heat mass transfer analogy (Table 2). This means that the emission rate of formaldehyde released from the MDF increased because the mass transfer resistance $1/\alpha_m$ decreases with the rise in temperature of the test chamber. When measuring the emission rate of formaldehyde release from the MDF using a small-scale test chamber, for example, ADPAC (20L) or CLIMPAQ (50L), the average mass transfer coefficient is about 0.45 m/h and smaller than the test result for the full-scale test chamber (20 m^3). This indicates that emission rates measured for a small-scale test chamber tend to be

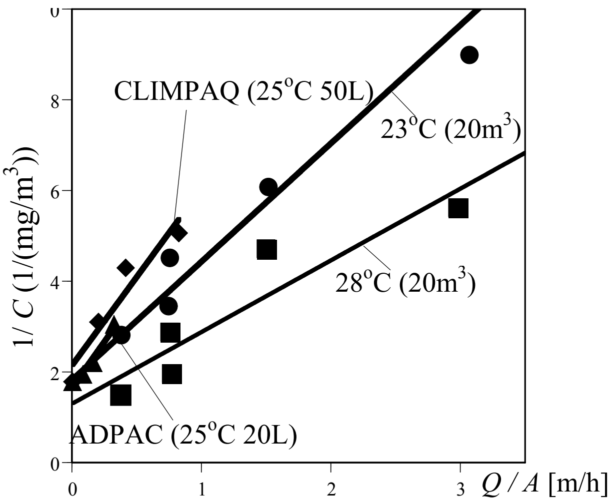


Figure 3 Correlation of formaldehyde concentration *C* and (*Q*/*A*) for different scale test chamber.

underestimated because the mass transfer resistance $1/\alpha_m$ is bigger than for a full-scale chamber.

Table 2 Average mass transfer coefficient

Test chamber	Temperature; relative humidity	Concentration C_s (mg/m^3)	Average mass transfer coefficient α_m (m/h)	Average heat transfer coefficient α_c (W/m^2/K)
Full-scale (20 m^3)	23°C; 50%	0.60	0.56 (cases 1–4) 0.08 (cases 5, 6)	0.24 (cases 1–4) 0.02 (cases 5, 6)
ADPAC (20L)	25°C; 50%	0.59	0.45	0.15
CLIMPAQ (50L)		0.46	0.43	0.14
Full-scale (20 m^3)	28°C; 50%	0.96	0.60 (cases 1–4) 0.10 (cases 5, 6)	0.28 (cases 1–4) 0.04 (cases 5, 6)

VOCs emitted from the television materials: After the TV had been aged in the test chamber at 23°C and 50%RH at 1 ACH (h^{-1}) for 48 h, a 200 l air sample was taken from the outlet of the test chamber with Tenax TA. Because the concentration emitted from TV was very low, about 17 h was spent to sample slowly in this case. A total of 17 VOCs were detected (Table 3). The concentration was below 0.001 mg/m^3 for individual compounds. Malodorous air was present in the experiment on the TV because of phenol and 2-ethyl-1-hexanol emitted by the TV materials (Reiser *et al.*, 2002). Using an adsorption thermal desorption measurement method, 2-ethyl-1-hexanol and di(2-ethylhexyl) phthalate (DEHP: C_6H_4 $(COOC_8H_{17})_2$) released from the plastic casing and terminal board of one disassembled TV were detected at an ambient temperature of 40°C (Zhu *et al.*, 2002). DEHP is sensitive to hydrolysis and decomposes to 2-ethyl-1-hexanol in alkaline media (Salthammer *et al.*, 1999). The existence of 2-ethyl-1-hexanol detected in the experiment means that DEHP was emitted from the TV into the air as gaseous substances. However, no semi-volatile organic compounds could be identified in the experiment using the sampling method with the sorption Tenax TA.

Table 3 VOCs emitted from the TV materials at 23°C, 50%RH at 1 ACH

Aromatic hydrocarbons	Benzene, toluene, ethylbenzene, p-xylene, styrene, 1,3-dimethylbenzene, alpha methylstyrene
Aliphatic hydrocarbons	Undecane, dodecane, tridecane, tetradecane, pentadecane, hexadecane
Others	Nonane, phenol, acetone, acetophenone, 2-ethy-l-hexanol

CONCLUSIONS

(1) In the case of the MDF, the formaldehyde concentration decreased with increasing (amount of ventilation/sample area). The emission of formaldehyde from the MDF increased because of the decrease in the mass transfer resistance with the rise in temperature in the full-scale chamber. The mass transfer resistance in the small-scale test chamber was bigger than in the full-scale chamber because of the difference of flow field (ventilation efficiency) for different scale test chamber. (2) A total of 17 VOCs emitted from the TV materials were

detected. In spite of low concentration in the full-scale chamber, malodorous air was present in the experiment with the TV because phenol and 2-ethyl-hexanol were released.

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REFERENCES

ASTM (1997). *ASTM-D5116-97*. Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products.

Claus Topp *et al.* (1997). Evaporation controlled emission in ventilated rooms. *Proceedings of Healthy Buildings/IAQ 97*, Vol. 3, pp. 557–562.

ECA-IAQ (1989). *Report No. 2*. Guideline for the Determination of Steady State Concentrations in test Chambers, Luxembourg.

ECA-IAQ (1991) *Report No. 8*. Guideline for the Characterization of Volatile Organic Compounds Emitted from Indoor Materials and Products Using Small Test Chambers, Brussels.

ENV13419-1 (1999). Building products—Determination of the emission of volatile organic compounds—Part 1: Emission test chamber method, Brussels: European Committee for Standardization.

Hoetjer, J.J. and Koerts, F. (1986). A model for formaldehyde release from particleboard. *American Chemical Society*, 125–144.

Knudsen, H.N. *et al.* (1999). Sensory and chemical characterization of VOC emissions from building products: impact of concentration and air velocity. *Atmospheric Environment* **33**, 1217–1230.

Murakami, S. *et al.* (2002). 3D-CFD analysis of diffusion and emission of VOCs in a FLEC cavity. *Proceeding of the 9th International Conference on Indoor Air Quality and climate—Indoor Air 2002*, Vol. 2, pp. 548–553.

Qingyu Zhu *et al.* (2002). Study on measurement of SVOCs emitted from building materials and products under actual room temperature conditions (Part 2). Measurement of SVOCs emitted from building materials and household electric appliances. *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*, D-2, pp. 859–860.

Reiser, R. *et al.* (2002). Indoor air pollution by volatile organic compounds (VOC) emitted from flooring material in a technical university in Switzerland. *Proceeding of the 9th international Conference on Indoor Air Quality and Climate—Indoor Air 2002*, Vol. 1, pp. 1004–1009.

Salthammer, T. *et al.* (1999). Emission of reactive compounds and secondary products from wood-based furniture coatings. *Atmospheric Environment* **33**, 75–84.

Tanabe, S., Funaki, R. *et al.* (2000). Measurement of aldehydes and vocs emission rates from building materials with a small chamber ADPAC. *Architectural Institute of Japan Journal of Technology* **Dec.** (10), 153–157.

Zhang, J.S. *et al.* (1997). Characterizing the emissions of volatile organic compounds from a workstation system. *Proceedings of Healthy Buildings/IAQ 97*, Vol. 3, pp. 521–526.