Integrated impacts of the indoor temperature on the characteristics of VOC emissions from local paints in Taiwan—solvent-based paints as example

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ABSTRACT

Many studies have revealed that the level of indoor harmful compounds in subtropical Taiwan is over 1000 times more than other temperate or frigid countries. This study was designed to investigate the relationship between indoor temperature and the VOC emission from local paints in Taiwan—the most utilized decoration material in Taiwan's home buildings. Three solvent-based paints—ready-mixed paint, oil varnish and lacquer sanding sealer—were tested for emission with a small VOC chamber test system following ASTM D5116-97. The following environmental parameters were set: 30°C, 50% RH and 25°C, 50% RH. After 24 h of emission testing, an obvious positive ratio between the emission and temperature was observed. The amended experience model, based on the first-order decay model, for VOC emission from solvent-based paints under Taiwan's high temperature in a small chamber was established.

INDEX TERMS

VOCs; Temperature; Experience model; Solvent-based paints; Subtropical

INTRODUCTION

From the literature review, we know that the characteristics of materials emission and sink were very dependent on the indoor environmental factors, especially the thermal environmental factors (Tichenor, 1989; Dr. Dagmar Schmidt Etkin, 1996; Ven Der Wal *et al.*, 1997). Taiwan, located in the subtropical region, is an island with hot climate in East Asia. The year-average temperature is 23.4°C, and most of the time the temperature is above it (Chou and Chiang, 2000). Moreover, natural ventilation is the most utilized method in Taiwan's home buildings, and paint is the most common decoration material used in great quantities, especially the locally made ones (Chen, 2002). Hence, the ambient temperature would have a great influence on the indoor VOC emission from the paint. Serious studies revealed that the concentrations of indoor harmful compounds in Taiwan were 1000 times higher than other countries located in temperate or frigid regions (Su *et al.*, 2001). This study was designed to find out the relationship between indoor temperature and VOC emission

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behaviour of locally made paint in Taiwan. Three kinds of solvent-based paint were tested for the large VOC emissions. The 24-h VOC emission test was carried out in a small environmental chamber VOC test system following ASTM D5116-97 (ASTM, 1997) and the standard VOC test procedure established by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan (Chiang and Lee, 2001). By statistically fitting the test data, the amended experience model for VOC emission from solvent-based paint in the small environmental chamber, based on the first-order decay model (Tichenor, 1991), could be established (Figure 1).

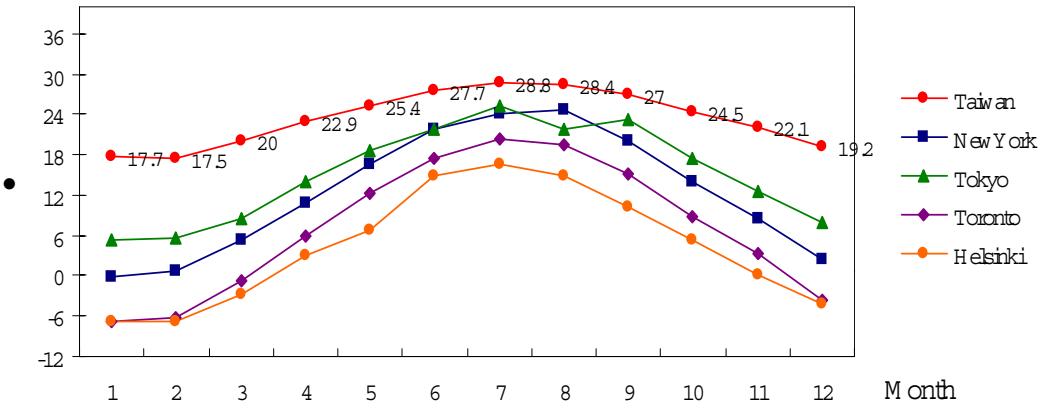


Figure 1 The month-average temperatures of the cities in different regions.

METHODS

Materials

Pure gases that were used are: helium (99.999% purity), hydrogen (99.999% purity), nitrogen (99.999% purity), and ultra-zero-grade air. Cartridges were stainless steel with a 3.2 mm inner diameter and contained three different adsorbents in turn: Carbotrap, Carboxen 1003 and Carboxen 1000. Three paint specimens were solvent-based ones selected from the local markets in Taiwan, which were made locally and used in the home-building decoration in large quantities. The three kinds of solvent-based paints were ready-mixed paint (RMP), oil varnish (OV) and lacquer sanding sealer (LSS). Substrates of the specimens were stainless steel plates with 100 mm × 100 mm in length.

Small Environmental Chamber System

The small-scale environmental chamber was established following ASTM D5116-97. The environmentally conditioned ranges of the chamber were: 10–90°C and 10–98% RH. The two environmentally conditioned settings of the chamber in this study were: 30°C, 50% RH and 25°C, 50% RH. The former represented the average indoor thermal-environment condition in Taiwan's house buildings using natural ventilation in the hot season, and the latter represented the ones in other temperate or frigid countries. Though the real RH in Taiwan house buildings without air-conditioning was always higher than 50%, the former setting was used to focus on

the VOC emission behaviour of the solvent-based paint at Taiwan's high temperatures. The air exchange rate (ACH) was 0.5 h^{-1} according to the ASTM criterion (Table 1). The relevant set-up for the experiment is shown in Figure 2.

Table 1 Small environmental chamber experimental set-up with three solvent-based paints, variations on temperature, relative humidity, air exchange rate and air velocity

Paints	Temperature (°C)		RH (%)	ACH (h^{-1})	Air velocity (m/s)
	25	30			
Ready-mixed paint	+		50	0.5	0.5
		+	50	0.5	0.5
Oil varnish	+		50	0.5	0.5
		+	50	0.5	0.5
Lacquer sanding sealer	+		50	0.5	0.5
		+	50	0.5	0.5

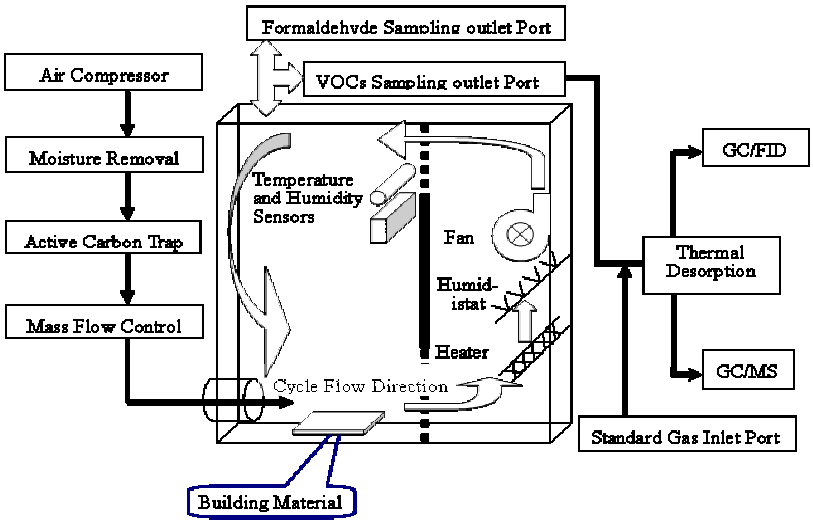


Figure 2 The diagram of the environmental chamber VOC test system.

Modelling

All test data were statistically analysed with the software 'Grapher' to fit the amended experience models. The original model was the first-order decay model for VOC emission from wet materials in a small chamber (Tichenor *et al.*, 1993):

$$C = (L)(\mathrm{EF}_0)\left(\frac{\mathrm{e}^{-kt} - \mathrm{e}^{-Nt}}{N - k}\right) \qquad (1)$$

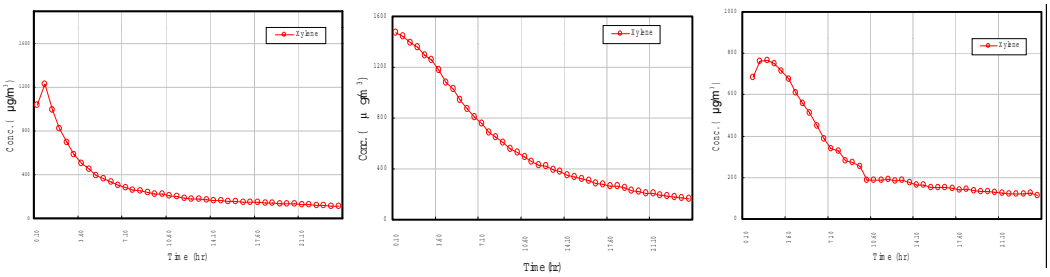
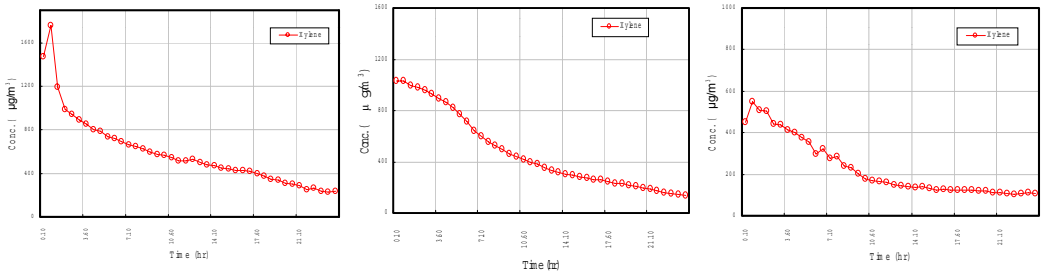
where C is the small chamber concentration (μg/m^3), L the loading factor of the paint (m^{-1}) (area of specimen/volume of the chamber), EF_0 the initial emission rate of the paint, k the first-order decay constant (h^{-1}), t the emission time (h) and N the air exchange rate (ACH) (h).

RESULTS

Time–Emission Decay Curves

According to the qualitative results, three compounds—*m*-xylene, *o*-xylene and *p*-xylene—were selected as the target compounds in this study. It was observed that when the temperature was 30°C, the emission would rise higher than the result at 25°C of oil varnish and lacquer sanding sealer. But for ready-mixed paint, the emission at 30°C decreased compared to the result at 25°C. From the time–concentration decay curves, we could find that the concentration of solvent-based paints in the chamber could reach the maximum at the second data (after 41 min). It meant that the VOC emission from solvent-based paints could reach the maximum in a vary short time and then begin to decay in the chamber. Table 2 shows the C_0 (initial concentration), total mass of xylene (emitted in the 24-h emission test), relative factors of the different emission and the time–concentration curves of three specimens.

Table 2 C_0, total mass of xylene (24 h emission) (Mass-X) and the time–concentration curves of different specimens

	30°C, 50% RH		
	RMP	OV	LSS
C_0	953.9353 μg/m^3	1471.978 μg/m^3	684.872 μg/m^3
Mass-X	19.80 μg	21.17 μg	36.60 μg
Time–emission decay curve			
	25°C, 50% RH		
C_0	1370.91 μg/m^3	1031.941 μg/m^3	449.0394 μg/m^3
Mass-X	39.59 μg	16.68 μg	28.66 μg
Time–emission decay curve			

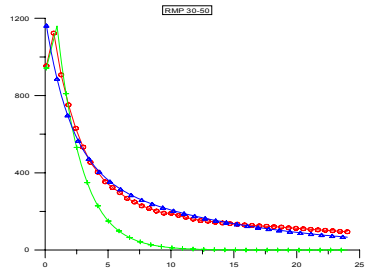
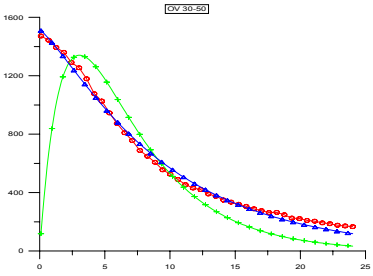
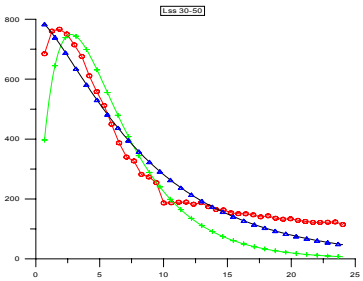
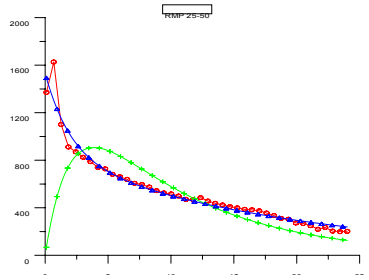
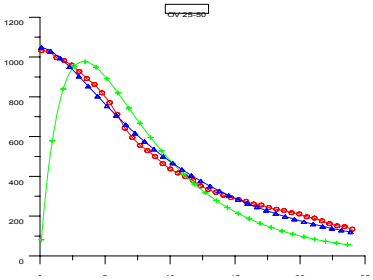
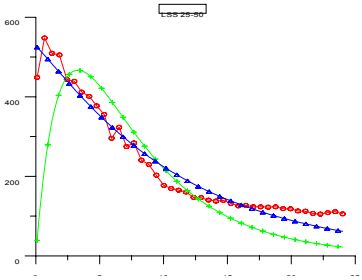
Amended Experience Models

The first-order decay model describes the emission behaviour of VOCs from wet materials including two steps: ramping up positively and decaying down. As the emission of the solvent-based paint could reach the maximum in a very short time, the first step could be ignored for the better fitting of the experience model. The amended model was:

$$C = L(r)\left(e^{-at} - (e^{-Nt})(\alpha)\right) \qquad (2)$$

where C is the small chamber concentration (μg/m^3), L the loading factor of the paint (area of specimen/volume of the chamber) (m^{-1}), t the emission time (h), N the air exchange rate (ACH) (h^{-1}) and r, a, α the parameters of regression. The comparison between two models fitting three specimens in different conditions is shown in Table 3.

Table 3 The comparison between two models fitting three specimens at different conditions

	RMP		OV		LSS	
30°C–50% RH						
R^2	1st Order Decay Model	0.671	1st Order Decay Model	0.551	1st Order Decay Model	0.803
	Amended Model	0.961	Amended Model	0.993	Amended Model	0.944
25°C–50% RH						
R^2	1st Order Decay Model	0.013	1st Order Decay Model	0.545	1st Order Decay Model	0.445
	Amended Model	0.956	Amended Model	0.992	Amended Model	0.953

—○— Test data, —□— Fitting result of amended model, —┼— Fitting result of first-order decay model.

DISCUSSION, CONCLUSION AND IMPLICATIONS

There is no doubt that the environmental characteristics of the subtropical nations can have great influences on the emission from materials. We carried out this study to discuss the

thermal environmental effects on the VOC emission from local solvent-based paints in Taiwan, and we found that not all emission of the materials' would increase when the temperature increases. The actual reason may come from the special characteristics of the products' properties, and it is worthy of further study. Besides, the study on the effects of high humidity on the local paints in Taiwan is in progress. As the results of fitting the first-order decay model with test data were not satisfactory, and they were contrary with the amended experience model according to this study (the value of R^2 could reach higher than 0.9), it was supposed that the first-order decay model was used to describe the emission behaviour with acute raise, decay and maintaining a steady low emission that did not suit the specimens in this study. In a further study the emission behaviour will be studied for detailed discussion.

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REFERENCES

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

Chiang, C.M. and Lee, C.C. (2001). *A Study to Establish a Standard of Test Method and Procedure to the VOC Emitted from Interior Materials*. Taiwan, ROC: Architecture and Building Research Institute, Ministry of the Interior.

Dr. Dagmar Schmidt Etkin (1996). *IEQ Strategies*.

Huey-Jen Su, Pei-Chih Wu *et al.* (2001). Exposure assessment of indoor allergens, endotoxin, and airborne fungi for homes in southern Taiwan. *Environmental Research Section A*, 135–144.

Chou, P.C. and Chiang, C.M. (2000). A study on the naturally ventilated performances of the envelop openings. Doctoral Dissertation, Deptartment of Architecture, National Cheng Kung University, Taiwan, ROC.

Chen, T.Y. (2002). A study on the impact of the interior temperature in Taiwan on VOC emissions from building materials—varnish for example. Masters Dissertation, Department of Architecture, National Cheng Kung University, Taiwan, ROC.

Tichenor, B.A., Guo, Z. and Sparks, L.E. (1993). Fundamental mass transfer model for indoor air emission from surface coating. *Indoor Air* **3**, 263–268.

Ven Der Wal, Hoogeveen and Wouda (1997). The influence of temperature on the emission of volatile organic compound. *Indoor Air* **7**, 215–221.