



Evaluation of impact factors on VOC emissions and concentrations from wooden flooring based on chamber tests

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ABSTRACT

In this study, the impact factors of temperature, relative humidity (RH), air exchange rate, and volatile organic compound (VOC) properties on the VOC (toluene, *n*-butyl acetate, ethylbenzene, and *m,p*-xylene) specific emission rates (SERs) and concentrations from wooden flooring were investigated by chamber test for 8 days. The tested wood in this study is not common solid wood, but composite wood made of combined wood fibers. The experiments were conducted in a stainless-steel environmental test chamber coated with Teflon. The experimental results within 8 days of testing showed that, when the temperature increased from 15 to 30 °C, the VOC SERs and concentrations increased 1.5–129 times. When the RH increased from 50% to 80%, the VOC concentrations and SERs increased 1–32 times. When the air change rate increased from 1 to 2 h⁻¹, the VOC concentrations decreased 9–40%, while the VOC SERs increased 6–98%. The relations between the boiling points of the VOCs and each of the normalized VOC SERs and concentrations were linear with negative slopes. The relations between the vapor pressures of the VOCs and each of the normalized VOC SERs and concentrations were linear with positive slopes. At 15 °C, RH50%, the relations between the diffusivities of VOCs and each of the normalized VOC equilibrium SERs and concentrations were linear with a positive slope.

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1. Introduction

The volatile organic compounds (VOCs) emitted from building materials have been recognized as pollutants that may deteriorate indoor air quality in terms of odor annoyance, and eye and airway irritation, which may be related to the sick building syndrome [1–5]. Some studies have shown that air temperature and humidity have a strong impact on the perception of air quality or VOC emissions from building materials [4,6–9].

Wolkoff [4,7] measured the time course emissions of VOCs from five building materials (carpet, PVC flooring, sealant, waterborne wall paint, and floor varnish). After ventilation of the materials for 1 week, most of the VOC emissions increased when the temperature increased. Increasing the relative humidity (RH) by 50% was seen to increase the emission of VOCs emitted from carpet, sealant, and wall paint. However, after being ventilated for 3 weeks, most of the VOC emissions from the materials were independent of air temperature and humidity. Overall, the effect

of temperature and RH depended strongly on the type of building products and type of VOCs. A strong impact of temperature and humidity on the emission of formaldehyde from chipboard was observed by Andersen et al. [9]. They found that within the temperature range 14–35 °C, the chemical emission rate of formaldehyde was doubled for each 7 °C temperature rise. Also, the emission rate was doubled when the relative air humidity increased from 30% to 70% at 22 °C. Sollinger et al. [10] studied the impact of temperature and humidity on the VOC emission from textile floor coverings by determining equilibrium concentrations (zero air change) at elevated temperatures in the range 23–71 °C and at a RH of 0% and 45%. They found that emission of the relative volatile compounds such as styrene showed little dependence on temperature. Strong temperature dependence was found for the emission of low-volatility compounds such as benzothiazol. However, the emission of all VOCs identified in the experiment was found to be independent of temperature in the typical indoor temperature range 23–30 °C. The effect of RH on VOC emission from the carpet tested was found to be negligible, except for aniline.

Air velocity impact of VOC emission was also studied by some researchers. Wolkoff [7] showed that primary source emissions

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were not affected by air velocity after a few days to a large extent. The primary VOC emissions from most building products were shown to be independent of air velocity, while increased air velocity may result in increased secondary VOC emissions if the building product surface is sensitive to oxidative degradation [11].

The objective of this study is to investigate the effects of temperature, RH, and air change rate on the VOC specific emission rates (SERs) and concentrations from wooden flooring, one of the common building materials for interior decoration. The relations between the VOC SERs and concentrations and the properties of VOCs were also studied. The VOC emission experiments were conducted in an environmental test chamber. The double-exponential model developed by Colombo et al. [12] was selectively picked to fit the observed VOC concentration–time profiles. The results could be used to predict VOC SERs and concentrations and evaluate the occupant exposure to VOCs.

2. Experimental methods

2.1. Materials

The wooden flooring tested was hardwood plywood provided by a local manufacturer. The dimensions of the wooden flooring specimen were 11 cm × 11 cm × 1.2 cm. Before the experiments, the wooden flooring was wrapped in aluminum foil and stored in a 4 °C refrigerator for storage. We got the specimens right after they were produced. They were stored up to 3 months before testing.

2.2. Methods

The wooden flooring specimen was cut into small pieces and then ground into powder. The powder was collected in a 1-L glass vessel; then the vessel was purged with 0.5 L/min of nitrogen gas (purity = 99.9%). The headspace gas effluent was analyzed by GC–MS (Finnigan Mat GCQ Mass Spectrometer, with an HP-1 capillary column Rtx-624, 60 m × 0.25 mm ID, 1.00 μm film). According to the GC–MS analysis results, toluene (content percentage = 2.79%), m,p-xylene (content percentage = 8.51%), ethylbenzene (content percentage = 9.44%), 2-ethylhexyl acrylate (content percentage = 31.3%), and n-butyl acetate (content percentage = 44.7%) were the dominate VOC species. Thus, we selected these five VOC species as target compounds. These selected VOCs are not typical for untreated solid soft or hard wood. The reason is probably that the tested wood in this study is not common solid wood, but composite wood made of combined wood fibers.

The experiments were conducted in a 40 cm × 40 cm × 35 cm stainless-steel environmental test chamber with Teflon coated all over inner walls in order to minimize VOC interaction with chamber walls so that VOC loss on the wall was assumed to be negligible in data analysis later on (Fig. 1). The test chamber was checked thoroughly and no leakage was found. Moreover, the difference in flow rate between the inlet and the outlet was insignificant; hence, the VOC loss by leakage could be ignored. There was no recovery test carried out. One wooden flooring specimen was placed on the middle of the chamber floor. Supply air for the test chamber was provided by an air compressor and the VOCs, humidity, and particle matter in the supply air were removed by an active carbon filter, a diffusion silicate dryer, and an HEPA filter, respectively. The temperature of the chamber was maintained at 15 °C (or 25 or 30 ± 1 °C) by a thermostatic chamber (DENG TNG Instruments Co., Ltd). The RH of the chamber was

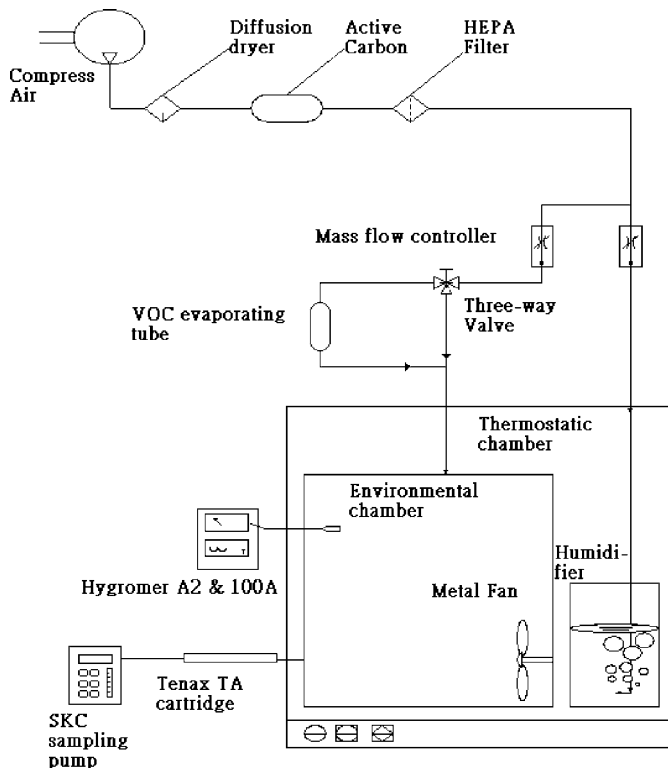


Fig. 1. Small-scale environmental chamber.

controlled at 50% (or 80%) by adjusting the air flow rate passing through the humidifier. The air exchange rate through the chamber was controlled at 1 h⁻¹ (or 2 h⁻¹) by electronic mass flow controllers (SIERRA Instruments, INC). A metal fan was installed in the chamber for mixing air. CO₂ gas was used as a gaseous tracer and the CO₂ concentration was monitored by Q-Trak (TSI, 8550). The mixing level determination was based on the ASTM D5116-97 standard practice [13] as follows:

$$\eta = \left\{ 1 - \frac{\sum_{i=1}^n [C_{tr}(t_i) - C_{th}(t_i)](t_i - t_{i-1})}{\sum_{i=1}^n [C(t_i)(t_i - t_{i-1})]} \right\} \times 100\% \quad (1)$$

where η is the mixing level (%), t_i the elapsed time of the i th sample (h), n the serial number of the sample, $C_{tr}(t_i)$ (ppm) the CO₂ concentration in the outlet at t_i , and $C_{th}(t_i)$ (ppm) the theoretical CO₂ concentration under completely mixing condition, calculated by the following equation:

$$C_{th}(t_i) = C_{tr}(0) e^{-ACH t} \quad (2)$$

where $C_{tr}(0)$ is the initial CO₂ concentration (~6000 ppm), and ACH is the air exchange rate (h⁻¹). The mixing level of each experiment was maintained above 80%.

The VOC sampling device included 500-mg Tenax TA (60/80 mesh) cartridges (SUPELCO) and sampling pump (SKC). The sampling flow rate was 30 mL/min and sampling time varied from 10 min during the first day to 30 min after 4 day of sampling. Immediately after sample collection, the Tenax TA cartridges were thermal desorbed and cryofocused by TEKMAR 6000 Aero Trap Desorber and then injected into the GC column and analyzed by the flame ionization detector (FID; HP5890 series II, with HP-1 capillary column SPB-5, 30 m × 0.53 mm ID, 0.5 μm film, SUPELCO).

The quantification was conducted as the following. First, 1 μL of TO 1 (toxic organic mixture, SUPELCO) reference solution was injected into a 125-mL glass sampling bulk (SUPELCO). After the

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