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An Experimental Investigation about the Levels of $PM_{2.5}$ and Formaldehyde Pollutants inside an Office

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Abstract: $PM_{2.5}$ and formaldehyde are two main indoor pollutants potentially threatening the health of human beings. In this paper, the concentrations of $PM_{2.5}$ and formaldehyde inside an office were measured under different conditions. The effects of temperature on the formaldehyde originating from the decoration materials, including flooring, gypsum powder, joint mixture and corestock, were also assessed. The results show that window ventilation can produce the same $PM_{2.5}$ purification as an air cleaner. The concentration of formaldehyde released from the decoration materials is highly correlated to the indoor temperature, but it is not significantly influenced by humidity. In particular, the percentage of formaldehyde grows approximately linearly with the increase in the heating temperature. The importance of the different sources responsible for the release of formaldehyde is as follows: joint mixture, gypsum powder, corestock and flooring. The concentration of released formaldehyde from the four decoration materials was found to vary from 0.08 ppm to 0.4 ppm when the heating temperature was increased from 16°C to 30°C.

Keywords: $PM_{2.5}$; formaldehyde; release; pollutants; decoration material

1 Introduction

Particles less than 2.5 micrometers in diameter are referred to as "fine" particles ($PM_{2.5}$). Compared with coarser atmospheric particles, fine particles have a small particle size, rich in toxic and harmful substances, have a long residence time in the atmosphere, and have a long transport distance, thus having a greater impact on human health, such as cancer, cardiovascular and pulmonary diseases [1]. Each country and organization has different standard limits of $PM_{2.5}$. The limit for 24-hour $PM_{2.5}$ in the World Health Organization is 0.0375 mg/m^3. The limit for 24-hour $PM_{2.5}$ in China is 0.075 mg/m^3. Recently, the indoor air quality caused by $PM_{2.5}$ has become a main issue, because a large majority of people spend approximately 80–90% of their time indoors [2]. Many studies have been performed in residences, schools and offices [3–12]. However, few studies are focused on the removal of indoor $PM_{2.5}$ by using window ventilation and air cleaners.

With the development of society, human beings are increasingly pursuing the quality and quality of daily life by creating a comfortable and healthy living environment for themselves. However, environmental

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pollution caused by indoor decoration materials is very worrying.The decoration materials release a lot of toxic and harmful chemicals, of which formaldehyde is the most serious. The maximum allowable concentration of formaldehyde in room air is generally 0.08 mg/m^3. The release rate of formaldehyde from building materials depends on surrounding air temperature and humidity [13–15]. A theoretical model was developed using indoor temperature, humidity, and air change rate to predict indoor formaldehyde concentrations [16]. The improvement of the performance of a simple box model was carried out using CFD modeling to predict indoor air formaldehyde concentration [17]. The infiltration rates and indoor formaldehyde concentrations in five climate zones of China were investigated [18]. A few studies of removing formaldehyde have also been carried out [19,20].

The objectives of this paper are (i) to investigate indoor $PM_{2.5}$ pollutant decay by window ventilation and an air cleaner; (ii) to study the release of indoor formaldehyde of different factors, including test time, heating temperature and decoration materials.

2 Materials and Methods

The experiment was performed in an office with the air volume of 20 m^3 (Fig. 1). The same two PC-3A type particle detectors were used to measure indoor and outdoor $PM_{2.5}$ concentrations, respectively. The measurement ranger of the detectors is from 0 to 10 mg/m^3. The resolution of the detectors is 0.001 mg/m^3. Indoor formaldehyde concentration was measured by a PPM-HTV formaldehyde instrument with the accuracy of 2%. The maximum measurement range and resolution of the formaldehyde detector are 10 ppm and 0.001 ppm, respectively. An air cleaner produced by Daikin was used to clean indoor $PM_{2.5}$ pollutant. Four typical decoration materials were selected, including flooring with the thickness of 12 mm, gypsum powder with the mass of 500 g, joint mixture with the volume of 500 mL and core stock with the thickness of 15 mm to study the formaldehyde release from them.

Figure 1: Photo of tested office

Firstly, the decay of indoor $PM_{2.5}$ pollutant in cigarettes was recorded with particle sample interval of 1 minute for several cases. Then, indoor formaldehyde concentration in the office was measured in a time period of one morning and afternoon. Finally, the effects of temperature on the release of the decoration materials in the office cabinet as an environmental simulation cabin were performed. In the experiment, the air conditioner in the room was used to heat the air in the room and the cabinet door was opened. The air conditioner was turned off after the air temperature was to the set temperature, the instrument and a

material were put into the cabinet, and the crevice of the cabinet door was sealed with tapes. Then the measurement began.

3 Results and Discussion

3.1 Indoor $PM_{2.5}$ Pollutant Decay

Fig. 2 is the comparison of indoor $PM_{2.5}$ concentrations for three cases. The cigarette as a source of indoor pollutants after ignition was used. For case 1, the window was closed and the air cleaner was off. For case 2, the window was opened and the air cleaner was turned off. The third case was that the window was closed and the air cleaner was turned on. The middle air flow mode of the cleaner (198 m^3/h) was chosen. As can be seen from Fig. 2, the outdoor $PM_{2.5}$ concentrations and initial indoor $PM_{2.5}$ concentrations for three cases are almost the same. This provided equal conditions for the comparison of indoor pollutants in the three cases. For case 1, the indoor $PM_{2.5}$ firstly decreased quickly and then almost kept constant. After 60 minutes, the indoor and outdoor $PM_{2.5}$ concentrations were almost the same. For cases 2 and 3, after 55 minutes, the concentration of the indoor $PM_{2.5}$ were lower that of the outdoor $PM_{2.5}$. This is because opening windows and air clearer can increase the air exchange rate and speed up the decay of $PM_{2.5}$ concentrations. It is also noted that window ventilation and purifier purification for $PM_{2.5}$ removal are almost the same.

3.2 Indoor Formaldehyde Pollutant

Fig. 3 shows the temperature and humidity and indoor formaldehyde concentration measured in the morning and afternoon of the day. The indoor temperature gradually increases from 8:38 am to 9:38 am, while the indoor relative humidity gradually decreases. The indoor formaldehyde concentration is variable due to the temperature change in the morning. The measured indoor temperature is decreasing and the indoor relative humidity keeps constant from 16:58 pm to 17:58 pm, as can be seen from Fig. 3. Different from the case in the morning, the indoor formaldehyde concentration in the afternoon is gradually decreasing with decreasing indoor temperature.

3.3 Formaldehyde Release of Decoration Materials

Fig. 4 shows the release of formaldehyde pollutants of decoration materials at different heating temperatures. Overall, the formaldehyde concentrations increase with the increase of the heating temperature. Except for a few points, the formaldehyde concentrations change little during the time of measurement.

It is also founded that the joint mixture among the four decoration materials can release the most formaldehyde pollutant (Fig. 4c). The averaged formaldehyde concentration from the joint mixture is about 0.12 ppm at the heating temperature of 16°C. The maximum formaldehyde concentration from the joint mixture is 0.4 ppm at the heating temperature of 30°C. Due to the thermal diffusion and convection [21,22], the concentration from the joint mixture at the heating temperature of 30°C is two point three times higher than that at the heating temperature of 16°C.

The gypsum powder can release the second most formaldehyde pollutant (Fig. 4b). The averaged formaldehyde concentrations from the gypsum powder at the heating temperature of 16°C and 30°C are about 0.1 ppm and 0.35 ppm, respectively. It is also noted that the formaldehyde concentrations from gypsum powder basically increase linearly from 16°C to 30°C.

The core stock can release the third most formaldehyde pollutant (Fig. 4d). The averaged formaldehyde concentrations from the core stock at the heating temperature of 16°C and 30°C are about 0.1 ppm and 0.26 ppm, respectively.

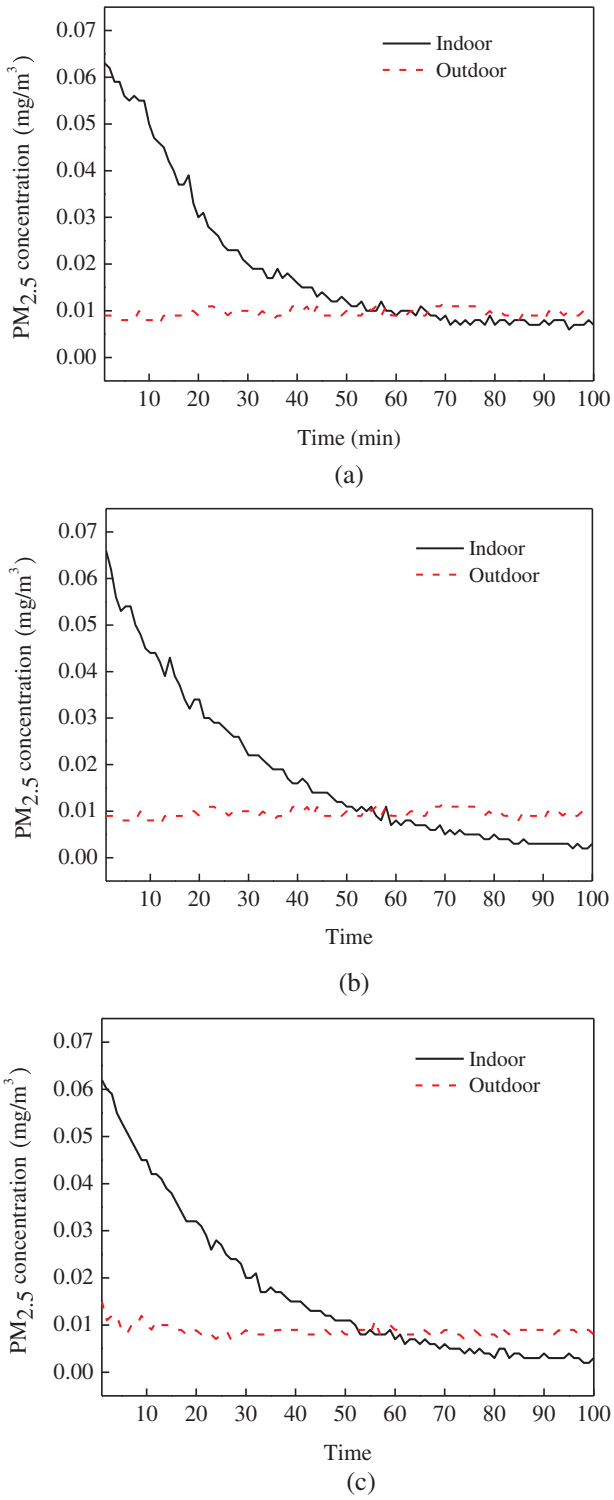

Figure 2: Indoor $PM_{2.5}$ concentrations from a cigarette with time under ventilation and purification. (a) Window closed, cleaner off (b) Window opened, cleaner off (c) Window closed, cleaner on

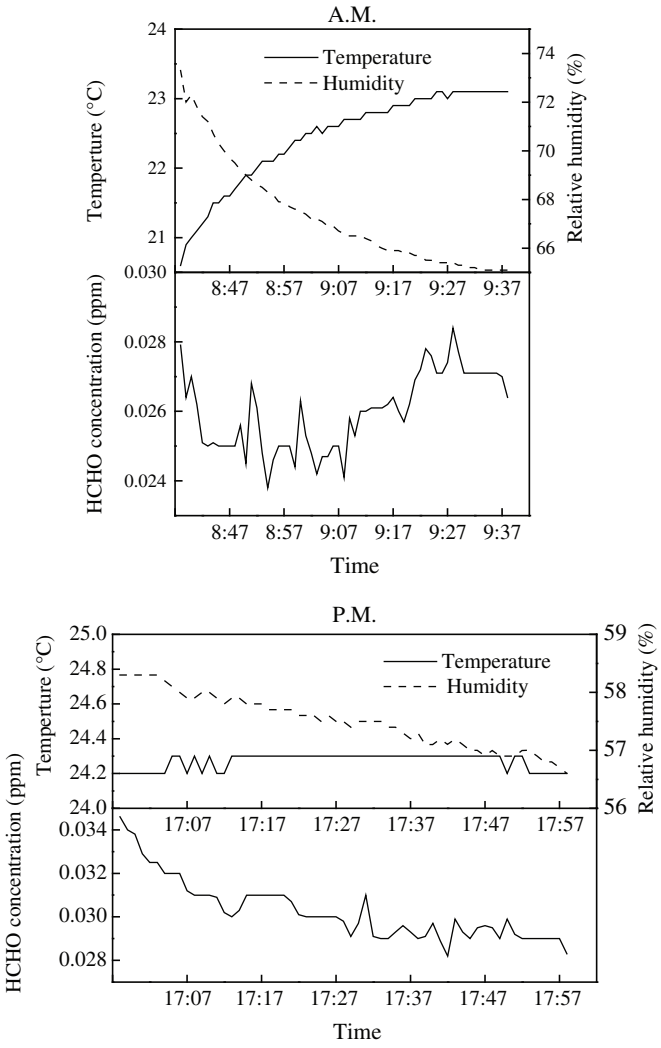

Figure 3: Indoor formaldehyde concentrations in the morning and afternoon

Compared to the other three decoration materials, the flooring releases the least formaldehyde (Fig. 4a). The averaged concentrations of released formaldehyde from the flooring at the heating temperature of 16°C and 30°C are about 0.08 ppm and 0.25 ppm, respectively. Compared with the other three decoration material, the flooring has the largest fluctuation of the formaldehyde concentration.

4 Conclusions

Opening window can achieve the same indoor $PM_{2.5}$ purification effect as an air cleaner. For the room air volume of 20 m^3, the indoor and outdoor $PM_{2.5}$ concentration is basically balanced within one hour with the outdoor $PM_{2.5}$ concentration of 0.01 mg/m^3 and the initial indoor $PM_{2.5}$ concentration of 0.06 mg/m^3. The formaldehyde release of the decoration materials linearly increases with the increase of the heating temperature. Compared with corestock and flooring, joint mixture and gypsum powder can release more formaldehyde.

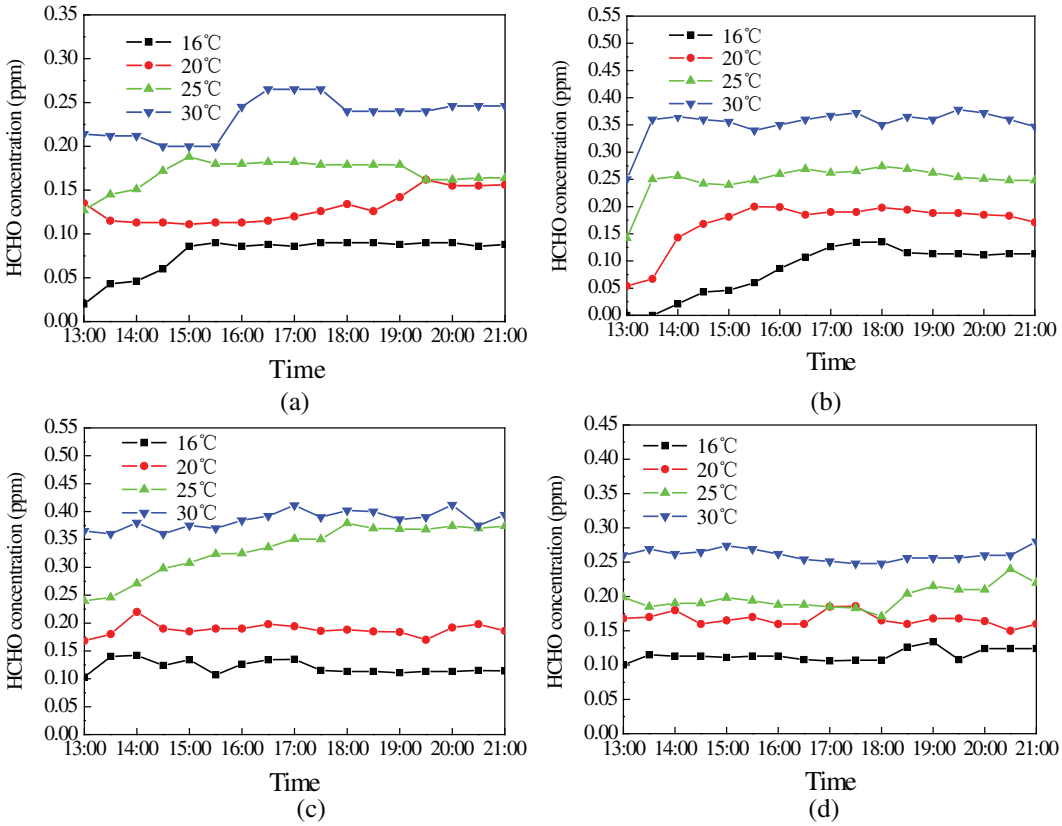

Figure 4: Formaldehyde concentrations of decoration materials at different heating temperatures. (a) Flooring (b) Gypsum powder (c) Joint mixture (d) Corestock

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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