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Measurement of Air Quality during a Decorating Engineering

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ABSTRACT

Air quality studies during a decorating engineering in northern Taiwan were carried out. Sampling was undertaken during the decorating engineering including the dismantling old decorating, water and electrical pipe engineering, tiling engineering, window installation, pre-system furniture installation, flooring engineering, post- system furniture installation and finishing engineering. The levels of carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), temperature, relative humidity and bacterial/fungal concentrations were recorded during the decorating engineering. Results show that the averaged CO concentrations ranged from 1.05 to 22.1 ppm during various engineering. The averaged HCHO concentrations ranged from 0.08 to 0.69 ppm and the HCHO increased apparently after system furniture installation. The averaged $PM_{2.5}$ and PM_{10} concentrations ranged from 97.2 to 6,445 µg/m^3 and 129 to 6,837 µg/m^3, respectively. The PM concentrations for the tiling engineering were more than two times of the recommended exposure limit (REL) of respirable particles of 5 mg/m^3. The mean respirable fractions, R_b and R_f, for bacteria and fungi, ranged from 27.8%–97.0% and 29.4%–93.8%, respectively. It should be noticeable that over 75% of R_b and R_f were higher than 50% during the decorating engineering. The relatively high respirable fractions of bioaerosols and the high PM concentrations for some specific decorating engineering probably implies a higher adverse health risk for sensitive workers. There are limited information about the air quality for the decorating engineering and this preliminary study can provide references to the Taiwan government on air quality management for workplaces.

Keywords: Decorating; Formaldehyde; Bacteria; Fungi.

INTRODUCTION

Donkelaar *et al.* (2010) mapping global ground-level $PM_{2.5}$ concentrations made people around the world deeply impressed by the health impact of air pollutions. WHO reports that around 7 million people died in 2012- one in eight of total global deaths – as a result of air pollution exposure (WHO). Pope *et al.* (1995) indicated particulate air pollution was associated with cardiopulmonary and lung cancer mortality. There should be more focused on the indoor air quality. Because many people might spend up to 90 % of daytime indoors whatever at home, work or school. WHO also reminded a total of 3.3 million deaths linked to indoor air pollution and 2.6 million deaths related to outdoor air pollution in the WHO South-East Asia and Western Pacific Regions (WHO). The quality of the air we breathe indoors pose a strongly direct impact on our health (Bruce *et al.*, 2000).

Many people are aware of the environmental health risk by air pollutions, especially the indoor air pollutions. Most of the studies investigated the indoor air quality of offices (Lee *et al.*, 2002; Fang *et al.*, 2004), houses (Bruce *et al.*, 2004; Taneja *et al.*, 2008), hospitals (Nordstrom *et al.*, 1995; We Jr., 1993), shopping malls (Li *et al.*, 2001), dental clinics (Godwin *et al.*, 2003; Helmis *et al.*, 2007) and classrooms (Lee and Chang, 1999; Daisey *et al.*, 2003). People pay more and more attention on the exposure under new decorated house. However, the information of air quality for a decorating workplace is very limited and it's probably much worse for the working labor. Liu *et al.* (2012) indicated if children moved to the new interior decoration house as soon as possible, therefore, the proportion of having cough, sputum and asthma will increase. Mo *et al.* (2012) investigated 30 residential buildings and 5 office buildings after decorating in Guangxi Nanning city for formaldehyde, benzene, total volatile organic compounds (TVOC), ammonia and radon. 80.0% of the measured building for TVOC concentration exceed the national standard. Some VOCs, including formaldehyde, in combination might result in sensory irritation under certain environmental and occupational

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conditions. The TVOCs, PM, O_3, CO HCHO are always the measurement targets for most sampling sites, but the bacterial and fungal concentrations are often excluded.

This study was to evaluate the air quality of a decorating workplace during the decorating engineering. The distribution of air quality during the decorating engineering was monitored and compared. This preliminary study can provide references to the Taiwan government and other countries on the management for the air quality of workplaces.

MATERIALS and METHODS

Sampling Information

A decorating workplace in an apartment was selected in northern Taiwan. The apartment was 64 square meter on the fourth floor. The sampling location was shown in Fig. 1. The CO, CO_2, temperature, and relative humidity were monitored for 5 minutes by an AirBoxx monitoring system (KD Engineering, USA), marked by sample A1–A6. Airboxx recorded data every 15 seconds. The level of HCHO was monitored for 5 minutes by a Formaldemeter htv monitoring system (PPM, United Kingdom), also marked by sample A1–A6. Formaldemeter recorded data every 50 seconds. Two six-stage microbial cascade impactors (TE-10-830, Tisch Environmental, Inc.) were used to sample airborne bacteria and fungi, marked by sample M1–M3. The aerodynamic diameter ranges include > 7 µm (stage 1), 4.7–7 µm (stage 2), 3.3–4.7 µm (stage 3), 2.1–3.3 µm (stage 4), 1.1–2.1 µm

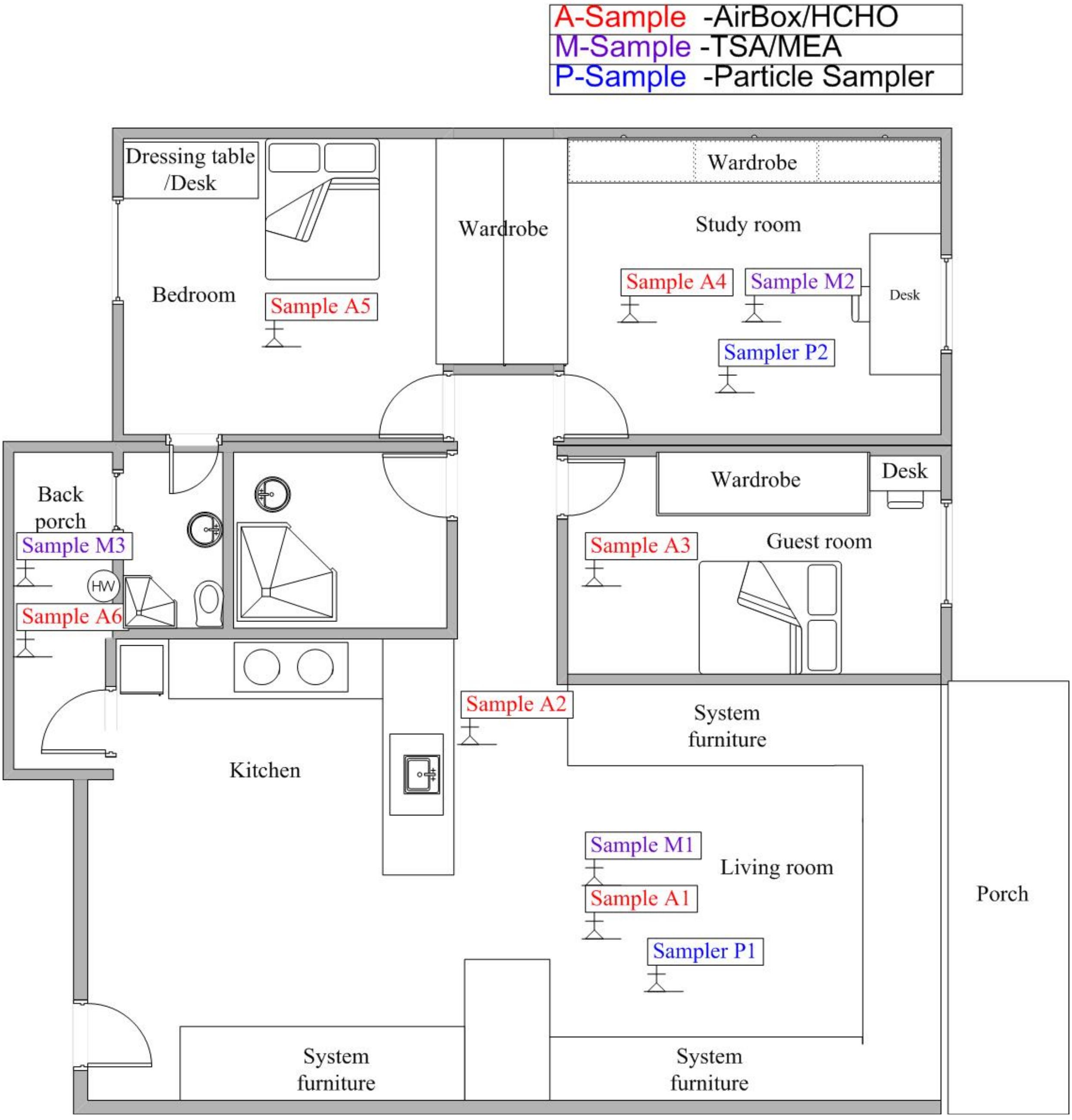

Fig. 1. Sampling location for the decorating engineering.

(stage 5), and 0.65–1.1 µm (stage 6). The sampling flow rate was 28.3 L/min, the sampling time was 5 minutes, and the sampling height was approximately 150 cm. Two personal particle samplers PEM was located on the living room and study room, marked by sample P1–P2 and the sampling time was 24 hours.

Sampling was undertaken during the decorating engineering including the dismantling old decorating, water and electrical pipe engineering, tiling engineering, window installation, pre-system furniture installation, flooring engineering, post- system furniture installation and finishing engineering. The windows were always open during all decorating engineering. Airboxx and HCHO sampler were set in the living room, corridor, guest room, study room, bedroom and back porch. Microbial cascade impactors were set in the living room, study room and back porch. As PEM sampler was set in the living room and study room. The sampling location was showed in Fig. 1. The diagram of the apartment is the as-built drawing.

Measurement and Analysis

Trypticase soy agar (TSA) with cycloheximide and malt extract agar (MEA) with chloramphenicol were used for capturing bacteria and fungi samples, respectively. Field blanks were also tested during the sampling. After sampling, the Petri dishes were incubated for 48 hrs at 37°C (Taiwan EPA method E301.11C) for bacteria and 120 hrs at 25°C (Taiwan EPA method E401.11C) for fungi. The concentrations of airborne bacteria and fungi (CFU/m^3) were calculated by dividing the total colonies counts on agar plate by air volume. The fractions for each stage of bacteria and fungi were defined as follows:

$$B_i = C_i/C_b \times 100\% \quad (1)$$

B: bacterial fraction (%)
C_i: the i stage concentration for bacteria, which is 1 for the first stage (> 7 µm), 2 for the second stage (4.7–7 µm), 3 for the third stage (3.3–4.7 µm), 4 for the fourth stage (2.1–3.3 µm), 5 for the fifth stage (1.1–2.1 µm), and 6 for the sixth stage (0.65–1.1 µm)
C_b: total concentration of bacteria

$$F_i = C_i/C_f \times 100\% \quad (2)$$

F: Fungal fraction (%)
C_i: the i stage concentration for fungi
C_f: total concentration of fungi

$$R_b = (C_3 + C_4 + C_5 + C_6)/C_b \times 100\% \text{ (Kim and Kim, 2007)} \quad (3)$$

R_b: Respirable fraction for bacteria

$$R_f = (C_3 + C_4 + C_5 + C_6)/C_f \times 100\% \quad (4)$$

R_f: Respirable fraction for fungi.

Data Analysis

This study uses SPSS 13.0 to calculate the descriptive statistics and the spearman's rank correlation test. It is a nonparametric measure of statistical dependence between the indoor air pollutants pairs. The test assesses how well the relationship between the indoor air pollutants pairs can be described using a monotonic function.

RESULTS AND DISCUSSION

Level of CO and CO_2 Concentration

The individual CO_2 concentration ranged from 334 to 711 ppm during the decorating engineering. The averaged CO_2 concentration for various engineering was between 378 and 586 ppm, happening in the windows installation and finishing engineering, respectively (Table 1). The variation of

Table 1. Worker's exposure to airborne bacteria, fungi and indoor pollutants (mean ± SD).

Engineering	CO (ppm)	CO_2 (ppm)	HCHO (ppm)	$PM_{2.5}$ PM_{10} (µg/m^3)	Bacteria (CFU/m^3)	Fungi (CFU/m^3)
[1]dismantling old decorating	1.05 ± 0.21	451 ± 11.4	0.11 ± 0.08	108 ± 59.0 396 ± 250	85 ± 32.8	390 ± 176
[2]water and electrical pipe engineering	22.1 ± 16.2	494 ± 122	0.13 ± 0.02	6445 ± 6333 6837 ± 6427	973 ± 445	495 ± 305
[3]tiling engineering	14.3 ± 3.01	457 ± 25.5	0.51 ± 0.16	431 ± 250 1490 ± 427	652 ± 277	306 ± 24.9
[4]window installation	6.67 ± 1.36	378 ± 44.7	0.16 ± 0.06	347 ± 299 399 ± 309	468 ± 313	1067 ± 423
[5]pre-system furniture installation	3.10 ± 0.69	450 ± 10.8	0.24 ± 0.20	97.2 ± 48.6 129 ± 59.0	145 ± 64.9	576 ± 106
[6]flooring engineering	3.43 ± 0.96	471 ± 57.2	0.08 ± 0.02	629 ± 295 910 ± 20.8	495 ± 259	484 ± 108
[7]post-system furniture installation	4.32 ± 0.59	543 ± 53.1	0.69 ± 0.43	350 ± 300 400 ± 310	253 ± 222	530 ± 57.7
[8]finishing engineering	7.60 ± 2.43	586 ± 97.4	0.55 ± 0.32	2229 ± 1028 3434 ± 712	151 ± 90.0	149 ± 30.6

CO_2 concentration in various location for the same decorating engineering was not obvious. The RSD ranged from 2.41% to 24.7%. The highest variation of CO_2 concentration occurred in the water and electrical pipe engineering.

The individual CO concentration ranged from 0.85 to 44.3 ppm during the decorating engineering. The averaged CO concentration for various engineering was between 1.05 and 22.1 ppm (Table 1), happening in the dismantling old decorating and water and electrical pipe engineering, respectively. The variation of CO concentration in various location for the same decorating engineering was more obvious than CO_2 concentration. The RSD ranged from 13.4% to 74.3%. The highest variation of CO concentration also occurred in the water and electrical pipe engineering. The higher variation for CO concentration possibly because the drill was rotated on the ground of living room during sampling, leading friction and heat loss between drill and cement. That probably resulted in the high CO concentration in the living room and hallway.

Fig. 2 showed the CO_2 to CO ratio during decorating engineering. Because the CO_2 concentration variation was not obvious, the CO concentration was lowest for dismantling old decorating. The CO_2 to CO ratio was consistent for tiling engineering and window installation, which was much simpler relative to other engineerings.

Level of HCHO Concentration

The individual HCHO concentration ranged from 0.05 to 1.3 ppm during the decorating engineering. The averaged HCHO concentration for various engineering was between 0.08 and 0.69 ppm (Table 1), happening in the flooring engineering and post-system furniture installation, respectively. The variation of HCHO concentration in various location for the same decorating engineering was apparent. The RSD ranged from 18.6% to 84.3%. The highest variation of HCHO concentration occurred in the post-system furniture installation. There are three peaks for HCHO concentration during decorating engineering, including the tiling engineering, pre-system furniture installation and post-system furniture installation (Fig. 3). The system furniture was set most in the living room and kitchen, partly in the guest room and study room (Fig. 1). After the system furnitures settled, the HCHO concentration increased apparently and lasted to the finishing engineering (the duration of sampling was 15 days). Lin (2010) measured HCHO concentration before and after a new decorating apartment. The result showed the HCHO concentration before and after decoration was 0.03 ppm and 0.05 ppm, separately. However, the HCHO concentration of an old house increased to 0.09 ppm. In this study, the high HCHO concentration for tiling engineering should be paid more attention. It was probably due to the tile adhesive emission, which needs further investigation in the future.

The individual temperature ranged from 25.0 to 32.4°C during the decorating engineering. The average temperature for various engineering was between 25.3 and 32.0°C (Table 1), happening in the flooring engineering and tiling engineering, respectively. The variation of temperature in various location for the same decorating engineering was so little. The RSD are all less than 2.0%. The situation was similar for the relative humidity. The individual relative humidity ranged from 54.9% to 80.6% during the decorating engineering. The averaged relative humidity for various engineering was between 61.1% and 79.9%, happening in the post-system furniture installation and finishing engineering, respectively. The variation of relative humidity in various location for the same decorating engineering was not obvious. The RSD are all less than 10.0%. The variation of

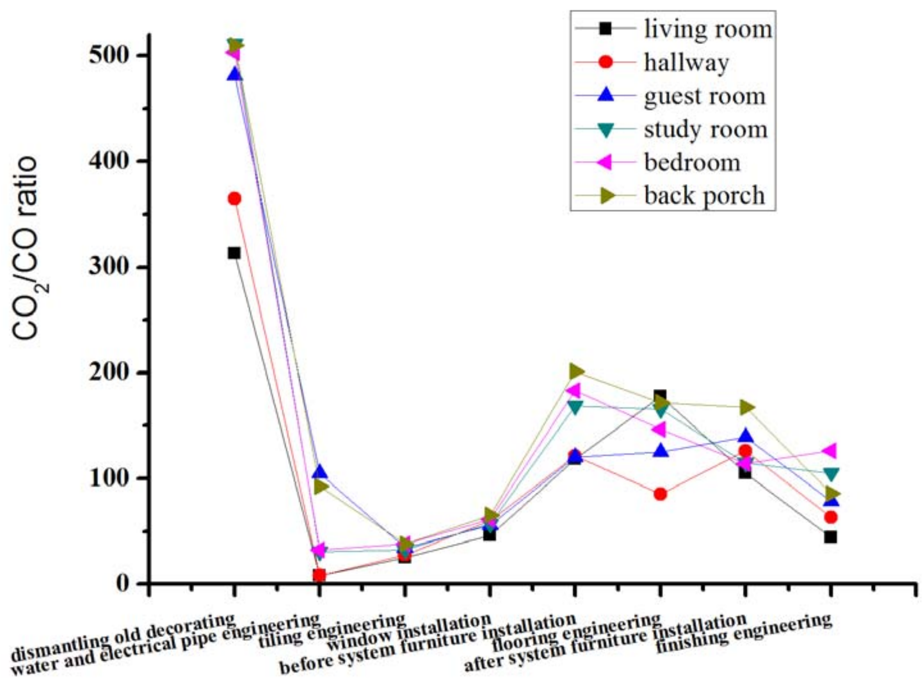

Fig. 2. The CO to CO_2 ratio during the decorating engineering.

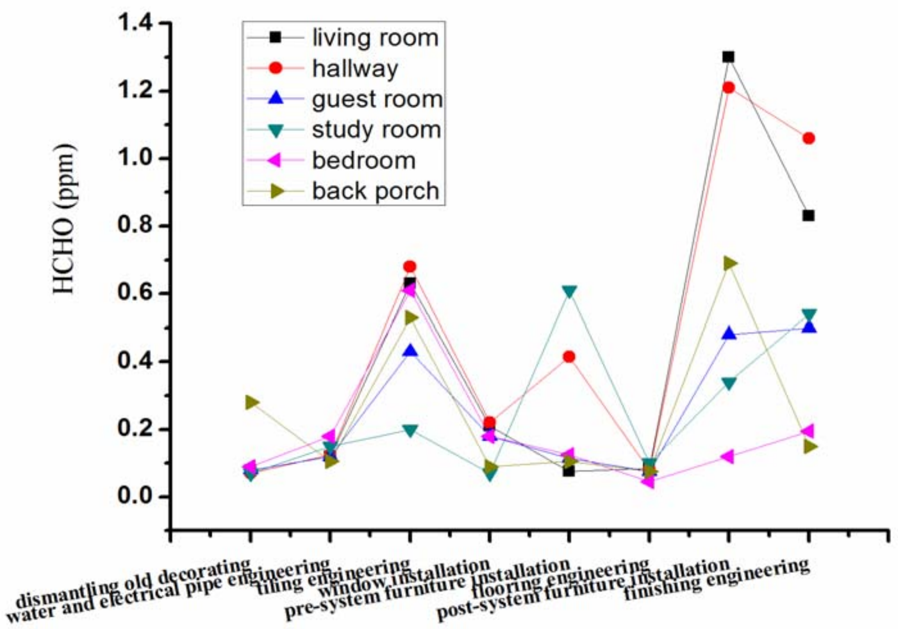

Fig. 3. The HCHO concentrations during the decorating engineering.

temperature and relative humidity were related with the sampling month, which was from August to October (Summer to Autumn).

Level of PM Concentration

The PM samples were taken for 24 hours. The sampling locations were chosen in the study room and living room owing to the limited samplers. The individual $PM_{2.5}$ concentration ranged from 48.6 to 1,201 µg/m^3 for the study room and 146 to 12,778 µg/m^3 for the living room, during the decorating engineering, respectively (Fig. 4(a)). The individual PM_{10} concentration ranged from 69.4 to 2,722 µg/m^3 for the study room and 188 to 13,264 µg/m^3 for the living room, respectively (Fig. 4(b)). The ratio of $PM_{2.5}$ to PM_{10} concentration ranged from 0.17 to 0.70 for the study room and 0.26 to 0.99 for the living room, respectively (Fig. 4(c)).

There is no standard for $PM_{2.5}$ or PM_{10} concentration for the working place in Taiwan, but the recommended exposure limit (REL) of respirable particles is 5 mg/m^3. The $PM_{2.5}$ and PM_{10} concentration of the tiling engineering was 12,778 and 13,264 ug/m^3, which was more than two times of the REL. The highest PM concentration occurred during the water and electrical pipe engineering, which used the drillto

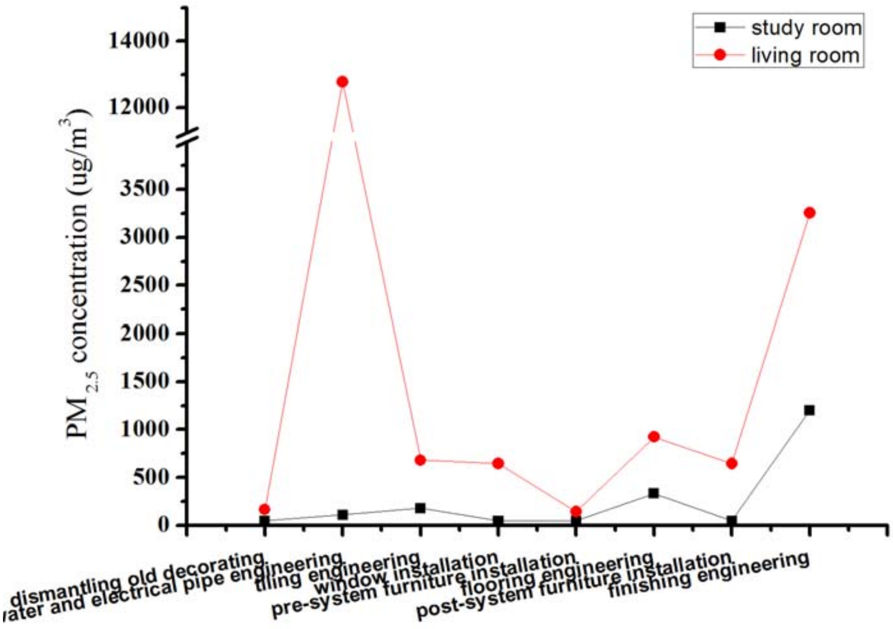

Fig. 4. The (a) $PM_{2.5}$ concentration (b) PM_{10} concentrations (c) $PM_{2.5}$ to PM_{10} ratio during the decorating engineering.

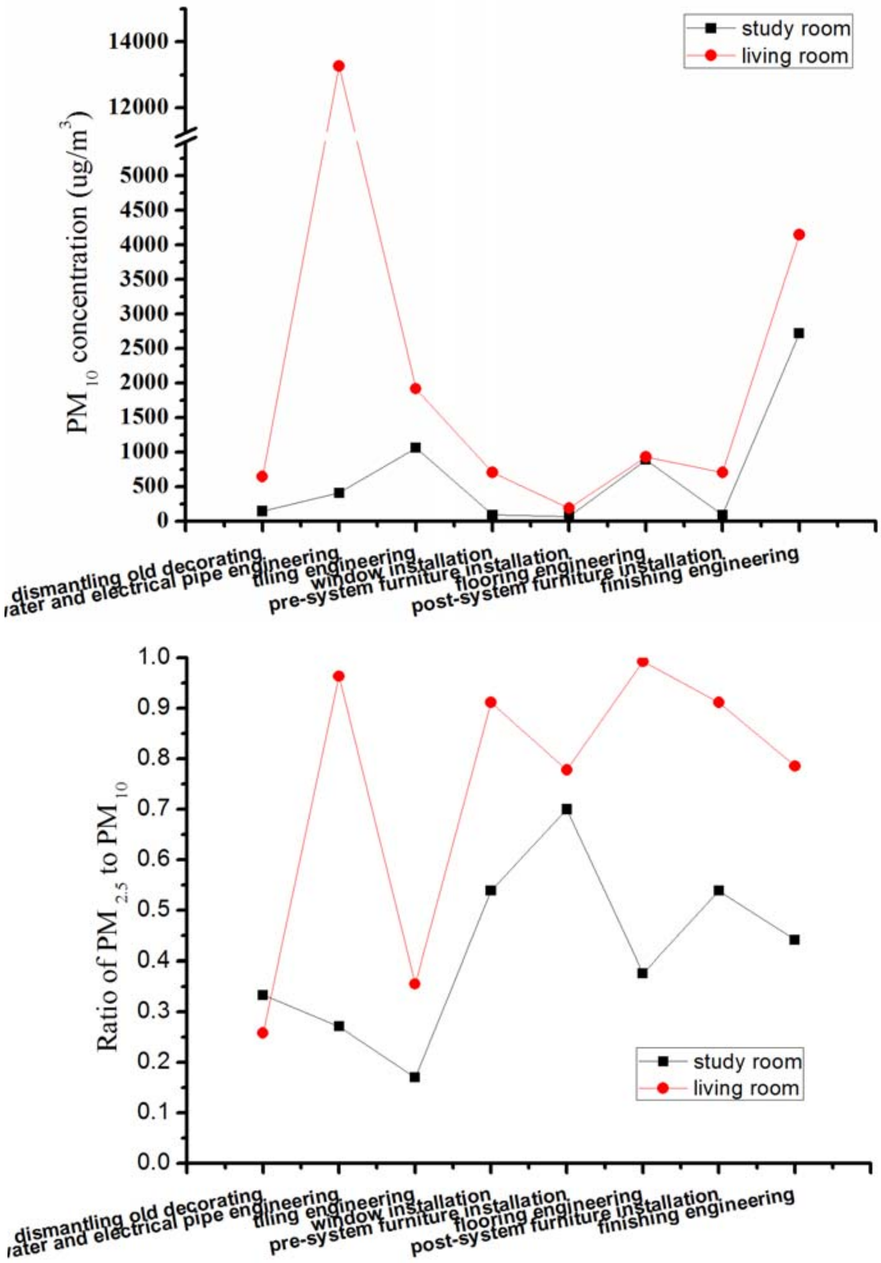

Fig. 4. *(continued).*

bore the holes on the ground. This led to lots of particles suspended in the air. The working environment for the decorating labor warrants further investigation in the future.

Level of Bioaerosol Concentration

Bacteria and Fungi samples were taken only in the living room and study room for the limited samplers. The bacterial concentration for living room ranged from 71 to 1731 CFU/m^3. The highest bacterial concentration happened in the water and electrical pipe engineering. The bacterial concentration for study room ranged from 85 to 855 CFU/m^3. The highest bacterial concentration also happened in the water and electrical pipe engineering (Fig. 5). The distribution of the bacterial concentrations for the living room and study room was similar, which probably indicated that the similar source during the engineering (Fig. 5). There were always four labors working during the decorating engineering. The relative high bacterial concentration occurred in the water and electrical pipe engineering, tiling engineering and flooring engineering, which contributed to more PM agitation during the engineering.

The fungal concentration for living room ranged from 134 to 1,463 CFU/m^3. The highest bacterial concentration happened in the window installation. The fungal concentration for study room ranged from 170 to 898 CFU/m^3. The highest fungal concentration also happened in the window installation. The distribution of the fungal concentrations for the living room and study room was similar (Fig. 6), however, not similar with the distribution of bacterial concentrations. This indicated that the different source for

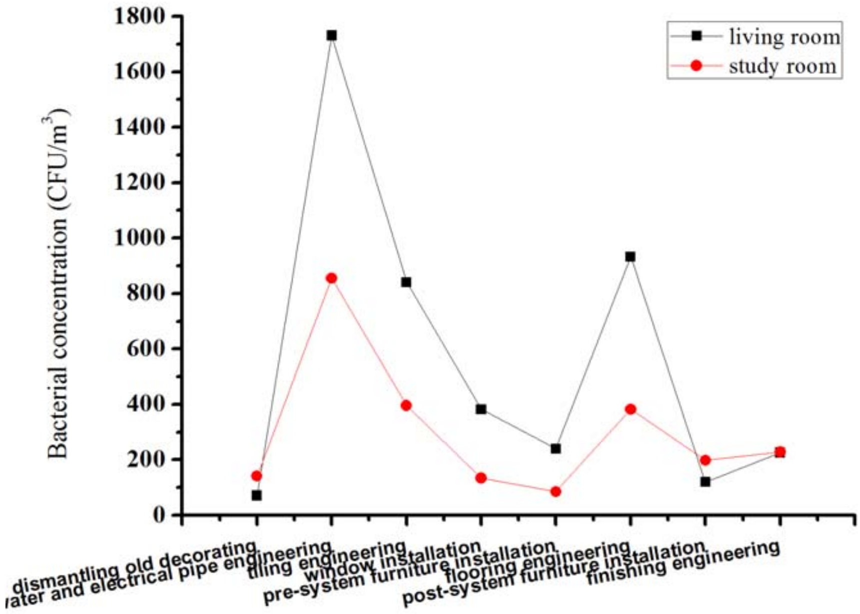

Fig. 5. The bacterial concentrations during the decorating engineering.

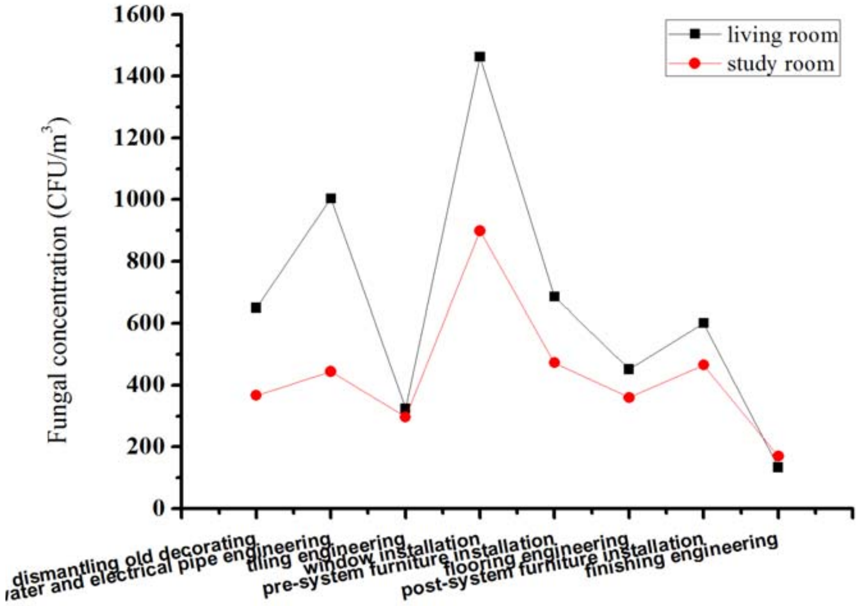

Fig. 6. The fungal concentrations during the decorating engineering.

bacteria and fungi during the engineering. The results showed that the fungal concentration was more relative to outdoors environment.

The B1–B6/F1–F6 pattern of the mean fractions of airborne bacteria/fungi for living room and study room were very different (Figs. 7(a)–7(d)). The results were different with other studies processing in indoors (Lee and Kuo, 1993; Lin and Li, 1996). It indicated the unpredictable and variable airborne bacterial and fungal concentrations during the decorating engineering. Fig. 8 showed the mean respirable fractions, R_b and R_f, for bacteria and fungi, respectively. R_b for living room and study room ranged from 27.8%–97.0% and 40.0%–83.9%, respectively. R_f for living room and study room ranged from 29.4%–93.8% and 74.2%–83.2%, respectively. It should be noticeable that over 75% of R_b and R_f were higher than 50% during the decorating engineering both in the living room or the study room. The respirable fraction represents the fraction of bioaerosol easily penetrating into human trachea and bronchiole. The higher respirable fraction possibly implied the adverse health effect, such as asthma or allergy, would happen on those sensitive labors. Comparing with Kims' study (Kim and Kim, 2007), R_b and R_f ranged from 32.0–38.1% and 58.9–69.1%, the higher respirable fraction in the decorating engineering implies a higher adverse health risk for sensitive workers, and warrants further investigation.

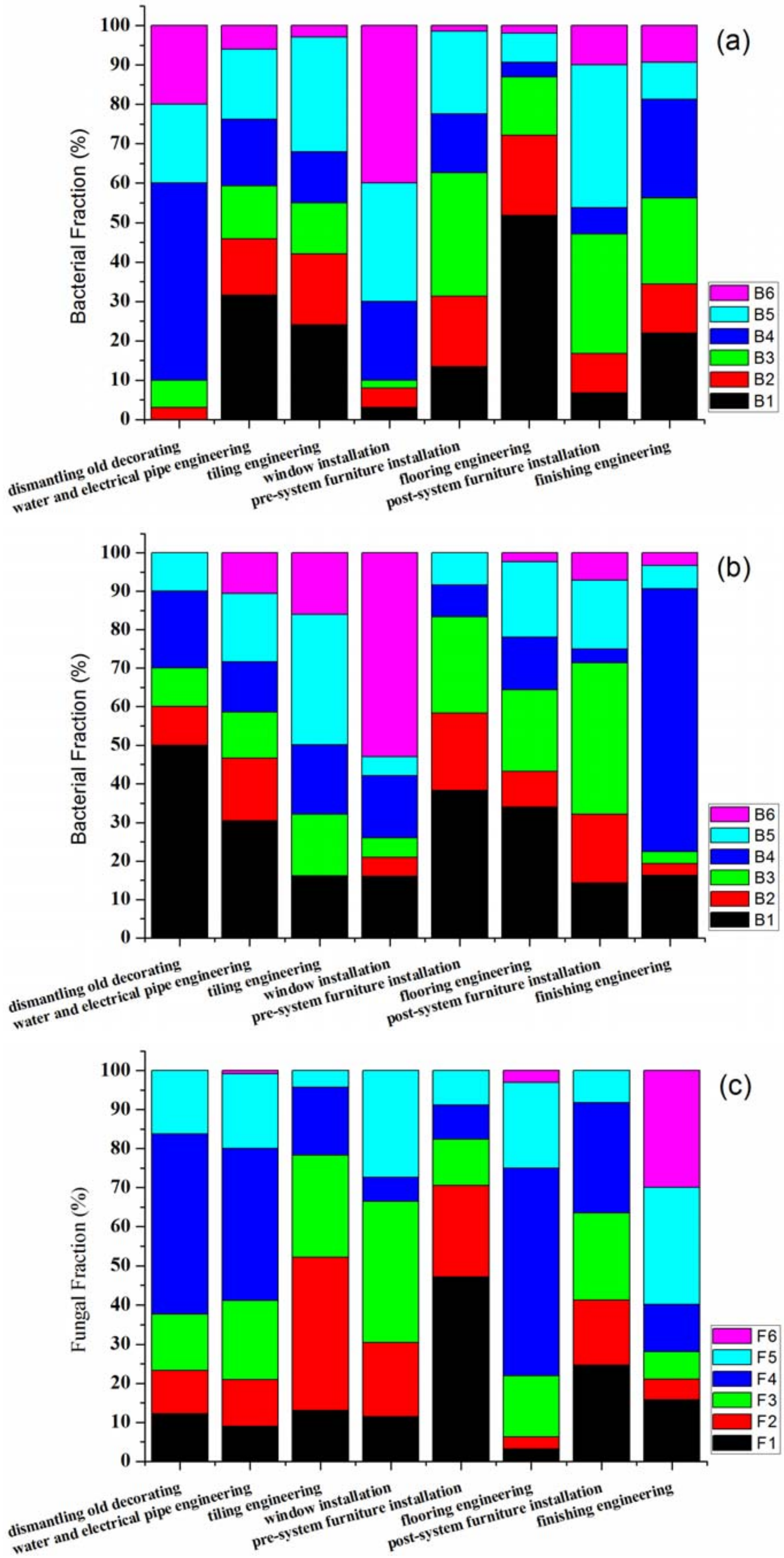

Fig. 7. The (a) bacterial fractions for living room (b) bacterial fractions for study rooms (c) fungal fractions for living room (d) fungal fractions for study rooms during the decorating engineering.

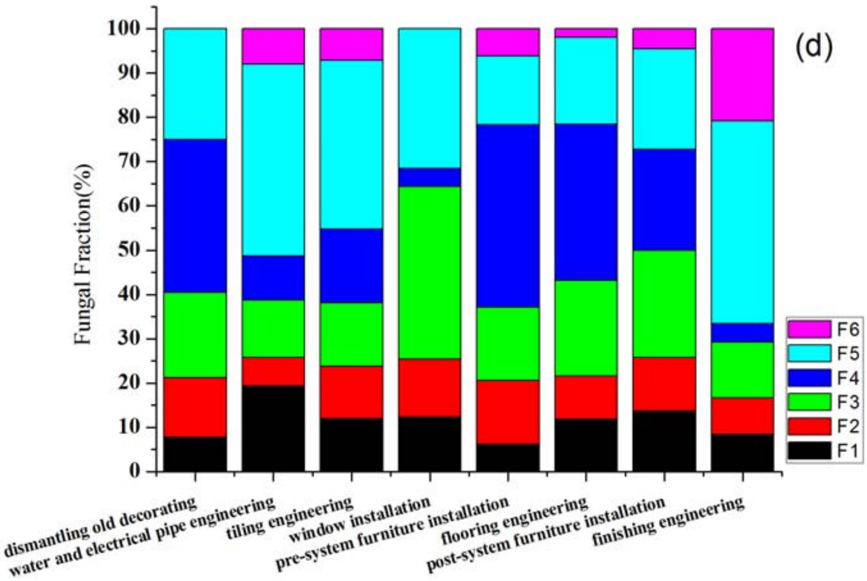

Fig. 7. *(continued).*

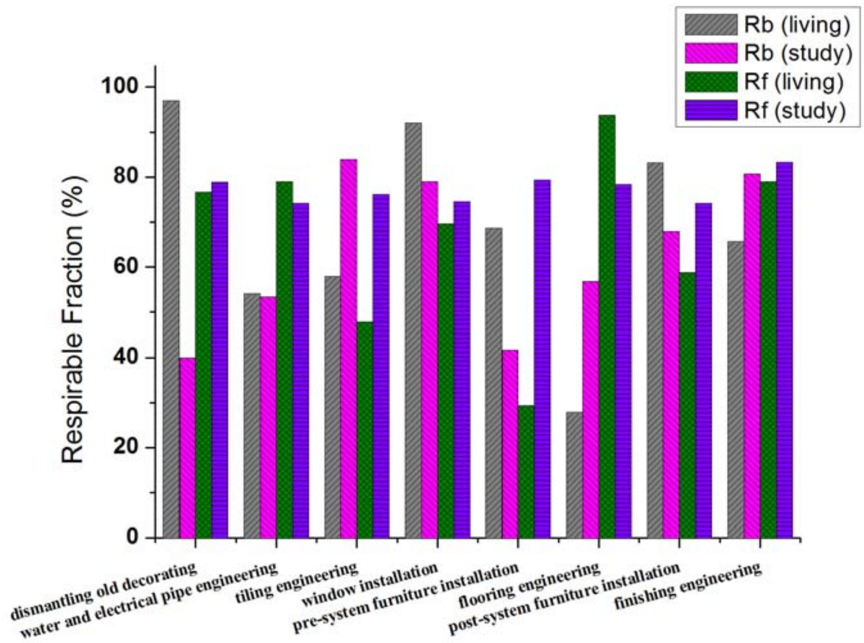

Fig. 8. The respirable fractions of bioaerosols during the decorating engineering.

Associations among Pollutants and Environmental Parameters

Table 2 listed the result of spearman's rank correlation test. There exited positive relationships for the following pairs: HCHO and CO, HCHO and CO_2, CO and temperature, CO and bacterial concentration, $PM_{2.5}$ and PM_{10}, the humidity and fungal concentration. Additionally, the negative relationships were found for the following pairs: CO and fungal concentration, $PM_{2.5}$ and fungal concentration, PM_{10} and fungal concentration, the humidity and PM_{10}. The positive correlation coefficients of $PM_{2.5}$ and PM_{10} was the highest, 0.844 ($p < 0.001$). The negative correlation coefficients of PM_{10} and fungal concentration was the highest, –0.762 ($p < 0.001$). It indicated no matter the various engineering process, the $PM_{2.5}$ concentration could possibly be closely predicted from the PM_{10} concentration during the decorating engineering. The exposure risk assessment could probably be evaluated based on the limited information.

CONCLUSION

The studies related with measurements of air quality during decorating engineering were limited. This preliminary study will provide references for further exposure risk assessment. The CO concentration was very high for the drill rotating on the ground in the water and electrical pipe engineering. Additionally, the system furnitures installation contributed lots of HCHO in the workplace. The high $PM_{2.5}$

Table 2. Spearman's rho coefficient for indoor air pollutants.

	CO	CO_2	HCHO	temp	humidity	$PM_{2.5}$	PM_{10}	Fungal fraction	Fungal concentration	Bacterial fraction	Bacterial concentration
CO	1.000										
CO_2	0.036	1.000									
HCHO	0.467*	0.431*	1.000								
temp	0.329*	−0.230	0.094	1.000							
humidity	−0.279	−0.133	−0.034	−0.049	1.000						
$PM_{2.5}$	0.295	0.335	0.167	−0.080	−0.506	1.000					
PM_{10}	0.517	0.346	0.325	0.086	−0.576*	0.844*	1.000				
fungal fraction	0.097	0.055	−0.048	0.111	0.051	−0.244	−0.299	1.000			
fungal concentration	−0.219	−0.443*	−0.193	−0.242	0.539*	−0.701*	−0.762*	−0.004	1.000		
bacterial fraction	0.167	−0.017	0.046	0.037	−0.108	0.107	0.319	0.013	−0.094	1.000	
bacterial concentration	0.569*	−0.294	−0.112	0.134	0.002	0.284	0.437	−0.014	0.054	0.108	1.000

* $p < 0.05$.

and PM_{10} concentration for the tiling engineering was more than two times of REL. The exposure risk assessment of the working environment for the decorating labors warrants further investigation in the future.

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