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Indoor Formaldehyde Pollution and Its Influencing Factors of Newly Decorated Residential Buildings in Kunshan City, Jiangsu Province

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Abstract

40 newly decorated residences in Kunshan city were selected and investigated. Formaldehyde concentrations were detected in the winter (January to February) and summer (July to August) respectively in 2019. A total of 324 indoor air samples were collected from 162 sampling sites. The average formaldehyde concentration was (0.0219 ± 0.0119) mg/m^3 and (0.0963 ± 0.1072) mg/m^3 in winter and summer respectively, the concentration in summer is higher than in winter with a significant difference (Z = −5.484, $P < 0.001$). The unqualified rate was 0.0% and 28.3% in winter and summer respectively, the maximum value in summer was 1.0403 mg/m^3, 10.4 times higher than the relevant standard. The seasonal formaldehyde distributions were not different by type of residence, residence grade, bedroom number, decoration style, floor space, decoration costs, whether occupancy at detection and heating mode ($P > 0.05$). The formaldehyde concentrations in summer were different between types of rooms (H = 8.800, $P = 0.030$) and whether most furniture was new (Z = 9.259, $P < 0.001$). Formaldehyde concentration was positively correlated with temperature in winter and summer (winter: r = 0.288, summer: r = 0.151, $P < 0.05$), negatively with humidity in Winter (r = −0.243, $P <$ 0.05), but not correlated with humidity in summer ($P = 0.841$). The average days from complete decoration to formaldehyde detection were 130.1 and 303.3 d in winter and summer. It was not found that the formaldehyde concentration decreased with the extension of days after renovation in the two seasons ($P >$ 0.0.05).

Keywords

Newly Decorated, Residential Houses, Formaldehyde Concentration, Influencing Factors

1. Introduction

People spend more than 3/4 of their lives in relatively closed rooms, therefore indoor air quality is very important to public health (Wu et al., 2011; Wainman et al., 2001). The increase in the frequency of indoor decoration and the application of a variety of new decoration materials have caused serious risks to the indoor air quality in residential houses (Liu et al., 2017). Formaldehyde is one of the important contributors of indoor Total Volatile Organic Compounds (TVOC) (Huang et al., 2013). It is also one of the main pollutants controlled by GB/T 18883-2002 "Indoor Air Quality Standard" (GAQSIQ, 2002). Its cancer risk ranks high in TVOC (Loh et al., 2007), and it ranks second in the priority control list of toxic chemicals in China. It was listed as a human carcinogen and teratogen by the International Agency for Research on Cancer (IARC) in 2004 and believed that there was a causal relationship between formaldehyde exposure and the occurrence of leukemia (Tang et al., 2009). The exposure risk of indoor formaldehyde pollution among people in China is getting higher and higher (Liang et al., 2017). The hazards of formaldehyde to human health are mainly manifested in stimulation, sensitization, carcinogenic and cancer-promoting effects and other effects. It can also cause dizziness, headaches and other neurasthenic symptoms, and lead to abnormal lung, liver, and immune function severely (Yang et al., 2017). During the six years from 2010 to 2015, Liang XJ inspected 1249 various public places in Kunshan City, and found that formaldehyde can be detected in all places, with an average mass concentration (hereinafter referred to as concentration) of 0.57 mg/m^{-3}. The risk of excessive formaldehyde in public places is very high (Liang et al., 2018). Compared with public places, living rooms are more luxuriously decorated and have longer exposure time. Therefore, it is necessary to study the current status, changing laws and influencing factors of formaldehyde pollution in newly decorated residential rooms.

2. Materials and Methods

2.1. Inclusion Criteria and Measurement Time

In the winter of 2019 (January 16-February 22) and summer (July 1-August 23), 40 households in 18 communities belonging to Kunshan City will be newly renovated or refurbished and completed within one year. Furniture Formaldehyde surveys are conducted in rooms with complete appliances, and 162 detection points are set up in winter and summer.

2.2. Methods of Detection and Investigation

Formaldehyde detection is carried out in accordance with GB/T 18204.2-2014 "Public Place Hygiene Inspection Methods Part 2: Chemical Pollutants" (HFMPC, 2014). It is a phenol reagent spectrophotometric method. The absorbing liquid is prepared for immediate use, and the bubble absorption of 5 mL of the absorbing liquid is installed. The sample is collected at a flow rate of 0.5 L/min, the sampling time is 45 minutes, and the temperature, humidity and atmospheric pressure of the sampling point are recorded. The sensitivity of this method is 0.0028 mg HCHO/abs. The detection limit is 5×10^{-5} mg/5mL, the linear range is 0.0001 - 0.002 mg/m^3, and the minimum detection concentration is 0.002 mg/m^3. The number of parallel samples in each batch of samples (on-site sampling in the same day is a batch) shall not be less than 10%, and the relative deviation between the measured value of the parallel samples and the average value shall not exceed 10%, and the result shall be expressed as the arithmetic mean.

During the on-site sampling process, data such as room type, housing grade, number of rooms, decoration cost, new and old composition of furniture, and heating method were obtained through on-site surveys and interviews.

2.3. Testing Specifications

The sampling process is carried out in accordance with GB/T18883-2002 "Indoor Air Quality Standard" (GAQSIQ, 2002), and the number of sampling points is determined according to the size of the indoor area. The sampling point should avoid vents and should be more than 0.5 m away from the wall. The sampling height is between 0.5 and 1.5 m. The sampling pump needs to be calibrated by the flow meter before sampling. Before sampling, close the doors and windows, open the cabinet door for 12 h, and close the doors and windows during the sampling process.

2.4. Testing Equipment

Digital thermometer and hygrometer (TES-1360A, China), sampling pump (GilAir PLUS, USA), bubble absorption tube (with 10 ml scale, China), UV-Vis spectrophotometer (TU-1901, China), flow calibrator (TSI 4146, USA), formaldehyde standard solution (Ministry of Environmental Protection Standard Sample Research Institute, China), phenol reagent (Fluka 65875, Switzerland), ferric ammonium sulfate (Guangdong Taishan Chemical Plant, China), etc.

2.5. Statistical Analysis

The SPSS 26 software was used for statistical analysis. The test results were all descriptive analysis. The difference in temperature, humidity, and formaldehyde concentration between winter and summer was tested by the Wilcoxon analysis. Friedman rank sum test analysis was used to determine the difference of formaldehyde concentration in different types of rooms and the main influencing factors. The relationship between the formaldehyde concentration in winter and summer and the temperature and humidity and the time (d) of the decoration completion at the time of the test were the Spearman rank correlation analysis. Two-sided inspection, inspection level α = 0.05.

3. Result

3.1. Formaldehyde Pollution

Analyzing the differences in temperature, humidity and formaldehyde concentration between winter and summer, the results are statistically significant (Z = −5.511, $P < 0.0001$; Z = −3.572, $P < 0.0001$; Z = −5.484, $P < 0.0001$), the temperature, humidity and formaldehyde in summer are higher than those in winter. The concentration levels of formaldehyde in winter and summer are shown in Table 1. Formaldehyde in winter is lower than the standard limit of 0.1 mg/m^3, and the exceeding rate in summer is 28.3%. The maximum value is 1.0403 mg/m^3, exceeding the standard by 10.4 times.

It was found that the difference in formaldehyde concentration between winter and summer was not statistically significant in the distribution of room type, housing grade, number of rooms, decoration style, house area, decoration cost, whether to check in or not and heating method. There was no statistically significant difference in the concentration of formaldehyde in the room type and whether the decorated furniture was mainly new furniture in winter. The results are shown in Table 2. In addition, the summer formaldehyde concentration is statistically significant (Z = 9.259, $P < 0.0001$) between whether the decoration furniture is mainly new furniture (Z = 9.259, $P < 0.0001$), seen in Table 2.

Analyzing the concentration of formaldehyde in different room types in winter and summer, the concentration of formaldehyde in summer is significantly higher than that in winter (Z = −5.484, $P < 0.0001$), and the overall over-standard rate is higher (28.3% in summer and 0.0% in winter). The difference of formaldehyde concentration between room types is statistically significant (H = 8.800, $P = 0.030$), as shown in Table 3.

Table 1. The distribution of formaldehyde concentration, temperature and humidity in 40 new decorated residential buildings in Kunshan city.

Index	Winter			Summer		
	Median	Average ± Standard	scope	Median	Average ± Standard	Scope
temperature/˚C	10.5	11.0 ± 3.4	2.7 - 23.3	27.8	27.8 ± 2.7	22.1 - 32.0
humidity/%	62.9	62.9 ± 12.7	14.9 - 89.2	74.1	71.9 ± 10.5	46.4 - 92.5
Formaldehyde concentration/($mg \cdot m^{-3}$)	0.0189	0.0219 ± 0.0119	0.0047 - 0.0761	0.0739	0.0963 ± 0.1072	0.0002 - 1.0403

Table 2. The fundamental information and the difference of formaldehyde concentration in 40 new decorated residential buildings in Kunshan city.

Type	Grouping	Sample size	Winter				Summer				Statistic
			Scope	P25	P50	P75	Scope	P25	P50	P75	
Room type	Bedroom	90	0.0047 - 0.0646	0.0143	0.0193	0.0242	0.1380 - 0.2130	0.1610	0.1700	0.1833	winter: H = 0.600, $P = 0.896$ summer: H = 8.800, $P = 0.030$
	Living room	39	0.0047 - 0.0761	0.0133	0.0198	0.0265	0.0134 - 0.2993	0.0463	0.0739	0.1015	
	Children room	6	0.0132 - 0.0647	0.0164	0.0209	0.0360	0.0143 - 0.1581	0.0273	0.0728	0.1218	
	Study	27	0.0051 - 0.0535	0.0117	0.0168	0.0257	0.0254 - 0.2184	0.0531	0.0694	0.1005	
type	New housing	24	0.0095 - 0.0546	0.0171	0.0202	0.0224	0.0251 - 0.4549	0.0601	0.0815	0.1038	winter: Z = −0.314, $P = 0.753$ summer: Z = −0.215, $P = 0.881$
	The secondary	6	0.0111 - 0.0264	0.0116	0.0177	0.0251	0.0187 - 0.0546	0.0242	0.0341	0.0459	
Residential grade	Villa	5	0.0053 - 0.0302	0.0115	0.0220	0.0295	0.0752 - 0.309	0.0774	0.0938	0.2201	winter: H = 0.400, $P = 0.819$ summer: H = 5.200, $P = 0.074$
	High-end residential	5	0.0110 - 0.0264	0.0127	0.0186	0.0238	0.0550 - 0.1809	0.0613	0.0893	0.1767	
	Normal housing	30	0.0095 - 0.0546	0.0164	0.0202	0.0229	0.0187 - 0.4549	0.0496	0.0779	0.1019	
The room number	2 bedrooms	4	0.0111 - 0.0218	0.0113	0.0145	0.0207	0.0318 - 0.0653	0.0346	0.0488	0.0626	winter: H = 0.500, $P = 0.779$ summer: H = 0.000, $P = 1.000$
	3 bedrooms	19	0.0095 - 0.0546	0.0184	0.0206	0.0241	0.0187 - 0.2464	0.0581	0.0809	0.1038	
	Room 4 and above	17	0.0053 - 0.0335	0.0125	0.0203	0.02644	0.0264 - 0.4549	0.0620	0.0869	0.1284	
Decorate a style	Modern simplicity	19	0.0095 - 0.0546	0.0172	0.0206	0.0247	0.0261 - 0.2464	0.0584	0.0788	0.1038	winter: Z = −1.087, $P = 0.277$ summer: Z = −1.121, $P = 0.904$
	Other	20	0.0053 - 0.0304	0.0145	0.0202	0.0225	0.0187 - 0.4549	0.0554	0.0802	0.1079	

Continued

House area	<100 m^2	6	0.0111 - 0.02410	0.0116	0.0207	0.0274	0.0430 - 0.1038	0.0517	0.0720	0.0988	winter: H = 1.000, P = 0.607 summer: H = 0.333, P = 0.846
	100 - 150 m^2	18	0.0095 - 0.0546	0.0183	0.0207	0.0274	0.0187 - 0.2464	0.0493	0.0779	0.1059	
	>150 m^2	16	0.0053 - 0.0302	0.0123	0.0173	0.0224	0.0251 - 0.4549	0.0592	0.0881	0.1300	
Renovation cost	<20 million	7	0.0095 - 0.0247	0.0111	0.0218	0.0241	0.0187 - 0.2464	0.0261	0.0546	0.0788	winter: H = 2.143, P = 0.543 summer: H = 6.600, P = 0.086
	20 - 30 million	9	0.0171 - 0.0462	0.0184	0.0208	0.0284	0.0318 - 0.1362	0.0499	0.0820	0.1082	
	30 - 50 million	11	0.0110 - 0.0546	0.0178	0.0199	0.0212	0.0518 - 0.1725	0.0676	0.0785	0.0893	
	>60 million	13	0.0053 - 0.0302	0.0137	0.0176	0.0244	0.0251 - 0.4549	0.0651	0.0938	0.1563	
Whether new furniture is the main thing	Yes	29	0.0095 - 0.0546	0.0172	0.0203	0.0233	0.0187 - 0.2464	0.0555	0.0785	0.0100	winter: Z = 1.509, P = 0.603 summer: Z = 9.259, P < 0.0001
	No	11	0.0053 - 0.0302	0.0129	0.0176	0.0264	0.0251 - 0.4549	0.0550	0.0938	0.1809	
Check in at the time of inspection	Yes	20	0.0110 - 0.0462	0.0123	0.0190	0.0220	0.0264 - 0.4549	0.0551	0.0827	0.1031	winter: Z = −0.709, P = 0.478 summer: Z = −1.120, P = 0.263
	No	20	0.0053 - 0.0546	0.0171	0.0211	0.0260	0.0187 - 0.3087	0.0576	0.0792	0.1220	
Heating way	Floor heating	12	0.0095 - 0.0247	0.0131	0.0205	0.0224	0.0187 - 0.2464	0.0459	0.0720	0.1104	winter: H = 0.7982, P = 0.457 summer: H = 3.012, P = 0.0615
	Air conditioning or otherwise	21	0.0110 - 0.0546	0.0171	0.0199	0.0264	0.0251 - 0.1809	0.0574	0.0796	0.0953	
	No heating	7	0.0053 - 0.0302	0.0129	0.0220	0.0289	0.0264 - 0.4549	0.0550	0.0938	0.3087	

Table 3. Formaldehyde concentrations in 40 newly decorated residences grouped by different room types in Kunshan city of Jiangsu province in 2019.

Type	Sample	Winter			Summer		
		Scope	P50 (P25, P75)	Statistics	Scope	P50 (P25, P75)	Statistics
Bedroom	90	0.0047 - 0.0646	0.0193 (0.0143, 0.0242)	H = 0.600, P = 0.896	0.0002 - 1.0403	0.1700 (0.1610, 0.1833)	H = 8.800, P = 0.030
Living room	39	0.0047 - 0.0761	0.0198 (0.0133, 0.0265)		0.0134 - 0.2993	0.0739 (0.0463, 0.1015)	
Children room	6	0.0132 - 0.0647	0.0209 (0.0164, 0.0360)		0.0143 - 0.1581	0.0728 (0.0273, 0.1218)	
Study	27	0.0051 - 0.0535	0.0168 (0.0117, 0.0257)		0.0254 - 0.2184	0.0694 (0.0531, 0.1005)	

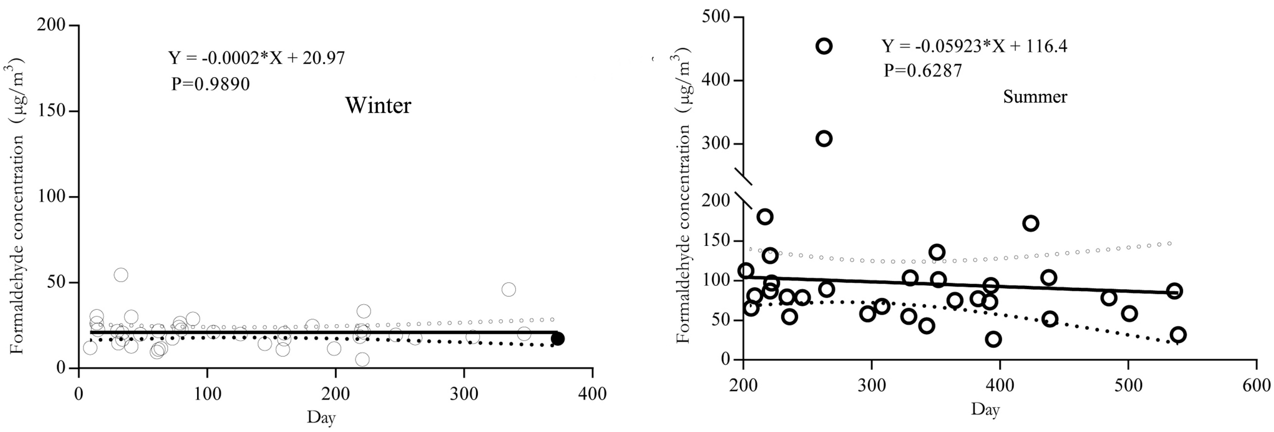

Figure 1. The relationship diagram between formaldehyde concentration and days from the completion of the room decoration when detection proceeded.

3.2. Main Influencing Factors

The concentration of formaldehyde is positively correlated with temperature in winter and summer, and the correlation coefficients (r) are 0.288 and 0.151 respectively, and both are statistically significant. Formaldehyde concentration is negatively correlated with humidity in winter (r = −0.243, P = 0.002), and in summer The correlation was not statistically significant (P = 0.841).

Count the number of days from the completion of the decoration during the winter and summer inspections, as shown in Figure 1. The average time from complete the decoration was 130.1 days in winter and 303.3 days in summer. Wilcoxon signed rank test (Z = −4.323, P < 0.0001). It shows that the number of days from the completion of the decoration during the summer inspection is significantly greater than the number of days during the winter inspection. Spearmen correlation analysis was carried out on the relationship between the room decoration completion time (d) and the concentration of formaldehyde during the winter and summer testing. The results are shown in Figure 1. In both winter and summer, it is not found that the formaldehyde concentration has a decreasing trend with the extension of the decoration time (winter: $P = 0.9892$, summer: $P = 0.6287$). In winter, the average time decoration completion time is 130.1 d, less than 303.3 d in summer ($Z = -4.323$, $P < 0.0001$). Therefore, it is not a feasible solution to reduce the formaldehyde concentration by extending the "closed" time of the newly decorated or redecorated residences bedroom both in summer and winter.

4. Discussion

In this study, the indoor formaldehyde concentration of 40 newly-decorated or re-decorated residential houses in Kunshan City was tested in winter and summer. The concentration of formaldehyde in 40 newly-decorated houses was generally lower in winter. The pass rate was 100.0%, and the concentration level was (0.0219 ± 0.0119) mg/m^3. In summer, the level of formaldehyde pollution increased, and the concentration level rose to (0.0963 ± 0.1072) mg/m^3, an average increase of 5.57 times. Although the date on which the detection conducted in summer was an average 5.4 months from that in winter, the concentration of formaldehyde has not decreased, but has increased significantly. This is consistent with the results of Chi Xin et al. (Chi et al., 2007; Guan et al., 2007). As the temperature increases, the concentration of formaldehyde can reach a peak in the months with high summer temperatures. Studies have shown that the indoor formaldehyde concentration of newly decorated rooms can still reach 0.138 mg/m^3 after two years (Zhang et al., 2007). Generally speaking, the indoor formaldehyde concentration level in summer will be higher than that in winter (Xu, Shang, & Cao, 2007; Yao et al., 2005). The results of this study are similar to the above studies. With the extension of time after renovation, the concentration of formaldehyde will not decrease significantly, and the concentration of formaldehyde will reach a peak in the first summer of the year.

The concentration of formaldehyde in the winter in this study was lower than that in Beijing in the winter of 2003 (0.210 ± 0.152) mg/m^3, in Shanghai in the winter of 2003 (0.205 ± 0.135) mg/m^3, and in Tianjin in the winter of 2003 (0.267 ± 0.170) mg/m^3, the (0.142 ± 0.084) mg/m^3 in the winter of 2003 in Chongqing and the research results of Changchun, Shizuishan, Dalian. The results are also significantly lower than the Chongqing New City District in 2010 (0.158 mg/m^3) (Wang, Ding, & Li, 2010), the research results of Luzhou City, Sichuan Province (0.331 mg/m^3) in 2010 (Si & Zhang, 2010). The summer concentration (0.0963 ± 0.107) mg/m^3 is also lower than the domestic survey results of formaldehyde concentration in newly decorated rooms in summer from 2002 to 2006. It shows that the overall pollution level of formaldehyde concentration in newly decorated rooms in Kunshan is not serious compared with other cities.

This study shows that the type of room, the grade of the house, the number of rooms, the decoration style, the area of the house, the cost of decoration, whether to move in during the test and the heating method has limited influence on formaldehyde, indicating that these factors are not the main factors affecting the concentration of formaldehyde in the room. The summer formaldehyde concentration is statistically significant in the room type and whether the decoration furniture is mainly new furniture. The summer bedroom concentration level is higher than that of the living room, study, and children's room. This trend of higher bedroom trends is consistent with other studies. It is basically the same (Liu et al., 2017; Si & Zhang, 2010; Xue et al., 2011). Which is likely to be related to the use of wooden furniture and floors in the bedroom. This suggests that new furniture is likely to have an important impact on formaldehyde pollution in Kunshan City.

The concentration of formaldehyde is positively correlated with temperature in winter and summer, and humidity is negatively correlated in winter, and the correlation is not statistically significant in summer, indicating that temperature is the most important factor affecting formaldehyde in this survey. Studies have shown that indoor air formaldehyde concentration is positively correlated with air humidity. The higher the humidity, the higher the formaldehyde concentration. This study is not consistent with this conclusion (Gong et al., 2017). This may be due to the fact that Kunshan City has high humidity throughout the year, or it may be that formaldehyde is more sensitive to high temperature than high humidity, and high temperature is often accompanied by high humidity, leading to the bias of "the greater the humidity, the higher the concentration of formaldehyde". In this study, the relationship between the completion time (d) of the room decoration and the concentration of formaldehyde was analyzed. It was not found that with the extension of the time after the decoration, the concentration of formaldehyde had a tendency to decrease. The concentration of formaldehyde did not decrease significantly with the extension of time (Dong & Wang, 2009; Bradman et al., 2017; Ho et al., 2016; Huang et al., 2016; Barrese et al., 2014).

Based on this study, the following several suggestions will help to reduce the indoor formaldehyde concentration in newly decorated homes. 1) The selection of high-glass or low formaldehyde content building materials is the primary condition to reduce the health risk of formaldehyde. 2) The use of wooden furniture in decorating process should be restricted as far as possible because wooden materials are often an important source of formaldehyde release. 3) The extension of time between the completion of the room decoration and living in the room should be greater than one year. More than one year is the best. 4) Reasonable ventilation and air purification equipment will also reduce the pollution concentration of formaldehyde.

This study did not conduct an in-depth analysis of the sources of indoor formaldehyde pollution, nor did it investigate the use of indoor air purification equipment and ventilation in the living rooms. However, this study proved that the main influencing factor of formaldehyde concentration in newly decorated rooms in Kunshan within one year is temperature. With the increasing of summer temperature, the concentration of formaldehyde will increase significantly. New furniture is likely to have an important impact on formaldehyde pollution in Kunshan. This provides an important basis for the timing of indoor formaldehyde treatment and the implementation of control measures in Kunshan City.

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Ethical Approval

The study protocol and formaldehyde monitoring data were obtained from the Kunshan CDC, Jiangsu province, China and no ethical issues were identified. Therefore, ethical statement was not necessary because the data are for public access data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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