Total volatile organic compound concentration and its influencing factors in urban indoor air after decoration

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The indoor total volatile organic compound (TVOC) concentrations and their relationship to potential influencing factors were evaluated. Samples ($n=2302$) were collected from 2007 to 2009 both in old structures and new construction in the city of Hangzhou from bedrooms, sitting rooms and studies that had been decorated within the previous year. The average TVOC concentration in all the newly decorated rooms was 0.65 ± 0.69 mg/m³. 35.8% of samples exceeded the China standard. Over the past 3 years, the TVOC concentration decreased and then increased ($P<0.05$). The percentage of samples exceeding the China standard in the three rooms decreased in the following order: sitting room>study>bedroom. The characteristics of the TVOC source were a key factor influencing the TVOC concentration. In addition, the TVOC concentration was also ($P<0.05$) related to the temperature, humidity, time from the end of decoration to sampling (DR), and the amount of time windows and doors were closed before sampling (DC). The temperature and humidity were less important than the DR and DC. A model to relate the TVOC concentration to the five factors (temperature, humidity, source, DR, and DC) was established based on 288 samples ($R^2=0.83$). The model illustrated that the time for the TVOC concentration to meet the China standard was different for the various rooms, and when the other factors were fixed, the impact of DC (t_1) on the TVOC concentration could be quantified as $((t_1+1)/2)^{0.212}-1\times100\%$.

indoor air, total volatile organic compound, air quality, factor analysis

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Recently, the contribution of indoor decoration and a variety of decoration materials to indoor air pollution has attracted increasing attention. Both urban residents and researchers are interested in the evaluation and improvement of indoor air quality. Volatile organic compounds (VOCs) can be emitted from paints, coatings, artificial board, glue, and carpet, and the total VOC (TVOC) concentration has been widely used as a key indicator of indoor air quality [1]. VOCs can cause sick building syndrome (SBS), which affects the nervous system, respiratory system, and skin [2,3], and some such as benzene can cause cancer as indicated by

USEPA. Because of their potential adverse health effects, VOCs are listed as pollutants for priority control to improve the indoor air quality by the World Health Organization, U.S. National Academy of Sciences/National Research Council and other agencies.

Indoor VOCs pollution has been studied extensively, and most studies have focused on indoor TVOC concentrations [4,5] and VOCs emission patterns from indoor materials [6–8]. Studies on TVOC concentrations allow the VOCs pollution in a specific region at a given time to be evaluated, but do not allow evaluation of the concentrations in other regions or at other times. Many studies have evaluated VOCs emission patterns using small chamber test to identify

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factors that influence the release of VOCs and to characterize VOCs emission. VOCs emission patterns can be either physical or empirical. The physical emission pattern is based on the fundamentals of mass transfer and has clear practical significance. However, it is difficult to apply in practical situations, as it is too complicated to calculate the many variables. Many emission experiments are required to establish the empirical emission pattern. Although it is simple, and some of the empirical pattern can describe the indoor materials well in terms of the VOCs release rate, the physical meaning of parameters is unclear and it is difficult to identify the independent effects of source characteristics and environmental variables on the VOCs release rate. Hence, to acquire a better understanding on TVOC emission characteristics and its control mechanism, it is necessary to identify and quantify the potential factors including source characteristics and environmental variables contributing to the indoor TVOC emission.

In this study, the TVOC concentrations and their variation with time and space in more than two thousand newly decorated sitting rooms, studies, and bedrooms both in old structures and new construction were investigated. The effects of the dominant source and environmental variables on the indoor TVOC concentrations were explored to obtain an equation to quantify the effect of various factors on the TVOC level. This study will add to the database of indoor air pollution monitoring results, aid understanding of VOCs emission characteristics, and provide useful data for policy makers to establish indoor air quality standards. The results could also help residents to determine when it is safe to move into a newly decorated room.

1 Materials and methods

1.1 Instruments and reagents

Samples were collected into seamless stainless steel tubes packed with 0.20 mg of Tenax-TA adsorbent (60–80 mesh) using an electronically controlled air sampler (DDY-1.5, Xingyu, Jiangsu, China). The temperature and humidity, and air pressure were recorded using an electronic temperature and humidity instrument (HTC-1, Boyang, Zhengzhou, China) and digital air pressure equipment (BY-2003P, Taishi, Suzhou, China), respectively. Samples were analyzed using a gas chromatograph (FULI 9790, Fuli, Wenling, China) with a capillary column (SE-30 50 m×0.32 mm I.D., Jianuo, Nanjing, China), and by thermal desorption (FULI 9700, Fuli, Wenling, China).

1.2 Sampling of VOCs

VOCs samples were collected in 2302 rooms that had been decorated within the last year in Hangzhou. These rooms were in 902 separate dwellings that were occupied by 1598 families. All the rooms, including 1981 bedrooms, 187 living

rooms, and 134 studies, were in Class I residential buildings. Samples were collected from January, 2007 to December, 2009 (Table 1). Hangzhou is the second largest city in terms of economy in the Yangtze River Delta, China, and has a total area of 16600 km² and population of 810000000 (as of late 2009). In the past 3 years, 7639500–9482400 m² of new housing was constructed in Hangzhou each year. This is similar to the level of urban household decoration in other parts of China.

All the rooms were kept under normal conditions before sampling. Windows and doors were closed during sampling. The air sampler was set 1.5 m above the floor, and VOCs were sampled at 0.4 L/min for 10 min. When sampling was complete, both ends of the sampling tube were sealed, and samples were brought back to laboratory for immediate processing. The temperature (*T*), relative humidity (RH), time the windows and doors closed for before sampling (DC) (*t*₁), time from the end of decoration to sampling (DR) (*t*₂), and atmospheric pressure (*P*) were recorded at the sample collection time (Table 2).

1.3 Experimental methods

A sampling tube was activated using N₂ for 1 h at 350°C before sampling, then sealed with seal film and a plastic cap. The VOCs in the sample were separated by gas chromatography, and then analyzed by thermal desorption at 250°C

Table 1 Number of air samples collected each month from 2007 to 2009

	2007	2008	2009	Total
January	49	48	69	166
February	42	12	30	84
March	29	26	44	99
April	55	46	77	178
May	18	95	66	179
June	24	103	73	200
July	42	109	103	254
August	114	130	67	311
September	72	88	29	189
October	36	86	91	213
November	28	115	73	216
December	43	108	62	213
Total	552	966	784	2302

Table 2 Sampling conditions

Impact factors	Min	Max	Mean	S.D	<i>n</i>
<i>T</i> (°C)	1.5	40.0	22.5	8.4	2302
RH (%)	32.0	93.0	67.5	9.7	2302
<i>t</i> ₁ (h)	0.0	240.0	7.2	16.7	2302
<i>t</i> ₂ (months)	0.3	12.0	4.4	3.6	288

for 10 min. The chromatographic conditions and analytical methods are detailed in GB 50325-2001 [9].

Data batch processing and analysis was performed using Excel 2007, SPSS 16.0 and Eviews 6. Factor analysis was performed using the function of bivariate correlations of SPSS to calculate the correlation coefficient and significant level (P) between factors and TVOC concentrations. If $P < 0.05$, it indicates that the variable is correlated with TVOC concentrations; if $P < 0.01$, it demonstrates that the variable is significantly correlated with TVOC concentrations.

2 Results

2.1 TVOC concentrations in urban indoor air

TVOC concentrations in the examined rooms were listed in Table 3. The average TVOC concentration for all the rooms was $0.65 \pm 0.69 \text{ mg/m}^3$, with a maximum of 7.2 mg/m^3 , which was around 14 times higher than the limit set by the China standard (0.50 mg/m^3) [9]. Among the samples, 37.3% were above the China standard. The mean TVOC concentration and percentage of samples exceeding the China standard decreased from 2007 to 2008 ($P < 0.05$) and then increased from 2008 to 2009 ($P < 0.05$).

TVOC concentrations in the three types of rooms are summarized in Table 4. The mean concentration of TVOC in all types of rooms monitored in this study was higher than the China standard. Among the three types of rooms, the mean TVOC concentration was highest in the living room, where many people spend most of their time during the day. This was followed by the study and then the bedroom, but the difference was not significant among the different types of rooms. Results indicate that the overall pollution levels in the 3 types of rooms were serious, and could pose a serious threat to residents' health.

2.2 Correlation analysis between TVOC concentrations and environmental factors

Factor analysis was performed to examine the potential contributors to the indoor TVOC concentration. The indoor TVOC concentration is thought to be mainly associated with characteristics of the source, such as the quantity and nature of building materials and furniture, and environmental conditions, such as the temperature, humidity, atmospheric pressure, outdoor concentration and ventilation. In addition to the known sources of cigarettes, mosquito coils, and outdoor sources such as fumes, decoration materials and room furnishings were identified as the main TVOC emission sources in newly decorated rooms. Environmental factors also have an important impact on the indoor TVOC concentrations. Temperature, humidity, DR, DC, and source characteristics were selected as the potential factors that contributed to the TVOC concentration, and their relationships to the TVOC concentration were quantified in this study.

Linear and logarithmic correlations between each factor and the TVOC concentration are shown in Table 5. The TVOC concentrations were significantly negatively correlated with DR (t_2) ($P < 0.01$), significantly positively correlated with DC (t_1) ($P < 0.01$), and positively correlated ($P < 0.05$) with T and RH. The relationship between each factor and the TVOC concentration was optimized to establish a proper model.

2.3 Quantitative relationship between various factors and TVOC concentration

Based on the correlation analysis, a regression model was developed to determine the contribution of these factors to the variance in the TVOC concentration. Samples without

Table 3 TVOC concentrations and percentage of samples exceeding the China standard for recently decorated rooms in 2007–2009

Year	n	TVOC concentration (mg/m^3)				Number of samples exceeding standard	Percentage of samples exceeding standard (%)
		Min	Max	Mean	S.D.		
2007	552	0.04	5.80	0.92	0.74	364	65.9
2008	966	0.05	6.80	0.51	0.56	254	26.3
2009	784	0.08	7.20	0.64	0.77	241	30.7
Total	2302	0.04	7.20	0.65	0.69	859	37.3

Table 4 TVOC concentrations and percentage of samples exceeding the China standard in the three types of rooms

Room	n	TVOC concentration (mg/m^3)				Number of samples exceeding standard	Percentage of samples exceeding standard (%)	Total percentage of samples exceeding standard (%)
		Min	Max	Mean	S.D.			
Bedroom	1981	0.04	6.8	0.64	0.68	713	36.0	37.3
Living room	187	0.06	7.2	0.77	0.85	89	47.6	
Study	134	0.09	5.5	0.71	0.77	57	42.5	

Table 5 Correlation analysis between the TVOC concentrations (C_{TVOC}) and T , RH, DC (t_1), and DR (t_2)

C_{TVOC}		T	RH	t_1	t_2
	Correlation coefficient (r)	−0.022	0.036	0.152 ^{b)}	−0.250 ^{b)}
	P	0.293	0.087	0.000	0.000
$\text{Ln}(C_{\text{TVOC}})$		$\text{Ln}(T)$	$\text{Ln}(\text{RH})$	$\text{Ln}(t_1)$	$\text{Ln}(t_2)$
	Correlation coefficient (r)	0.048 ^{a)}	0.062 ^{b)}	0.259 ^{b)}	−0.220 ^{b)}
	P	0.020	0.003	0.000	0.000

a) Significance level at 0.05; b) significance level at 0.01.

complete statistic information were eliminated. Modified variables and the TVOC concentration from the remaining 288 samples were fitted by EvIEWS software. An optimum expression of the regression model was generated as follows:

$$\text{Ln}(C_{\text{TVOC}}) = C_{(1)} \times \frac{273.15}{T + 273.15} + C_{(2)} \times \frac{1}{\text{RH}} + C_{(3)} \times \text{Ln}(t_1 + 1) + C_{(4)} \times t_2^2 + C_{(5)}, \quad (1)$$

where C_1 , C_2 , C_3 and C_4 are the corresponding coefficients for the variables, and C_5 is a constant.

Fitting results are shown in Table 6. The R^2 was 0.210364, which indicates that the 4 variables used in the model contributed to approximately 20% of the variance in the TVOC concentration. Clearly, none of the 4 variables was the dominant factor controlling the TVOC concentration. This was mainly because source characteristics, including the background value and release rate of TVOC from the decoration materials, were not taken into account, even though they were identified as key factors for determining release of VOCs. If it is assumed that the source characteristics and four environmental variables could explain all the variance in the TVOC concentration, then the source characteristics contribute nearly 80% of the variance in the TVOC concentration. However, it was difficult to accurately quantify the source characteristics in the empirical model because the VOCs were emitted from a variety of sources. To integrate the factor of source characteristics in the regression model

and simplify the factor analysis, source characteristics were classified into three categories in the following three steps. First, a range for C_5 could be obtained according to eq. (1) based on the data collected and known parameters, which represented the effect of the source characteristics on the TVOC concentration. Second, based on C_5 range, the source characteristics were equally divided into three levels. Levels -A, -B, and -C represented the sources with relatively low, moderate and high, respectively, background concentrations and VOCs release rates. Third, non-dimensional values of −1, 0, 1 were assigned to levels -A, -B, and -C, respectively, and these are expressed as parameter d in eq. (2).

By integration of the factor for source characteristics, a new regression equation was developed as follows:

$$\text{Ln}(C_{\text{TVOC}}) = C_{(1)} \times \frac{273.15}{T + 273.15} + C_{(2)} \times \frac{1}{\text{RH}} + C_{(3)} \times \text{Ln}(t_1 + 1) + C_{(4)} \times t_2^2 + C_{(5)} \times d + C_{(6)}, \quad (2)$$

where d represents the source characteristics variable, as discussed above; C_1 , C_2 , C_3 , C_4 and C_5 are the corresponding coefficients for the variables; and C_6 is a constant.

By classifying the source characteristics into 3 categories, a correlation coefficient R^2 of 0.830657 was obtained as shown in Table 7. This indicates that the 5 variables can account for 83% of the total variance in the indoor TVOC concentration. The origin of remaining 17% of variance is uncertain, but probably can be attributed to the simplification

Table 6 Fitting results from equation (1)

Variables	Coefficient	Coefficient value	Std. error	t -statistic	P
T	C_1	−570.1527	425.7125	−1.33929	0.182
RH	C_2	−53.0120	20.8418	−2.54355	0.012
t_1	C_3	0.1855	0.0385	4.82336	0.000
t_2	C_4	−0.0057	0.0009	−6.39858	0.000
Constant	C_5	2.0593	1.4170	1.45325	0.147
R^2	0.210364			F -statistic	18.84824
Adjusted R^2	0.199203			Durbin-Watson statistic	0.720357
P (F -statistic)	0.000				
Dependent variable: $\text{Ln}(C_{\text{TVOC}})$		$n = 288$			

Table 7 Fitting results from equation (2)

Variables	Coefficient	Coefficient value	Std. error	<i>t</i> -statistic	<i>P</i>
<i>T</i>	<i>C</i> ₁	−1.518902	0.723242	−2.10013	0.037
RH	<i>C</i> ₂	−44.058150	9.672832	−4.55484	0.000
<i>t</i> ₁	<i>C</i> ₃	0.212336	0.017862	11.88767	0.000
<i>t</i> ₂	<i>C</i> ₄	−0.005419	0.000416	−13.04294	0.000
<i>d</i>	<i>C</i> ₅	0.952206	0.029627	32.13953	0.000
Constant	<i>C</i> ₆	1.395317	0.657703	2.12150	0.035
<i>R</i> ²	0.830657		<i>F</i> -statistic		276.65210
Adjusted <i>R</i> ²	0.827655		Durbin–Watson statistic		1.629525
<i>P</i> (<i>F</i> -statistic)	0.000				
Dependent variable: Ln(<i>C</i> _{TVOC})		<i>n</i> =288			

of the source characteristics, which produced a small amount of error, and other factors that were not taken into account in this study. The fitting results explained most of the variance in the TVOC concentration. A final expression was obtained as follows:

$$\begin{aligned} \text{Ln}(C_{\text{TVOC}}) = & 0.212 \times \text{Ln}(t_1 + 1) - 5.42 \times 10^{-3} \times t_2^2 - 1.52 \\ & \times \frac{273.15}{T + 273.15} - 44.1 \times \frac{1}{\text{RH}} + 0.952 \times d + 1.40. \end{aligned} \quad (3)$$

3 Discussion

3.1 VOC pollution in newly-decorated homes in different cities and countries

Indoor VOCs pollution levels in 4 major cities in China from this study and earlier studies are detailed in Table 8. The TVOC concentrations in Beijing are the highest out of these cities, with the percentage of samples exceeding the China standard at 76.8%, followed by Harbin, Chengdu, and Hangzhou. The differences among the cities could be attributed to the decoration patterns of urban residents, quality of decoration materials and furniture available in the local market, and local environmental conditions. The indoor TVOC concentrations in China are also compared with those in Europe in Table 8. Although the percentage of samples

exceeding national standards was also high in Germany, the mean TVOC concentration was much lower than those observed in Chinese cities, perhaps because of the different national standards in China and Europe. Germany has the lowest mean TVOC concentration at 0.29 mg/m³ in this comparison, and is closely followed by England at 0.30 mg/m³. By comparison, the mean TVOC concentration in Hangzhou was twice that in Germany, and that in Beijing was 6 times higher than that in Germany. However, it is generally considered that a TVOC concentration of 0.20 mg/m³ would affect the human body, which is lower than the national standards in most countries [3,10]. Further studies on the toxicology of VOCs need to be carried out to determine reasonable national standards for TVOC concentrations and to reduce the health risks to urban residents from TVOC exposure.

3.2 Time needed for TVOC concentration to decrease to meet the current China standard after indoor decoration

For indoor air pollution, residents are most concerned about the presence of indoor pollution in a room, the level of pollution, and how long it would take for pollution in newly decorated rooms to dissipate to meet current national standards. The answers to the first two questions can be easily obtained by testing or prediction using the model proposed

Table 8 Mean TVOC concentrations in different cities and countries

City and/or Country	Mean [TVOC] (mg/m ³)	Percentage of samples exceeding the national standard (%)	<i>n</i>	National standard (mg/m ³)	Reference
Hangzhou, China	0.65	37.3	2302	0.5	This study
Harbin, China	—	44.0	25	0.5	[11]
Beijing, China	1.81	76.8	82	0.5	[12]
Chengdu, China	0.55	38.0	80	0.5	[13]
England	0.30	not available	876	0.3	[14]
Germany	0.29	47.0	79	0.3	[1]

in this paper. However, further studies are required to answer the last question, which can be expensive, and time consuming. Many studies have shown by qualitative analysis of a small amount of data that VOCs pollution may last several months. However, these results cannot be used to derive acceptable generalizations because practical situations depend on a variety of factors. Therefore, to provide an answer to this last question, rooms decorated in different months and with various emission sources were investigated, and the relationship of the five dominant factors to the TVOC concentrations was evaluated. The windows and doors were set as being shut for 1 h before sampling as recommended by the China standard. The *T* and RH in each month were averages obtained over the past 30 years as stated in the Hangzhou yearbook (Table 9) [15].

The time required for the TVOC concentration to decrease to meet the current China standard after indoor decoration for rooms with the three levels of source characteristics (Section 2.3) is presented in Table 10. Two weeks were required for level-A rooms, 6 to 8 months for level-B rooms, and 15 to 16 months for level-C rooms. For level-B rooms, the time required for the TVOC concentration to decrease to meet the current China standard in level-B was related to the month when decoration of the room was completed. This time decreased in the order winter > autumn ≈ spring > summer. This suggests VOCs emission in level-B rooms was mainly related to the temperature. In summer, high temperatures would promote the release of VOCs, especially when it was present in the source material at high concentrations. While in winter, TVOC decayed in a relatively slow rate. For level-C rooms, the time for the TVOC

concentration to decrease to meet the current China standard was mainly determined by the emission source rather than environmental factors such as the temperature and humidity. Thus, the TVOC concentration decayed at a stable rate, which was independent of the month when the decoration finished.

3.3 Quantitative analysis of the variation in TVOC concentration with DC

The indoor TVOC concentration could fluctuate greatly because of the effect of DC, which may influence the air transfer from indoors to outdoors. However, the extent of the impact of DC on the indoor TVOC concentration is not known. To quantify the effect of DC on the TVOC concentration, DR, source characteristics, temperature, and humidity were fixed. The TVOC concentration when *t*₁ was 1 h was used as the reference value. It showed that the TVOC concentration would increase by $\frac{((t_1+1)/2)^{0.212}-1}{t_1} \times 100\%$ as DC (*t*₁) increased above 1 h. Two weeks after decoration, the TVOC concentration in level-A rooms was within the China national standard after 36 h of window and door closure under normal temperature and humidity conditions, which were selected as the average mean of the values recorded during the sampling over 3 years (*T*=16.2°C, RH = 80%). Whereas in extreme temperature and humidity conditions (*T* = 40°C, RH = 93%), window and door closure for 24 h may lead to the TVOC concentrations exceeding the China standard. For the other two levels (-B and -C), greater changes in TVOC concentrations were observed under different DR and DC. The results are shown in Table 11. These

Table 9 Average monthly temperature and humidity over the past 30 years in Hangzhou

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	All year
<i>T</i> (°C)	3.8	5.1	9.3	15.4	20.2	24.3	28.6	28.0	23.3	17.7	12.1	6.3	16.2
RH (%)	77.0	80.0	80.0	80.0	81.0	83.0	80.0	81.0	84.0	80.0	79.0	78.0	80.0

Table 10 Time (months) required for TVOC concentrations to decrease to meet the China standard in different situations

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Level-A	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5
Level-B	8	8	8	7	7	7	6	6	6	7	8	8
Level-C	15	15	16	16	16	16	16	15	15	15	15	15

Table 11 Quantitative relationship between TVOC concentration (mg/m³) and DC

<i>t</i> ₁ (h)	Time after decoration in level-B rooms (months)					Time after decoration in level-C rooms (months)					Percentage increase in concentration (%)
	1	3	6	9	12	1	3	6	9	12	
1	0.64	0.61	0.53	0.42	0.30	1.66	1.59	1.37	1.08	0.77	—
2	0.70	0.67	0.58	0.45	0.32	1.81	1.73	1.50	1.17	0.83	9.0
3	0.74	0.71	0.61	0.48	0.34	1.92	1.84	1.59	1.25	0.89	15.8
6	0.84	0.80	0.69	0.54	0.39	2.17	2.07	1.79	1.40	1.00	30.4
12	0.95	0.91	0.79	0.62	0.44	2.47	2.37	2.04	1.60	1.14	48.7
24	1.10	1.05	0.91	0.71	0.50	2.84	2.72	2.35	1.84	1.31	70.8
36	1.19	1.14	0.98	0.77	0.55	3.08	2.95	2.55	2.00	1.42	85.6

results indicate that window and door closure for 12 h would increase the TVOC concentration by nearly 50% compared to 1 h for all times after decoration. Nine months after decoration in level-B rooms with window/door closure for 1 h, the TVOC concentration was below the China standard. As the window/door closure time increased, the TVOC concentration eventually exceeded the China standard. These results complement current indoor air quality standards, because currently no mandatory closure period before testing is stated in the China standard (GB 50325-2006).

The indoor TVOC concentration in a newly decorated room varied with T , RH, DC, DR, and source characteristics of the room. To better understand and lower the potential health risks from TVOC exposure, there are many factors to be considered. During decoration, source control is considered as the most effective way to reduce TVOC emission. This can be controlled by choosing low-emission building materials and furniture and reducing the use of high-emission building materials and furniture. After decoration, the most effective approach to reduce TVOC concentrations is to vacate and ventilate the room for a reasonable period.

4 Conclusions

TVOC concentrations were measured and evaluated in 2302 rooms in Hangzhou during 2007–2009. Rooms were selected that had been decorated within the last year. The factors contributing to TVOC pollution were identified and quantified. The conclusions can be summarized as follows:

(1) The average TVOC concentration in the rooms was $0.65 \pm 0.69 \text{ mg/m}^3$. 35.6% of the samples exceeded the China standard. The TVOC concentrations decreased in the following order: living room > study > bedroom. Generally, indoor TVOC concentrations were relatively low in Hangzhou compared with other Chinese cities, but higher than in some European countries.

(2) The source characteristics, DR, DC, temperature, and humidity were significantly correlated to the TVOC concentration ($P < 0.01$). Specifically, the source characteristics contributed most to the concentration of TVOC, followed by DR, ventilation, temperature, and humidity, which had a relatively low contribution. The relationship among the five dominant factors can be expressed as

$$\begin{aligned} \ln(C_{\text{TVOC}}) = & 0.212 \times \ln(t_1 + 1) - 5.42 \times 10^{-3} \times t_2^2 - 1.52 \\ & \times \frac{273.15}{T + 273.15} - 44.1 \times \frac{1}{\text{RH}} + 0.952 \times d + 1.40 \end{aligned}$$

($R^2 = 0.83$).

(3) Based on the relationship among the five dominant factors, variance of TVOC concentration in rooms decorated with three levels of source characteristics under different environmental conditions were evaluated. Two weeks were required to meet the current China standard for rooms decorated with level-A materials, 6 to 8 months for those with level-B materials, and 15 to 16 months for those with level-C materials. If the values of the other factors were fixed, increasing the window/door closure time would increase the TVOC concentration by $((t_1 + 1)/2)^{0.212} - 1 \times 100\%$, with the concentration at $t_1 = 1 \text{ h}$ as the reference value.

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