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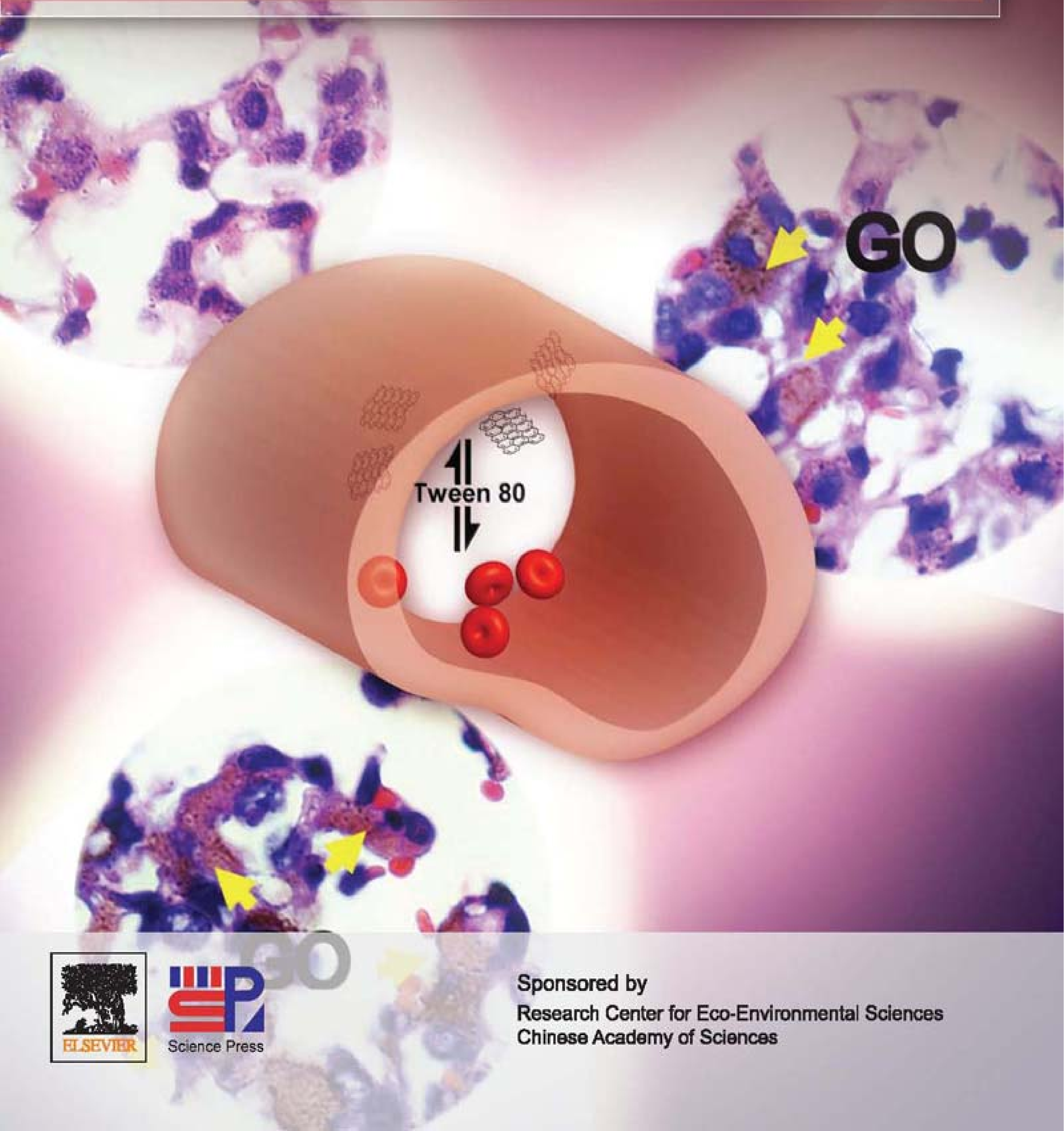

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Formaldehyde concentration and its influencing factors in residential homes after decoration at Hangzhou, China

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Abstract

Air pollution surveys of formaldehyde (HCHO) were conducted in 2324 rooms decorated within one year in 2007–2009 in Hangzhou, China. The mean HCHO concentration (C_{HCHO}) was 0.107 ± 0.095 mg/m^3, and 38.9% of samples exceeded the Chinese National Standard GB 50325-2010. Over the past 3 years, the C_{HCHO} decreased with time ($p < 0.05$). Relationships of potential factors to indoor C_{HCHO} were also evaluated. C_{HCHO} was related to temperature (T), relative humidity (RH), time duration of the windows and doors being closed before sampling (DC), time duration from the end of decoration to sampling (DR) and source characteristics (d). A model to relate indoor C_{HCHO} to these five factors (T, RH, DC, DR, d) was established based on 298 samples ($R^2 = 0.87$). Various factors contributed to C_{HCHO} in the following order: T, 43.7%; d, 31.0%; DC, 10.2%; DR, 8.0%; RH, 7.0%; specifically, meteorological conditions (i.e., RH plus T) accounted for 50.7%. The coefficient of T and RH, R_{TH}, was proposed to describe their combined influence on HCHO emission, which also had a linear relationship ($R^2 = 0.9387$) with HCHO release in a simulation chamber test. In addition, experiments confirm that it is a synergistic action as T and RH accelerate the release of HCHO, and that is a significant factor influencing indoor HCHO pollution. These achievements could lead to reference values of measures for the efficient reduction of indoor HCHO pollution.

Key words: formaldehyde; indoor air quality; emission; factor analysis; temperature; relative humidity
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Introduction

Formaldehyde (HCHO) is the most ubiquitous and well-known indoor air pollutant (Salthammer et al., 2010). Discussion concerning HCHO exposure has attracted increasing attention due to its health risks, such as asthma and sick building syndrome symptoms in both adults (Wieslander et al., 1997) and children (Daisey et al., 2003; Rumchev et al., 2002). HCHO is even classified as carcinogenic to humans (Group 1) by the International Agency for Research on Cancer (Cogliano et al., 2005). The guideline of the World Health Organization, 0.1 mg/m^3 HCHO, is considered preventive of carcinogenic effects in compliance with epidemiological findings (Nielsen and Wolkoff, 2010). However, exposure to HCHO is higher indoors than outdoors due to stronger sources and low natural ventilation rates in the indoor environment (Salthammer et al., 1995). HCHO emitted from veneered and laminated wood-based products are mainly from adhesives and gluing processes (Salthammer et al., 2010). In addition, residential cooking activities (Huang et al., 2011) and cigarette smoke (Heroux et al., 2010) also constitute important sources for indoor HCHO.

Characterizing typical exposure levels and identifying the most accurate potential factors that affect HCHO levels are important to avoid HCHO-associated indoor health risks and to estimate population exposure for risk analysis. The mitigating effects of ventilation on indoor HCHO concentration (C_{HCHO}) with time are available, and source removal is suggested to be the most effective way to decrease chronic exposures to HCHO (Hun et al., 2010). Experimental results also prove that the emittable HCHO concentration increases significantly with increasing temperature (T) (Xiong and Zhang, 2010). However, during our field survey, a regular phenomenon was found that detected rooms with higher HCHO levels had higher indoor T and humidity (RH), simultaneously. Hardly any previous studies have discussed the internal relation of T and RH on HCHO emission, or focused on the relationship

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between HCHO emission and the combined effect of *T* and RH. The objectives of this study were to evaluate the HCHO pollution levels at homes measured from 2007 to 2009 in Hangzhou, China; to quantify the relationships between indoor HCHO levels and potential influencing factors, including household source characteristics and indoor environmental conditions; and to make clear the extent to which *T* and RH could influence HCHO emission.

1 Materials and methods

1.1 Sampling sites

Air samples were collected in 2324 rooms within the first year after decoration in Hangzhou. These rooms covered 1598 families in 902 separate dwellings. Samples were collected from January, 2007 to December, 2009 (**Table 1**). All the rooms, including 1999 bedrooms, 136 studies, and 189 living rooms, were in Class I residential buildings.

1.2 Sampling technique

All the rooms monitored on the survey were kept under normal conditions before sampling with doors and windows closed during the whole process. The personal pump (PC-A, Hengda, China) was set at a flow rate of 0.5 L/min for 20 min with a height of 1.5 m above the floor. When sampling was finished, the tubes were sealed in a specially designed cartridge (Ziguang, China) and brought back to the laboratory for immediate analysis. Potential factors, including *T*, RH, time duration of the windows and doors being closed before sampling (DC), time duration from the end of decoration to sampling (DR), atmospheric pressure (*P*), the sorts of decoration material, furniture load (superficial area of decoration material and furniture per unit) and living habits of householders, etc., were recorded simultaneously and summarized in **Table 2**.

To ascertain the link between HCHO emission and the combined effect of *T* and RH, an environmental chamber test system was set up, where *T* (including 10°C, 20°C, 30°C and 40°C and RH (including 15%, 40%, 65% and 90%) conditions were adjustable. An aluminum board (15 cm in diameter) uniformly covered with 3.6 g of polyvinyl acetate emulsion, i.e., the white latex (Lingqiao, Zhejiang, China) which has a high domestic market share, was put in the chamber called the field and laboratory emission cell (FLEC) (Wolkoff, 1996). The FLEC chamber can carry out nondestructive emission testing on surfaces within the framework of field investigations (Risholm-Sundman, 1999), and the HCHO releases of white latex with different *T* and RH conditions at unit time were calculated.

Table 1 Number of air samples collected each month during 2007–2009

	2007	2008	2009	Total
January	48	50	73	171
February	43	12	30	85
March	30	26	44	100
April	53	49	77	179
May	18	97	66	181
June	23	104	73	200
July	42	112	103	257
August	117	133	67	317
September	71	88	29	188
October	40	88	91	219
November	28	115	73	216
December	44	106	61	211
Total	557	980	787	2324

Table 2 Description of sampling conditions

Impact factor	Min.	Max.	Mean	S.D.	*n*
T (°C)	1.5	40.0	22.5	8.4	2324
RH (%)	32.0	93.0	67.5	9.7	2324
DC (hr)	0	240	7.1	16.6	2324
DR (month)	0.25	12.0	4.5	3.6	298

DC: time duration of the windows and doors being closed before sampling; DR: time duration from the end of decoration to sampling.

1.3 Experimental methods

HCHO was determined by the 3-methyl-2-benzonthiazolinone hydrazone method through a UV-Vis recording spectrophotometer (detector UV@630 nm, UV-2401PC, Shimadzu, Japan). The reagent preparation and analytical methods are detailed in the Chinese National Standard GB/T 18204.26-2000. The recoveries of HCHO ranged from 93% to 101%, and the detection limit was 0.056 μg. The relative standard deviations for the corresponding measurement were less than 5%.

The statistical analysis was performed using Excel 2007, SPSS 16.0 and Eviews 6. Factor analysis was performed using SPSS to obtain the correlation coefficients and significant levels (*p*) between factors and C_{HCHO}. Genetic algorithm (GA) was applied to calculate the optimal weight factors with Matlab 7.0. Eviews 6 was used to perform data fitting and modeling, which is more trustworthy when the Durbin-Watson statistic is closer towards constant 2 (Moorthy et al., 2011; Nerlove and Wallis, 1966).

2 Results and discussion

2.1 Pollution status of field survey

The average C_{HCHO} for all the sampled rooms was 0.107 ± 0.095 mg/m^3, with a maximum value of 0.776 mg/m^3, more than 9 times higher than the Chinese National Standard GB 50325-2010 limit of 0.08 mg/m^3 (**Table 3**). Overall, 38.9% of the total samples were over the standard, with the mean C_{HCHO} and percentage of samples exceeding the standard decreasing up to 50% from 2007 to 2009 ($p < 0.05$). This indicates that the indoor air quality (IAQ) with respect to HCHO in Hangzhou has been significantly improved. Nevertheless, over standard households still remained up to 20% (date in 2009), demonstrating that the

Table 3 Formaldehyde concentration (C_{HCHO}) and percentage of samples exceeding the Chinese National Standard for recently decorated rooms in 2007–2009

Year	Sample number	C_{HCHO} (mg/m^3) Min.	Max.	Mean	S.D.	Number of samples exceeding standard	Percentage of samples exceeding standard (%)
2007	557	0.006	0.664	0.149	0.111	368	66.1
2008	980	0.005	0.739	0.109	0.096	370	37.8
2009	787	0.010	0.776	0.074	0.064	167	21.2
Total	2324	0.005	0.776	0.107	0.095	905	38.9

need to control indoor air pollution is as serious as before.

The data were classified into 4 groups according to the variation of seasons. **Figure 1** shows seasonal variations, with summer having the highest mean C_{HCHO} and over standard ratio, followed by spring, fall and winter, respectively (**Fig. 1**). On the other hand, we can keep an eye on the variations of meteorological conditions (i.e. T and RH) (**Fig. 2**), where exactly similar rules occur. Previous studies (Jarnstrom et al., 2006; Dingle et al., 2000; Khoder et al., 2000) put more emphasis on temperature as the key reason influencing indoor C_{HCHO}. Nevertheless, other factors (e.g. RH, DR, DC, etc.) should not be ignored. A quantifying method was utilized to analyze the influencing factors on C_{HCHO} from both the field survey and simulation chamber test point of view.

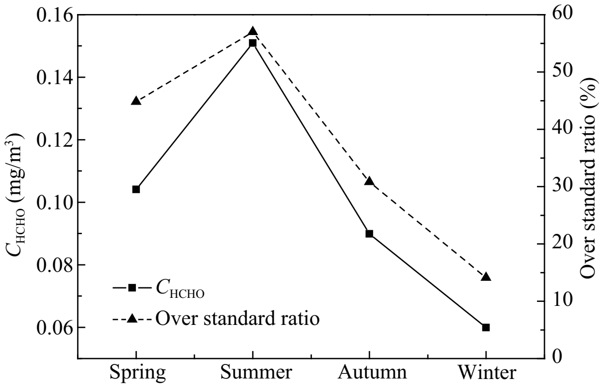

Fig. 1 Seasonal variations in HCHO concentration and over standard ratio of HCHO.

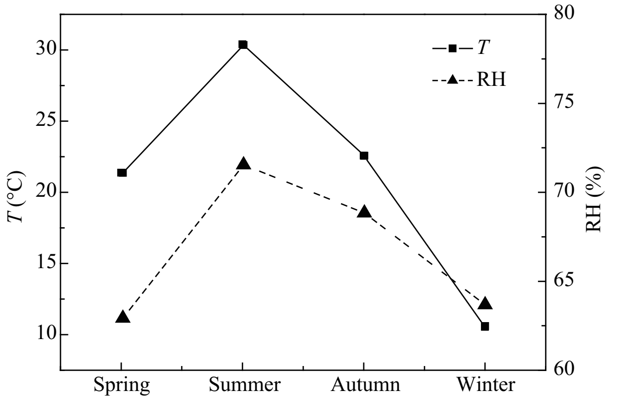

Fig. 2 Variations of the seasonal average temperature (T) and relative humidity (RH).

2.2 Quantitative relationships between various factors and HCHO concentrations

Factor analysis was performed to identify the potential contributors to the indoor C_{HCHO}. It is well recognized that indoor C_{HCHO} is mainly associated with source characteristics (e.g., quantity and nature of building materials and furniture, etc.) and environmental conditions (e.g., T, RH, outdoor concentration and ventilation, etc.). Consistent with some earlier research (Xue et al., 2011; Liu et al., 2012), indoor decorating and refurbishing materials and furniture are identified as one of the main HCHO emission sources, other than cigarettes, mosquito coils and outdoor sources, etc. In addition, environmental factors also have an important impact on the indoor C_{HCHO}. Linear and logarithmic correlations between each factor adopted in this survey and indoor C_{HCHO} are shown in **Table 4**. The C_{HCHO} was significantly positively correlated with T, RH and DC ($p < 0.01$), and negatively correlated with DR. In accordance with the description above, these four factors (T, RH, DC and DR) were optimized to establish a model compatible with C_{HCHO}.

To obtain the correct correlation between various factors and C_{HCHO}, samples without complete statistical information(e.g., without DR) were eliminated for this analysis, and the remaining 298 samples were fitted with the Eviews software. Consequently, an optimum expression of the regression model was generated as follows:

$$\ln(C_{\mathrm{HCHO}}) = C_{(1)} \times \frac{273.15}{T + 273.15} + C_{(2)} \times \frac{1}{\mathrm{RH}} + C_{(3)} \times \ln(\mathrm{DC} + 1) + C_{(4)} \times \mathrm{DR}^2 + C_{(5)} \quad (1)$$

where, $C_{(1)}$, $C_{(2)}$, $C_{(3)}$ and $C_{(4)}$ are the corresponding coefficients for the variables, and $C_{(5)}$ is a constant.

As shown in **Table 5**, all of the variables passed the t-test ($p < 0.05$). The R^2 was 0.5215, which indicates that the four variables used in the model contributed to

Table 4 Correlation analysis between C_{HCHO} and factors

C_{HCHO}		T	RH	DC	DR
	Correlation (r)	0.4216^{a}	0.206^{a}	0.122^{a}	–0.036
	p	0.000	0.000	0.000	0.530
ln(C_{HCHO})		ln$T$	lnRH	lnDC	lnDR
	Correlation (r)	0.469^{a}	0.202^{a}	0.269^{a}	0.063
	p	0.000	0.000	0.000	0.277

^{a} Significant level at 0.01.

Table 5 Fitting results from Eq. (1)

Variable	Coefficient	Coefficient value	Std. error	t-Statistic	p
T	$C_{(1)}$	–19.0097	1.1348	–16.7523	0.0000
RH	$C_{(2)}$	–31.7267	14.4896	–2.1896	0.0293
DC	$C_{(3)}$	0.1258	0.0280	4.4960	0.0000
DR	$C_{(4)}$	–0.0026	0.0007	–3.9250	0.0001
Constant	$C_{(5)}$	15.6470	1.0382	15.0712	0.0000
R^2	0.521489				
Adjusted R^2	0.514957				
p (F-statistic)	0.000				
F-statistic	79.82914				
Durbin-Watson statistic	1.27953				
Dependent variable: ln(C_{HCHO})		n = 298			

more than half of the total variance of C_{HCHO}. Clearly, none of them was the dominant factor controlling C_{HCHO}. This was mainly because source characteristics (including distribution and content of HCHO in decoration materials etc.) were not taken into account, though they were generally identified as the pivotal factors determining indoor C_{HCHO}. In this study, the source characteristics contributed nearly 50% to the variance of C_{HCHO} with the assumption that source characteristics together with the above four variables could explain the total variance of C_{HCHO}. However, it was difficult to accurately quantify the source characteristics in the empirical model because HCHO derived 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 via the following three steps. First, a range of $C_{(5)}$ could be obtained according to Eq. (1) based on the collected data and known parameters, which represented the effect of the source characteristic on C_{HCHO}. Second, based on the range of $C_{(5)}$, the source characteristic was equally divided into high (A), moderate (B), and low (C) levels based on the background concentration and the release rate of HCHO. Third, non-dimensional values –1, 0, 1 were assigned to the levels –A, –B, and –C, which were expressed by parameter d in the Eq. (2). By adding the integrated factor of source characteristics, a new regression equation could be expressed as Eq. (2):

$$\ln(C_{HCHO}) = C_{(1)} \times \frac{273.15}{T + 273.15} + C_{(2)} \times \frac{1}{\text{RH}} + C_{(3)} \times \ln(\text{DC} + 1) + C_{(4)} \times \text{DR}^2 + C_{(5)} \times d + C_{(6)} \quad (2)$$

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.

As shown in **Table 6**, the resulting correlation coefficient R^2 was 0.8698, which indicates that these five variables can account for more than 86% of the total variance of indoor C_{HCHO}. The origin of remaining nearly 14% of variance was uncertain, but probably can be ascribed to the simplification of the source characteristics, which also caused a small amount of error, and yet some other factors that were not taken into account in this study. The final expression was obtained as follows:

$$\ln(C_{HCHO}) = -20.2 \times \frac{273.15}{T + 273.15} - 27.6 \times \frac{1}{\text{RH}} + 0.124 \times \ln(\text{DC} + 1) - 2.85 \times 10^{-3} \times \text{DR}^2 + 0.8 \times d + 16.6 \quad (3)$$

Equation (3) indicates the quantitative relationship between C_{HCHO} and T, RH, DC, DR, and d, thus giving a better description of the changing regularity. In order to verify the practicability of Eq. (3), 10 characteristic newly decorated homes were selected for continuous inspections from August, 2010 to April, 2011. Each home was determined three times: first, 7 or 15 days after decoration; second, 3 months after decoration; and third, 6 months after decoration. Parameter d was derived from the calculation of the first inspection through Eq. (3), then the predicted C_{HCHO} after 3 and 6 months were obtained through Eq. (3). The field test results had a good correlation (R^2 = 0.8604) with model-predicted results (**Fig. 3**), proving that Eq. (3) has reference value in real life. Furthermore, the time required for indoor C_{HCHO} to decrease to meet IAQ standards after decoration can be estimated approximately using Eq. (3). The detailed process of the calculation method was described in our previous studies (Liu et al., 2011).

2.3 Analysis concerning influence of *T* and RH on HCHO concentration

Keeping the fitting forms of variables unchanged, we used GA to calculate the optimal weight of each factor. Because DR was negatively correlated with C_{HCHO}, we need an additional minus to make all the independent variables and dependent variables positively correlated. Before calculation, all the variables should undergo a 0–1 process with the following equation:

$$X' = (X' - X'_{\text{Min}})/(X'_{\text{Max}} - X'_{\text{Min}}) \quad (4)$$

In addition, we integrated the environmental factors of HCHO time dependence into parameter S, and defined as:

$$S = w_1 \times T' + w_2 \times \text{RH}' + w_3 \times \text{DC}' + w_4 \times \text{DR}' + \text{w}_5 \times d \quad (5)$$

Table 6 Fitting results from Eq. (2)

Variable	Coefficient	Coefficient value	Std. error	t-Statistic	P
T	$C_{(1)}$	–20.1744	0.5944	–33.9381	0.0000
RH	$C_{(2)}$	–27.5783	7.5733	–3.6415	0.0003
DC	$C_{(3)}$	0.1241	0.0146	8.4919	0.0000
DR	$C_{(4)}$	–0.0029	0.0003	–8.3656	0.0000
d	$C_{(5)}$	0.7998	0.0286	27.9456	0.0000
Constant	$C_{(6)}$	16.6261	0.5437	30.5816	0.0000
R^2	0.869775				
Adjusted R^2	0.867545				
p (F-statistic)	0.000				
F-statistic	390.05590				
Durbin-Watson statistic	1.84263				
Dependent variable: ln(C_{HCHO})		n = 298			

where, w_1, w_2, w_3, w_4 and w_5 (range of values is 0 to 1 respectively, the sum of the five coefficients is 1) are the weights of T, RH, DC, DR, and d (-A, -B, -C), respectively. Changing w_1, w_2, w_3, w_4 and w_5 to calculate the correlation coefficients R^2 and S, and choosing the one that results in the largest R^2, we obtained the best weight (T, 43.7%; RH, 7.0%; DC, 10.2%; DR, 8.0%; and d, 31.0%, respectively). After 82 times of calculation by GA, the maximum of R^2 was 0.8673. Among the factors, T and RH had the highest and lowest weight, respectively, indicating that T and RH had the largest and smallest influence on C_{HCHO}.

According to the analysis above, the combined weight of T and RH contributed an important part (50.7%) to C_{HCHO}. In a typical room with a certain DR and ventilated condition, T and RH were the main environmental factors that affected C_{HCHO}. Windows and doors were kept closed for 1 hr (i.e., DC was 1) suggested by the China Standard, DR was assumed to be 6 months, T and RH in each month were averages obtained over the past 30 years in Hangzhou (HLCCC, 1998), then indoor C_{HCHO} at levels (-A, -B, -C) in the four seasons were varied (**Table 7**). Among them, all the C_{HCHO} of level-A decorated rooms conformed to standard; only the summer C_{HCHO} of level-B decorated rooms was over standard significantly; as for level-C decoration, only the winter C_{HCHO} did not exceed the standard. T, RH and indoor C_{HCHO} of the four seasons all showed the same phenomenon of being the highest in summer, followed by autumn, spring and winter. So T and RH may be the main reasons for the seasonality of indoor C_{HCHO}.

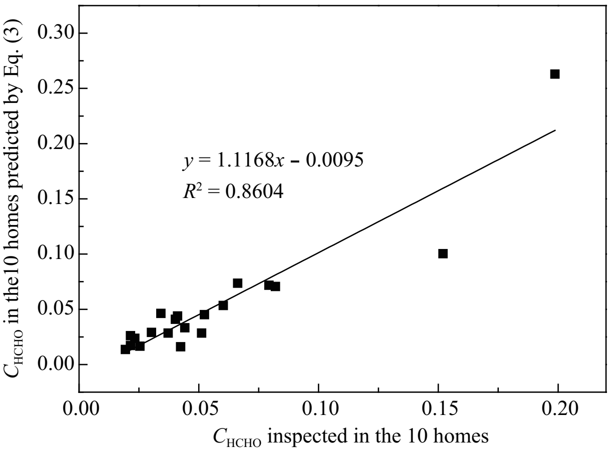

Fig. 3 Relationship between the inspection results and the results predicted by Eq. (3).

Table 7 Predictive values of C_{HCHO} of level (-A, -B, -C) decorated rooms decorated in four seasons

Season	Meteorological conditions		Indoor C_{HCHO} (mg/m^3)		
	T (°C)	RH (%)	Level-A	Level-B	Level-C
Spring	15.0	80.3	0.027	0.059	0.131
Summer	27.0	81.3	0.057	0.127	0.284
Autumn	17.7	81.0	0.032	0.071	0.158
Winter	5.1	78.3	0.013	0.030	0.066

The temperature-humidity coefficient (TH) was defined to combine T and RH as one parameter and the transformation details are as shown in Eq. (6):

$$\mathrm{TH}\,(T,\mathrm{RH}) = -20.2 \times \frac{273.15}{T + 273.15} - 27.6 \times \frac{1}{\mathrm{RH}} \tag{6}$$

To standardize TH into the interval between 0 and 1, the relative temperature-humidity coefficient (R_{TH}) was introduced. R_{TH} = (TH–TH$_{Min}$)/(TH$_{Max}$–TH$_{Min}$). Based on our field testing data, T ranged from 0 to 40°C, and RH ranged from 20% to 100%. Therefore, TH$_{Min}$ = TH (0, 20), TH$_{Max}$ = TH (40, 100). The over standard ratio of samples in each of the 10 intervals is listed in **Table 8**.

We obtained a linear relationship (R^2 = 0.9883) between the median of each R_{TH} interval and the corresponding over standard ratio (**Fig. 4**). By applying parameter R_{TH} we can achieve further insight into the combined effect of T and

Table 8 Statistics of R_{TH} values for 2324 samples

R_{TH} interval	Median	Over standard number	Sample number	Over standard ratio (%)
0.2–0.3	0.25	0	1	0.0
0.3–0.4	0.35	6	108	5.6
0.4–0.5	0.45	30	293	10.2
0.5–0.6	0.55	78	335	23.3
0.6–0.7	0.65	130	385	33.8
0.7–0.8	0.75	288	603	47.8
0.8–0.9	0.85	361	583	61.9
0.9–0.10	0.95	12	16	75.0

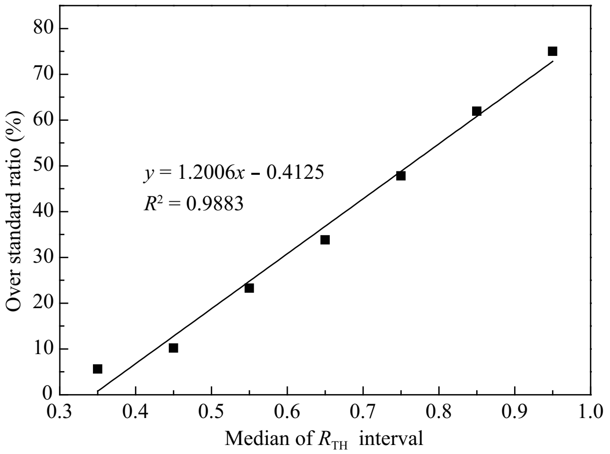

Fig. 4 Relationship between R_{TH} and over standard ratio of HCHO.

RH on indoor C_{HCHO}, thus obtaining a clear link between meteorological conditions and over standard ratio.

2.4 Analysis concerning influence of *T* and RH in the single source of HCHO emission

Based on the empirical regularity of the field testing data, higher T and RH lead to an increase of over standard ratio of indoor C_{HCHO}. The combined influence weight was estimated to be as high as 50.7%, but we still cannot confirm the inner interaction mechanism of T and RH on HCHO release. Is it a synergistic, antagonistic, additive, or independent action? In order to make clear to what extent the promoting effect exists in HCHO emission, a representative kind of white latex (free HCHO content 2.18 g/kg) was chosen as the single source of HCHO emission and the indoor environment was simulated in the FELC chamber, excluding the interference of other factors except T and RH. Since the emittable C_{HCHO} was found to tend towards stability after 6000 min through preliminary testing, the quantity of HCHO was calculated as the integral area covering the beginning 6000 min with the background concentration deducted. Both T and RH have notable effects on the increasing content of emittable HCHO in the white latex: the higher the RH value, the bigger the gap between the released HCHO levels under different T conditions (**Fig. 5a**); similarly, the higher the T value, the wider the gap between the released HCHO levels under different RH conditions (**Fig. 5b**).

As shown in **Table 9**, with the assumption that when T increases 10°C and RH is unchanged, HCHO release increases x%; when T is unchanged and RH increases 25%, HCHO release increases y%; if T and RH increase a corresponding amount at the same time, the actual HCHO release increases more than $(x+y)$%. In other words, the sum of the separate temperature and RH influences is generally less than their combined influence, demonstrating that T and RH have a synergistic impact on the emission of HCHO. As discussed above, the phenomenon that T and RH accelerate the release of HCHO was defined as the synergy between T and RH for HCHO release.

Converting the T and RH in the FLEC experiment to R_{TH}, we also obtained a linear relationship (R^2 = 0.9387)

Table 9 Form of statistics on the influence of RH and T on HCHO emission

Initial conditions	Condition's change	HCHO content's change	Sum of two changes	Actual change
15%, 10°C	15% → 40% 10°C → 20°C	46.7% 20.8%	67.5%	139.4%
15%, 10°C	15% → 40% 10°C → 30°C	46.7% 51.3%	98.0%	217.8%
15%, 10°C	15% → 40% 10°C → 40°C	46.7% 122.8%	169.5%	305.3%
15%, 10°C	15% → 65% 10°C → 20°C	48.3% 20.8%	69.1%	187.5%
15%, 10°C	15% → 90% 10°C→ 20°C	64.0% 20.8%	84.8%	238.2%
40%, 20°C	40% → 65% 20°C → 30°C	20.1% 32.7%	52.8%	59.8%
40%, 20°C	40% → 65% 20°C → 40°C	20.1% 69.3%	89.4%	112.2%
40%, 20°C	40% → 90% 20°C → 30°C	41.3% 32.7%	74.0%	128.4%
65%, 30°C	65% → 90% 30°C → 40°C	42.9% 32.8%	75.7%	84.7%

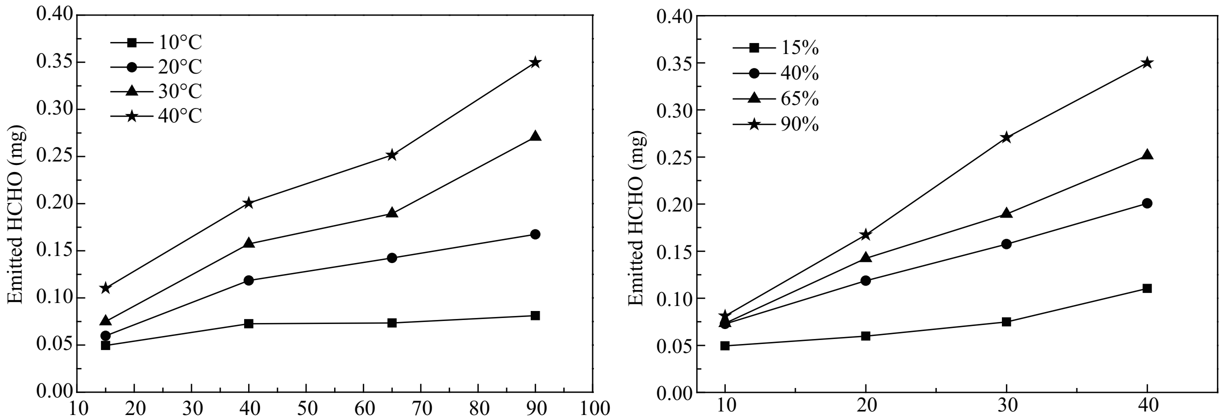

Fig. 5 Isotherm of emitted HCHO content under different RH (a) and T (b).

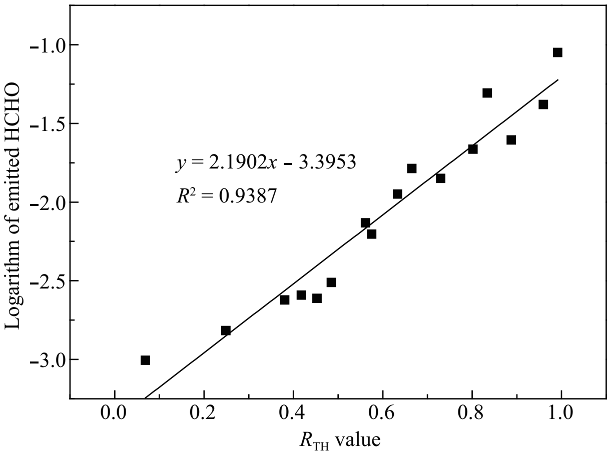

Fig. 6 Relationship between R_{TH} and logarithm of emitted HCHO content.

between R_{TH} and the HCHO content emitted from the white latex (**Fig. 6**). The result suggests that the combined meteorological condition is the most important factor influencing indoor C_{HCHO} from another perspective.

3 Conclusions

Formaldehyde (HCHO) concentrations were measured in 2324 rooms decorated within a year in 2007–2009 in Hangzhou, China. Potential factors influencing HCHO pollution were quantified and explored from field and simulation testing. The conclusions can be summarized as follows:

(1) The average indoor C_{HCHO} was 0.107 ± 0.095 mg/m^3. About 38.9% of the total samples exceeded the Chinese National Standard GB 50325-2010, although the trend decreased with time ($p < 0.05$). The variations of C_{HCHO} and over standard ratio with seasons were in the following order: summer > spring > autumn > winter.

(2) Indoor C_{HCHO} was significantly correlated ($p > 0.01$) to T, RH, DC, DR and source characteristics (d). The weight of each factor in order was: T, 43.7%; d, 31.0%; DC, 10.2%; DR, 8.0%; RH, 7.0%. Specifically, the combined weight of T and RH contributed more than 50% of the total, making the combined meteorological condition the most significant factor influencing the indoor C_{HCHO}. The relationship among five dominant factors can be expressed as:

$$\begin{aligned}\ln(C_{\mathrm{HCHO}}) = {} & -20.2 \times \frac{273.15}{T + 273.15} - \\ & 27.6 \times \frac{1}{\mathrm{RH}} + 0.124 \times \ln(\mathrm{DC} + 1) - \\ & 2.85 \times 10^{-3} \times \mathrm{DR}^2 + 0.8 \times d + 16.6 \ \ (R^2 = 0.87)\end{aligned} \tag{7}$$

(3) The temperature-humidity coefficient (R_{TH}) first defined in this article was used to relative accurately describe the combined influence of T and RH on the emission of HCHO. R_{TH} was also proved to have linear correlations with the over standard ratio and the release of HCHO. Furthermore, the synergy between T and RH that accelerates HCHO emission was detected in the FLEC test. Considering the increasing attention to IAQ arising all over the world, the R_{TH} merits further exploitation for building an indoor C_{HCHO} prediction model and could be utilized as a non-ignorable control reference factor.

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