Establishment of Pollutant Concentration Model for Laminate Flooring Based on the Coupling Effects of Time and Temperature

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Abstract. Modern people are entering the third period of pollution, marked by indoor air pollution. The aim of this paper is to investigate the relationship between decorative materials and the pollution concentrations of typical indoor pollutants such as HCHO, C6H6 and VOC, using a combination of qualitative and quantitative methods. The environmental test chamber method is used to carry out the experimental measurement of the laminate flooring, and the numerical analysis is carried out according to the test release concentration and environmental parameters. The Levenberg-Marquardt optimization algorithm was selected to develop a first-order exponential (ExpDec1) mathematical model based on the concentrations of HCHO, C6H6 and VOC released from laminate flooring at different temperatures. The results show that the model predicts the characteristics of HCHO, C6H6 and VOC concentrations with time and temperature and there is a positive correlation between environmental parameters and release concentration, with correlation coefficients of 0.993, 0.925, 0.856, 0.992, 0.906 and 0.879 between measured and predicted values, and slopes of regression lines of 0.993, 0.932, 0.872, 0.994, 0.916 and 0.893. There is good consistency between measured and predicted values. The model provides a necessary basis for in-depth study of this issue and a solid evidence foundation for air quality.

1 Introduction

Driven by strong economic growth, China's construction industry output value exceeded RMB 25 trillion in 2020^[1]. It is estimated that the gross output value of China's construction industry will reach around RMB 33.05 trillion in 2023^[2], with the accompanying decoration boom is in the spotlight. More than 90 % of a person's life spent indoors (including transportation)^[3], and the quality of human air intake accounts for nearly 90% of the total quality of intake (water, food and air)^[4]. Composite materials are widely used in residential buildings. A large number of adhesives and presser vatives are added to the composite reinforced floor in the production process. Various paints are sprayed on the surface, containing a large number of HCHO, C6H6 and VOC (volatile organic compounds), and indoor air is polluted. Indoor pollution can pose serious health risks to the human respiratory system, blood circulation system, nervous system and other systems of the human systems^[4]. When the concentration of indoor pollutants reaches a certain threshold, people will experience headaches, nausea, dizziness and other symptoms. In 2010, the World Health Organization (WHO) issued a 'Guide to Indoor Air Ouality' at its headquarters in Geneva, Switzerland, where formaldehyde pollution was included among the major pollutants^[5]. In 2018, the Ministry of Health and Ecological Environment of

China, in conjunction with the Health and Health Commission, developed the 'List of Toxic and Hazardous Air Pollutants (2018)', in which formalde - hyde is on the list^[6].

In October 2015, the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China clearly put forward the task of promoting the construction of healthy China, and elevated 'healthy China' as a national strategy. In October 2016, the "Healthy China 2030' Plan" approved by the Political Bureau of the CPC Central Committee was released to promote the construction of a healthy China and improve people's health. In November 2017, the report of the 19th National Congress of the Communist Party of China clearly put forward the "Implementation of the Healthy China Strategy". In July 2019, the State Council issued the 'Opinions of the State Council on the Implementation of Healthy China Action', and established the Healthy China Action Promotion Committee at the national level to formulate and issue the Healthy China Action (2019-2030). In October 2020, the Fifth Plenary Session of the Nineteenth Central Committee of the Communist Party of China adopted the 'Proposals of the Central Committee of the Communist Party of China on the formulation of the fourteenth five-year plan for national economic and social development and the vision target of 2035', which put forward the major task of 'comprehensively

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promoting the construction of healthy China'. In March 2021, the fourteenth five-year plan of the national economic and social development of the People's Republic of China and the outline of the 2035 vision goals (draft) reviewed by the Fourth Session of the Thirteenth National People's Congress proposed to comprehensively promote the construction of healthy China. The proposal and improvement of these policies have played an important role in the construction of healthy buildings and a healthy China. However, according to the Environmental Monitoring Center of China Interior Decoration Association, the number of deaths caused by indoor air pollution has reached 111,000 annually^[7]. The latest sampling test results of indoor air in Beijing offices by Environmental Monitoring Center of China Association of Interior Decoration show that the exceeding rates of harmful substances such as ammonia, formaldehvde and ozone are 80.56 %, 42 % and 50 %, respectively^[7]. Zhang Pengyi et al^[8] used 46 residential rooms in Beijing newly renovated within 6 months as the test object, it is found that the exceeding standard rate of rooms dominated by panel furniture is 86.36 %, and that of rooms dominated by solid wood furniture is only 29.17 %. Studying the influence of building materials on indoor pollution can provide theoretical guidance for improving indoor air quality and provide a solid evidence basis for preventing or controlling indoor air pollution.

In summary, in order to explore the effects of time and temperature on typical indoor pollutants, a combination of qualitative and quantitative methods was used to study the laminate flooring, which was experimentally measured by the environmental test chamber method to construct a mathematical model of typical pollutant concentrations in laminate flooring based on the coupled effects of time and temperature. The results of the research contribute to further understanding of the hazards of indoor decoration pollution, help to further improve indoor air quality and have potential application value for predicting indoor pollution levels.

2 Experimental programme

According to the relevant national standards of the People's Republic of China, this experiment measures the laminate flooring, and clarifies the release characteristics of the laminate flooring in the experimental chamber.

2.1 Experimental standards

At present, there are two indoor air quality standards in force in China, namely the Indoor Environmental Pollution Control Standards for Civil Construction Projects^[9] (hereinafter referred to as GB 50325-2020) issued by the Ministry of Housing and Urban-Rural Development and the Indoor Air Quality Standards^[10] (hereinafter referred to as GB/T 18883-2020 Draft for Public Comments) jointly issued by the Ministry of Health and the State Environmental Protection Administration.

 Table 1. Standard comparison.

Pollutants	GB 50325-2020	GB/T 18883-2020
НСНО	0.08 mg/m ³	0.08 mg/m ³
C6H6	0.09 mg/m ³	0.03 mg/m ³
TVOC	0.50 mg/m ³	0.60 mg/m ³

The first edition of the national standard 'Indoor Environmental Pollution Control Standards for Civil Construction Projects' GB 50325-2020 was issued in 2001, which undergone 'three editions and two revisions'. After 20 years, it has played a positive role in promoting the development of indoor environmental testing laboratories, promoting the development of indoor environmental purification materials and decorative and furniture materials with indoor environmental purification functions, improving the indoor environmental awareness of the whole society, promoting the progress of China 's green environmental protection building decoration materials industry and promoting the development of China's indoor environmental protection industry. GB/T 18883-2020 (draft for comments) is not officially issued and is not taken into account only as a reference standard.

In summary, in order to grasp the release characteristics of typical pollutants released from laminate flooring, using the National Standard of the People's Republic of China 'Indoor Environmental Pollution Control Standards for Civil Construction Projects' GB 50325-2020, Appendix B Environmental Test Chamber Method for the Determination of Free Formaldehyde and VOC Release from Decorative Materials as the experimental standard.

2.2 Environmental test chamber experiment

This experiment adopts the environmental test chamber method as the research method, selects the laminate flooring as the typical research object, takes HCHO, C6H6, VOC as the experimental typical test indexs, places the material at room temperature sealed and kept under shade, tests the release concentration and environmental parameters of laminate flooring under different time and temperature conditions. Environmen -tal test chamber to determine the release of pollutants of decorative materials, is a certain area of the test sample, placed in a certain environmental parameter of the environmental test chamber, the test sample volatile pollutants and test chamber air in the chamber fully mixed, and then the test chamber mixed air cycle sampling. Experimental testing equipment for 15.624m³ for the nested environmental test chamber (temperature 15°C-40°C, temperature measurement accuracy ± 0.5 °C, humidity 40%-70%, humidity measurement accuracy \pm

5%), as shown in Fig.1. The experimental steps refer to the 'Indoor Environmental Pollution Control Standards for Civil Construction Projects ' GB 50325-2020 regulations, the experimental test conditions are shown in Table 2.



Fig. 1. Environmental test chamber.

 Table 2. Experimental test conditions.

Material Name	laminate flooring	
Temperature	23°C	28°C
Relative Humidity	50%	50%
Air exchange rate	0 times/hour	0 times/hour
Loading rate	$0.34 \text{ m}^2/\text{m}^3$	$0.34 \text{ m}^2/\text{m}^3$
Measuring time	10 days	10 days

2.3 Experimental Test

According to the principle of no cutting and no splicing laying in the bottom area of the environmental test chamber, choose 56 pieces of laminate flooring with dimensions of 800mm × 120mm (length × width) for single-sided release experiments. The experimental materials were paved at the bottom of the chamber, and the air was circulated above the floor to fully release the pollutants. Through the test chamber sampling port using portable formaldehyde tester (measurement range 0-13.4mg/m³, accuracy 2%) and gas detector (measure - ment range 1ppb-10000ppm, accuracy of 10-2000ppm isobutylene calibration point of \pm 3%) on the sampling samples for concentration determination.

In the environmental test chamber, 4×2 lines are arranged equidistantly along the length and width directions, and 3 measurement points are arranged equidistantly along the height direction on each line, totaling 24 temperature and humidity measurement points are connected to the automatic control system panel to monitor the temperature and humidity inside the chamber in real time; there is a sampling port on the side of the environmental test chamber connected to the formaldehyde detector and multi-functional gas detector to regularly extract the gas inside the chamber to detect its pollutant content.



Fig. 2. Arrangement of experimental measuring points.

To ensure that the background concentration values of pollutants in the chamber before the experiment meet the experimental requirements, and to smoothly connect with the subsequent experiments should purify the air in the chamber, two types of purification equipment are used in the process of this experimental study, one is the environmental test chamber with its own air treatment equipment purification outside, and the other is IQAir-Health 250 air purifier (HCHO CADR 161.5 m³/h, C6H6 CADR 100.8 m³/h, TVOC CADR 80.4m³/h). The experimental equipment and the state of the sample is shown in Fig.3.



(a) formaldehyde tester (b) gas detector(c) air purifier



(d) laminate flooring

Fig. 3. Experimental equipment and the state of the sample.

3 Experimental result

In order to investigate the influence of time and temperature on the concentration of material release, the pollutant release was measured under different time and temperature conditions was determined according to the experimental standard.

3.1 Test results of environmental test chamber

This paper begins by investigating the relationship between time and temperature and typical pollutants HCHO, C6H6 and VOC concentrations, and Fig.4. shows experimental data on the release of typical pollutants from the material in the chamber. Fig.4. (a c) compares the HCHO, C6H6 and VOC concentrations in the environmental test chamber under constant relative humidity conditions with the material at the temperature parameters of 23°C and 28°C. It can be clearly seen that the material releases significantly higher concentrations of HCHO, C6H6 and VOC at an ambient temperature of 28°C than the material releases contaminant concentrations at 23°C. Generally speaking, the higher the temperature is and the longer the time is, the higher the concentration of pollutants is measured, and even far more than several times of the national standard limit, which can cause death in serious cases. The concentration of HCHO released at 28°C was 1.1-3.1 times of that at 23°C. The concentration of C6H6 released at 28°C was 1.0-1.4 times of that at 23 °C. The concentration of VOC released at 28°C was 0.9-1.8 times of that at 23°C.





Fig. 4. Concentration of pollutants in the environmental test chamber at different temperatures for different time periods.

Individual data does not match the experimental expectations, the possible reason for this phenomenon is that the measurement data process is not waiting for the test chamber sample delivery tube is full of pollutant gas molecules have been formaldehyde detector and gas detector built-in pumping into the sensor, so that the extracted gas samples exist a certain number of air molecules, the volume of pollutants pumped into the insufficient, resulting in low values of pollutant concentration. In addition, the test chamber sampling port and sample delivery port and the air is not completely closed, part of the gas will escape through the test chamber sampling port and sample delivery port, which is also one of the reasons for this phenomenon. Immediately after that, because the temperature inside the chamber is above absolute zero, formaldehyde molecules, benzene molecules and VOC molecules have different degrees of internal energy, which is the source of irregular molecular movement of formaldehyde molecules, benzene molecules and VOC molecules, making the molecules inside the chamber move continuously, filling with pollutant molecules

and increasing the concentration of pollutants inside the chamber.

3.2 Effect of temperature on release of laminate flooring

This section will attempt to further dissect the impact of temperature on HCHO, C6H6 and VOC concentrations. Taking a 24-hour period as an example, taking the measurement time (hours) as the abscissa, and the concentrations of HCHO, C6H6 and VOC (mg/m³) as the ordinates, the variation curves of typical pollutant concentrations with temperature at different moments were plotted. The effect of two temperatures on the release of pollutant concentrations was clarified at onehour intervals, and Fig.4. (d - f) provides a vertical plot of typical pollutant concentrations at different temperatures for 24 hours. The concentrations of HCHO, C6H6 and VOC increase with temperature at the same moment, and the change with temperature is a straight line with a positive correlation (slope greater than 0). The concentration increased significantly with temperature from 1h to 4h, and gradually increased with temperature after 4 h, and the growth rate slowed down.

Taking 6h as an example, the concentration of HCHO at 23°C was 0.071mg/m³, and the concentration of HCHO at 28°C was 0.103mg/m3, the concentration of HCHO increased by 0.45 times; the concentration of C6H6 at 23°C was 0.422mg/m³, and the concentration of C6H6 at 28°C was 0.454mg/m³, the concentration of C6H6 increased by 0.08 times; the concentration of VOC at 23°C was 0.610mg/m3 at 23°C and 0.642mg/m3 at 28°C, an increase of 0.05 times in VOC concentration. It can be seen that the slow increase in the relative increase in concentration with time and temperature is due to the temperature material accumulating in the chamber to reach the saturation concentration in the chamber, and time and temperature have a facilitating effect on the release of HCHO, C6H6 and VOC concentration.

HCHO, C6H6 and VOC are mainly derived from a large number of adhesives used in the production of laminate flooring^[11], of which urea-formaldehyde resin (UF) is one, which is the condensation of $CO(NH_2)_2$ with HCHO under the action of a catalyst (alkaline or acidic catalyst) to form an initial urea-formaldehyde resin^[12], which is a reversible exothermic reaction $\Delta H < 0$. Based on Le Based on Le Chatelier's Principle, an increase in temperature shifts the equilibrium in the heat-absorbing direction (i.e., the reverse direction) and a decrease in temperature shifts the equilibrium in the exothermic direction (i.e., the positive direction). Secondly, an increase in temperature accelerates the rate of volatilisation, diffusion and release of pollutants^[13]. Therefore, when the temperature in the chamber increases from 23°C to 28°C, the chemical equilibrium shifts towards the reverse reaction direction, prompting an increase in HCHO concentration. Professor Yang Xudong^[14] and others demonstrated that the higher the temperature the higher the concentration of formaldehyde measured in the working conditions, the results of the concentration test at 18°C were 1.1 times higher than that at 12°C; the results of the concentration

test at 23°C were 1.4 times higher than that at 12°C; and the results of the concentration test at 30°C were 1.8 times higher than that at 12°C. In summary, the contribution of this subsection is to confirm that there is a link between HCHO, C6H6 and VOC concentrations and temperature and time, which has a certain reference value for analyzing the degree of indoor air pollution.

4 Constructing mathematical model of pollutant concentration

This section will attempt to construct a mathematical model of pollutant concentrations using environmental parameters as independent variables and test concentrations as dependent variables.

4.1 Mathematical model

As previously mentioned research has shown that HCHO, C6H6 and VOC concentrations are significantly correlated with time and temperature. The mathematical model is established by using the experimental data of the environmental test chamber, and the Levenberg-Marquardt optimization algorithm was selected to construct a mathematical model based on the first order exponential (ExpDec1) of HCHO, C6H6 and VOC concentrations released from laminate flooring at different temperatures. Detailed parameters of the mathematical model for each indoor pollutant prediction: detailed values of the model equations, y0, A1, and t1 are in Fig.5.





Fig. 5. Mathematical model of pollutant concentrations.

The prediction model fit in Fig. 5(c) is 0.835, which is a good fit from the perspective of goodness of fit greater than 0.8. Since there was a certain gap between the measured data and the predicted values during the 7-8 days of experimental measurements, which led to the overall trend showing a decline for a period of time, which did not match the expectation and resulted in some differences between the predicted and measured values of the model. However, the prediction results are scientifically credible because of the high fit of the prediction model.

4.2 Assessing the consistency between predicted and measured values

In this section, the ASTM D5157-97 (2014) Standard Guide for Statistical Evaluation of Indoor Air Quality Models^[15] was used to assess the accuracy of the first-order exponential (ExpDec1) mathematical model and to assess the agreement between the predicted and measured values. A comparative analysis of the experimentally obtained release concentrations against the predicted concentrations from the first order exponential (ExpDec1) mathematical model is provided in Fig.6. If the measured values coincide perfectly with the predicted values, the points and lines in Fig.6. should be distributed along the proportional function y=x. The six mathematical models constructed in this paper are slightly different from the ideal state, and most of the model predictions fluctuate above and below y=x. The correlation coefficients of measured and predicted concentrations of HCHO, C6H6 and VOC amounts released from laminate flooring at 23°C/28°C are 0.993, 0.925, 0.856, 0.992, 0.906 and 0.879 respectively, and the slopes of the regression lines are 0.993, 0.932, 0.872, 0.994, 0.916 and 0.893 respectively. The results show that the correlation coefficients and the slope of the regression line are greater than 0.850, the goodness of fit is high and the predicted values of the mathematical model are highly consistent with the measured values.





(f) VOC (28℃)

Fig. 6. Consistency analysis.

5 Conclusion

a) This study investigated the effects of time and temperature on the release of HCHO, C6H6 and VOC concentrations from laminate flooring. Higher pollutant concentrations were measured at higher temperatures and for longer periods of time at constant relative humidity. 1.1 to 3.1 times higher concentrations of HCHO were released at 28°C than at 23°C, 1.0 to 1.4 times higher concentrations of C6H6 were released at 28°C and 0.9 to 1.8 times higher concentrations of VOC were released at 28°C than at 23°C. This study confirms the previous findings and provides additional evidence that sets the stage for further research.

b) This study objectively measured and evaluated the release characteristics of laminate flooring over a 24 hour period. The concentrations of HCHO, C6H6 and VOC increased with temperature at the same moment, and the change with temperature was a straight line with a positive correlation (slope greater than 0). The concentration increased significantly with temperature from 1 h to 4 h, and gradually increased with temperature after 4 h, and the growth rate slowed down. c) This study is important for further understanding and appreciation of the role of time and temperature, and provides a basis for further research in the future.

This study developed a first order exponential (ExpDec1) model for predicting the release of HCHO, C6H6 and VOC concentrations from materials. The correlation coefficients between the predicted and measured values of the constructed 23° C/28° C model were 0.993, 0.925, 0.856, 0.992, 0.906 and 0.879, respectively, and this new insight should help to improve the prediction of the effects of time.

d) This study assessed the consistency between predicted and measured values, using the ASTM D5157-97 (2014) standard, the slopes of the regression lines between measured and predicted values were 0.993, 0.932, 0.872, 0.994, 0.916 and 0.893 respectively, which were greater than 0.850, with good fit and high consistency between the mathematical model predictions and measured values. These findings will assist others in predicting material release concentrations.

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