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Review Article

Research Progress on Formaldehyde Emission of Wood-Based Panel

Jijuan Zhang,[1,2] Feifei Song,[1,2] Jing Tao,[1,2] Zhongfeng Zhang,[1,2] and Sheldon Q. Shi[3]

[1]*College of Furniture and Art Design, Central South University of Forestry and Technology, Changsha, 410004 Hunan, China*
[2]*Hunan Green Home Engineering Center, Changsha, 410004 Hunan, China*
[3]*Mechanical and Energy Engineering Department, University of North Texas, Denton, TX 76203-5017, USA*

Correspondence should be addressed to Sheldon Q. Shi; sheldon.shi@unt.edu

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Current research progress on the mechanism and influencing factors of formaldehyde emission from wood-based panel is reviewed. The formaldehyde analysis and test methods are summarized, putting forward a new idea to research the relevance of formaldehyde emission and the loading ratio of wood-based panel under the combined action of influencing factors. The quantitative indicators of wood-based panel load in a specific space according to the formaldehyde emission requirements are determined, which provide technical precondition support to improve the interior decoration and furniture design.

1. Introduction

Wood-based panel is widely used in furniture manufacturing and interior decoration projects due to the advantages of easy processing and dimensional stability. However, wood-based panel will release formaldehyde, if a formaldehyde-based resin is used, and other harmful gases, causing indoor air pollution. Guo et al. [1] conducted a survey of 2324 rooms in Hangzhou for one year and found that 38.9% of the samples exceeded the requirements of Chinese national standards. Formaldehyde has been classified as a potentially dangerous carcinogen and an important environmental pollutant by the World Health Organization and the United States Environmental Protection Agency. Chen et al. [2] found that high concentration of formaldehyde is toxic on the nervous system, immune system, and the liver. The objective of this report is to review the formaldehyde emission regulation at different countries, and the influencing factors, so that the formaldehyde pollution of the wood-based panel and its products can be effectively controlled.

2. The Research Progress of Formaldehyde Emission from Wood-Based Panel

2.1. The Source and Mechanism of Formaldehyde Emission from Wood-Based Panel. A considerable amount of research has been conducted on the issue of formaldehyde emission from wood-based panels during the last decade. The formaldehyde emissions are mainly from three sources: (1) formaldehyde compound in wood material, (2) residual free formaldehyde of the formaldehyde-based resin that is not involved in the reaction, and (3) formaldehyde released by the structural degradation of the wood-based panel used. Among them, the residual free formaldehyde in the panel is the main source of indoor air pollution.

Formaldehyde of wood-based panels can be divided into two parts, free formaldehyde easier to be released and more difficult to release with bonded formaldehyde. Formaldehyde emission rates can be in two stages. In the first stage, the emission is mainly free formaldehyde. The emission rate depends on the diffusion rate of free formaldehyde in the panel, which is affected by the formaldehyde concentration

Table 1: Standards for determining formaldehyde emission from wood-based panels in China, USA, Europe, and Japan.

Standard	Limit value	Grade	Testing method	Application scope
EN13986:2005	$\leq$3.5 mg/(m^2·h) $\leq$8 mg/(m^2·h)	E_1 E_2	Gas analysis	Plywood
	$\leq$8 mg/100 g $\leq$30 mg/100 g	E_1 E_2	Perforation	MDF PB
Formaldehyde Emission Standards for Composite Wood Act (S.1660, H.R.4805)	$\leq$0.05 ppm $\leq$0.09 ppm $\leq$0.11 ppm $\leq$0.13 ppm		Chamber	Plywood PB MDF $\leq$8 mm MDF
JIS A 1460-2001	$\leq$0.3/0.4 mg/L $\leq$0.5/0.7 mg/L $\leq$1.5/2.1 mg/L	F☆☆☆☆ F☆☆☆ F☆☆	Desiccator	Plywood MDF PB
GB/T9846.3-2004	$\leq$0.5 mg/L	E_0	Desiccator	Plywood
GB18580-2001	$\leq$1.5 mg/L $\leq$5.0 mg/L	E_1 E_2	Desiccator	Plywood
	$\leq$9 mg/100 g $\leq$30 mg/100 g	E_1 E_2	Perforation	MDF PB

gradient in the panel. Ventilation can speed up the release of formaldehyde. This stage can be 1-2 weeks or 1–3 months, depending on the amount of free formaldehyde in the board. In the second stage, the emission is from the bonded formaldehyde, which the release rate depends on the bonding force, and ventilation would have little effect. Stage 2 can be up to several years.

Liu [3] found that the necessary and sufficient conditions of formaldehyde release from wood-based panels were when the air pressure inside the wood-based panel is greater than the environment and the channel for air circulation is available so that the formaldehyde can release. Xing et al. [4] concluded that the formaldehyde emission was mainly from the edges of panel, which was more than 2 times than that from the panel surface. Therefore, the thinner the board, the more formaldehyde emission. Meng and Hong [5] separated the formaldehyde emission process from wood-based panels into three stages: rapid release, slow release, and full release.

2.2. Formaldehyde Emission Standards of Wood-Based Panel. Because of the hazard for the formaldehyde to human health, many countries establish the formaldehyde emission requirements and testing methods of formaldehyde emission from wood-based panel.

Wang et al. [6] and Luo [7] conducted a comparative study on different testing methods on formaldehyde emission of wood-based panel among China, the European Union (EU), the United States, and Japan. The current EU standards related to formaldehyde emission include one emission standard, 4 product standards, and 4 method standards. The United States has 2 regulations, 3 product standards, and 3 method standards related to formaldehyde emission. Japan has 4 product standards and 4 method standards. Chinese national standards of formaldehyde emission include an emission standard: "GB 18580-2001 Indoor decorating and refurbishing materials-Limit of formaldehyde emission of wood-based panels and finishing products," more than 50 product standards, and 3 method standards (see Table 1).

There are three testing methods described in the US standard for the formaldehyde emission: large chamber, small chamber, and desiccator. The US standards do not classify formaldehyde emission limitation levels. The US standard gives a limit value of formaldehyde emission by the chamber method.

Japanese standards state the limit values by the desiccator method with 4 levels of formaldehyde limit, including the average and the maximum value. F★★★★ is the most stringent level of formaldehyde emission with the average value of less than 0.3 mg/L. The so-called zero formaldehyde emission is defined as $\leq$0.3 mg/L, because the formaldehyde emission from the natural wood is generally 0.1~0.3 mg/L tested by desiccator method.

Chinese and EU standards have more similarities: (1) the limited classification: both Chinese standards and EU standards have the E-level classification of formaldehyde emissions, such as E0, E1, and E2. In EU standards, there is no E0 level. Chinese standards of wood-based panel have E0 level in GB/T 5849-2006 "Block board" and GB/T 15104-2006 "Decorative Veneer decorated wood-based panel," which use desiccator method to test formaldehyde. No E0 level is provided in other standards of wood-based panel, such as medium-density fiberboard (MDF) and particle board (PB). (2) The test methods: the Chinese mandatory standard uses desiccator, perforation, and chamber method. The gas analysis method is only used in the recommended product standard. The EU standard uses perforation, gas analysis, and chamber methods. (3) The limited value: the E1 limit value of perforation method in Chinese mandatory standard is higher than that of EU. E1 value of GB/T 11718 is the same as that in the European standard. The E1 limit value of chamber method in Chinese mandatory standard is lower than that in the EU, while the E1 value of GB/T 11718 is slightly higher than that in the European standard. The limit value of gas analysis method has two levels in the

EU, while the GB/T 11718 standard only provides one limit value, which is equivalent to the EU E1 level.

The implementation of these standards provides the basis for effective control of formaldehyde pollution. But there are also shortcomings, the differences of the limited value and the test methods between the standards cause the difference of judgment results.

2.3. Formaldehyde Testing Methods. Formaldehyde content and formaldehyde emission are two different concepts. Formaldehyde content refers to the number of milligrams of formaldehyde per 100 grams of panel, which is tested by using the perforation method. Formaldehyde emission is the amount of formaldehyde released from wood-based panels to a certain volume of air or a certain amount of water within a specified period of time, which is always tested by using chamber or desiccator method.

Zhu et al. [8] divided the testing methods of formaldehyde as three categories: total amount testing method such as perforation; static emission testing method such as desiccator; and dynamic emission testing method such as chamber. The chamber method is widely used in the United States and Germany. In the EU standards, chamber, gas analysis, and perforation methods are used. In Japanese standards, the desiccator method is used. According to Chinese mandatory national standard GB 18580-2001, MDF and PB are tested by perforation method, and plywood and block board are tested using the (9–11) L desiccator method. For the desiccator method, a 40 L desiccator is usually used to test the laminate flooring and parquet. If there is a controversy for the result, an arbitration method is used using a 1 m^3 chamber.

Each testing method has its own advantages and disadvantages. The chamber method is more close to the practical application in terms of temperature, relative humidity, loading rate, air exchange rate, and air velocity on the sample surface. The chamber body is large, and the testing time is long.

The unit and value of formaldehyde limit indicators of all levels (E0, E1, E2, and F★★★★) are different due to different testing methods. The units of formaldehyde content and emission are mg/100 g, mg/L, mg/m^3, and $mg/m^2 \cdot h$, corresponding to different test methods. mg/100 g is the unit of formaldehyde content in wood-based panel that refers to the formaldehyde content per 100 g wood-based panels, using the perforation test method. Three units mg/L, mg/m^3, and $mg/m^2 \cdot h$ are used for the formaldehyde emission. The unit mg/L corresponds to the desiccator method, which is related to temperature, specimen area, dryer volume, water volume, and collection time. The unit mg/m^3 corresponds to the chamber method related to the temperature and humidity, loading rate, ventilation, sampling port, sample size, sampling time, and analysis methods. The unit $mg/m^2 \cdot h$ corresponds to the gas analysis method using the measured concentration of formaldehyde, extraction time, and exposed area of the specimen to calculate the amount of formaldehyde emission and currently less used.

In the existing formaldehyde emission limited standards of wood-based panels, different types of wood-based panels are usually tested by different methods. Different countries have their own limits, coupled with the testing conditions, the difference between the pretreatment methods, and the type of panel. The test results of formaldehyde content in wood-based panel vary greatly, which is difficult to determine whether it is suitable for other national standards by using proprietary testing methods. Some scholars have analyzed and compared different testing methods, fitting a general formula by using data induction to convert the data of different testing methods. Li and Wang [9] calculated the slope of formaldehyde emission curve by using the one-way regression and analyzed the relationship of testing results between the perforation and the desiccator. Yu et al. [10] concluded that there was a certain linear correlation between the formaldehyde emission from MDF of perforation and gas analysis. Gu et al. [11] analyzed the correlation of different testing methods of formaldehyde emission from wood-based panels and converted the limited value corresponding to different methods of US ASTMD6007-2002, European EN717-2: 1994, Japanese JISA1460-2001, and Chinese GB18580-2001 by using the regression equation, which provide a reference for the enterprises to control formaldehyde emission of the products exporting to different countries. Research on the correlation of the different testing methods of formaldehyde emission from wood-based panels can use one method to predict the results of other testing methods, which provide a reference for the wood-based panel enterprise to control quality.

3. Factors Affecting the Formaldehyde Emission from Wood-Based Panel

Formaldehyde emission from wood-based panel can be a complicated process, which can be affected by (1) factors related to the materials, such as type of panel, wood species, adhesive, and overlay used for the panels; (2) factors related to the environment, such as temperature, humidity, air velocity, and air exchange rate; (3) factors related to treatment; and (4) factors related to panel fabrication process, such as resin content, moisture content of the panel, and others.

3.1. Factors Related to the Materials. Formaldehyde emission from the wood-based panels is affected by the physical and chemical properties of the products, such as formaldehyde content, component structure, chemical composition, density, thickness, and surface properties of the material.

The main source of formaldehyde is the adhesive. For example, the molar ratio (formaldehyde to urea, f/u) for the urea formaldehyde adhesive is an important factor affecting the formaldehyde emission. The higher the molar ratio (f/u), the greater the formaldehyde emission. Resin with a higher molar ratio will have more free formaldehyde, from which a large number of formaldehyde monomer are generated after consolidation of the panels. However, reducing the f/u molar ratio will lower the viscosity of the resin, and the activity and stability of adhesive can be affected. The amount of resin content significantly affects the formaldehyde emission of wood-based panels, especially during hot pressing. He [12] found that the content of formaldehyde in the adhesive is the main factor affecting the formaldehyde emission of wood-based panels. A correlation was obtained between the formaldehyde emission of the adhesive and the formaldehyde emission factor of the wood-based panel. That is, the higher the content of formaldehyde in the adhesive, the higher the level of formaldehyde emission from wood-based panel, and there is a good linear relationship between them.

Chemical composition of wood will change during cutting, drying, hot pressing, and other processing of wood-based panel, which may affect the formaldehyde emission of wood-based panels. Generally, the formaldehyde emission of PB made from low-density wood is higher than those made from high-density species [12].

MDF uses more adhesive than PB, which causes higher initial formaldehyde emission of MDF than PB. Li [13] tested the amount of volatile organic compound (VOC) emission and its composition of six kinds of commercial wood-based panels in a period of time for 28 days. It was found that the formaldehyde emission level from high to low was high-density fiberboard, medium-density fiberboard, PB, plywood, veneer MDF, and oriented strand board (OSB).

For the compression molded panels, less resin consolidation happens at the inner layers than that on the outer layers due to the lower temperature, higher moisture content, and lower pH value, which is easier to produce formaldehyde by hydrolysis, and a greater amount of free formaldehyde emission is from the core of the panel. Kim et al. [14] found that the amount of formaldehyde released from the edge of PB was significantly higher than that from the MDF because of a greater porosity of PB. Wang et al. [15] analyzed the influencing factors of formaldehyde emission from PB and concluded that hot pressing parameters and environmental factors had significant effects on the formaldehyde emission. The higher the moisture content of raw material, the greater the formaldehyde emission. Higher temperature or longer hot pressing time will reduce the amount of formaldehyde emission, but increase the cost. Usually, the formaldehyde emission of thicker panel is lower than the thinner one because of more energy absorption.

3.2. Factors Related to the Environmental Conditions. Many scholars have studied the influence of environmental factors on the formaldehyde emission from wood-based panel, such as temperature, relative humidity, and ventilation rate, and tried to establish various mathematical models and formulas.

3.2.1. Ambient Temperature. Lin et al. [16] found that formaldehyde emission rate and its concentration increased 1.5–12.9 times when the temperature was raised from 15°C to 30°C. Chi [17] tested the formaldehyde emission of plywood, MDF, block board, and laminate at different temperatures and loading rates using the 1 m^3 small chamber. The results showed that the higher temperature accelerated the formaldehyde release. The higher the temperature, the faster the initial growth rate and the greater the final concentration. It was found that the formaldehyde emission would increase 10%–30% if the temperature was increased by 5°C [17]. Temperature increases the kinetic energy and speeds up the diffusion rate of formaldehyde molecules. In the meantime, high temperature leads to decomposing adhesive, which increases the formaldehyde release. However, these methods that they used cannot estimate the emission under other temperature. Therefore, the correlation equation will have more practical value. According to the studies carried out by Mayers [18], the effect of temperature on the indoor formaldehyde concentration showed an exponential relationship. The diffusion coefficient (D), partition coefficient (K), and the initial emittable concentration ($C_{\mathrm{m},0}$) are the three key parameters used to predict the formaldehyde emissions. Zhang et al. [19] found that D and K may be strongly affected by temperature, the partition coefficients (K) decrease while the diffusion coefficients (D) increase with increasing temperature, and they developed a formula to study the influence of temperature on K by experiments and theoretical analysis, which is as follows:

$$K = P_1 T^{1/2} \exp\left(\frac{P_2}{T}\right), \tag{1}$$

where P_1 and P_2 are constant for a given adsorbent and adsorbate.

Deng et al. [20] derived a new correlation between D and T based on the assumption that molecular diffusion is dominant. The equation is as follows:

$$\frac{D}{T^{1.25}} = B_1 \exp\frac{B_2}{T}, \tag{2}$$

where B_1 and B_2 are constants for a given adsorbent and adsorbate.

Huang et al. [21] derived the relationship between $C_{\mathrm{m},0}$ and temperature:

$$C_{\mathrm{m},0} = \frac{C}{\sqrt{T}} \exp\left(-\frac{A}{T}\right), \tag{3}$$

where $\mathrm{C} = \mathrm{C}_{0,\mathrm{total}} \exp(B)$, $C_{0,\mathrm{total}}$ is the total concentration, $A = \varepsilon_0/k_B$, and B is a constant. The derived correlations (3) quantitatively establish the relationship between P, $C_{\mathrm{m},0}$, and T for formaldehyde emissions from building materials. When the parameters A and C in (3) are obtained from available results, the derived correlations can be used to predict the emittable ratio P and $C_{\mathrm{m},0}$ at other temperatures. This is very helpful for predicting the emission characteristics of pollutants at various temperatures.

3.2.2. Humidity. Mayers [18] showed that the higher the humidity, the more the formaldehyde emission. A linear relationship between humidity and formaldehyde concentration in the test chamber was found for the wood-based panel. Lin et al. [16] found that the formaldehyde concentration and release rate increased up to 32 times, when the relative humidity in the chamber was increased from 50% to 80%. Frihart et al. [22, 23] tested the formaldehyde emissions from urea formaldehyde- (UF-) bonded PB and found that the emission rate increased 6–9 times when the RH was increased from 30% to 100%. Parthasarathy et al. [24] tested the steady formaldehyde concentration in the chamber and found that the formaldehyde release rate increased 1.8–3.5 times when the relative humidity increased from 50% to 85%, because the reaction of weak acidic steam in the air and the free dimethylol oligomer in the UF resin can generate formaldehyde, which can be hydrolyzed to release formaldehyde. It should be pointed out that these studies mainly focused on the analysis of formaldehyde concentrations or emission rates at steady or equilibrium conditions, and the results would not be appropriate to be applicable to actual indoor spaces with variable environmental conditions.

3.2.3. Combined Environmental Factors. Li [13] studied the formaldehyde emission of wood-based panel at different environmental factors, such as temperature, relative humidity, and gas exchange rate. The results showed that temperature affects the formaldehyde emission rate interacting with the vapor pressure of the compound inside the panel. Relative humidity affects the formaldehyde emission rate interacting with the evaporation of water vapor inside the panel. Gas exchange rate affects the formaldehyde emission rate interacting with the concentration gradient of boundary layer of the panel. Therefore, the formaldehyde emission rate of panel can be increased by raising the temperature, relative humidity, and gas exchange rate, especially at the early stage when the panel is used.

Guo et al. [1] studied the relationship of the mean formaldehyde concentration (C_{HCHO}) and potential factors, such as 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 correlating the indoor average formaldehyde concentration to these five factors (T, RH, DC, DR, and d) was established based on 298 samples ($R^2 = 0.87$). The relationship among five dominant factors can be expressed as

$$\begin{aligned} In(C_{\mathrm{HCHO}}) = & -20.2\left(\frac{273.15}{T+273.15}\right) - 27.6\left(\frac{1}{\mathrm{RH}}\right) \\ & + 0.124 \times In(\mathrm{DC}+1) - 2.85 \times 10^{-3} \times \mathrm{DR}^2 \\ & + 0.8 \times d + 16.6\left(R^2 = 0.87\right). \end{aligned} \tag{4}$$

Each factor contributes to the formaldehyde concentration in the following order: T, 43.7%; d, 31.0%; DC, 10.2%; DR, 8.0%; and RH, 7.0%. Specifically, meteorological conditions (i.e., RH plus T) accounted for 50.7%. The coefficient of T and RH, RTH, was proposed to describe their combined influence on formaldehyde emission, which also had a linear relationship ($R^2 = 0.9387$) with formaldehyde release in a simulation chamber test. In addition, experiments confirmed that it is a synergistic action as T and RH accelerated the release of formaldehyde and that it is a significant factor influencing indoor formaldehyde pollution. These achievements could lead to reference values of measures for the efficient reduction of indoor formaldehyde pollution.

Yang et al. [25] studied the combined effects of relative humidity and temperature on the formaldehyde emission and the emission parameters (K, D, and $C_{\mathrm{m},0}$), and a theoretical model of the emission parameters K, D, and $C_{\mathrm{m},0}$, relative humidity, and temperature was developed.

$$C_{\mathrm{m},0} = a \cdot \mathrm{RH} + b \cdot T + c \cdot \mathrm{RH}^2 + d \cdot T^2 + e, \tag{5}$$

where $a = -26.75$, $b = 12953.85$, $c = 0.319$, $d = -21.56$, $e = -1{,}940{,}260$, and $R^2 = 0.971$.

$$K = a + bIn(\mathrm{RH}) + cIn(T), \tag{6}$$

where $a = 49857.35$, $b = -295.89$, $c = -8399.03$, and $R^2 = 0.994$.

$$D = a + b \cdot \mathrm{RH} + c \cdot \exp\,(d \cdot T), \tag{7}$$

where $a = 2.249 \times 10^{10}$, $b = -4.667 \times 10^{10}$, $c = -4.833 \times 10^{10}$, $d = -0.315$, and $R^2 = 0.974$.

These models can predict the emission parameters of formaldehyde in different temperatures and humidity and predict the equilibrium concentration of formaldehyde in the air by combining with the panel release model.

Huang et al. [26] developed a theoretical model (8) using indoor temperature, humidity, and air change rate, to predict indoor formaldehyde concentrations.

$$V\frac{dC}{dt} = Q(C_{\mathrm{a}} - C) + E(t) \cdot A - S(t), \tag{8}$$

where C_{a} is the ambient formaldehyde concentration (μg/m^3), C is the indoor formaldehyde concentration, V is the volume of the room (m^3), Q is the ventilation rate of the room (m^3/h), $E(t)$ is the formaldehyde emission rate from the indoor sources per unit area (μg/(m^2·h), A is the emission area of the sources (m^2), $S(t)$ is the adsorptive rate of indoor sinks (μg/h), and t is the emission time (h).

Analysis using this equation showed that the indoor formaldehyde concentrations in northern China were 4.0 times greater than those in southern China. This result was indirectly affected by China's heating policy and building energy efficiency standards.

The above studies show that the higher the temperature and humidity, the better ventilation and the more conducive to the formaldehyde emission. So during the interior decoration, increasing the environment temperature, humidity, and air change rate can accelerate formaldehyde emission.

3.3. Treatment of Wood-Based Panel on Formaldehyde Emission

3.3.1. Surface Sealing Method. For most wood-based panel products, such as PB or MDF, surface overlays are usually used for decoration purpose, which can effectively reduce the formaldehyde emission.

Barghoor [27] compared the formaldehyde emission of the wood-based panels with different methods for surface overlays using test chamber, and the results are summarized in Table 2.

Barry and Corneau [28] evaluated the effectiveness of 10 different surface treatment methods as emission barriers for formaldehyde and total volatile organic compounds

Table 2: Effect of different surface sealing methods on the indoor formaldehyde concentration.

Sealing methods	Formaldehyde concentration (ppm)
Substrate, no sealed edge	1.20
Veneer, sealed edge	0.81
Slim wood veneer, sealed edge	0.10
Panel decorated by melamine, no sealed edge	0.10
Panel decorated by melamine, sealed edge	0.02
Polyester paint panel, no sealed edge	0.09
Polyester paint panel, sealed edge	0.02
SH covered panel, sealed edge	0.08
Stick film, sealed edge	0.03

(TVOC). These include paint, UV topcoat, acrylic topcoat, vinyl resin system (ethyl-vinyl acetate), phenolic saturated film, melamine saturated paper, multiple (3) topcoat wet process, foil resin system (polyvinyl acetate), and powder coating. Three MDF and four unfinished PB products from different manufacturers were used in the experiments. The results showed that the epoxy powder coatings used to finish the MDF samples performed the best, achieving 99+% emission reduction in formaldehyde and up to 94% reduction of TVOC emissions (noted as 99+%/94%). This was compared to reductions of 89%/85% for the UV paint and 11% (27% increase) for the acrylic-painted topcoat on MDF. A multiple (3) topcoat wet process treatment showed a 28% reduction in formaldehyde emissions but an increase in TVOC emissions, suggesting that the coating may have a high solvent content. The respective formaldehyde/TVOC emission reductions for the laminates were 99%/88% for phenolic paper laminates, 99%/66% for vinyl, 93%/85% for the 80 g melamine paper, and 73%/75% for the 60 g foil on PB. These very limited data suggest that several of the treatments are very efficient formaldehyde and TVOC emission barriers when applied to PB and MDF, although epoxy powders are typically applied only to MDF.

Chen et al. [29] studied the effect of different surface finishes of PB on reducing TVOC and formaldehyde emission. These finishes and coatings include wood veneer, polypropylene film paper, low-pressure melamine-impregnated paper (80 g, 120 g), water-based polyurethane coatings, and water-based polypropylene coatings. The experiment results showed that formaldehyde and TVOC concentrations were different for surface finishing treatments. Among these finishes and coatings, polypropylene film paper was the best barrier to TVOC and formaldehyde, which reduced 84.18% of TVOC and 71.43% of formaldehyde, while the TVOC concentrations of water-based coatings containing high VOC were higher than those of the unfinished PB. Twenty-one kinds of VOCs were identified from the unfinished PB and 15 kinds of VOCs from the veneer-overlaid PB by the method of GC-MS, and the content of VOCs from the veneer-overlaid PB was over 50% lower than that of VOCs from the unfinished boards.

Park et al. [30] conducted a study to understand the effect of surface laminating materials on the formaldehyde emission from PB and MDF with or without edge sealing, using 24-hour desiccator method. For the PB, the edge sealing could reduce the formaldehyde emission by 37.4% for low-pressure laminate (LPL) and 80.7% for polypropylene (PP) film lamination. The surface-laminated MDF with the sealed edges also showed a decrease in the emission up to 57.8% and 54.3%, with the poly(vinyl chloride) (PVC) film bonded by a solvent-based adhesive or with coating cured by ultraviolet radiation, respectively. However, the coated MDF samples showed 5.3% increase in the emission when their edges were sealed, indicating the formaldehyde was formed the solvent used for coating. Therefore, the type of surface lamination materials on wood-based panels has a great impact on their formaldehyde emission.

3.3.2. Edge Sealing Method. A great number of experiments show that the main channel of formaldehyde emission is the side face, which is generally at least two times more than the surface. So edge sealing can effectively reduce formaldehyde emission when using the wood-based panels in making the decorative components and furniture parts. Kim et al. [14] tested the formaldehyde emissions from PB and MDF by the desiccator according to Japanese Industrial Standard (JIS A 1460), and the edges of each sample were sealed by paraffin film, polyethylene wax, or aluminum foil; the results showed that the difference between the edge seal methods was much smaller than that from the unsealed specimen.

The edge sealing can only slow down the formaldehyde emission rate, while the overall formaldehyde content in the board remains the same. However, the advantage of the edge sealing is to reduce the formaldehyde emission during a certain period so that the formaldehyde effect on the human health is much reduced.

3.4. The Structure of Wood-Based Panel Products on Formaldehyde Emission. The furniture and decoration components made from wood-based panel are usually assembled with hardware, from which many predrilled holes and notches are on the panels. The amount of holes on the side panels of the furniture is usually dozens to hundreds. Many holes are deep to the center of the panel. A greater amount of formaldehyde escapes from these structural holes and notches because the intermediate layer of wood-based panel generally has a higher formaldehyde emission capacity than that from the surface layer. Therefore, it will not be able to truly reflect the actual level of formaldehyde emission if the test of formaldehyde emission from wood-based panel products does not consider the impact of these factors. One of the effective ways to reduce the formaldehyde release is to use the reasonable connection structure to minimize the number of holes on the panels in the practical application of wood-based panels.

3.5. The Relevancy of Formaldehyde Emission and Loading Ratio of Wood-Based Panel. The formaldehyde emission of wood-based panel is not only related to the content of formaldehyde and environmental factors but also to the surface treatment of wood-based panel products and structure processes. For the recent years, people pay more attention to the mechanism of formaldehyde emission from wood-based panel and environmental factors and put forward some targeted measurements to reduce formaldehyde emission. However, in the existing technical conditions of wood-based panel manufacturing, even if the panel meets the current national or international standards, it will still have the accumulation of release in a certain indoor space which lead to the indoor formaldehyde concentration exceeds the limit value of the indoor air quality standards. Therefore, the development of formaldehyde limit standards should also take into account the amount of wood-based panel (i.e., the loading ratio). The so-called loading ratio refers to the ratio of the total surface area of wood-based panels exposed to the air and the volume of indoor space, $L\ (=S/V)\ \mathrm{m}^2/\mathrm{m}^3$.

The studies conducted by Andersen et al. [31] found that with an increase of loading ratio, the indoor formaldehyde concentration per cubic meter space increased significantly. Therefore, the interior decoration design must consider the amount of wood-based panel. Using 1 sheet or 10 sheets of wood-based panels in the same space, the indoor formaldehyde concentration is completely different.

According to Li [13], the concentration of VOC in the chamber will increase with the higher loading ratio, but the concentration in the chamber is not proportional to the loading ratio; the release rate of high loading ratio will be lower than the value of low loading ratio times the corresponding multiple, because the high loading ratio increases the concentration in the chamber and the concentration gradient of the boundary layer decreases which inhibited formaldehyde release from the panel. Chi [17] found that increasing the loading ratio can reduce the formaldehyde emission from per unit volume of panel.

At present, from the formaldehyde release standards in all countries, only the United States standards (ANSI) are established on the basis of a certain loading ratio to limit formaldehyde emission of wood-based panel.

Increasing temperature and loading rate will increase the indoor formaldehyde content. The temperature will promote the formaldehyde release from panel, and the loading ratio will increase the release source. So, the designing of decoration and furniture will not only select qualified wood-based panel as raw materials but also consider how to properly control the amount of wood-based panels under the influence of various environmental factors.

4. Conclusions and Discussion

The review provides the basis for the improvement of the design of interior and furniture design by reasonably determining the quantitative index of wood-based panel loading rate in a specific space, which can provide technical support for the interior decoration design, and change from passive monitor and governance after the completion of the project to actively predict indoor air pollution level at the design stage, ultimately to guide the design and control the amount of wood-based panels to optimize the indoor air quality. Based on the actual interior design project, take the residential interior space as the sample and the wood-based panel as the research object, analyzing the influencing factors of formaldehyde emission from the wood-based panel and conducting the orthogonal experiment and multiple regression analysis of the experimental data to establish the model of formaldehyde emission and loading rate to determine the quantitative index of wood-based panel in specific space. At the same time, with the help of computer simulation technology, Airpak software can be used to simulate indoor formaldehyde gas distribution and establish prediction model of indoor formaldehyde concentration, which can predict the indoor formaldehyde concentration based on the space volume, temperature and humidity, ventilation status, and exposed area of wood-based panel, then to determine conditions of the indoor formaldehyde concentration to meet the standards, and verify the feasibility of the simulation results by the specific design. This will provide new ideas for the study of formaldehyde emission from wood-based panels, which will be a strong social utility and significant theoretical innovation.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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