Study on the Influence of Building Materials on Indoor Pollutants and Pollution Sources

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Abstract. The paper summarizes the achievements and problems of indoor air quality research at home and abroad. The pollutants and pollution sources in the room are analyzed systematically. The types of building materials and pollutants are also discussed. The physical and chemical properties and health effects of main pollutants were analyzed and studied. According to the principle of mass balance, the basic mathematical model of indoor air quality is established. Considering the release rate of pollutants and indoor ventilation, a mathematical model for predicting the concentration of indoor air pollutants is derived. The model can be used to analyze and describe the variation of pollutant concentration in indoor air, and to predict and calculate the concentration of pollutants in indoor air at a certain time. The results show that the mathematical model established in this study can be used to analyze and predict the variation law of pollutant concentration in indoor air. The evaluation model can be used to evaluate the impact of indoor air quality and evaluation of current situation. Especially in the process of building and interior decoration, through pre-evaluation, it can provide reliable design parameters for selecting building materials and determining ventilation volume.

1. Introduction
The room is the main place for human life and work. With the development of society and economy and the improvement of people's living standard, the function room is not only a shelter, more important is to provide a good working and learning environment, and the elegant and comfortable rest of humanity. A large number of surveys show that the amount of fresh air inhaled per person per day is 10 ~ 12m³, while the average 80% ~ 90% of the time is spent indoors [1]. Thus, indoor environment has an important impact on human health and work efficiency. The indoor environment includes air environment, thermal environment, wet environment, light environment, sound environment and many other environmental elements. To provide a healthy and comfortable indoor environment is the basic purpose of modern residential construction [2]. However, since the 1970s, due to the extensive use of organic synthetic materials in interior decoration and equipment, the volatile organic compounds (VOCs) have been widely distributed, which has seriously deteriorated the indoor air quality (IAQ) [3]. In order to save energy, the building closures continue to improve, correspondingly reducing the amount of indoor and outdoor air exchange. As a result, indoor air pollution caused a variety of diseases, and it is collectively referred to as "sick building syndrome" (SBS). From the development trend, indoor air pollution is becoming more and more serious [4]. The study of indoor air quality has
become a hot topic in the field of environmental science and engineering. In recent decades, experts and scholars at home and abroad have done a lot of research on the issue of indoor air quality, and gradually deepened their understanding of indoor air quality. In the developed countries, such as the United States and Japan, the research work has been carried out earlier and achieved certain results. However, the prospect of a comprehensive and systematic solution to this problem is still not optimistic.

In the mid-1980s, the World Health Organization (WHO) proposed a new concept of healthy housing. This is the people's quality of life after the increase in the construction of the inevitable requirements [10]. In the process of a comprehensive realization of a well-off society in China, people hope that modern housing is not only safe, beautiful, but also healthy and comfortable, which is consistent with the world's value orientation. In other words, healthy residential is undoubtedly the future of China's urban construction in the sustainable development goals and direction [9]. Healthy homes require the use of environmentally friendly building materials and a scientific indoor environment design. Today, China's housing construction is developing rapidly, and the interior decoration is booming [5]. The impact of building materials and decoration works on indoor air quality has become the focus of attention. The room here is not confined to the space where we live in. It includes all the interior space of daily life and work, such as offices, conference rooms, classrooms, hospitals and other indoor space environment and hotels, shops, theaters, libraries, stadiums, gymnasiums, dance halls, and other indoor public places and civil aircraft, passenger cars, trains and other transport. Some new ideas now suggest that indoor microclimate should also include indoor work and production sites [8]. In the standard ASHRAE62-1989 issued by the American Society of Heating, Refrigeration and Air Conditioning Engineers, an acceptable concept of indoor air quality is proposed, which basically improves the definition of indoor air quality. The standard is defined as follows: The concentration of contaminants known in indoor air does not meet the harmful concentration targets identified by recognized authorities. And in the vast majority of people in the space (more than 80%) have not expressed dissatisfaction on the indoor air. This definition reflects the leap in people's cognition, which combines objective evaluation with subjective evaluation. It is more scientific and comprehensive [6]. Therefore, the definition has been widely recognized and accepted and applied by the international community [7].

2. Methodology

2.1. Factors affecting indoor air quality

Indoor air quality indicators can be divided into chemical, physical, biological and radioactive. These indicators are related to indoor and outdoor environmental factors. Outdoor environmental factors include ventilation system parameters such as air quality and ventilation, and building parameters such as building volume, area, airtightness, insulation and so on. Indoor environmental factors include indoor air pollution sources, such as building materials, human activities and indoor products, and pollutant attenuation and purification performance. Indoor air quality is the result of a variety of factors and process interactions. These factors and processes are constrained by architectural design, decoration works, and residential activities. Indoor air quality indicators are mainly determined by the composition of indoor air. Indoor pollution sources will increase the concentration of pollutants and worsen indoor air quality. The introduction of clean outdoor air can improve indoor air quality. In addition, air exchange rate, pollutant characteristics and mixing model also affect indoor air quality.
Concentration of outdoor contaminants: The outdoor air quality varies with time and space, while indoor air changes with the outdoor air pollutant concentration [15]. However, indoor variation lags behind outdoor and the peak concentration is lower than outdoor. The speed and degree of indoor air quality in response to outdoor air quality depends primarily on the air exchange rate. If the concentration of a contaminant in the room is constant, the indoor and outdoor concentrations of the contaminant will eventually be balanced.

Concentration of indoor contaminants: According to the release characteristics of pollutants, indoor pollution sources can be divided into two types of intermittent and continuous pollution sources. Disruptive sources of cooking and smoking are triggered by human activities. Once the activity stops, the contaminant concentration drops sharply. The longer the activity lasts, the greater the intensity, the higher the maximum concentration of indoor pollutants. The construction and decoration materials, furniture and other continuous pollution sources release pollutants relatively stable. The concentration of indoor pollutants is proportional to the rate of pollutant release [11]. With the increase of source intensity and temperature, the pollutant release rate increases, and the indoor pollutant concentration increases.

Indoor and outdoor air exchange: In accordance with the work of power, indoor and outdoor air exchange is divided into natural ventilation and mechanical ventilation. According to the scope of work, it is divided into local ventilation and comprehensive ventilation. The air exchange rate is the rate of indoor and outdoor air exchange, which is expressed in units of time through the ratio of the volume of air to the space in a particular space. The unit is time / hour (h⁻¹). The air exchange rate directly affects the rate of indoor pollutant concentration with outdoor changes [12]. The higher the air exchange rate, the faster the indoor concentration follows the outdoor changes. In addition, the air exchange rate also determines the time required to reduce the concentration of pollutants. For the same indoor pollution event, the higher the air exchange rate, the shorter the time required for indoor concentration reduction. The air exchange mode also affects the indoor air quality, and the ventilation mode should be chosen according to the characteristics of indoor pollution.

Area and volume of a building: The concentration of indoor pollutants is related to the indoor area and volume of the building, and the indoor space area determines the amount of pollutants used in the construction and decoration materials [16]. The larger the building area, the more the release of pollutants. The volume of indoor space determines the diffusion volume of pollutants. When the pollution source remains unchanged, the indoor pollutant concentration decreases as the volume of the building increases. Under normal circumstances, the distribution of pollutants in buildings is not uniform, and the specific distribution depends on the location of the source of pollution and air circulation. When the location of the pollution source is determined, the concentration inside the building will depend mainly on the air circulation [13].
The nature of the pollutant: The nature of the pollutants is also an important factor in determining the concentration of the room. Whether the pollutants are produced indoors or outdoors, it may be depleted in some way. These ways include gas conversion, particulate matter sedimentation, surface absorption and adsorption. Indoor pollutants have different chemical reactions and physical changes in the ability, which makes the concentration of pollutants with the time of the attenuation process is very different [14].

Pollutant purification: The air purifier can improve indoor air quality without increasing the air exchange rate. The improvement depends on the nature of the pollutants and the performance of the air purifier.

2.2. Test device
The volume of the environmental test chamber is usually between a few liters and several tens of cubic meters. Small environmental test cabin volume is 60L or 1m³. The enclosure of the environmental test chamber is made of chemically inert material and does not adsorb or desorb the test object. The test device consists of the following parts: test cabin, humidification and humidity regulation, constant temperature and temperature regulation, cabin environmental monitoring and control, clean air generation, sampling and analysis. The small environmental test chamber diagram is as shown in Figure 2.

![Figure 2. The small environmental test chamber diagram](image)

2.3. Test condition
The test conditions and performance requirements of the environmental test chamber are shown in Table 1.

| Parameter                 | Performance requirements                  |
|---------------------------|------------------------------------------|
| Temperature               | 18 ~ 35 °C, commonly used 23 °C ± 1 °C   |
| Relative humidity         | 20% ~ 80%, commonly used 45% ± 5%        |
| Air exchange rate         | 0.5~3h⁻¹, commonly used 1h⁻¹              |
| Sample surface wind speed | > 0.3m · s⁻¹                              |
| Sample loading rate       | 0.4 ~ 2.0m² · m⁻³, commonly used 1.0m² · m⁻³ |

2.4. Sample preparation and handling
Solid material refers to the solid building materials used in the room, including man-made sheet, chemical fiber wallpaper, plastic and so on. Wet material is liquid or paste, including coating, paint and so on.

Sample preparation: When collecting samples from the site (production, distribution, use), the solid material samples should be sealed with aluminum foil and the wet material samples should be kept in the original packaging. And record the sampling time, production time, storage environment and other
relevant information. Place the material sample in a room similar to the air condition of the test room for two weeks.

Sample treatment: When the solid material sample is thick, the cross-sectional area of the sample area is more than 5%. When testing, it should be done with edge sealing, and the cross section shall be sealed with aluminum foil to eliminate the error caused by the release of the section. The wet material itself has no fixed shape. When testing, this material should be coated on the support plate to form a film with a thickness of 0.1 ~ 0.2mm, and then the supporting plate coated with film will be hung in the cabin. Sample quantity: according to the test sample filling rate L and the test chamber volume V, the material sample area is A = L * V (m²), and the sample filling rate should be close to the actual value.

2.5. Gas sampling and analysis
The release properties of pollutants in different materials are very different, and it is difficult to meet the requirements with a set of fixed sampling methods. The sampling time and sampling frequency depend on the time during which the test chamber concentration reaches equilibrium. At the beginning of the test, the concentration change is large, the sampling time is short and the sampling frequency is high. While the late concentration decreased slowly and the concentration was low. The sampling time can be lengthened and the sampling frequency should be reduced accordingly. In general, wet materials are larger than the initial release rate of solid materials and are attenuated quickly. Therefore, at the beginning of the experiment, it must collect the instantaneous sample to truly represent the change in the concentration of the cabin.

The environmental test chamber can be automatically measured, recorded and controlled. The concentration of pollutants in the tank can be measured directly by the automatic analyzer, continuously measuring the change of the concentration, plotting the pollutant concentration with time to change the curve, and then establish the pollutant release model of the measured material. In addition, the concentration of contaminants in the effluent gas from the chamber can be measured by spectrophotometer or gas chromatograph.

3. Experiments

3.1. Determination of model parameters
The initial release rate E₀ and the decay constant k of formaldehyde were determined by the equilibrium method of small environmental test chamber.

Test conditions: the small environmental test chamber capacity is 60L. The loading rate of the block board sample is \( L = 1.0 \text{m}^2 \cdot \text{m}^{-3} \). The area is 10cm × 30cm × 2 surface = 0.06m². Air exchange rate \( N = 1.0 \text{h}^{-1} \). The cabin temperature is 23 °C ± 1 °C. Cabin relative humidity of 45% ± 5%. The gas flow in the tank is 1.0L · min⁻¹.

Test results: the test results are listed in Table 2, and the unit is ppm. And the conversion of the relationship of 1 ppm = 1.24 mg · m⁻³ at 23 °C is converted into data in mg·m⁻³ units of measurement. The steady state release mode was used to calculate the rate of formaldehyde release. Since \( L = 1.0 \text{m}^2 \cdot \text{m}^{-3} \), \( N = 1.0 \text{h}^{-1} \), the formaldehyde emission rate is equal to the formaldehyde concentration.

As can be seen from Figure 3, the rate of formaldehyde release (or concentration) changes with time. In 0 ~ 60min, the formaldehyde concentration increases rapidly, which is called the growth period, as shown in Figure 3 (a). In 4 ~ 12h, the formaldehyde release is relatively stable, which is called the stability period, as shown in Figure 3 (b). In the stable period, every 1h is measured once, until the result of four successive measurements is within the range of ± 5% of the mean. The measurement result is the equilibrium concentration of formaldehyde. The equilibrium concentration of formaldehyde was 3.57 mg · m⁻³. In 10 ~ 90d, formaldehyde concentration decreased rapidly, which is called the decay period, as shown in Figure 3 (c) below.
Table 2. The formaldehyde releases velocity of wood-based panels in environmental test chamber

| Time  | Test results / ppm | Formaldehyde concentration / mg · m$^{-3}$ | Release rate / mg · m$^{2}$ · h$^{-1}$ |
|-------|--------------------|--------------------------------------------|--------------------------------------|
| 0min  | 0.00               | 0.00                                       | 0.00                                 |
| 10min | 1.38               | 1.71                                       | 1.71                                 |
| 20min | 2.01               | 2.49                                       | 2.49                                 |
| 30min | 2.48               | 3.08                                       | 3.08                                 |
| 40min | 2.78               | 3.45                                       | 3.45                                 |
| 50min | 3.01               | 3.73                                       | 3.73                                 |
| 60min | 3.17               | 3.93                                       | 3.93                                 |
| 90min | 3.31               | 4.10                                       | 4.10                                 |
| 120min| 3.18               | 3.94                                       | 3.94                                 |
| 150min| 3.14               | 3.89                                       | 3.89                                 |
| 180min| 3.59               | 4.45                                       | 4.45                                 |
| 4h    | 3.71               | 4.60                                       | 4.60                                 |
| 5h    | 3.31               | 4.10                                       | 4.10                                 |
| 6h    | 3.43               | 4.25                                       | 4.25                                 |
| 7h    | 3.15               | 3.91                                       | 3.91                                 |
| 8h    | 3.45               | 4.28                                       | 4.28                                 |
| 9h    | 3.02               | 3.74                                       | 3.74                                 |
| 10h   | 2.91               | 3.61                                       | 3.61                                 |
| 11h   | 2.79               | 3.46                                       | 3.46                                 |
| 12h   | 2.81               | 3.48                                       | 3.48                                 |
| 10d   | 2.58               | 3.20                                       | 3.20                                 |
| 20d   | 1.56               | 1.94                                       | 1.94                                 |
| 30d   | 1.11               | 1.38                                       | 1.38                                 |
| 60d   | 0.85               | 1.06                                       | 1.06                                 |
| 90d   | 0.60               | 0.75                                       | 0.75                                 |
| 120d  | 0.66               | 0.82                                       | 0.82                                 |
| 150d  | 0.59               | 0.73                                       | 0.73                                 |
| 180d  | 0.52               | 0.65                                       | 0.65                                 |

(a) The growth period
3.2. Discussion and analysis
Through the practical application of the above mathematical model, the prediction results and the changes of formaldehyde concentration are analyzed, and the following conclusions can be drawn: Formaldehyde concentration in the room in a relatively short period of time will grow rapidly. After a dozen hours, the formaldehyde concentration reached its maximum and then began to decline. In the process of decline, at first it drops rapidly, then gradually tends to be smooth.

The mathematical model can not only be used to analyze and describe the variation of pollutant concentration in indoor air, but also has the following practical purposes: The model can predict the concentration of contaminant concentration in indoor air for a certain period of time, thus providing the owner with the best time to check in and improve indoor air quality. Under the condition that the indoor air quality and parameters are certain, the model can be used to calculate the use of various building materials, and to provide reference for the selection of building materials. In the design of indoor ventilation and air conditioning, it can provide reliable parameters for determining indoor ventilation.
There are many kinds of materials used in interior decoration and decoration. In the pre-evaluation of indoor air quality, the concentration of pollutants released by each material should be calculated first. Then, the pollutant concentrations of various materials are superimposed. Finally, considering the background value of pollutants, the impact assessment of indoor pollutant concentration is carried out. The above example shows that the mathematical model can be used to analyze the variation law of pollutant concentration in indoor air. In the evaluation of indoor air quality in building decoration projects, it can be used to predict the concentration of indoor pollutants at a given time, and provide reliable parameters for the selection of building materials and the determination of ventilation volume.

4. Conclusion
This paper first analyzes the various factors that affect the quality of indoor air. According to the principle of mass balance, the basic mathematical model of indoor air quality is established. Then, the building materials are taken as the main indoor pollution sources, and the release and diffusion laws of pollutants are analyzed. Finally, the mathematical prediction model of indoor air pollutants is deduced. By using the balance concentration method of environmental cabin, two parameters of initial release rate $E_0$ and attenuation constant $k$ in the model are determined. The experimental results show that the species and air exchange rate of building materials are important parameters to determine indoor air quality. The mathematical model can be used to analyze and describe the variation of pollutant concentration in indoor air, and to predict and calculate the concentration of pollutants in indoor air during a certain period of time. In addition, it also provides a scientific basis and method for the pre-evaluation of indoor air quality for building renovation projects.

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