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Emission Law of Chemical Pollutants in Buildings

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The indoor environmental quality in a building is one of the most important conditions that guarantee people's work and life. Indoor air pollution has become a burning issue that needed to be settled now. To grasp the emission law of indoor fine particles and drill down the control technology for chemical pollutants in the house, this paper traces a field survey on how the airborne pollutants will diffuse and what they will have an impact on air quality in the residential buildings. An experiment is also conducted on 100 new buildings randomly chosen as samples to trace and measure the concentrations of chemical pollutants in the houses, so that the relationship between the concentration of chemical pollutants and measurement schedules is built herein. Then, further analyze the change law of concentrations of fine particles. It is found by experiments that the concentrations of benzene and its series in the residential houses rise up rapidly after the room is filled with furniture, but roughly remains constant after 100 days of test. The results from experimental analysis help plot an indoor air quality decision tree to provide the clues to improving indoor air quality and reducing health threats.

1. Introduction

Fine particles refer to those whose aerodynamic equivalent diameter is less than 2.5 μm in the environment (Logue et al., 2011). Fine particles feature minor equivalent diameter, large specific surface area, strong activity, easy to adsorb toxic and hazardous substances, long transport distances and long dwell time in the air, as well as severe detriment to human health. In particular, they attack the human cardiovascular system and respiratory system more strongly (Kagi et al., 2007; Aranyi et al., 1986). The chemical composition of particles is also more complex and can be divided into three layers both inside and outside: the innermost layer includes organic and inorganic carbon, polycyclic aromatic hydrocarbons and other components generated during the combustion process; the interlayer has industrial emissions, soil and metals and trace elements generated during the combustion, e.g. silicon, zinc, copper, iron, and platinum, etc.; while in the outermost layer, there are water-soluble ion components generated by chemical reaction of gases such as SO_2, NO_x and NH_3 (Yinet al., 2015; Ishimoto et al., 2014). These components are easily digested as toxic and harmful substances to accumulate in the body and cause organs to appear local inflammation, and even endanger human health and life (Alaves et al., 2013).

In recent years, many countries in the world have been seriously polluted by fine particles, and these in the atmosphere have become the primary pollutants in many cities and countries (Zhang et al., 2012). Fine particles in the air can enter the house by ways of penetration or fluxion, they will ruin the indoor environment and pose a threat to human health (Zhang et al., 2016; Ullah et al., 2011). The indoor environment in the building includes a series of physical conditions such as the heat and humidity, temperature, light, air flow, and chemical trace gases in the air. To improve the indoor environmental quality and fit the bill for people's comfort, it is compulsory to conduct the survey on how indoor chemical pollutants transmit in a law and how to reduce indoor pollutant concentrations, so as to improve indoor air quality (Veltman et al., 2009, Zhang, et al., 2007; Holt, 2000). The available literature that involve the emission law of existing particles all focus on outdoor observation data. Most of the time, people work and have a rest in the houses, so that people are exposed to indoor pollutants more frequently. Chemical components, particle sizes and concentrations of indoor and outdoor air pollutants also differ a lot. In this sense, it is imperative to conduct a survey to find out what the emission law of chemical contaminants in the building seems (Skóra et al., 2016; Inamul, 2003).

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2. Emission law of indoor chemical pollutants

2.1 Experiment method

The concentrations of indoor pollutants are tested with a passive sampler. Activated carbon gas sample tube and 2,4-dinitrophenylhydrazine are used to absorb volatile organic compounds and benzene series in the indoor air. Among them, 10L formaldehyde is sampled at a flow rate of 0.5L/min, and then detected using gas chromatography. Benzene and xylene in the air should be collected using activated charcoal tube, and desorbed with carbon disulfide, separated by capillary column chromatography, and measured by a hydrogen flame ionization detector. At last, the retention time is qualitatively evaluated and the peak area is quantitatively analyzed; 10L benzene and xylene are sampled at 0.5 L/min, at the sample inlet temperature of 200°C, the detector of 250°C, analyzed under chromatographic conditions: column temperature: initial temperature, 40°C, maintained for 4 minutes, and heating at a rate of 8°C/min up to 200 °C, maintained for 1 min.

2.2 Sample drawn

A hundred houses are sampled in a city to trace and measure the chemical pollutants in the indoor air. Mainly test the air quality of the parlor and the master bedroom in the four new built houses for six months, and measure the formaldehyde, toluene and benzene series (ethylbenzene, xylene and styrene) in the indoor air of the remaining 96 houses. The basic conditions of the selected four houses are shown in Table 1. The furniture configuration factor in the table is the ratio of the area of the interior furniture to the floor area.

Table 1: Situation of the selected houses

Household number	Floor arear(m^2)	Orientation	Floor	Furniture loading coefficient
1	100.8	Southwest	23	0.433
2	137	Northwest	20	0.443
3	154	Southwest	19	0.432
4	154	Southwest	15	0.503

2.3 Emission model for indoor chemical pollutants

Table 2: The main model of indoor chemical pollutant emission

Model name	Expression	Type	Application process
First-order model	$R=M_0ke^{-k\tau}$	Experience	Evaporation
Second-order model	$R=R_0/[1+(k/\lambda)\tau R_0]$	Experience	Evaporation and diffusion
VB model	$R=h_m(p_vM/M_0-C_\infty)$	Mass transfer	Evaporation
Double exponential model	$R=R_1e^{-k1\tau}+R_2e^{-k2\tau}$	Experience	Evaporation and diffusion
Power-exponent model	$R=a_1b_1e^{-b1\tau}+cf(\tau+d)^{f-1}$	Mass transfer	Evaporation and diffusion
Numerical model	$\frac{\partial C}{\partial \tau}=D\frac{^2}{\partial x_j^2}$ $\frac{\partial}{\partial \tau}(\rho\Phi)+\frac{\partial}{\partial x_j}(\rho\ _j\Phi)=\frac{\partial}{\partial x_j}\|\Gamma\ \frac{\partial\Phi}{\partial x_j}\Big)+S_\Phi$	Mass transfer	Evaporation and diffusion
Diffusion model 1	$R=\|\ \pi^{-\frac{1}{}}\lambda\ )M_{D0}(D/\tau)^{\frac{1}{2}}$	Mass transfer	Diffusion
Diffusion model 2	$R=(0.632/\lambda)M_D(D/\tau)^{\frac{1}{2}}$	Mass transfer	Diffusion
Source model	$R=M\ \ ke^{-k\tau}\quad a(0.632/\lambda)M_D(D/\tau)^{\frac{1}{2}}$	Mass transfer	Diffusion
John Little model	$V\frac{\partial C_\infty}{\partial \tau}=-D\frac{\partial C}{x}\|_{X=L}-QC$	Mass transfer	Diffusion

The empirical models for the emission of chemical pollutants in the materials are relatively mature. Models are generally built based on mass transfer theory to play back experiment process and describe the emission of chemical contaminants in indoor materials. Nowadays, the most widely used models investigate the adsorption effect of various materials in the room and determine the double-exponential decay by regression

analysis, given the curve of the VOCs emission from most indoor materials (Ramlan et al., 2017). The primary model for studying indoor chemical pollutant emissions is shown in Table 2.
The establishment of the above model lays a solid foundation for theoretical study on the emission and diffusion law of chemical pollutants in the building. Based on the above study, we test and theoretically characterize the diffusion process and the impact factors in the building, interspersing analysis of how degree different factors impact the concentration and the emission path of pollutants.

3. Analysis of experimental results

3.1 Air pollutant concentration in four houses

During the test, in No. 1, No. 2, and No. 3 houses, all the furniture are moved in on the 4th, 8th, and 19th days, respectively. For No. 4 house, inhabitant moves in a few of furniture on the 17th day, but in a lot of furniture on the 26th day after the test starts to run. Based on the above statistical data and the concentrations of indoor pollutants benzene and benzene series tested during each time frame, the relationship between the concentrations of airborne pollutants and the testing time in the parlor and the master bedroom of four houses is analyzed, as shown in Fig. 1 ~ 6. This experiment traces and tests the time points where pollutant concentration in four houses changes, further to find out more easily when the earliest occupancy time in new houses is allowed, so as to provide the clues to determining whether the living time is safety for people in the house.

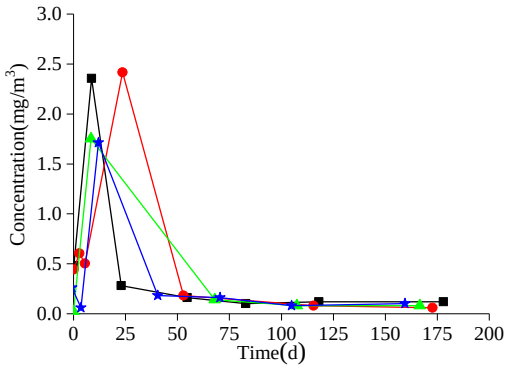

Figure 1: The change of toluene concentration in the living room of 4 sets of residence

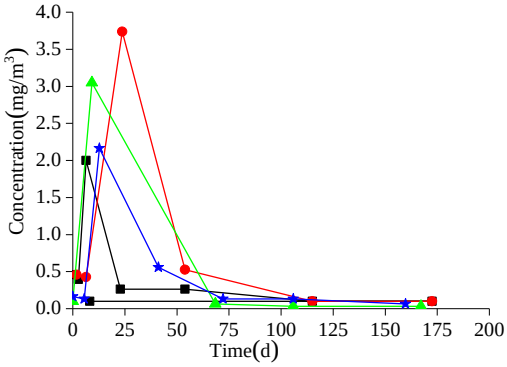

Figure 2: The change of benzene concentration in the main bedroom of 4 sets of residence

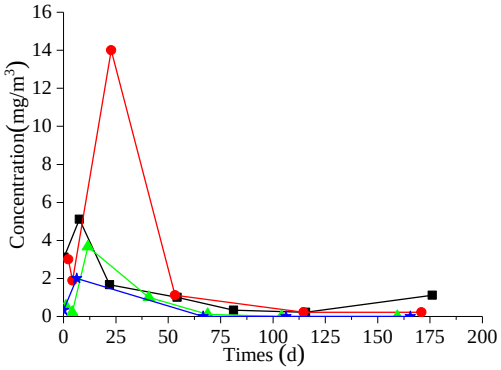

Figure 3: The change of toluene concentration in the living room of 4 sets of residence

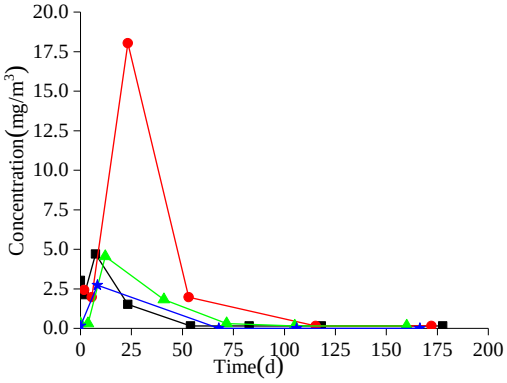

Figure 4: The change of toluene concentration in the main bedroom of 4 sets of residence

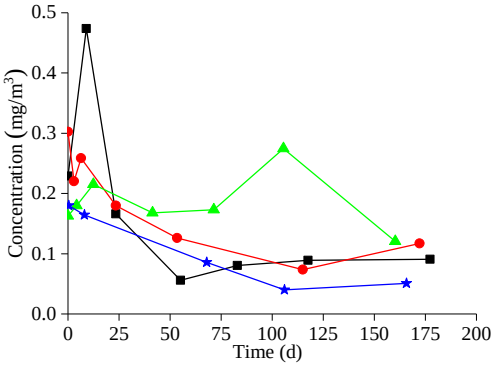

Figure 5: The change of xylene concentration in the living room of 4 sets of residence

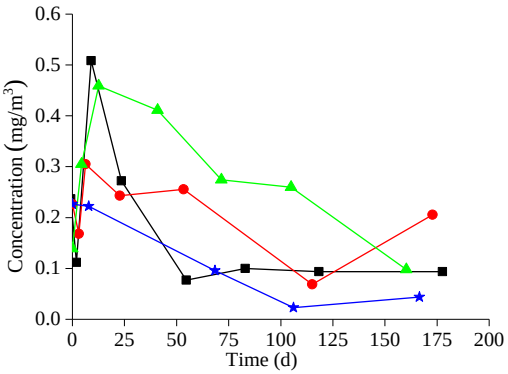

Figure 6: The change of xylene concentration in the main bedroom of 4 sets of residence

Since the samples selected are new houses renovated concurrently, it is considered that the concentrations of pollutants are identical at the onset of the experiment. From data analysis graphics 1 ~ 6, we can see that chemical pollutants benzene, toluene, and xylene in four houses all have peaks. Although the concentrations of indoor benzene and benzene series vary from house to house before the furniture is moved in, they rise up rapidly, and then remain roughly constant after 100 days of test. Therefore, the study reveals that after the building is renovated, the safety requirements of people's occupancy will be met in 100 days after the renovation.

3.2 Concentrations of benzene and benzene series in 96 houses

The benzene and benzene series in the remaining 96 houses among the samples are measured and analyzed. The highest concentrations of formaldehyde, toluene, ethylbenzene, xylene, and styrene in the room reach 229.3μg/m^3, 172.8μg/m^3, 16.78μg/m^3, 9.61μg/m^3 and 12.04μg/m^3, respectively, and other indicators (including detection rate, average concentration, top and lowest concentrations) are listed in Table 3.

Table 3: Concentration of indoor air chemical pollutants

Detection index	Detection rate (%)	Maximum concentration (μg/m^3)	Minimum concentration (μg/m^3)	Mean concentration (μg/m^3)
Formaldehyde	93.8	229.3	2.34	57.97
Toluene	94.1	172.8	0.27	9.21
Ethylbenzene	51.5	16.78	2.21	3.89
Xylene	42.7	9.61	1.25	2.47
Styrene	17.9	12.04	1.95	3.92

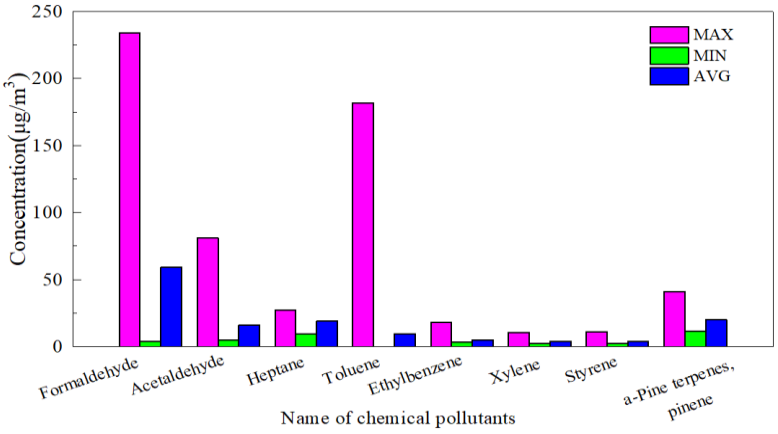

Figure 7: Concentration comparison of indoor air pollutants in residence

The experimental results show that aldehyde, heptane, acetate butyl ether, nonane, α-pinene, pinene and other substances are also measured in residential houses, among which, the average concentration of acetaldehyde is 17.24μg/m^3, the detection rates of remaining components are 3.5%, 4.7%, 3.1%, and 6.7%, respectively. There is a comparative analysis for the minimum, average, and maximum concentrations of indoor chemical pollutants tested in 96 houses, as shown in Fig. 7.

As can be seen from the above figure, average concentrations of formaldehyde, acetaldehyde, heptane, toluene, and ethylbenzene are highest, they are all the main contaminants polluting indoor air in the house.

3.3 Statistical analysis of survey results and physical truth

Study shows that several factors such as schedules for decoration, construction completion, building construction area and household population have a great impact on the emission and diffusion of chemical pollutants in the building. In order to judge the indoor air quality and analyze the principal components that destroys the air quality, based on the theory of Operations Research, indoor air quality survey information (residential basic conditions) and test data are statistically analyzed using multivariate statistical analysis. Among them, test data includes toluene, formaldehyde, and indoor organic gaseous substances.

The data sources and settings of the decision system are as follows: (a) Take the indoor organic gaseous matter concentration as the object when making the decision tree; (b) Use “Y” represent indoor smoking, “N” represent no smoking; (c) “Y” means wearing shoes indoors, “N” means no wearing shoes; (d) Indoor air quality is defined as “E”, very satisfied, “B”, relatively satisfied, and “G”, basically satisfied. The Weka software is used to plot out an indoor air quality decision tree for the buildings, as shown in Fig. 8.

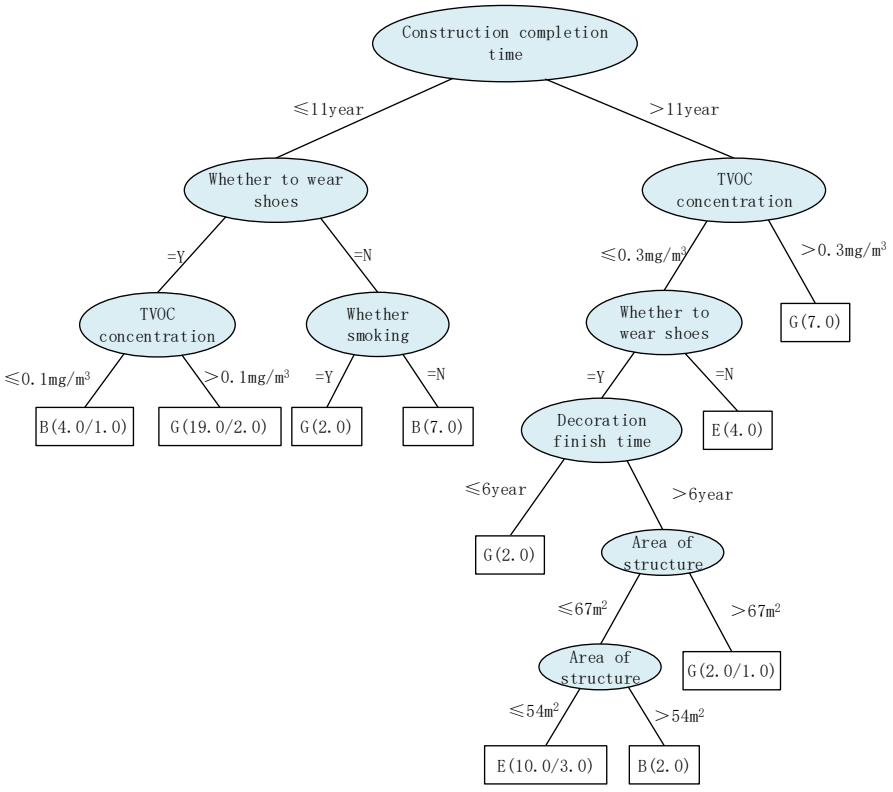

Figure 8: Decision tree of Weka run result

4. Conclusions

We deeply study the chemical pollutants in the indoor air of buildings that impairs people's lives and health, and bear out the emission and diffusion laws of them. Along with this, the decision tree as built herein measures the indoor air quality and analyzes principal components that spoil air quality. The main conclusions are drawn as follows:

(1) For newly built residences, the concentrations of benzene and benzene series in the residential houses vary, but rise up after there are a full of furniture, then roughly remain constant after the 100 days. Therefore, it is believed that the air quality in the houses will reach a safety level for people's residence in 100 days after the decoration of the building.
(2) Analysis of pollutant concentration in the building unveils that chemical pollutants whose average concentrations rank top in the air come in turn the formaldehyde, acetaldehyde, heptane, toluene and ethylbenzene. These components are all tested as principal chemical pollutants in building houses.
(3) Factors such as decoration schedule, construction completion schedule, building construction area and household population have a great impact on the emissions of indoor chemical pollutants. In the end, an indoor air quality decision tree is plotted out to provide the clues to improving indoor air quality and reducing health threats.

References

Alaves V.M., Sleeth D.K., Thiese M.S., Larson R.R., 2013, Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in salt lake county, Utah, USA, International Journal of Environmental Health Research, 23(5), 419-433, DOI: 10.1080/09603123.2012.755152.

Aranyi C., O'Shea W.J., Graham J.A., Miller F.J., 1986, The effects of inhalation of organic chemical air contaminants on murine lung host defences, Fundamental & Applied Toxicology Official Journal of the Society of Toxicology, 6(4), 713-720, DOI: 10.1093/toxsci/6.4.713.

Holt M.S., 2000, Sources of chemical contaminants and routes into the freshwater environment, Food & Chemical Toxicology An International Journal Published for the British Industrial Biological Research Association, 38(1S), S21-S27, DOI: 10.1016/s0278-6915(99)00136-2.

Inamul H., 2003, Environmental impact assessment study: leaching of chemical contaminants from a municipal dump site hastsal, delhi (capital of India), International Journal of Environmental Studies, 60(4), 363-377, DOI: 10.1080/00207230304732.

Kagi N., Fujii S., Horiba Y., Namiki N., Ohtani Y., Emi H., 2007, Indoor air quality for chemical and ultrafine particle contaminants from printers, Building & Environment, 42(5), 1949-1954, DOI: 10.1016/j.buildenv.2006.04.008.``

Logue J.M., Mckone T.E., Sherman M.H., Singer B.C., 2011, Hazard assessment of chemical air contaminants measured in residences, Indoor Air, 21(2), 92-109, DOI: 10.1111/j.1600-0668.2010.00683.x.

Ramla, N., Ahmad S.N.H., Aminuddin E., Hamid H.A., Yaman S.K., Abdullah A.H., 2017, Assessment of indoor air quality in comparison using air conditioning and fan system in printing premise, MATEC Web of Conferences, 101, 04006, DOI: 10.1051/matecconf/201710104006.

Skóra J., Matusiak K., Wojewódzki P., Nowak A., Sulyok M., Ligocka A., 2016, Evaluation of microbiological and chemical contaminants in poultry farms, International Journal of Environmental Research & Public Health, 13(2), 192, DOI: 10.3390/ijerph13020192.

Ullah R., Sun H., Wang S., Hua M.A., Tadé M.O., 2011, Wet-chemical synthesis of intao4 for photocatalytic decomposition of organic contaminants in air and water with uv–vis light, Industrial & Engineering Chemistry Research, 51(4), 1563-1569, DOI: 10.1021/ie200544z.

Veltman K., Mckone T.E., Huijbregts M.A.J., Hendriks A.J., 2009, Bioaccumulation potential of air contaminants: combining biological allometry, chemical equilibrium and mass-balances to predict accumulation of air pollutants in various mammals, Toxicology & Applied Pharmacology, 238(1), 47-55, DOI: 10.1016/j.taap.2009.04.012.

Yin X., Liu J., Pei J., Hou Y., 2015, A new calculating model for the suitable area of air cleaners purifying indoor gaseous chemical contaminants, Procedia Engineering, 121, 1467-1474, DOI: 10.1016/j.proeng.2015.09.071.

Zhang L., Tian F., Nie H., Dang L., Li G., Ye Q., 2012, Classification of multiple indoor air contaminants by an electronic nose and a hybrid support vector machine, Sensors & Actuators B Chemical, 174(11), 114-125, DOI: 10.1016/j.snb.2012.07.021.

Zhang Q., Zhang G., 2007, Study on tvocs concentration distribution and evaluation of inhaled air quality under a re-circulated ventilation system, Building & Environment, 42(3), 1110-1118, DOI: 10.1016/j.buildenv.2005.11.012.

Zhang Y., Xiong J., Mo J., Gong M., Cao J., 2016, Understanding and controlling airborne organic compounds in the indoor environment: mass transfer analysis and applications, Indoor Air, 26(1), 39-60, DOI: 10.1111/ina.12198.