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Indoor Pollutants Detection in Buildings Based on Numerical Simulation

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According to statistics, the proportion of indoor activities in today's society has reached more than 70%. Indoor air quality has become a major factor affecting the people's quality of life and health. In order to realize the detection and monitoring of diversified indoor air pollutants, this paper proposes one research idea of detecting indoor pollutants based on numerical simulation method. The visualization program ITES2.0 was used as the numerical simulation software to simulate and evaluate the indoor indexes such as formaldehyde, carbon dioxide, temperature and airflow velocity etc. in the building. Besides, the two schemes of the actual instrumental measurement and the subjective evaluation questionnaire were set up respectively for comparison. By taking one indoor office in Changsha city as the example, the numerical simulation was conducted to make comparation and validation of pollutant concentrations between instrument measurement and subjective evaluation. The experimental comparison results show that the relative error of the average index values between the numerical simulation results and the actual measured values at each detection point is 10%, which is consistent with the subjective evaluation of the indoor air quality grade.

1. Introduction

Bituminous coal pollution, photochemical smog pollution, and indoor air pollution have been recognized as the three major air pollution, among which indoor air pollution has the widest range of influence and the most affected population. So, it has become the most concerned air pollution in the current era (Bruce et al., 2000). The volatile organic compounds (VOCs) emitted from indoor buildings and decoration materials have exposed people who stay indoors for a long time to indoor air pollution; when these volatile substances such as formaldehyde, toluene, ammonia, etc. exceed the standard, they shall cause serious harm to health and life quality of the human body (Kurmi et al., 2010). With the increasing awareness of indoor pollution hazards, there have been more and more researches on the detection of indoor pollutants in buildings.

The detection of indoor pollutants first promotes the research of various types and categories of indoor pollutant detection instruments. In foreign theoretical research, more attention is paid to the mathematical model research of indoor air quality, and research methods such as fuzzy comprehensive evaluation method, grey clustering method, analytic hierarchy process, and computer fluid dynamics (CFD) numerical simulation etc. have been proposed (Cesar et al., 2015). On the basis of foreign scholars' research on CFD in energy consumption, indoor air quality, cold and heat comfort etc., domestic scholars have carried out the prospect research of building indoor air pollution control and evaluation simulation software; some scholars have written building indoor environmental numerical simulation software, validating its correctness by comparing with the results of foreign mature simulation software (Chung, 1986). At present, there is still a big gap in the numerical detection of indoor pollutants combining domestic theoretical techniques with actual cases. Based on this, this paper started the research on indoor pollutants detection (Hidalgo-Gato et al., 2015).

By selecting an office building in Wuyi Square of Changsha City as the research object, the subjective evaluation of air quality by office workers and the fixed-point measurement of air pollution instruments were carried out. Also, the numerical simulation model was established after the boundary conditions and other conditions were determined (Yin and Rui, 2017). Then, the subjective evaluation results, measurement results, numerical simulation results were compared and analysed. Finally, the reliability of the grey correlation evaluation results in numerical simulation was verified by questionnaire survey, and the comparison between

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instrument detection and numerical simulation modelling showed that the concentration error of the formaldehyde concentration and carbon dioxide at each test point is within 10%.

2. Building indoor pollutant detection experiment

2.1 Numerical simulation experiments and software

2.1.1 Empirical diffusion model of indoor pollutants

The diffusion of indoor pollutants conforms to the characteristics of gas flow dynamics. By considering the internal and external factors of indoor pollutants diffusion and synthesizing the diffusion coefficients of different materials, empirical models were presented in the form of data reproduction (Lai and Chan, 2007). Besides, based on the first-order model and the double-exponential model, the second-order model is improved as:

$$S(t) = \frac{S_0}{1+(k/\lambda)tS_0} \quad (1)$$

where, S_0 is the initial emission rate, and k and λ are both empirical constants. This second-order empirical model meets the requirements for indoor gas evaporation and diffusion. In addition, the law of conservation of mass, the law of conservation of momentum, the law of conservation of power, and the law of conservation of mass are observed in the indoor gas diffusion process (Foy et al., 2009). The finite volume method was used to discretize and solve the gas CFD control equations and determine the key pollution source parameters (Kim et al., 2001).

2.1.2 ITES2.0 software

The numerical simulation software for building indoor pollutant detection used in this paper is ITES2.0. ITES2.0 has developed on the basis of ITES1.0 with the rapid development of computer graphics technology and programming technology. The visualization of VB.Net and numerical calculation advantage of Compaq Visual Fortran 6.6 are utilized, to discretize and solve the gas CFD control equation and determine the indoor gas diffusion model such as key pollution source parameters using the finite volume method, which is then embedded in ITES2.0 (Jenny et al., 2003). ITES2.0 includes three main parts: pre-processing, core calculation program and post-processing: the pre-processing unit includes numerical problem solving setting panel, geometric model setting panel, meshing panel, numerical simulation convergence factor and detection point setting; core calculation program mainly describes the function of the core subroutine and the programming of the program; the post-processing unit outputs the numeral simulation results for obtaining the concentration distribution of the pollutants (Mrazovac et al., 2013).

2.2 Instrument testing and subjective survey

One 35-floor office building in Wuyi Square of Changsha City was taken as the actual research object. The 16th floor was selected for fix-point sampling and testing; the company managers and staffs on the 16th floor were invited to conduct subjective evaluation survey of office air.

2.2.1 Indoor air test instruments

(1) Office sampling point layout

According to the relevant national regulations, the number of sampling points for indoor air pollutant detection is: 1-3 within 50 square meters, 3-5 for 50-100 square meters, and at least 5 for 100 square meters. The distance between the two sampling points should be greater than 5m. The sampling point should avoid the venting port, and the best sampling point height is 1.1m. Since the office area reached 500 square meters, 8 sampling points were arranged in the experimental study, and the sampling frequency was 2 hours.

(2) Test instruments

Table 1 lists the main parameters of the test instrument.

Table 1: The test instrument

Test items	Instrument name	Response time	Test range	Accuracy
Temperature	TSI-7565 Indoor air quality detector	20s	0~60C°	$\pm 0.4C°$
Relative Humidity	TSI-7565 Indoor air quality detector	20s	5~95% RH	$\pm 3\%RH$
Formaldehyde	PPM-HTV formaldehyde detector	8-45s	0~10ppm	2%
Carbon dioxide	TSI-7565 Indoor air quality detector	20s	0~5000ppm	40ppm

The detection frequency was measured at each testing point in the office as shown in Table 1, and the values of each measurement were counted and recorded (Morrison et al., 2006).

2.2.2 Subjective survey of indoor air quality

A total of 80 questionnaires were issued to 80 employees in the office, and 70 valid questionnaires were collected. The questionnaire mainly includes: the basic conditions of the respondents include: gender, age, whether smoking, and whether suffering chronic respiratory disease; indoor air quality is evaluation by five grades: very good, good, ordinary, bad, very bad; the indoor air quality status is scored from 1 to 5 points in three aspects: dirtiness, odour, and non-circulation; the office smell is scored from 1 to 5 points in the tastes of the document, carpet, copier, and decoration; for the symptoms during office hours such as dizziness, tinnitus, tears, poor breathing, nasal congestion, and eye fatigue, the score of 1 to 5 points is given; for the office air quality, airflow quality, thermal environment, wet environment, light environment, acoustic environment, the score of 1 to 5 points is given. Finally, two options that are acceptable and unacceptable are given for the evaluation of the overall indoor environment (Finel et al., 2017).
Effective statistics were collected on the 70 collected questionnaires: the acoustic environment satisfaction rate was only 73.5%, the indoor air satisfaction was 85.8%, and the overall dissatisfaction was 17.6%. Combining with the survey of other indicators and the international indoor air evaluation standard ASHRAE62-1989, the office air was in “good indoor air quality”.

3. Simulation detection and verification of building indoor pollutant data

3.1 Office model description and boundary settings

Fig.1 shows a simplified office model diagram of the ITES 2.0 boundary. This numerical simulation model map is an indoor measurement point layout diagram of the company manager office.

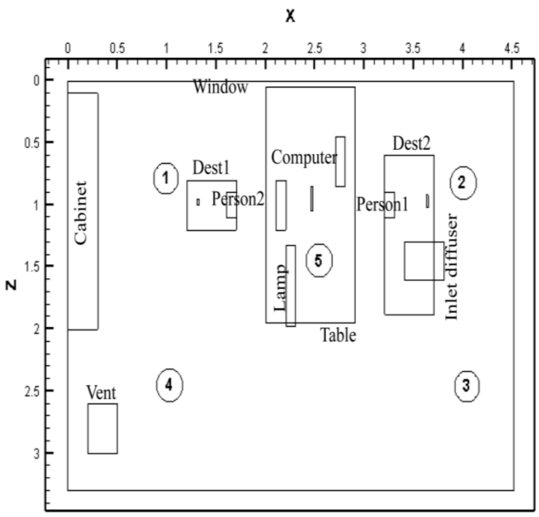

Figure 1: Indoor measuring points arrangement

In order to simplify the indoor pollutant simulation calculation model and increase the calculation speed, the boundary conditions of the model were simplified: the glass windows, indoor tables, stools, ceilings and floors are all set as insulation surfaces; the supply air temperature is 20°C, the speed is 0.85m/s, relative humidity 60%, and carbon dioxide concentration is 300ppm; formaldehyde diffusion coefficient and separation coefficient do not change with concentration and indoor temperature

3.2 Accuracy verification of numerical simulation results

3.2.1 Comparative analysis of formaldehyde concentration

Fig.2 shows the numerical simulation results of formaldehyde concentration on the horizontal plane. It can be clearly seen from the figure that the simulated concentration of formaldehyde in the places closer to the pollution source such as the cabinet and desk etc. is the highest. The comparison between the numerical simulation results and the instrument measured results is shown in Table 2.

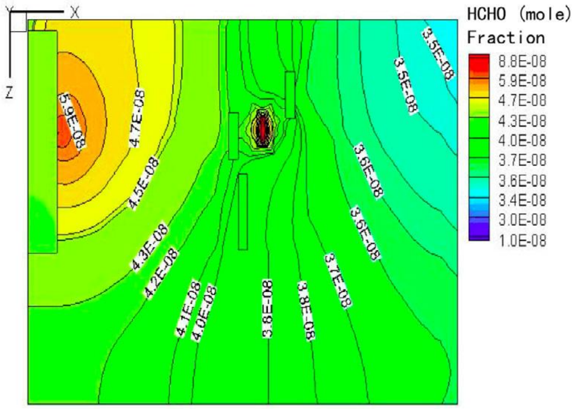

Figure 2: The concentration distribution of formaldehyde on the horizontal plane

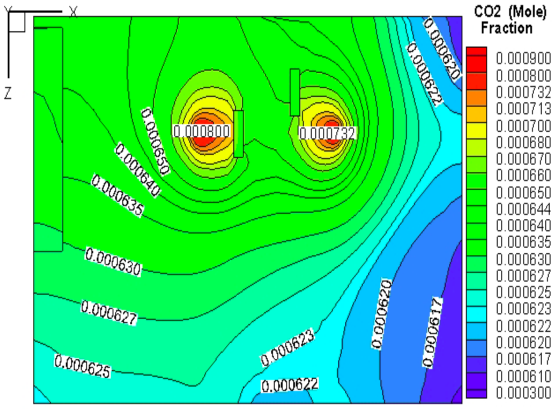

Figure 3: The concentration distribution of carbon dioxide on the horizontal plane

Table 2: Comparision of experiment and computing value about formaldehyde

Formaldehyde (PPM)	Simulation value	Measured value	Error percentage
Test-point 1	0.052	0.048	8.33%
Test-point 2	0.036	0.039	7.79%
Test-point 3	0.042	0.039	7.79%
Test-point 4	0.035	0.032	9.37%
Test-point 5	0.061	0.065	6.15%
Test-point 6	0.047	0.043	9.30%
Test-point 7	0.032	0.035	8.57%
Test-point 8	0.035	0.038	7.89%

3.2.2 Comparative analysis of carbon dioxide concentration

Fig. 2 shows the numerical simulation results of carbon dioxide concentration on the horizontal plane. The two local high points of carbon dioxide in the office appeared with the presence of office workers and the concentration of carbon dioxide was 732-800ppm. The overall carbon dioxide concentration in the office is 610-650ppm, and the daily average concentration is lower than the indoor air quality standard of 1000ppm. The numerical simulation results and instrumental measured results are shown in Table 3.

Table 3: Comparision of experiment and computing value about carbon dioxide

Formaldehyde (PPM)	Simulation value	Measured value	Error percentage
Test-point 1	635	643	1.09%
Test-point 2	641	637	0.06%
Test-point 3	620	625	0.80%
Test-point 4	629	640	1.71%
Test-point 5	650	664	2.11%
Test-point 6	634	638	0.06%
Test-point 7	642	651	1.38%
Test-point 8	630	635	0.08%

3.2.3 Comparative analysis of temperature concentration

It can be seen from Fig. 3 that the temperature average at each point of the simulated value and the measured value is between 19 and 20 °C.

3.2.4 Analysis of comparison results

From the distribution of formaldehyde, carbon dioxide and temperature concentration, it can be seen that the error between the simulated value and the measured value is within 10%. The measured values at each test point are in good agreement with the simulated values. Although certain idealized assumptions have been made in the model boundary conditions and calculation models etc., the comprehensive relative humidity and convective velocity indicators indicate that the ITES 2.0 numerical simulation method has high accuracy in measuring the concentration of pollutants in the office.

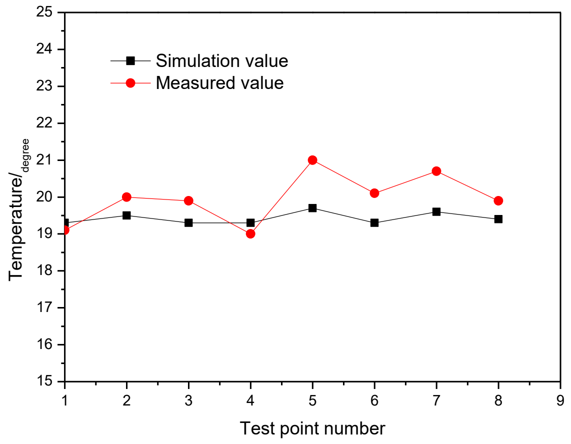

Figure 4: Contrast between measured and simulated values of temperature

3.3 Grey relational analysis

Grey relational analysis is using the known effective information to weigh the overall impact, and make up for the shortcomings caused by the irregularity of sample size and sample when using the mathematical statistics analysis method (Ip et al., 2009). It can be judged according to the degree of similarity between the comparison sequence and the reference sequence curve. In this paper, the grey system was applied to perform the relational analysis for the simulation values of indoor air quality. The formula and procedure of the relational degree were shown found in the related reference (Gang et al., 2011).

The average value of the numerical simulation results was taken as the raw data for the grey relation grade evaluation, and compared with the standard sequence of domestic dimensionless indoor air quality evaluation. The correlation coefficient and relational degree of temperature, relative humidity, flow rate, formaldehyde, and carbon dioxide were also calculated. The calculation results show the three grades of air quality: very comfortable, comfortable and uncomfortable. The relational degrees are 0.622, 0.775, and 0.448, respectively; the grey evaluation grade of the numerical simulation is comfortable, which is consistent with the statistical results of the questionnaires.

4. Conclusions

With the increasing awareness of environmental protection and self-protection, people have higher and higher requirements for indoor office air quality. In order to analyse indoor air pollutants and other air indicators, this paper combines the methods of subjective evaluation, quantitative measurement and numerical simulation to measure the indoor air index of one certain office in Changsha. Then, it demonstrates the effectiveness of numerical simulation technology in the building indoor air pollutant detection. The main conclusions of this paper are as follows:

(1) The ITES2.0-based numerical simulation method with high accuracy can be widely used in indoor pollutant detection.

(2) The error of simulated results and measured results at each detection point for temperature, formaldehyde and carbon dioxide concentration is within 10%.

(3) In terms of the comfort evaluation of indoor air, the grey relation evaluation results of subjective survey are consistent with that of the numerical simulation.

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