The effect of Volatile Organic Compounds emission caused by decoration paintings on the indoor air quality

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Abstract: The goal of this study is to demonstrate the VOCs emission situation caused by interior decoration paintings which used widely in interior design. Experimental painting samples of VOCs emission are to be obtained in an environmental chamber. Their quantity and category would be identified by GC/MS. The data would be then input into CFD software Flovent 6.1 to simulate the distribution situation in a room. Refining measures by changing interior wind field would be simulated and compared. The results revealed that: (1) Toluene concentration of interior decoration painting analysis by GC/MS is 320.77mg/L. (2) Volume of air inlet and outlet and the wind direction are two essential factors of VOCs concentration. They reduce the emission of VOCs amount up to 60%. (3). Artificial ventilation helps a lot. In the case of Mode C, the average reduction ratio of VOCs density is ca. 47.6%. (4). The problem of interior VOCs concentration and interior wind field can be improved by the optimal solution through an effective air exchange and ventilation control.

Key-words: VOCs, CFD, interior decoration painting, environmental chamber, IAQ, interior wind field .

1. Introduction

People's activities in the indoor environment are about 90% in their life.□Sick Building Syndrome□is a common interior problem of developed countries, especially in the modern buildings which highly demand for air condition. Aerosols have been found to be one of the most serious issues national air quality report in Taiwan in the past several years [1], not only for urban areas but also for interior space. Volatile Organic Compounds □VOCs□ are categorized as chemical aerosols, and their pollution in IAQ is a critical issue for human health. People feel teary and uncomfortable very often after they move in their new decorated residential space [2]. It is signified highly relationship to human respiratory diseases. Recent medical studies show that some of the VOCs could influence the human respiratory system and immune system deeply. VOCs have strong relationship to many health problems, such as death of premature infants, aggravation of asthma, an incentive respiratory symptom, increasing respiratory infection risk, weakening the lung function etc. In recent researches, most building materials comprise of many different chemical components, like alkane series, terpene series, halogen etc. Carpet, wallpaper and plywood release not only odor and mineral gases but also Benzene, Toluene, Xylene, and Formaldehyde etc . Decoration paintings and adhesives are the main sources of VOCs in the indoor environment. [3].

In order to integrate the issues of emissions and their spread, chemical experiments (GC/MS) and CFD simulation would be carried out, that could demonstrate the contour of the emission concentration.

After identifying the quantity and category of the VOCs, environmental fluid dynamic theory was adopted to analyze VOCs emission situation that can offer new insights for studying ventilation solutions and provide a healthier interior space design by the database we built. It is to expect, that could identify the quality and quantity, and more important, could locate the pollutants in interior space, so it is possible to protect people from the minacity of VOCs emission.

The research goals are: (1) identifying major chemical components of interior decoration painting which be used widely, (2) simulating emission situations of interior decoration painting including window opening and mechanical ventilation as the main factors to evaluate the VOCs distribution in the interior and (3) demonstrating and analyzing effects of different ventilation conditions on wind field and their influences on the VOCs distribution.

2. Instrument and Method

2.1 Instrument

The experimental equipments included an air pump□Grab Air Sampler, SKC□for getting the air samples from environmental chamber. Then

the hypodermic needle was used to abstract 5ml specimen and to inject into the pre-concentrate device（Sample Concentrator, OI Analytical Model 4560）. After the process of Purge and Desorbs, the specimen would enter to GC（Gas Chromatograph, Agilent 6890N GC with EPC） and would be analyzed by MS（Mass Spectrometer Agilent 5973 with turbo Pump Option/MS), to identify the variety of the VOCs automatically.
We constructed a test system as shown in Fig.1 in this experiment, that consist of 4 major parts, (1) Environmental Chamber Unit, (2) Clean Air Supply system, (3) Monitoring and Control System. (4) Sampling and Analysis System.

2.2 Method

A two-phase study was designed for the identification and the classification of the emissions caused by the interior decoration painting VOCs. Firstly, VOCs are sampled and analyzed. Secondly, CFD（computational fluid dynamic）simulation of software Flovent 6.1 would be applied. The experiment of the first phase is according to ISO16000-1（(General aspects of sampling strategy, 2004), ISO16000-9（（Determination of the emission of volatile organic compounds from building products and furnishing -- Emission test chamber method, 2006）, ISO16000-11（(Determination of the emission of volatile organic compounds from building products and furnishing -- Sampling, storage of samples and preparation of test specimens , 2006), ASTM D5116-97 and NRC.CNRC（National Research Council Canada ）etc. The concept is to put the building material specimen into an environmental chamber, in which temperature, humidity and aeration ratio are under controlled. Then the air of VOCs emission samples would be input into the pre-concentrate device. After concentrating procedure the samples will be injected into GC and MS automatically. After analysis, peaks of different signal strength will display on the monitor.

2.2.1Qualitative method of VOCs

(1)The experiment have applied GC and MS to identify the components of interior decoration painting. In Fig. 2, Peaks of components from GC/MS (oil painting) would be compared with chemical database to identify the variety of components. According to the retention time and the original formula, a cross-comparison could insure the accuracy of qualitative results.

(2)Result

The analysis results by GC and MS revealed that interior decoration painting comprise of many different Volatile Organic Compounds. Qualitative results of the oil painting as shown in Fig. 2. Peaks of components from GC/MS (oil painting). The most amount of component is Toluene, and the second one is Xylene.

2.2.2 Quantitative method of VOCs

(1). Calibration

The object of this experiment focuses on benzene series (BTEX). Before the analysis of target chemical component, 5 different densities of standard liquids were prepared. And the External Standard method (ESTD) was used to establish Calibration to identify the quantity of VOCs as shown in Fig. 3 for Calibrations of Toluene and Xylene-o.

(2). Quantification

Peaks will be translated to signal strength after Calibration established. Target peak area will be integrated to compare to Calibration area and to calculate the density of component.

2.2.3 Result (oil painting and water painting)

Toluene density of oil painting is 320.77mg/L, Xylene (-m,-o,-p) is about 118.32-356.97mg/, Toluene density of water painting is 27.33mg/L, Xylene (-m,-o,-p) is about 1.27-2.70mg/L. These amounts revealed that emissions of paintings are quite huge and they are influenced by different kinds of thinners.

3. Simulations of CFD

The movement and spread of VOCs' particles in space would be effected by many factors such as temperature, humidity, urban and/or indoor wind field etc. "Aerosol Technology" and "computational fluid dynamic" were adopted for analyzing these key factors on the distribution of VOCs in interior space. Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that consists of numerical methods and algorithms to solve and analyze problems involved fluid flows. Uniform Particle Motion includes settling velocity, mechanical mobility, diffusion model etc. And Environmental Fluid Mechanics includes boundary layer flow, viscous sub layer etc. For this study, all particles are assumed to be spherical shape, with one dimensional liner movement in a uniform air flow and only influenced by gravity [5].

3.1 Mathematical Model of CFD

CFD software Flovent6.1 uses the Reynolds Averaged Navier-Stokes Equation modeling, (RANS) as the mathematical model. The equation assume that air is instability, compressible, variable, viscosity fluid. Continuity is□

$$\mu_T = C_\mu \rho \frac{k^2}{\varepsilon} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (0.1)$$

CFD model of Flovent6.1 for the airflow simulation is k-ε model. μ_T is eddy viscosity. ρ is fluid density. k represents the turbulence kinetic energy. ε is disperse ratio of kinetic energy. k and ε Equation of motion is□

$$\frac{\partial \rho \bar{U}_i k}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu T}{\sigma k}\right)\frac{\partial k}{\partial x_i}\right) + P + G - \rho\varepsilon \quad \ldots \ldots\ldots (0.2)$$

$$\frac{\partial \rho \bar{U}_i \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu T}{\sigma k}\right)\frac{\partial \varepsilon}{\partial x_i}\right) + C_1 \frac{\varepsilon}{k}\left(P + C_3 G\right) - C_2 \rho \frac{\varepsilon^2}{k} \quad \ldots\ldots.\ldots (0.3)$$

P is shear, G represents the turbulence momentum from buoyancy□

$$P = \mu_{eff} \frac{\partial \bar{U}i}{\partial x_j}\left(\frac{\partial \bar{U}i}{\partial x_j} + \frac{\partial Uj}{\partial x_i}\right) \quad \ldots\ldots\ldots.. (0.4)$$

$$G = \frac{\mu_{eff}}{\sigma_T} \beta g_i \frac{\partial T}{\partial x_i} \quad \ldots\ldots\ldots\ldots\ldots..\ldots\ldots (0.5)$$

When a polluted particle is released from a wall, the turbulence momentum from buoyancy□G□ and the turbulence kinetic energy□k□ have effect on the particle.

3.2 VOCs and Air Diffusion

In this investigation, two different CFD simulations were carried out.

(1) Mode A□Open the door and the window for the inlet of outdoor air as reset condition.

(2) Mode B□Open the door and the window for the inlet of outdoor air plus one ventilator to refine the wind field of interior.

1. Background parameter□

(1) Taiwan is a sub-tropical island with high temperature and humidity. The parameter of environment setting as temperature 28 □ , humidity 70□.

(2) The dimensions of outdoor boundary layer was defined as 50m*50m*50m. All area was divided as 112000 grids. Airflow velocity of outdoor is 2.5 L/S.

(3) Modeling parameter: pollution resource of interior space consider as a 24 □ panel□8*3m□. Major component of pollution is toluene. □molecular weight is 92.14 g/mol□Density of first hour is 320.77mg/L sampling from environment chamber.

2. Space Parameter:

(1) Interior object:

Setup a desk □L=1.5m, W=0.6 m, H=1.0m□to simulate the influence of interior object to regional wind field.

(2) Dimension:

Length of the space is 8m*8m*3m. Observation points setting as Fig. 4 Layout of Observation points.

3.3 Analysis of CFD simulations

3.3.1 Mode A :open door and window

1. Condition:

All the parameters of environment are steady as original settings. Apertures were created to simulate the entrance (1.5 m *2.1m) and the window (1.5 m *1.4m).

2. Results of simulation:

□1□wind field:

Interior wind field interfered with mass airflow. Wind came from outside as shown on Fig.6.□c□ Wind field in Mode A □ h=1.6m □ . The distribution of pollutants was disarranged by turbulence. Viscosity of eddy μ_T increased with kinetic energy. The reduction of disperse ratio of kinetic energy ε accrued eddy current in the corner of interior. Velocity of interior airflow enhanced substantially.

□2□emission:

As shown on Fig.6.□a□Emission of VOCs in Mode A □ h=1.6m □ . The distribution of pollutants on areas O and P are lower than areas M and N. "The calm zone" accrued because the turbulence kinetic energy k *was* approximate zero. Areas O and P are outlying from the mainly airflow route without any apertures, that made the density of VOCs highly concentrate there .

□3□Improvement:

Concentrations of VOCs were reduced about 66% in Mode A. Because of the location and the size of apertures, pollutants were influenced by the increasing air exchange and wind velocity.

3.3.2 Simulation-B open door and window

Mode B: open door and window with mechanical ventilation

1. Condition:

All the parameters of environment are steady as original settings. Apertures were being created as Mode A. One ventilator (1 m *0.75 m) was added on 2m height. The velocity of ventilator is 8L/S.

2. Result of simulation:
□1□wind field:
Wind from outdoor was led into interior through apertures and ventilator. Turbulence kinetic energy *k* increased and the "alley of airflow" accrued through areas M,N,P except area O. The change of wind field accrued eddy current in the corner of interior. Velocity of interior airflow enhanced dramatically as shown on Fig.6.□d□Wind field in Mode B □h=1.6m□.
□2□emission:
As shown on Fig.6.□e□emission of VOCs in Mode B□section V-V□. Different density of pollutants distribution was presented in vertical section. Most of the pollutants were removed at 2m height especially for area R. Some of pollutants still concentrated in area O because it is outlying from the mainly airflow route.
□3□Improvement: As shown on Fig.6.(f) Emission of VOCs in Mode B□section V-V□. Compared to Mode A and B, obviously the reductions of pollutants in this space are at most. The most efficient reduction of pollutants is 72.41□ which located at the observation point j4 of area P. Reduction ratios of pollutants was all up to 50□ in those areas where closed to the ventilator.

4. Conclusion

The simulation demonstrates that the average ratio of pollutants reduction is up to 47.6□. The differences of pollutants concentration present as Fig. 5, which shows the comparison of simulated data Mode A & B. The ventilator is definitely an effective means to improve the indoor air quality. The results revealed that:

1. VOCs emission of the painting is the major influence factor of indoor air quality. In this studied case, concentration of Toluene is 320.77mg/L in average. Public agencies should establish the regulations or standards to organize the usage of paintings for living space.
2. Volume of air inlet and outlet, change of wind direction are important factors of VOCs density. And they worked differently from spot to spot. It is helpful to reduce the interior air pollution up to 60% interior area.
3. Analysis by the CFD simulation, interior air exchange and ventilation are important factors to the indoor air quality. In the case of Mode C, the results revealed that the reduction ratio of VOCs density is 47.6□ in average.
4. The problem of VOCs emission caused by paintings could be improved by interior air exchange and ventilation. In terms of environmental fluid mechanics, an optimal solution and adaptation of the building mass, the opening design and the layout in a room can effectively reduce the emission concentration. A healthy building demands a scientific integration between aerosol engineering, architectural design and urban design.

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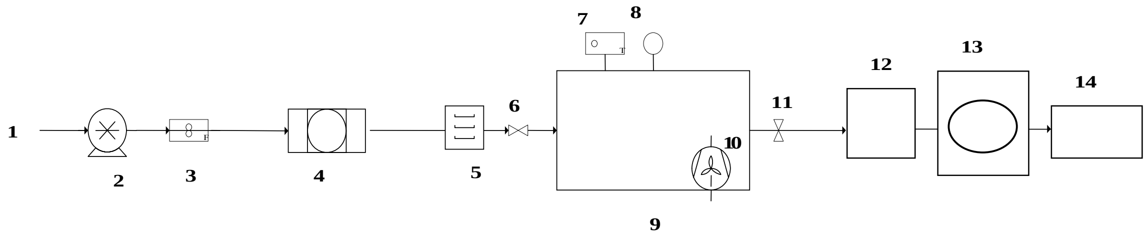


1：Ambient Air 2：Pump 3：MFC (mass flow controller) 4：Particle Filter 5：Drying Column 6：Inlet 7：Hygrometer 8： Thermometer 9：Air Quality Testing Chamber 10：Mixing Fan 11：Outlet 12:Concentration 13: GC 14: MS

Fig. 1 System of experimental equipment

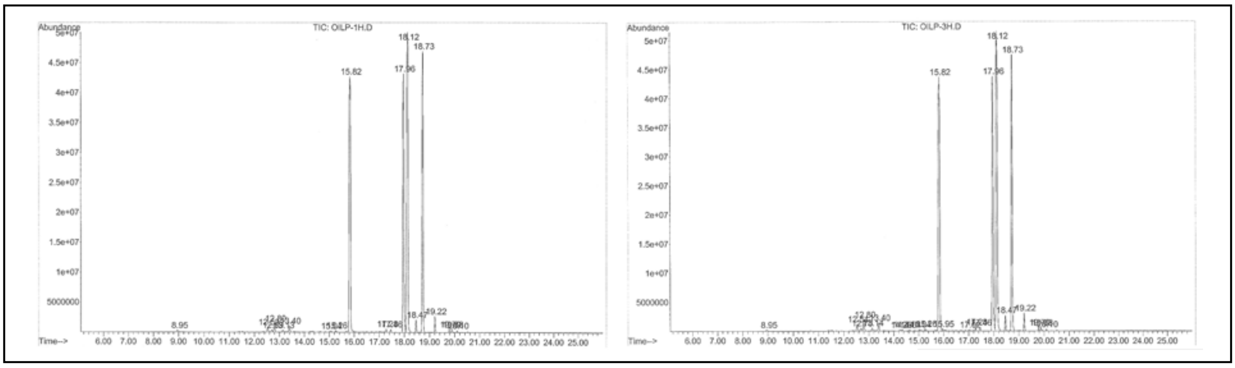


Fig. 2 Peaks of components from GC/MS (oil painting)

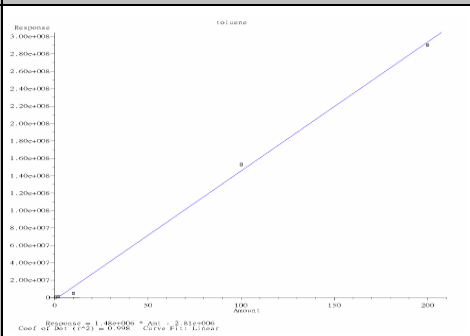
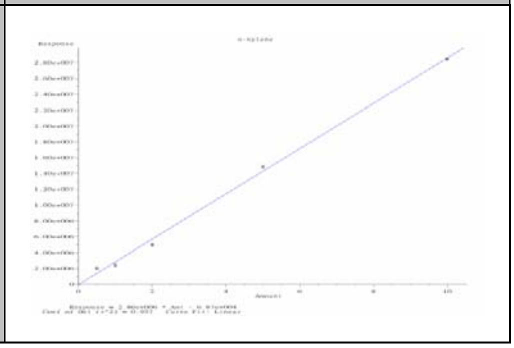
Component	Calibration	Component	Calibration
Toluene		Xylene -o	

Fig. 3 Calibrations of Toluene and Xylene-o

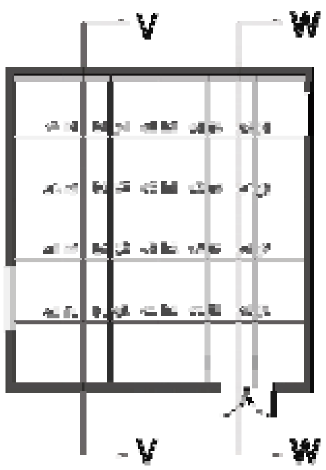


Fig. 4 Layout of Observation points

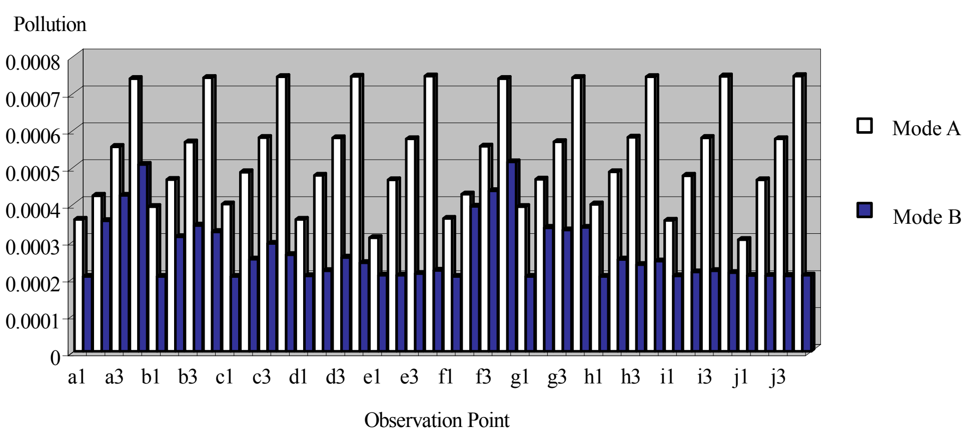
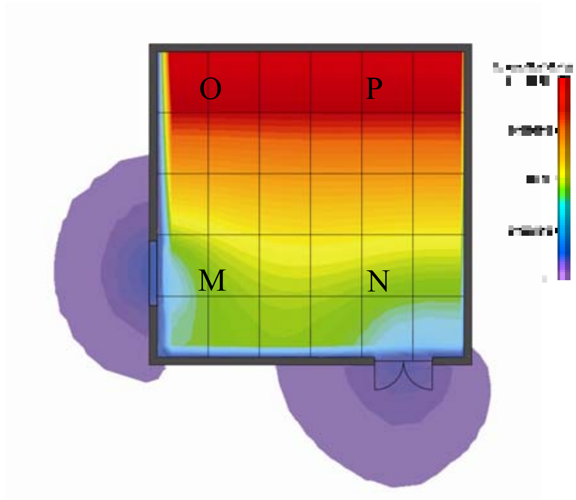
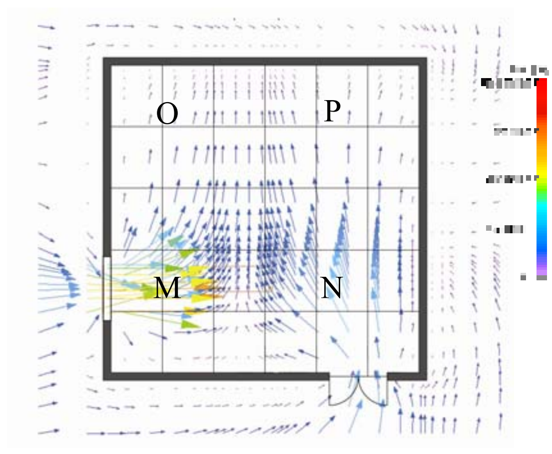


Fig. 5 Comparison of simulated data Mode A & B

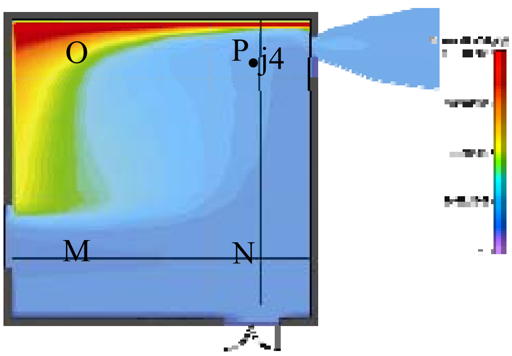
a Emission of VOCs in Mode A h=1.6m



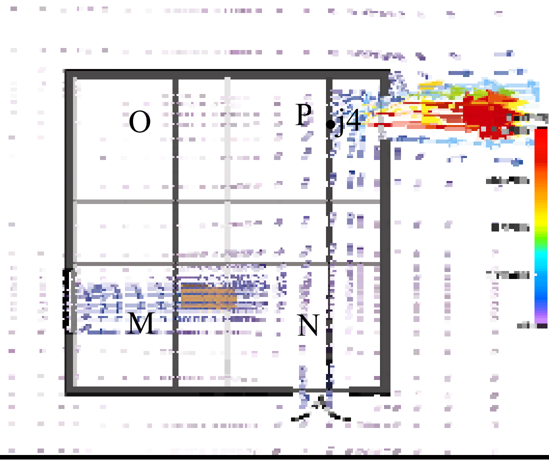
c Wind field in Mode A h=1.6m



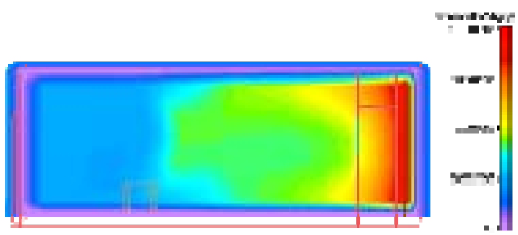
b Emission of VOCs in Mode B h=1.6m



d Wind field in Mode B h=1.6m



e Emission of VOCs in Mode B section V-V



f Wind field in Mode B section V-V

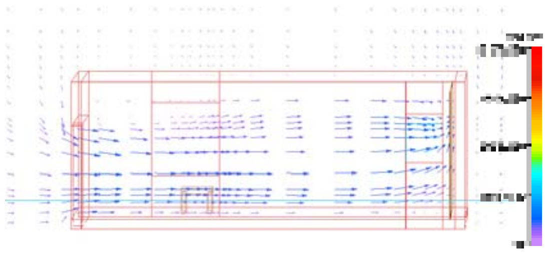


Fig. 6 **Emission of VOCs and Wind field Map in Mode A & B**