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Assessment of Indoor Air Quality on Campus of Zhejiang International Studies University

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Abstract

The Indoor Air Quality (IAQ) was determined by the levels of specific indoor air pollutants. The major pollutants after decoration are formaldehyde (HCHO) and Volatile Organic Compounds (VOCs). The residue pollutants (VOCs, especially HCHO) of indoor environment was investigated on campus of Zhejiang International Studies University after construction and decoration, to conduct IAQ assessment before opening ceremony. Four typical sampling sites were set up, including the living area, teaching area, activity area, and construction area, factors such as temperature, humidity and human flow rates were considered as the reference for monitoring indicators. VOCs and HCHO were monitored for each sampling site, to assess the pollution state on campus and analyze the certain source of the indoor pollution. In conclusion, the indoor air pollution was very complicated, associated with many different environmental factors, and the concentrations of HCHO and TVOC can only indicate the reference for indoor air quality.

Keywords: Formaldehyde, Volatile Organic Compound, Indoor Air Quality.

1. Introduction

Indoor Air Quality (IAQ) has been more and more concerned by the public recently. The air quality was detected and evaluated in a designated space and a specific time interval, various substances in the detected air should be kept in a relatively balanced state under detection [1]. In order to test whether the indoor environment can meet the requirements for people's daily living, indoor air quality is usually taken as an important indicator, to define whether the environment is healthy or harmful to human health. The main indicators of indoor air quality include relative humidity in the air, concentration of inhalable particulate matter, in-situ oxygen content, concentration of organic matter, etc., which can reflect many indicators and test items, to assess the air quality status in a certain environmental area based on integrative data [2].

Zhejiang International Studies University is located near Xiaoheshan National Forest Park, the campus is close to the Xiaoheshan mountain and adjacent to a lake. The second-phase construction project of the university is being carried out on campus, with a relatively long term plan. In the process of construction and decoration, the indoor environment of the construction area will inevitably have high concentrations of formaldehyde and TVOC.

Indoor air pollution were contributed by various factors, including pollutants released by indoor decoration materials, air pollution from outdoor environment, indoor air circulation, effective air exchange per unit time, living load and personnel flow in designated space on campus, etc. Modern buildings with closed space also contributed to the deterioration of indoor air environment. Currently, more and more innovative decoration materials and innovative decoration technology are used in daily room decoration

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[3]. Meanwhile, people have learned more and more knowledge about environmental management and air purification recently. In daily life, people can also get in touch with more knowledge about the pollution prevention, pollutants detection and control of air pollution. Controlling the air pollution from the source in the room was urgent, to improve the indoor living environment, and reduce people's potential safety risks in the indoor space [4-5].

Formaldehyde is highly volatile and potentially dangerous to human health. In a closed indoor environment with limited space area, if subsequent air purification was not well taken after a decoration process, the high concentrations of formaldehyde gas in the air will pose a potential threat on the health of the people live and work in the designated position. The negative influence of formaldehyde in the indoor air was tremendous, therefore the existing formaldehyde concentration is usually used to evaluate whether the room air quality met the requirements of the safety standard [2, 5]. Formaldehyde is everywhere, due to use of all sorts of building and coating materials, and different greening degree for indoor and outdoor environment, the indoor environmental formaldehyde concentration is usually higher than outdoor, when the adsorption of formaldehyde was not well taken. What is even worse, the formaldehyde concentration inside the building can be higher than national safety standard.

The human body is exposed to the air every day, with long time contact, a series of uncomfortable symptoms to formaldehyde gas may be observed. The adverse effect of the excessive indoor environment formaldehyde to human health is difficult to assess, various symptoms may be observed under different levels of pollution and distinct conditions, including the environment temperature and humidity, and other various environmental factors [6-7]. The indoor environment of high temperature and high humidity will aggravate the release intensity and rate of formaldehyde gas from the decorating materials, coupled with a variety of other environmental conditions, the formaldehyde concentration will easily exceed the safety standard. First of all, high formaldehyde concentration had an allergy effect on the human body. Long-term exposure to formaldehyde in the indoor environment will lead to allergic dermatitis and other skin diseases. Long-term exposure to high formaldehyde in the environment may induce bronchial asthma in the human body. Pregnant women live in certain concentrations of formaldehyde may cause fetal abnormalities [5, 7].

Table 1. Effect of formaldehyde with different concentrations on human

Formaldehyde (ppm)	Symptoms
0.1-0.5	Allergic skin, other dermatitis diseases, immunity reduced
0.6-0.9	Eczema; function change of the lung
>0.9	Certain kinds of cancer

Total volatile organic compounds (TVOCs) have been defined as very important air pollutants by the National Academy of Sciences, the National Research Council and the World Health Organization. The World Health Organization noted that the melting point is below room temperature and the boiling point ranges from 50 ℃ to 260℃. At present, there are more than 900 kinds of known chemical and biological substances in the indoor environment, among which the number of volatile organic compounds reaches 350 or more, and carcinogenic and mutagengenic substances account for more than 20 kinds [8]. However, the proportion of their content in the whole indoor environment is relatively small and the concentration is low, so it is difficult to detect the concentration of each pollutant alone.

At present, it is difficult to detect the concentration of TVOCs in the indoor air quantitatively with current instruments, because there are a large number of volatile organic compounds in the closed indoor environment. The TVOCs concentration in indoor environment may cause the damage to genetic materials of human. Previous studies have shown that if the residents were exposed to TVOC in the indoor environment for a long time, especially under a certain excessive concentration, the skin and other organs will suffer from a relatively large stimulation effect [9-10].

Table 2. Effect of TVOCs with different concentrations on human

TVOCs (ppm)	Symptoms
<50	No irritation, no discomfort
50-750	Impatience, discomfort
750-6000	Impatience, discomfort, headache
>6000	Headache and other nervous problem

In this paper, the indoor air quality was investigated in different sampling sites in Zhejiang International Studies University, the air quality condition and developing trend was studied on campus, the factors affecting formaldehyde pollution and TVOC pollution were analyzed in various area on campus, the major source for formaldehyde pollution and TVOC pollution were discussed based on the data analysis, the results was compared with current air quality standard, and certain measures were suggested for air pollution control, to maintain the health of teachers and students.

On campus of Zhejiang International Studies University, the students spent most of the time in various kinds of interior space for daily study and life, including the dorm, classroom, playground, supermarket and dining room, etc. Long time exposure to all kinds of volatile organic compounds (VOCs) in the indoor environment can cause damage to the nervous system and respiratory system of human. Formaldehyde, mold, radon, ammonia, nitrogen oxides and other VOCs are common pollutants in indoor environment. The teachers and students usually stay in the classroom and dorm for a continuous period, with long time exposure in the airtight environment, the indoor air quality played an important role in maintenance of health of teachers and students.

2. Materials and Methods

2.1. Study area

The selection of sampling sites in Zhejiang International Studies University for indoor air environment monitoring is very important. The rationality of sampling sites will directly affect the monitored results and the original data. From January to March, 2019, four sampling sites of Zhejiang International Studies University at living areas, teaching areas, activity areas, and construction areas are set up to detect the concentration of formaldehyde and TVOC concentration, the height of each sample site was in 1.2 meters distance from the ground, and the distance against the walls of the indoor environment was more than 0.5 meters. The selection of sampling sites are determined by sampling principles, detection methods, the locations of f Zhejiang International Studies University, the visitor flow, ventilation and other factors. The original data were collected on campus for a total of three days, with a total of 240 data completed. The sampling sites were set up at the construction area of Zhejiang International Studies University that has been decorated, but the visitor flow is relatively small. For the monitoring of concentrations of formaldehyde and TVOC for each sample site, it is not possible to control the indoor temperature, ventilated

environment and the visitor flow of sampling sites. Therefore, the sampling time (14:00-16:00) of three days was selected when the sampling environment was as similar as possible, including temperature, humidity and weather. The indoor air environment was kept airtight before data collection, and relative high visitor flow was avoided during the data monitoring period, to reduce the release of formaldehyde from sources and the contact area and time of formaldehyde with surface air, ensuring the accuracy of the original data.

2.2. Monitoring methods

Field survey method and literature research method were applied for the detection of indoor air quality in different areas of Zhejiang International Studies University. The four representative sampling sites were set up in the Zhejiang International Studies University, and intelligent air quality hand-held TVOC detector (PGM-7240), gas detector and formaldehyde analyzer (INTERSCAN, 4160-19.99m) were used on 2019/1/26, 2019/2/24, 2019/3/10 to monitor several common pollutants (HCHO and PM2.5, etc.), to compare the air quality in different places on campus, discussing the air quality changes in various places, to analyze the concentration and spatial and temporal distribution characteristic of air pollutants on campus. Meanwhile, daily forecast of air pollution index was incorporated for reference, to ensure the influence of infrastructure construction activities on air quality on campus.

2.3. Assessment methods

The first national standard for data comparison was GBT 18883-2002 issued by the general administration of quality supervision, inspection and quarantine, the ministry of health and the state environmental protection administration. This standard stipulates that the relative equilibrium concentration of formaldehyde within one hour in indoor environment is ≤0.10mg/m3, and the relative equilibrium concentration of TVOC within 8 hours in indoor environment is ≤0.60 mg/m3. The second is the GB 50325-2010 code for the control of indoor environmental pollution in civil construction projects jointly issued by the ministry of housing and urban-rural development of the People's Republic of China and the general administration of quality supervision, inspection and quarantine of the People's Republic of China. The formaldehyde concentration standard for second-class civil buildings shall be ≤0.1mg/m3 and TVOC concentration ≤0.6mg/m3. First-class of civil construction projects, including schools and hospitals, the elderly activity center, etc. Sampling sites were set up on campus of the university, so the data in this paper was compared in accordance with standards jointly issued by the ministry of construction of the People's Republic of China, and state administration of quality supervision, inspection and quarantine of the People's Republic of China on November 26, 2001. And the first-class of civil building engineering standards was implemented on January 1, 2002.

3. Results and Discussion

3.1. Detection of HCHO and TVOCs

The concentration of indoor formaldehyde and volatile organic compounds were detected in different building areas of Zhejiang International Studies University for three days with a certain time interval, it is concluded from the change trend of indoor formaldehyde and TVOC concentration that the indoor air quality level depends on various factors in Zhejiang International Studies University. The release process of formaldehyde is a long term and continuous process, generally speaking, the formaldehyde concentration in the bedroom after new decoration correlated positively with the decoration degree, along with decoration

more and more other harmful gas is inevitably released into the indoor air environment [6]. On Campus of Zhejiang International Studies University, three different instruments with different principles and accuracy were applied, to detect formaldehyde and TVOC concentrations in different indoor places on campus. In the process of monitoring, the accuracy of smart air detector with color screen was lowest, no data was obtained at some sampling sites, and the data had no statistical significance for other sampling sites, though smart air detector with color screen can simultaneously measured concentration of formaldehyde, TVOC, relative humidity, moisture and in the same space (Table 3). Besides, data measured from different parts on campus can be compared for reference. However, the detection principle varied between formaldehyde, TVOC and benzene, and indoor humidity, temperature and other gas had a significant effect on the air quality detector. Therefore, the accuracy of the instrument was low and the linear relationship of the data was not ideal (Table 4).

Table 3. Environmental conditions for four sampling sites on Mar. 10

Sites	Temperature (℃)	Humidity (%)	Area (m^2)
Living area	13	53	35
Teaching area	16	58	50
Activity area	14	56	100
Construction area	18	63	50

Table 4. TVOCs (ppm) and HCHO (ppm) for four sampling sites during the study period

NO.	Position	Date	TVOC	Average	Over standard rate	HCHO	Average	Over standard rate
1	Living	Jan. 26	65-84	73	0	15-61	31	0
2	Living	Feb. 24	59-77	68	0	13-56	28	0
3	Living	Mar.10	59-75	63	0	11-49	27	0
4	Teaching	Jan. 26	58-74	66	0	34-220	74	5.9
5	Teaching	Feb. 24	50-57	55	0	22-209	67	4.8
6	Teaching	Mar.10	49-56	53	0	19-205	62	3.3
7	Activity	Jan. 26	54-85	67	0	13-57	40	0
8	Activity	Feb. 24	44-59	53	0	14-59	37	0
9	Activity	Mar.10	49-56	52	0	14-56	37	0
10	Construction	Jan. 26	112-165	137	2	88-430	135	15.9
11	Construction	Feb. 24	108-145	127	1.4	16-135	78	6.4
12	Construction	Mar.10	47-69	55	0	16-112	68	4.3

3.2. Factors affecting the distribution of HCHO and TVOCs

3.2.1. Temperature and humidity

The formaldehyde concentration showed positive correlation with the temperature and humidity on March 10, 2019 (Table 3 and Table 4). The higher the room temperature and humidity, the higher the

formaldehyde concentration. Based on the monitoring data of the four sampling sites, the formaldehyde concentration was observed greater with high temperature and humidity. It is concluded that the release of formaldehyde from the decoration materials was promoted by high temperature and humidity. The temperature and humidity in construction and activity area is higher, resulting in higher formaldehyde concentration in these area. The TVOC concentration was relatively high in construction area on March 10, 2019, and temperature and humidity has little influence on the concentration of TVOCs in airtight indoor environment. Negative correlation was observed between TVOCs concentration with temperature and humidity, the TVOC concentration was higher in temperature the living area with lower humidity and temperature than that of activity area.

3.2.2. Time

During the study period, the concentration of formaldehyde and TVOCs reduced along with the monitoring time, whether the site was recently decorated or not on campus of Zhejiang International Studies University. It seemed that the effect of interior decoration on release of formaldehyde and TVOCs, can be mitigated by extension of time, causing a constant decline on concentration of formaldehyde and TVOCs. Especially in the construction area on campus, a few of the data investigated on January 26, 2019 exceeded the Class I of national civil construction standard, including the average formaldehyde concentration. For the following two monitoring time, the concentration of formaldehyde and TVOCs significantly decreased. The concentration of TVOCs reached the standard on March 10, 2019, while part of the concentrations of formaldehyde still exceeded the standard. Therefore, newly decorated indoor rooms should be empty for a period of time before coming into service.

Table 5. Advantages and Disadvantages of Indoor Pollution Control Methods

Control Methods	Advantages	Disadvantages
Regulation of Temperature and Humidity	Control the release of HCHO and TVOCs	Hard to control the indoor temperature and humidity
Ventilation	Reduce the concentration of HCHO and TVOCs, easy for volatilization of HCHO	Deferential concentration will encourage the release of HCHO and TVOCs
Source Control	Choose environmental friendly materials, prevent the pollution from the source	Newly decorated area is hard to avoid
Plant Purification	Green, economic and no secondary pollution	Low purification efficiency and many influence factors
Physical Adsorption	Simple, good effect	The gas will still release after capacity
Photo-catalysis	Pollutants degradation and air purification	UV light is required for the photo-catalysis process

3.2.3. Ventilation

During the study period, the concentration of formaldehyde and TVOCs were lower in living and teaching area on campus of Zhejiang International Studies University. The living and teaching area had better ventilation than construction and activity area, and the activity area are usually densely-populated. For living and teaching area, ventilation is an effective way to remove formaldehyde and TVOCs from

indoor environment. Besides, for the construction area, ventilation should be ensured when the air quality of outdoor environment was good.

3.2.4. Indoor decoration materials

The concentration of formaldehyde and TVOCs of the construction area on campus was highest among the four sampling sites. The paintings and waterproof materials used in the decoration process can release formaldehyde and TVOCs continuously [9]. Many kinds of decoration materials have been confirmed with harmful pollutants over the national standard. Though the safety of indoor air can not be guaranteed by use of qualified and high quality decoration materials throughout the construction and decoration process, it is still suggested to use high-standard and environment-friendly decoration and building materials.

3.3. Air pollution control

Recently, more and more young people choose to rent after graduation from school. It was reported online that the eggshell renting apartment posted their rooms online for rent the next day after decoration.

the tenant strong felt the pungent smell from the harmful gas released from the indoor decoration materials. For these long term renting platform, decoration materials with inferior quality were used in the decoration process due to cost saving. Professional air quality assessment was necessary to conduct before renting, for the health of the tenants. When living in the room with formaldehyde concentration within the range of 0.08 mg/m3 to 0.10 mg/m3, people would feel slight irritation and cause a series of abnormal symptoms. When living in the room with formaldehyde concentration within the range of 0.16 mg/m3 to 0.50 mg/m3, physical symptoms including dizziness, headache, sore throat and pain will be observed. When living in the room with formaldehyde concentration extremely high, people living in the environment will feel a series of chest tightness, cough, breathing difficulties and other symptoms.

Formaldehyde was listed as a category I carcinogen in the list of carcinogens published by the WHO cancer research institute on October 27, 2017. After the media report, The eggshell renting apartments platform issued a statement saying all the houses have been subjected to strict inspection by professional air quality monitors, but consumers still concerned about the safety of indoor air quality. Therefore, it is urgent for the government to strengthen the supervision on the quality of decoration materials in the market, and random supervision on the indoor air quality for those new decorated renting rooms.

Recently, more and more attention are paid on the air quality detector or equipment [11]. The risk of indoor air pollution on human health guided people to know the pollution level of various contaminants in the indoor environment. With increasing focus on the threat of air pollutants, more and more attention were paid to intelligence screen portable air detector and also the knowledge on how to purify the polluted air and live in the clean air. There are more and more kinds of decoration materials on the market for selection, so the challenge of air quality detection is getting bigger and bigger [12-13]. The attention of air quality detection instrument in the market is also getting more intensive. The detection range of pollutants will also get much wider with the development of detection technology [14-15].

3.3.1. Reasonable temperature and relative humidity

Previous study have confirmed the effect of temperature and humidity on the release of formaldehyde, if the temperature of indoor room is 20℃ and the environmental humidity is 30%, the measured volatilization volume of formaldehyde would be 20% of the content under temperature of 30℃ and humidity of 70%. The shift of temperature from 30℃ to 20℃, can effectively reduced the release of

formaldehyde by 70%, and the shift of humidity from 70% to 30%, can effectively reduced the release of formaldehyde by 40%. Because formaldehyde is a gas with a strong pungent odor at room temperature. Depolymerization is easy to occur when formaldehyde is heated. At room temperature, formaldehyde gas can be released slowly from decoration materials or furniture, and it can be released into the space with lower formaldehyde concentration before balance. And formaldehyde is easily soluble in water, increase of air humidity in the indoor environment can also encourage the speed and amount of formaldehyde in decorating material released to air. The boiling point of formaldehyde is -19.5℃, and the release of formaldehyde gas increases rapidly when the indoor temperature exceeds 25℃.

3.3.2. Ventilation

Under the same conditions, good and effective ventilation is conducive to diluting formaldehyde and other gases released by indoor decoration materials, and can also ensure the effective circulation of indoor and outdoor air, bringing fresh air to the indoor environment. When there was difference between the formaldehyde concentration of indoor and outdoor environment, ventilation can encourage the formaldehyde transfer from the place with high concentration to the low side (from indoor to outdoor). In a similar way, the greater of formaldehyde concentration the internal decoration materials than indoor environment, the easier for formaldehyde to volatile from the furniture and building materials. In order to keep the volatilization of formaldehyde, the concentration difference between the material surface and the indoor environment should be kept. Therefore, ventilation should be ensured to keep the formaldehyde concentration of indoor environment at a low level, to promote the volatilization of formaldehyde gas from decoration materials to a maximum degree.

Ventilation was suggested as frequent as possible, to form a negative air pressure between indoor and outdoor environment. It is a good measure to choose an effective air circulation device, which can effectively change the air in the indoor environment, especially when there is a difference on concentration of various substances between the outdoor air and the indoor environment. For the building and coatings materials used in the decoration process, there is a certain amount of incomplete polymerization of free formaldehyde, so the frequent use of numbers of adhesives in furniture is one of the main sources of formaldehyde gas, usually result in high formaldehyde concentration in the indoor environment. Therefore, take advantage of the placement of furniture and ventilation of the indoor environment after decorating, is the key to promote air change and ventilation, to remove and dilute the concentration of formaldehyde and TVOCs effectively.

3.3.3. Source control

Source control is the fundamental solution for indoor air pollution. Selection of decoration materials with good quality can reduce indoor air pollution, such as environmental friendly emulsion paint and sheet materials. Selection of construction materials and paints without formaldehyde, or put the furniture with formaldehyde in the position with good ventilation condition before use. Apply a surface barrier layer on the furniture containing formaldehyde, or reduce the temperature and humidity in the indoor environment to reduce the release of formaldehyde gas in the indoor environment. If household products or furniture are identified as sources of volatile hazardous substances, products of pollution sources containing contaminants should be replaced and cleaned as soon as possible.

3.3.4. Plant Purification

A few plants were reported as doing well in purifying formaldehyde, including adsorption and absorption of formaldehyde. But not all plants have the ability to purify formaldehyde, and the capacity of absorbing formaldehyde varied among different plants. Bracketplant and aloe have significant effect of removing formaldehyde, these green plants can accelerate the reduction on concentration of air pollutants in indoor environment. Plant purification was an environmental friendly way to reduce the contaminants and cause no second pollution to indoor environment. The combination of activated carbon unit and green plants is even more effective to remove trace organic pollutants in air. The absorption and purification efficiency of green plant on formaldehyde is affected by a range of factors, such as different varieties, different culture medium, external conditions such as temperature, light intensity, evaporation rate water for leaves and internal resistance of pollutants entering the leaves.

3.3.5. Physical adsorption

Physical adsorption method often used activated carbon to absorb formaldehyde and other harmful substances in indoor air environment. Activated carbon had advantage of many pores, low cost and simple using method. The characteristic of activated carbon is that there is no chemical additive. Activated carbon is used for deodorization and detoxication based on its physical function. After decoration, activated carbon is usually used in indoor environment to reduce the concentration of indoor air pollutants. If more effective removing effect are expected, chemical measures should be applied combined with activated carbon. Besides, in the process of indoor use with activated carbon, the adsorbents should be update on time, the formaldehyde does not decompose during the process, or else the adsorbed pollutants or harmful substance will release once saturated or heated. In order to avoid the secondary pollution caused by excessive adsorption, regular replacement of active carbon need to be conducted. For better indoor air quality, professional testing institutions with CMA qualification can be hired, to use regular testing equipment for daily monitoring, and scientific methods can be selected for follow-up treatment according to needs.

3.3.6. Photo-catalysis

Photocatalyst is technically defined as a semiconductor material with catalytic function, represented by nanometer titanium dioxide, which can be used as a catalyst to promote chemical reactions but does not change itself under light conditions. Under the condition of illumination, after absorbing sunlight or ultraviolet rays, nanometer titanium dioxide can form strong oxidizing free radicals, which can decompose the free harmful substances and microorganisms in the ambient air, making it become carbon dioxide and water, so as to decompose pollutants and purify air. Photocatalyst has a purification effect on formaldehyde, benzene, ammonia, sulfur dioxide, carbon monoxide, nitrogen oxides and other harmful organic compounds that affect human health. Photocatalyst can effectively kill many kinds of bacteria, decompose and treat the toxins released by bacteria or fungi harmlessly. It has formaldehyde removing, deodorant, anti-pollution, air purification and other functions. Photocatalyst only works when it is stimulated by ultraviolet light, but ultraviolet light does not exist indoors all the time, which limits the role of photocatalyst products in practical use.

4. Conclusions

During the study period, the concentration of formaldehyde and volatile organic compounds (TVOCs) in the construction area was relatively high, and the concentration of formaldehyde and TVOCs observed in the living and activity area was all below the standard. The activity area was relatively open for space,

with better ventilation and simple decoration, affected less by decoration and construction materials. The concentration of formaldehyde and TVOCs in the teaching area of Zhejiang International Studies University is higher than that in the living area and activity area, because the teaching area has a relatively larger flow of people, and the human activities and crowd flow in the indoor environment also have a certain impact on the concentration of formaldehyde and TVOCs.

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