Study on the Characteristics of Formaldehyde Pollution in Typical Teaching Machine Room

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Abstract. This study focused on measuring the pollution characteristics, the monthly and seasonal variation rule of formaldehyde in the teaching machine room of Guangxi Normal University from March 2016 to February 2018, and the correlation between formaldehyde concentration and temperature or humidity were also analyzed. The results indicated that seasonal and monthly variation rule of formaldehyde changed with temperature and humidity in the teaching machine room. The concentration of formaldehyde was higher in summer and autumn, while was lower in winter and spring. Further analysis indicated that there was a strongly positive correlation ($R^2 > 0.87$, $R^2 > 0.85$, $R^2 > 0.81$, $p < 0.01$) between formaldehyde concentration and temperature, relative humidity or absolute humidity. It concluded that the formaldehyde concentration increased with the increase in the temperature and humidity. The maximum concentrations of formaldehyde in sitting breathing area and standing breathing area were 0.442mg/m^3 , 0.445mg/m^3 and 0.184mg/m^3 , 0.213mg/m^3 in July 2016, 2017, respectively. After eleven years, the formaldehyde in the teaching machine room was still seriously exceeded the standard (0.1mol/L), and decreased the temperature or humidity could effective alleviate the level of indoor formaldehyde concentration.

1. Introduction

With the improvement of economic level and life style, people's concept of production and life is changing constantly [1], and in order to make the indoor environment more comfortable and beautiful, the upsurge of decoration continues to rise [2]. In recent years, the problem of indoor air pollution has become more and more seriously, which has critically endangered human safety that a lot of research has also been carried out at domestic and abroad [3, 4]. Formaldehyde is one of the causes of human disease [5], the weekly prevalence of rhinitis or eye, throat, skin symptoms were 18.8%, 11.6%, 15.6% and 11.1%, respectively [6]. The exposure of indoor formaldehyde may increase the risk of common cold in children [7, 8]. The release of pollutants (VOCs and formaldehyde) from the inner wall covered by wallpaper increased the prevalence of atopic dermatitis [9]. Formaldehyde is a common indoor air pollutant, which has obvious effect on human health [10].

Investigation 32 kinds of indoor pollutants in 18 schools indicated that formaldehyde was the main pollutant in the school [11], and the average formaldehyde concentration significantly exceeded the standard in a primary school of eastern Serbia towns [12]. The concentration of formaldehyde or acetaldehyde, acetone, toluene, hexanal in Beijing residential room was $55.1\mu\text{g/m}^3$ or $18.7\mu\text{g/m}^3$, $14.8\mu\text{g/m}^3$, $14.1\mu\text{g/m}^3$, $13.8\mu\text{g/m}^3$, respectively [13]. The concentrations of

formaldehyde and TVOC in Xi'an underground shopping malls ranged from $0.05\text{mg/m}^3 \sim 0.2605\text{mg/m}^3$ and $0.3405\text{mg/m}^3 \sim 3.5605\text{mg/m}^3$ [14], and the concentrations of TVOC (1.15mg/m^3) and formaldehyde (2.3mg/m^3) exceeded the national standard in the newly renovated shopping malls [15]. In the underground platform of subway station, the concentrations of TVOCs or PM10, PM2.5 were higher than the regulated standards stipulated by Taiwan's Environmental Protection Administration [16]. Analysis found that indoor formaldehyde concentration of $30.12\mu\text{g/m}^3$ was slightly higher than that of outdoor $27.80\mu\text{g/m}^3$ [17], and the concentration of formaldehyde in indoor were 0.21mg/m^3 , 0.11mg/m^3 , 0.04mg/m^3 after 3 months, 6 months, 12 months of decoration [18] which decreased with the passage of time [19, 20].

It existed positively correlated between indoor formaldehyde concentration and temperature or humidity [21, 22]. The average indoor formaldehyde concentration in North and South of China were $56\mu\text{g/m}^3$ and $40\mu\text{g/m}^3$ [23], and the indoor concentration of formaldehyde in Beijing of summer was 1.63 times of winter [24]. Studied found that the temperature and humidity have a great influence on the emission of formaldehyde from wood-based panels [25], humidity promoted the formaldehyde emission of medium density fiberboard [26]. In the newly house, furniture and building materials were the main source of formaldehyde [5], which contributed 45% and 43% to indoor formaldehyde

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concentration [27], and the release of formaldehyde from indoor wood materials was decrease with the passage of time [28]. Differences in building structure may affect the release of indoors formaldehyde [29], and VOC contaminants vary in two different types of wards [30]. Human activities will affect the release of pollutants that also increase the indoor concentration of formaldehyde [31, 32]. It can be seen that the indoor formaldehyde release were affected by indoor temperature or humidity, human activities, which the furniture and building materials were the main source. So far, numerous indoor air pollution studies in China have focused on the concentration of formaldehyde in public places, but little is known about the effect of indoor factors on indoor formaldehyde concentration. Considering these facts, a comprehensive study about the rule and external factors that formaldehyde emission in the teaching machine room seemed worthy of effort.

The main objective of this study was to study the monthly and seasonal variation rule of formaldehyde concentration in the teaching machine room, and the correlation between formaldehyde concentration and indoor temperature or absolute humidity, relative humidity were also analyzed.

2. Materials and Methods

2.1. Sampling Sites

In this study, the sampling point set in the teaching machine room of Guangxi Normal University. The teaching machine room (17600mm×9670mm×3900mm) was asemi-enclosed environment and built in March 2006, with a computer desk made of veneer particleboard. According to the HJ/T167-2004 "Technical Specification for Indoor Ambient Air Quality Monitoring" [33], the diagonal layout method was used for set sampling points in the teaching machine room. A total of 9 sampling points set in the teaching machine room, which 5 sampling points distributed on each diagonal line. The sampling points were located over 0.5m away from the ventilation and exterior wall, and the formaldehyde of sitting breathing area (1m from the floor) or standing breathing area (1.5m from the floor) were monitored. The sampling point distribution is shown in Figure 1. In order to ensure the reliability of the experimental data, the monitoring time of teaching machine room were 13:00pm-14:00pm every three days from March 2016 to February 2018, and repeat three times for each sample.

Fig. 1. Distribution map of sampling point in teaching machine room

2.2. Experiments and Methods

In this study, the bubble absorption tube was as the research object, and the sampled digital constant current sampler (HL- II / IV , Shanghai Buqing Technology Development Co, Ltd.) was used to study the formaldehyde in the teaching machine room. Before and after sampling, the sampling series flow rate was accurately calibrated with a soap flow meter (ZR-5310, Qingdao Chengxintong Instrument Co, Ltd.), with a sampling range of 0-1L/min and accuracy of $\pm 2\%$. The Phenol reagent spectrophotometry (GB/T18204.26-2000) [34] was a standard method for the determination of formaldehyde concentration, and correlation analytical methods for indoor formaldehyde can also be found in elsewhere [35]. In this paper, the concentration of formaldehyde was determined by phenol reagent spectrophotometer (China Shanghai Optical Instrument Factory Co, Ltd. 72N), which absorption peak was at 630nm. The temperature and humidity meter (TH108, Shenzhen Hongmao Instrument and Meter Factory) continuously record the values of indoor temperature and humidity. The indoor temperature measurement range was -10°C - 50°C which the accuracy was $\pm 1^{\circ}\text{C}$, and the indoor relative humidity was measured from 10% to 99% with an accuracy of 2%.

2.3. Statistical Analyses and Evaluation Standard

In this paper, statistical analysis of measurement data was performed on the measured data using Microsoft Excel (version 2010), Origin (version 8.5). The "Indoor Air Quality Standard (GB/T1883-2002)" [36] and the formaldehyde limit standard ($0.1\text{mg}/\text{m}^3$) were used as the evaluation criteria for indoor formaldehyde concentration to determine whether formaldehyde exceeded the standard in the teaching machine room.

2.4. Quality Assurance and Quality Control

In order to ensure the reliability and accuracy of the monitoring results, the analysis and determination of formaldehyde was strictly in accordance with the standard method (GB/T18204. 26-2000) [34]. Before sampling, the teaching machine room was sealed for 12h.

After the sampling was completed, the sample was placed in a plastic bag and measured within 24h at room temperature. A 1.0 $\mu\text{g}/\text{ml}$ aqueous formaldehyde solution was used as the calibration standard solution prior to analysis of the absorbed sample, and a formaldehyde concentration calibration curve was established using eight standard formaldehyde concentrations. Calibration standards include routine operational maintenance and standard sample calibration, and were run and tested daily using the same analytical procedure to ensure sample stability. To ensure the validity of the results, walking disturbances should be avoided during monitoring process and each sample should be analyzed in parallel.

3. Results and Discussion

3.1. Seasonal Variation Rule of Formaldehyde Concentration

In order to study the seasonal variation rule of formaldehyde in the teaching machine room of Guangxi Normal University from March 2016 to February 2018. We measured and analyzed the monitoring results of formaldehyde in sitting breathing area and standing breathing area of the teaching machine room. The seasonal variation rule of formaldehyde in different respiratory areas of the teaching machine room is shown in Figure 2.

Fig. 2. Seasonal variation rule of formaldehyde concentration:
(a) 2016.3-2017.2, (b) 2017.3-2018.2

The concentration of formaldehyde in the teaching machine room within two years is shown in Figure 2.

There are seven months concentration of formaldehyde exceeded the standard ($0.1\text{mg}/\text{m}^3$) in the sitting area (S1) and standing breathing area (S2) from March 2016 to February 2017. The over-standard rate of formaldehyde measured in the sitting breathing area and standing breathing area was 58.33%. The maximum concentrations of formaldehyde in sitting breathing area and standing breathing area were $0.432\text{mg}/\text{m}^3$, $0.435\text{mg}/\text{m}^3$ in July of 2016. The formaldehyde concentrations in summer and autumn exceeded the standard values, while it did not exceed the standard in spring and winter. The formaldehyde concentration in the sitting breathing area was slightly higher than that in the standing breathing area, except for April, May and June (Figure 2 (a)). There are three months concentration of formaldehyde exceeded the limit value ($0.1\text{mg}/\text{m}^3$) in the sitting area (S1) and standing breathing area (S2) from March 2017 to February 2018. The over-standard rate of formaldehyde measured in the sitting breathing area and standing breathing area was 25%, and only summer exceeded the standard value. The concentration of formaldehyde in the sitting and standing breathing areas reached a maximum of $0.184\text{mg}/\text{m}^3$, $0.213\text{mg}/\text{m}^3$ in July 2017. During the monitoring period, except for August and September, the formaldehyde concentration in the sitting breathing area was slightly higher than that in the standing breathing area (Figure 2 (b)).

It can also be seen from Figure 2, in the two-year monitoring period, the formaldehyde concentration of each month in the teaching machine room from March 2017 to February 2018 was lower than the corresponding month of formaldehyde concentration from March 2016 to February 2017. With the change of time, the formaldehyde concentration showed a change rule of increasing first and then decreasing (Figure 2 (a) and Figure 2 (b)). The change of formaldehyde in the sitting breathing area and standing breathing area of the teaching machine room was small. The seasonal variation rule of formaldehyde concentration in the sitting breathing area and standing breathing area was basically the same, while the formaldehyde concentration changes greatly in the different seasons. Formaldehyde is mainly derived from plywood such as tables and chair [37], and outdoor formaldehyde is also a cause of the increase of formaldehyde concentration in the room [38].

3.2. Monthly Variation Rule of Formaldehyde Concentration

According to the above analysis results, we select the typical months as monitoring point in the sitting breathing area and standing breathing area of the teaching machine room from March 2016 to February 2018. In order to study the monthly variation rule of formaldehyde in the teaching machine room, we further analyzed the concentration characteristics of formaldehyde. Figure 3 and Figure 4 show the monthly variation rule of formaldehyde in different respiratory areas of the teaching machine room.

Fig. 3. Monthly variation rule of formaldehyde concentration:
(a) 2016.5, (b) 2016.8, (c) 2016.10, (d) 2016.12

Fig. 4. Monthly variation rule of formaldehyde concentration:
(a) 2017.5, (b) 2017.8, (c) 2017.10, (d) 2017.12

The variation in formaldehyde concentration in the teaching machine room during the monitoring period of 2016.3-2017.2 is shown in Figure3. The formaldehyde

concentration in the standing breathing area was slightly higher than the sitting breathing area, and the over-standard rate of formaldehyde measured in the standing breathing area was 80%. The maximum and minimum concentrations of formaldehyde were $0.125\text{mg}/\text{m}^3$, $0.0756\text{mg}/\text{m}^3$ and $0.128\text{mg}/\text{m}^3$, $0.081\text{mg}/\text{m}^3$ in the sitting breathing area and standing breathing area, respectively (Figure 3 (a)). The maximum and minimum concentrations of formaldehyde were $0.412\text{mg}/\text{m}^3$, $0.254\text{mg}/\text{m}^3$ and $0.415\text{mg}/\text{m}^3$, $0.229\text{mg}/\text{m}^3$ in the sitting breathing area and standing breathing area, respectively. All concentration of formaldehyde measured in the sitting breathing area and standing breathing area exceeded the standard limit (Figure 3 (b)). The formaldehyde concentration in the standing breathing area was slightly lower than the sitting breathing area, except for 3th and 9th days. The over-standard rate of formaldehyde measured in the sitting breathing area and standing breathing area was 100% (Figure 3 (c)). The maximum and minimum concentrations of formaldehyde were $0.053\text{mg}/\text{m}^3$, $0.0252\text{mg}/\text{m}^3$ and $0.053\text{mg}/\text{m}^3$, $0.02\text{mg}/\text{m}^3$ in the sitting breathing area and standing breathing area, respectively. All concentration of formaldehyde measured in the sitting breathing area and standing breathing area were below the standard value ($0.1\text{mg}/\text{m}^3$) (Figure 3 (d)).

Figure 4 shows the change in formaldehyde concentration in the teaching room from March 2017 to February 2018. The maximum and minimum concentrations of formaldehyde reached $0.119\text{mg}/\text{m}^3$, $0.0125\text{mg}/\text{m}^3$ and $0.12\text{mg}/\text{m}^3$, $0.025\text{mg}/\text{m}^3$ in the sitting breathing area and standing breathing area, respectively. The over-standard rate of formaldehyde measured in the sitting breathing area and standing breathing area was 30% (Figure 4 (a)). All concentration of formaldehyde measured in the sitting breathing area and standing breathing area were above the standard value. The maximum in formaldehyde concentration in the sitting breathing area and standing breathing area were $0.154\text{mg}/\text{m}^3$ and $0.161\text{mg}/\text{m}^3$ (Figure 4 (b)). The concentration of formaldehyde in the sitting breathing area and standing breathing area gradually decreased except for the 27th and 30th days. The formaldehyde concentration in the sitting breathing area and standing breathing area reached a maximum of $0.124\text{mg}/\text{m}^3$ and $0.1\text{mg}/\text{m}^3$ on the third day (Figure 4 (c)). The formaldehyde concentrations in the sitting breathing area and standing breathing area were below the standard limit (Figure 4 (d)).

Comparing Figure 3 and Figure 4, it can be found that the daily concentration of formaldehyde in the sitting breathing area and standing breathing area from March 2016 to February 2017 was slightly higher than that of March 2017 to February 2018. There is little difference in the daily variation of formaldehyde concentration within one month. In general, the difference in formaldehyde concentration between month and month is mainly due to temperature [39].

3.3. Effect of temperature and humidity on Formaldehyde Concentration

In order to study the correlation between formaldehyde concentration and temperature or humidity in the teaching machine room, we systematically analyzed the relationship between formaldehyde concentration and temperature or humidity in the experimental data of three groups in the teaching machine room, as shown in Figure 5. And the relationship matrix between formaldehyde and temperature or humidity is shown Table 1.

Fig. 5. The correlation between formaldehyde concentration and indoor temperature or relative humidity, absolute humidity: (a) temperature, (b) relative humidity, (c) absolute humidity

Table 1. The matrix between formaldehyde concentration and temperature or humidity in the teaching machine room

Sit	Teaching machine room	
Temperature	Pearson R ²	0.87** (n=720)
Relative humidity		0.85** (n=720)
Absolute humidity		0.81** (n=720)

*Significance level at 0.01(two-tailed)

The effect of temperature and humidity on formaldehyde concentration is shown in Figure 5. It can be concluded that the release of formaldehyde was significantly correlated ($R^2 > 0.87$, $R^2 > 0.85$, $R^2 > 0.81$, $p < 0.01$) with temperature, relative humidity or absolute humidity (Table 1). The order of influence of environmental factors on formaldehyde concentration was temperature > relative humidity > absolute humidity. The indoor formaldehyde concentration gradually increase with the increase of temperature, relative humidity or absolute humidity (Figure 5 (a), (b), (c)), which further indicted that temperature and humidity were the main factors affecting the release of formaldehyde [35, 40]. The similar results were obtained in New Decorated Residential Buildings [21, 22].

Guangxi is a high-temperature and high-humidity climate. The maximum temperature is above 35°C and humidity is above 90%. Therefore, the concentration of formaldehyde in summer and autumn was higher, and it was lower in winter and spring, which was consistent with the results of Figures 2, 3 and 4. Some studies have also shown that indoor formaldehyde concentration was higher in summer, while it was lower in winter [38, 39]. We can reduce formaldehyde concentration by reducing indoor temperature and humidity to reduce the damage to the human body [41, 42].

4. Conclusions

The purpose of this paper was to study the characteristics, monthly and seasonal variation rule of formaldehyde in the teaching machine room. The results indicated that the concentration of formaldehyde in the sitting breathing area and standing breathing area was small difference, which was higher in summer and autumn, while it was lower in winter and spring. The daily variation of formaldehyde concentration was not much different, while the monthly variation was quite different.

During the monitoring period, the formaldehyde concentration in the sitting breathing area and standing breathing area in the teaching machine room reached a maximum of 0.442mg/m³, 0.445mg/m³ and 0.184mg/m³, 0.213mg/m³ in every summer(2016.7, 2017.6), respectively. After as long as eleven years, the concentration of formaldehyde in the teaching machine room was still seriously excessive.

The temperature and humidity were the main factors that affected the release of formaldehyde in the teaching machine room of Guangxi Normal University. The correlation ($R^2 > 0.87$, $R^2 > 0.85$, $R^2 > 0.81$, $p < 0.01$) between formaldehyde concentration and temperature, relative humidity or absolute humidity were strongly. As the temperature and humidity increase, the indoor formaldehyde concentration gradually increases. We can reduce the indoor formaldehyde concentration by reduce the temperature and humidity, thus reducing the harm to human body.

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