The Status of Indoor Formaldehyde in Residential Buildings in North China

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SUMMARY

Formaldehyde is a common indoor air pollutant. To characterize daily temporal and spatial variation in human exposure to formaldehyde in the bedroom, we installed some online formaldehyde sensors in residential areas in northern China, including Tianjin, Shenyang, Xi'an, and Urumqi, and achieved a 24-hour detection. We calibrated and amended the sensor to ensure that it can correctly reflect the indoor formaldehyde concentration. The time-weighted average concentration of bedroom formaldehyde in Tianjin, Shenyang, Xi'an, and Urumqi, was found to be 89, 58, 69, and 81 μg/m³ for each region, respectively. The peak value of formaldehyde concentration occurred between 18:00 to 24:00. It is suggested that the bedroom should be ventilated for a period of time before bedtime; furthermore, most of the lowest period appeared in the daytime, especially from 12:00 to 16:00.

INTRODUCTION

Formaldehyde (HCHO) is a common indoor air pollutant. Typically, its indoor concentration is between 2 and 10 times higher than its outdoor concentration (Plaisance et al. 2014). Exposure to formaldehyde can cause irritation of the eyes and upper respiratory tract. In addition, HCHO has been classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (Jiang et al. 2017). Traditionally, the regularity of formaldehyde has been tested via sampling of an indoor environment at regular intervals, followed by analysis of the samples in the laboratory. Chi et al.’s (2016) study of the indoor air in 3122 households has led to improvements in the TVOC concentration prediction model. Furthermore, Huang et al.’s (2017) research discussed the difference between formaldehyde concentrations in the north and south of China based on sampling household air. Although this method has the advantage of high measurement accuracy, formaldehyde concentrations cannot be tested continuously (they can be measured every few hours or every few days), thus making it difficult to determine daily temporal and spatial variations in human beings’ exposure to formaldehyde (Ellison et al. 2014). With the help of wireless detection, Internet technology, and smart devices, however, studies can be undertaken in which a portable formaldehyde detector is placed in the home. Through this method, a longer term evaluation can take place, and daily changes in formaldehyde can be ascertained more easily.

This article reports on the use of an online detector to track daily formaldehyde levels in north Chinese households.

METHODS

We installed online formaldehyde detectors based on electrochemical principles in homes in north China (in residential areas including Urumqi, Tianjin, Shenyang, and Xi'an) in order to achieve 24-hour indoor detection of formaldehyde concentration levels. Some of these houses are newly renovated, others are decorated for years. In each household, an online detector was placed in a bedroom. Most of the detectors are placed on the bedside or the table before the bed. The device was also able to detect temperature and
humidity levels. The detector had the capability of uploading data to our server once a minute via WiFi. We were able to download this data by logging on to the server website. In order to ensure that the formaldehyde test results would be accurate, we calibrated the online detector. Figure 1 illustrates the calibration device, which was based on the principle of the thermal decomposition of trioxymethylene vapor (Jiao 1994). The trioxymethylene gas in the diffuser is blown out by the clean carrier gas, then flows through a thermal catalytic column containing glass microbeads covered with phosphoric acid on its surface, finally, the gas is decomposed into formaldehyde of a high concentration. A dynamic air distribution system will dilute high concentrations of formaldehyde into 25, 118, 235, and 407 μg/m³ of standard gas using clean air. The formaldehyde concentration is calculated as follows:

\[ C_s = \frac{q}{r_1 + r_2} \quad (1) \]

Where \( C_s \) is the standard gas concentration, μg/m³; \( r_1 \) is the flow of formaldehyde gas generation system, L/min; \( r_2 \) is the flow of the clean air L/min; \( q \) is the diffusion rate of the gas generation tube.

We used the double-flow humidity generator method (Bo et al. 2003) to alter the humidity of formaldehyde gas from 13% to 73%. The dry dilution gas is divided into two, one is humidified by humidification bottle to saturation, then fully mixed with another one gas. We can get a different humidity of the dilution gas by changing the sharing factor \( F \). The sharing factor is calculated as follows:

\[ F = \frac{Q_w}{Q_w + Q_0} \quad (2) \]

Where \( Q_w \) is the wet air flow, L/min, \( Q_0 \) is the dry air flow, L/min. The online detector was placed in a 21 L calibration chamber, the internal surface of which was coated with tetrafluoroethylene. We also tested the concentration of formaldehyde in the calibration chamber using the 3-Methyl-2-benzothiazolinone (MBTH) method (GBT 18204.26 2000). Because the sensor has temperature calibration inside, so we did not carry out this calibration.

We utilized local weighted regression (Sun et al. 2017) to preprocess the sensor data, thus solving problems related to short-term data vacancy and data anomaly jumps. As the installation of the detector was not exactly the same in each household, the total amount of data collected differed. Table 1 gives the start and end times for the data collected in each household.

<table>
<thead>
<tr>
<th>Num</th>
<th>Start time</th>
<th>End Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>TJ3</td>
<td>2017/2/1 0:00</td>
<td>2017/3/14 23:59</td>
</tr>
<tr>
<td>Sy4</td>
<td>2016/12/20 16:51</td>
<td>2017/3/14 23:59</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Online Detector Calibration

Each detector measured four different concentrations of formaldehyde continuously for 1-2 hours. Figure 2 shows that each detector generated a different formaldehyde response curve. Figure 3 reflects the relationship between the concentrations detected and the humidity levels. It can be seen that when the humidity is less than 25%, the detector reading is less than the true value. As such, the figures had to be revised during the latter part of the data processing stage.

![Figure 2: The correlation between the online detector formaldehyde concentrations and MBTH concentrations](image)

![Figure 3: The correlation between the online detector formaldehyde concentration levels and humidity levels](image)

Changes to Formaldehyde Levels

We divided the detector data into 24 intervals by hours, taking an average of the concentration during each interval. Figure 4 demonstrates the specific concentration changes for (from top to bottom) Tianjin, Shenyang, Xi’an, and Urumqi. The time-weighted average concentration of formaldehyde in the
bedroom was found to be 89, 58, 69, and 81 μg/m³ for each region, respectively.

As demonstrated in Figure 5, the highest formaldehyde concentration level was detected in the evening, between 18:00 and 24:00 (68.5%)—the time at which northern Chinese families tend to cook meals. The situation of second highest was basically the same as the highest, with about 75% of the second highs between 18:00 and 24:00. The formaldehyde concentration was also high between 12:00 and 14:00 (12.5%)—another time of day when cooking tends to take place.

The lowest concentrations found in the different regions were scattered throughout the day, but 12:00 to 16:00 was most common here (50%). The second lowest concentration occurred at 6am (31.25%), which may be because this is when households open the windows in the morning.

What is interesting is that in virtually all the bedrooms (except Sy3 and Xj4), there was a downward trend in formaldehyde concentration at 0~6 am (0~3 am for Tj2 and Tj3). Generally speaking, bedroom doors and windows are closed during this time of day, and it could be that low ventilation rates led to an increase in formaldehyde concentration. Another factor might be that be due to that fact that nighttime activities produce formaldehyde, thus leading to night-time concentrations exceeding the equilibrium point. After this point, even in the case of doors and windows closed, the low air infiltration can also reduce the indoor formaldehyde concentration.

We know that natural ventilation can reduce indoor formaldehyde levels effectively (Liang et al. 2013). As some of the highest concentrations of formaldehyde appeared...
between 0:00 to 6:00, we suggest that in order to decrease formaldehyde levels, the bedroom should be ventilated for a period of time before bedtime.

CONCLUSIONS
In North China in winter, the formaldehyde concentration found in bedrooms tends to be highest between 18:00 and 24:00 (68.5%). The lowest levels tend to be found during the daytime, especially from 12:00 to 16:00 (50%). The question of whether or not cooking leads to an increase in formaldehyde concentrations need to be studied further.

ACKNOWLEDGEMENT
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REFERENCES


GBT-18204.26, 2000, Method for determination of formaldehyde in air in public places
