Study on Indoor Air Quality of an University Classroom in China

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Indoor air quality not only affects the comfort and health, but also has an impact on indoor work efficiency. The research concentrates on the study of a university in China and measures the air quality of classroom, with projects including CO2 concentration, temperature, relative humidity and particulate matter (PM10, PM2.5), in order to explore the impact of CO2 concentration factors and their impact on students’ learning outcomes. The study concludes that the biggest factor affecting college indoor air quality exceeded the indoor CO2 concentration, ventilation lacking and the classroom overcrowding; proving that the indoor CO2 concentration exceeded have a significant effect on students’ learning efficiency. The continuous monitoring reflects the growth of the indoor CO2 concentration of the number of ventilators, also higher in winter heating than the fall. Based on the premise of the feasibility, the paper proposed several new methods to lower the indoor CO2 concentration during winter.

Key words: Indoor air quality, CO2, Particulate matter, Ventilation rate, Ventilation.

Indoor air quality not only affects the comfort and health of the human body, but also has a significant impact on indoor work and learning efficiency. The good air quality can make people feel refreshed, energetic and happy. However, nearly 20 years of researches show that the indoor air environment is not optimistic in many countries. People complain about the bad indoor air quality because they always have certain pathological response such as headache, drowsiness, nausea, runny nose, etc. in the bad indoor air environment. Such symptoms are known as sick building syndrome (SBS)1-3. Indoor temperature, relative humidity, CO2 concentration and particulate matter (PM10, PM2.5) reflect four important indicators of indoor air quality, and the CO2 concentration is always used to characterize the indoor fresh air content and ventilation effect. Based on Chinese national indoor air quality standard, the daily average concentration of CO2 should be not greater than 0.10% (0.10% is volume fraction). The places that are poorly ventilated or people intensively gathered prone to higher concentration of CO2, and people who stay in the overweight environment for a long time can have a mild headache and the electrolyte balance in the body is destroyed, causing blood acidosis. A severe higher concentration of CO2 will lead to headaches, fatigue and symptoms of eye, nose and respiratory 4-6.

The classroom is the main place to school teachers and students for teaching activities. Though the CO2 concentration in the classroom would not cause death, it is always out of limits and exertsbad impact on teachers’ and students’ physical health. At the same time, high CO2 concentration would also impede effective teaching...
activities, especially more frequently occurred in the winter when the classroom doors and windows are closed and poor ventilation. According to a study about the CO₂ concentration in the classroom and its impact on students’ mental work capacity, it was found that air quality had a significant effect on students’ finishing the homework, and with the increase of CO₂ concentration, students’ mental work capacity decreased obviously. So it could be concluded that foul air is a key factor that cannot be ignored, causing fatigue and reducing the learning effect. At present, many investigations and studies about air environment in the classroom have been carried out at home and abroad, and it is generally found that classrooms which have poor ventilation, numbers of students in the classroom and highly frequent staff turnover, their air pollution is particularly serious, however, there are few researches in this area in our country.

This study carried out a field survey and analysis about indoor air quality of classrooms in a university in Dalian, China, which aimed to explore effects of CO₂ concentration, temperature, relative humidity and particle concentration on students learning efficiency (PM₂.₅, PM₁₀), to provide objective basis for improving the teaching environment and effect.

MATERIALS AND METHODS

Detection objects

Detection object was a classroom of university in Dalian, China, the size of which in the classroom was 11m (length) × 7m (width) × 3.8m (height) and with 72 seats. The windows of classroom were facing south, plant around the windows was cedar and road of the campus was near the classroom.

The classroom is shown in Figure 1.

Testing instrument and testing method

This study tested the indoor temperature, relative humidity, CO₂ concentration and particulate matter concentration (PM₂.₅, PM₁₀) in the classroom, using instruments as shown in Figure 2, Figure 3. Figure 2 is MCH-383SD CO₂ concentration, temperature, relative humidity automatic memory device, the units are ppm, °C, % respectively. The instrument could read data once per minute and automatically archived. Figure 3 is TSI dust meter, mainly used for measuring indoor particulate matter (PM₂.₅, PM₁₀), read data once per second, the unit is mg/m³.

Fig. 1. Physical model of testing classroom

Fig. 2. MCH-383SD CO₂/Humidity/Temperature Monitor

Fig. 3. TSI Dust Meter

In the study, MCH-383SD instrument was used to continuously monitor temperature, relative humidity and CO₂ concentration of typical classroom which is on class in autumn and winter respectively. Then according to the test results, variation rules of temperature, relative humidity...
and CO$_2$ concentration during class time were analyzed. Furthermore, two classrooms in two different locations were chosen for indoor particulate matter (PM2.5, PM10) measurement and comparative analysis. In this study, the test results were compared with the level limitations referred in the *Indoor Air Quality Standard* (GB/T 18883-2002)\textsuperscript{10}, which was shown in Table 1.

### Table 1. Indoor air quality of measuring items

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Standard values</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>22–28</td>
<td>Air conditioning in summer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16–24</td>
<td>Winter heating</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>%</td>
<td>40–80</td>
<td>Air conditioning in summer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30–60</td>
<td>Winter heating</td>
</tr>
<tr>
<td>The fresh air volume</td>
<td>m$^3$/(h· person)</td>
<td>30</td>
<td>The average for 1 hour</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>ppm</td>
<td>1000</td>
<td>Daily average</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>mg/m$^3$</td>
<td>0.15</td>
<td>Daily average</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>mg/m$^3$</td>
<td>0.075</td>
<td>Daily average</td>
</tr>
</tbody>
</table>

### Calculating equations and calculating parameters

It is assumed that the air is fully mixed inside the V volume room. Emission rate of pollutant is represented as $m$. $C_1$ is indoor air pollutant concentration before ventilation, and for time $\tau$ elapsed, the indoor pollutant concentration turns into $C_2$. $C_s$ is pollutant concentration in outdoor air. Fresh air volume is $Q$. So according to conservation of mass, the air pollutant concentration $C$ changes could be obtained.

$$V \frac{dC}{d\tau} = QC_s + m - QC$$  \hspace{1cm} (1)

The initial conditions is $T=0$, $C=C_1$.

Solving above equations are done

$$C_2 = C_1 \exp\left(-\frac{m}{V} \tau\right) + \left(\frac{m}{Q} + C_s\right)\left[1 - \exp\left(-\frac{Q}{V} \tau\right)\right]$$  \hspace{1cm} (2)

It can be seen that indoor pollutant concentration increases or decreases with index of rules, Its rate of increase or decrease depends on $\frac{Q}{V}$.

This value reflects the size of the room ventilation\textsuperscript{11} and it is defined as air change rate.

$$n = \frac{Q}{V}$$  \hspace{1cm} (3)

The deformation of Equation (2) is shown below.

$$\frac{QC_1 - m - QC_s}{QC_2 - m - QC_s} = \exp\left(\frac{Q}{V} \tau\right)$$  \hspace{1cm} (4)

When $\frac{Q}{V} \tau << 1$, on the type can be approximate to.

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$$\frac{QC_1 - m - QC_s}{QC_2 - m - QC_s} = 1 + \frac{Q}{V} \tau$$  \hspace{1cm} (5)

The fresh air volume could be obtained:

$$Q = \frac{m}{C_2 - C_s} - \frac{V}{\tau} \left(\frac{C_2 - C_1}{C_s - C_1}\right)$$  \hspace{1cm} (6)

In the equations,
- $Q$—fresh air volume, m$^3$/h
- $m$—emission rate of pollutant, m$^3$/h
- $V$—volume of the room, m$^3$
- $C_1$—initial pollutant concentration of room, ppm
- $C_2$—pollutant concentration of room in the end, ppm
- $C_s$—outdoor pollutant concentration, ppm
- $\tau$—elapsed time, h

The amount of CO$_2$ produced by humans is related to the metabolism of human body\textsuperscript{12}, that is

$$q = 1.44 \times 10^{-4} (M A_p)$$  \hspace{1cm} (7)

In the Equation (7)
- $q$—amount of CO$_2$ breathed out, m$^3$/h
- $M$—Metabolic rate, W/m$^2$
- $A_p$—human’s skin surface area, m$^2$

Human’s skin surface area can be calculated using the equation below:

$$A_p = 0.202 m_s^{0.425} H^{0.725}$$  \hspace{1cm} (8)
In the Equation (8),

\[ m = \text{weight, kg} \]

\[ H = \text{height, m} \]

For a normal Chinese, metabolism rate is about 70W/m² when he takes a little light exercise. According to Equation (8) and (7), human skin surface area is 1.69m² and one person breathing out CO₂ volume is about 0.02m³/h.

In this study, the standard calculating volume of classroom was 308m³. When the space occupied by such equipment as computer, desk and chair (in the research, this part was calculated on 10 percent volume of room) and human(0.3m³/ person, 30 students were assumed in the classroom) was considered, the actual calculating volume of classroom was 270m³.

**The outline of measurement**

For ease of comparison, four classrooms were measured in this study, the classroom were represented as A, B, C, D respectively. Measuring time was 90 minutes once. 10:05-10:50 was the third class, 10:55-11:40 was the fourth class, 13:30-14:15 was the fifth class, 14:20-15:05 was the sixth class. The specific measurement frequency and content were shown in Table 2.

<table>
<thead>
<tr>
<th>Classroom</th>
<th>CO₂ concentration</th>
<th>Relative humidity</th>
<th>Temperature</th>
<th>Particulate matter (PM₂.₅, PM₁₀)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Autumn measuring 2 times</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Winter measuring 4 times</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>Winter measuring 2 times</td>
<td>-</td>
<td>-</td>
<td>Winter measuring 2 times PM₂.₅</td>
</tr>
<tr>
<td>C</td>
<td>Autumn measuring 1 times</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Winter measuring 2 times PM₁₀</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

**The average CO₂ concentration and the fresh air volume during the class**

The average CO₂ concentration and fresh air volume of classroom during the class timewere shown in Table 3. Table 3 showed the minimum value of average CO₂ concentration in Classroom A was 553ppm in September 27. And during testing, only this time the CO₂ concentration was lower than the limit value 1000ppm of *Indoor Air Quality Standard* in China, and the CO₂ concentrations were all out of limits in the other classrooms during the class time. The highest average CO₂ concentration was measured on December 4 in Classroom B and reached 2471ppm, which exceeded nearly 2.5 times than limit value. Moreover, Table 3 showed the average CO₂ concentration was increased obviously in classroom when entering the winter heating period in November. This was becausethe closure of the classroom window during the winter heating period caused poor indoor ventilation and the rising of average indoor CO₂ concentration. This behavior would decline the indoor air quality seriously and influence the teaching effect and the students’ learning efficiency.

Moreover, Table 3 showed another important indicator was per capita fresh air volume. According to *Indoor Air Quality Standard*, per capita fresh air volume of adult should not be less than 30m³/h. In the measurements, excepted Classroom A in the fall and winter measurement on the date of November 8 and December 6 reached the requirement of per capita fresh air volume, the rest of the testing classrooms didn’t reach the standard in the measurement date. The per capita fresh air volume of Classroom A, B and C even did not reach 10m³/h in some measurement dates, and far below the national standard. The air quality of classroom remains worrying.

**Temperature, relative humidity and particulate matter content of Classroom**

Table 4 showed the temperature, relative humidity and particulate matter (PM₂.₅, PM₁₀) of classrooms. Based on *Indoor Air Quality Standard* and *Ambient Air Quality Standard (GB3095-2012)* in China, standard value for winter heating temperature is 16~24°C and standard value for relative humidity is 30~60% while the secondary
The temperature, relative humidity, CO$_2$ concentration and particulate matter, PM$_{2.5}$, PM$_{10}$, analysis of typical room changing over time

**CO$_2$ concentration, temperature, relative humidity**

Figure 4 showed the CO$_2$ concentration, temperature, relative humidity changes of Classroom A on September 27 in autumn. From Figure 4, it could be found that there was not much change for three indicators during class time. Just CO$_2$ concentration fluctuated slightly, but it was still below the standard value. Actually, it was related to ventilation because windows were open during the class day. During out of class on 10:50-10:55, the front and back doors were opened. Indoor natural ventilation was enhanced and the number of students inside reduced at the same time; CO$_2$ concentration had a small amplitude decrease.

Figure 5 showed the CO$_2$ concentration, temperature, relative humidity changes of a classroom on October 18, which CO$_2$ concentration was always in excessive and the highest CO$_2$ concentration reached 2,100 ppm. During the
first class, CO₂ concentration and relative humidity both increased at the same time. This was because the doors and windows were closed, resulting in poor indoor ventilation. Due to the windows and the front and back doors of class opened, the number of students who stayed inside was reduced, therefore, CO₂ concentration began to decrease about 10:50, and then relative humidity began to decrease, which showed the relative humidity hysteresis than the CO₂ concentration changes. By 11:05, the front and back doors were closed again during the class. CO₂ concentration and relative humidity stopped to reduce. At the same time, since the classroom windows were open at the second class, the indoor CO₂ concentration did not begin to rise again, maintained at around 1000ppm, relative humidity decreased and finally maintained at about 35%.

Figure 6 showed the CO₂ concentration and temperature and relative humidity changes of Classroom B on November 13. From Figure 6, it could be found that the indoor CO₂ concentration was in the excessive state from the beginning of the class, and continued to rise during class time. Although the front door was open, the number of students who stayed inside was reduced after class, but the CO₂ concentration was still in an upward trend. This was because the city Dalian had entered the winter heating period since November 13 and windows were closed during the class, leading to lack of air infiltration and unable to meet the needs.
of the people in the room.

Figure 7 showed the CO\textsubscript{2} concentration, temperature and relative humidity changes of Classroom B on December 4. Compared with Figure 6 and Figure 7, it was found there was little change in the indoor temperature and relative humidity. However, the CO\textsubscript{2} concentration changed obviously. The windows had been closed during the class in Figure 6, so the CO\textsubscript{2} concentration had been on the rise; the windows were opened after class in Figure 7, so the CO\textsubscript{2} concentration had a temporary decline, and then were all on the rise, and then out of limit. During the test, we observed the students who were sleepy and out of mind in the class, as a result, the excess of CO\textsubscript{2} showed that the value of indoor particulate matter concentration was related to indoor activities of the people closely. Student did more activities before and after class, causing indoor particulate re-suspended. So the particle concentrations in those periods were higher than recess. It was worth having further research about how human activity influences on particulate matter. In addition, the measuring value of indoor particulate matter in this study was lower than the national standard, so indoor particulate matter concentration (PM\textsubscript{2.5}, PM\textsubscript{10}) had little effect about the quality of indoor air.

Table 5 showed measurement of concentration of PM\textsubscript{10} in Classroom D on 5-Dec. It could be found that the average of concentration of PM\textsubscript{10} in Classroom D was under the limit of Indoor Air Quality Standard, but the maximum was still more than the standard limited 0.15mg/m\textsuperscript{3}.

The CO\textsubscript{2} concentration of different classrooms in the same season

Figure 9 showed the comparison of CO\textsubscript{2} concentration of Classroom A and C in autumn, and Figure 10 showed comparison of CO\textsubscript{2} concentration of Classroom A and B in winter. From these two figures, it could be seen that the value of indoor particulate matter concentration was related to indoor activities of the people closely. Student did more activities before and after class, causing indoor particulate re-suspended. So the particle concentrations in those periods were higher than recess. It was worth having further research about how human activity influences on particulate matter. In addition, the measuring value of indoor particulate matter in this study was lower than the national standard, so indoor particulate matter concentration (PM\textsubscript{2.5}, PM\textsubscript{10}) had little effect about the quality of indoor air.
different classrooms in the same season also had different CO₂ concentration.

Analyzing it, it was mainly about ventilation and person-density of the room. From Figure 9, it could be concluded that the concentration of Classroom A was declined and the Classroom B had been on the rise, which was mainly related to the open windows. The trend of CO₂ concentration in Classroom A was the same as Classroom B, but the CO₂ concentration in Classroom B was significantly higher than the Classroom A. The reason of this phenomenon was that the person-density in Classroom B was much larger than Classroom A.

The breathing was the main source of indoor CO₂ in winter heating period when the doors and windows were closed, and the penetration of fresh air was far from meeting the demand for indoor fresh air, so it was very likely to cause the CO₂ concentration exceeding the standard, and thus a threat to the health of teachers and students as well as learning outcomes cannot be guaranteed.

The CO₂ concentrations of same classroom in the different seasons

**Table 5. Measurement of Concentration of PM10 in Classroom D on 5-Dec**

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>Average (mg/m³)</th>
<th>Minimum (mg/m³)</th>
<th>Maximum (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.074</td>
<td>0.059</td>
<td>0.109</td>
</tr>
<tr>
<td>2</td>
<td>0.074</td>
<td>0.051</td>
<td>0.138</td>
</tr>
<tr>
<td>3</td>
<td>0.079</td>
<td>0.054</td>
<td>0.441</td>
</tr>
<tr>
<td>4</td>
<td>0.067</td>
<td>0.002</td>
<td>0.195</td>
</tr>
<tr>
<td>5</td>
<td>0.055</td>
<td>0.04</td>
<td>0.093</td>
</tr>
<tr>
<td>6</td>
<td>0.053</td>
<td>0.037</td>
<td>0.238</td>
</tr>
<tr>
<td>7</td>
<td>0.042</td>
<td>0.035</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Fig. 9. Concentrations of CO₂ in Classroom A and Classroom B in autumn

(Notes: The windows in Classroom A were closed during the class and opened after class; the windows in Classroom C were always closed)

Fig. 10. Concentrations of CO₂ in Classroom A and Classroom B in winter

(Notes: For it was in heating period, the windows were all closed)
seasons were also different. The CO$_2$ concentrations in winter heating period were significantly higher than those in autumn. The windows open state played a great role in the CO$_2$ concentrations.

**The relationship between the full rate of the room and the CO$_2$ concentration**

Table 6 showed the full rate of Classroom A and Classroom B. From the table, it could be seen that the full rate was also an important factor affecting the CO$_2$ concentration in rooms. Because of the limited space and seating in each classroom, there were many students in each classroom where the full rate was so high. Especially in the winter heating period, most of the students did not want to go outdoor to do some activities, so that a large number of indoor oxygen was consumed and it caused the rise of the CO$_2$ concentration in rooms. If the leaders of school made reasonable arrangements for the classroom according to the class size, for example, arranging a bigger classroom for more people to have class, so that the CO$_2$ concentrations in the room would not be so easy to excessive. In addition, if there were not many people in the room, we could get better using of doors and windows infiltration of outdoor air to dilute the CO$_2$ concentration. On the other hand, if the indoor air quality was improved, it would make a better learning environment and have a better effectiveness of student learning.

**CONCLUSIONS**

The research object of this study was classrooms of one university in Dalian, China. The air quality of classroom was measured and influencing factors of indoor air quality in the classroom were explored. In this study, the conclusions about effect on student learning were:

1) The measurement in the classroom during the school day, the average temperature range was 18.8 °C to 24.8 °C and the average relative humidity range was 32% to 72%. They were both qualified with the requirement of Indoor Air Quality Standard (GB/T1883-2002). The average concentration of CO$_2$ in the room was also out of limit and the maximum concentration value was up to 2471 ppm, which was nearly 2.5 times than the standard. Meanwhile, the per capita fresh air was less than 10 m$^3$/h after several tests, which was far under the national standard. The average concentration of PM$_{10}$ was 0.042 mg/
m³ to 0.074 mg/m³ and the average concentration of PM₂.₅ was 0.025 mg/m³. They were both qualified with the requirement of Indoor Air Quality Standard (GB/T1883-2002) and Ambient Air Quality Standard (GB3095-2012).

2) The main problems of indoor air quality of the college classroom were the CO₂ concentration in excess and lack of fresh air. Especially in the winter heating period, during the class time the classroom windows had been shut down, and the students produced large amounts of CO₂, causing classroom deterioration of air quality, seriously affecting the quality of teaching and student learning efficiency.

Recommendations
1) Try to increase ventilation, reduce the person-density in the room, in order to ensure the health of the college teachers and students in the heating period.
2) Take advantage of natural vents inside the classroom. Because the doors and windowsof classroom are always closed in the winter, then we can consider the transformation of natural ventilation ducts.
3) CO₂ adsorption material could be painted on the wall of the classroom.
4) Some CO₂ absorption plants are placed in the classroom.
5) Reasonable arrangements for school classrooms.
6) CO₂ alarm is placed in the classroom for monitoring the CO₂ concentration.

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