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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 CO_2 concentration, temperature, relative humidity and particulate matter (PM_{10}, $PM_{2.5}$), in order to explore the impact of CO_2 concentration factors and their impact on students' learning outcomes. The study concludes that the biggest factor affecting college indoor air quality exceeded the indoor CO_2 concentration, ventilation lacking and the classroom overcrowding; proving that the indoor CO_2 concentration exceeded have a significant effect on students' learning efficiency. The continuous monitoring reflects the growth of the indoor CO_2 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 CO_2 concentration during winter.

Key words: Indoor air quality, CO_2, 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 happyÿHowever, 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, CO_2 concentration andparticulate matter(PM_{10},$PM_{2.5}$) reflect four important indicators of indoor air quality,and the CO_2 concentration is always used to characterize the indoor fresh air content and ventilation effect. Based on Chinesenational indoor air quality standard, the daily average concentration of CO_2 should be not greater than 0.10% (0.10% is volume fraction).The places thatare poorly ventilated or people intensively gatheredprone to higher concentration of CO_2,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 CO_2 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 teachingactivities. Though the CO_2 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 CO_2 concentration would also impede effective teaching

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activities,especially more frequently occurred in the winter when the classroom doors and windows are closed and poor ventilation[7].According to a study about the CO_2 concentration in the classroom and its impact on students' mental work capacity,it was found that air quality had significant effect on students' finishing the homework, and with the increase of CO_2 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[8]. At present, many investigations and studies about air environment in the classroomhave 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, theirair pollution is particularly serious[9], however, there are few researches in this area in our country.

This study carried on a field survey and analysis about indoor air quality of classroomsin a university in Dalian, China, which aimed to explore effects of CO_2 concentration, temperature, relative humidity and particle concentration on students learning efficiency ($PM_{2.5}$,PM_{10}),to provide objective basis for improving the teaching environment and effect.

MATERIALSANDMETHODS

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 to the classroom.Testing physical modelof the classroom is shown in Figure1.

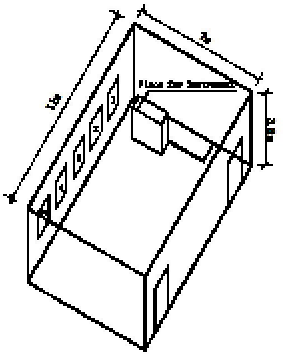


Fig. 1. Physical model of testing classroom

Testing instrument and testing method

This study tested the indoor temperature, relative humidity, CO_2concentration and particulate matter concentration ($PM_{2.5}$, PM_{10})in the classroom, using instruments as shown in Figure 2, Figure 3. Figure 2 is MCH-383SD CO_2 concentration, temperature, relative humidity automatic memory device,the units areppm,°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 ($PM_{2.5}$, PM_{10}), read data once per second,the unit is mg/m^3.

Fig. 2. MCH-383SDCO_2/Humidity/Temperature Monitor

Fig. 3. TSI Dust Meter

In the study, MCH-383SD instrument was used to continuously monitor temperature, relative humidity and CO_2concentration 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 comparedwith the level limitations referred in the *Indoor Air Quality Standard* (GB/T 18883-2002)[10], which was shown in Table 1.

Table 1. Indoor air quality of measuring items

Parameter	Unit	Standard values	Notes
Temperature	°C	22~28	Air conditioning in summer
		16~24	Winter heating
Relative humidity	%	40~80	Air conditioning in summer
		30~60	Winter heating
The fresh air volume	m^3/(h· person)	30	The average for 1 hour
CO_2	ppm	1000	Daily average
PM_{10}	mg/m^3	0.15	Daily average
$PM_{2.5}$	mg/m^3	0.075	Daily average

Calculatingequations and calculating parameters

Itis assumed that the air is fully mixed inside the V volume room.Emission rate of pollutantis represented as*m*.C_1 is indoor air pollutant concentrationbefore ventilation, and for timeÄ 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.

$$V\frac{dC}{d\tau}=QC_S+m-QC \qquad ...(1)$$

The initial conditions is T=0, $C=C_1$.
Solving above equations are done

$$C_2=C_1\exp(-\frac{Q}{V}\tau)+(\frac{m}{Q}+C_s)[1-\exp(-\frac{Q}{V}\tau)] \qquad ...(2)$$

It can be seen that indoor pollutant concentration increases or decreaseswith index of rules, Its rate of increase or decrease depends on $\frac{Q}{V}$. This value reflects the size of the room ventilation[11] and it is defined as air change rate.

$$n=\frac{Q}{V} \qquad ...(3)$$

The deformation of Equation (2) is shown below.

$$\frac{QC_1-m-QC_s}{QC_2-m-QC_s}=\exp(\frac{Q}{V}\tau) \qquad ...(4)$$

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

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

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

The fresh air volume could be obtained:

$$Q=\frac{m}{C_2-C_S}-\frac{V}{\tau}\frac{C_2-C_1}{C_2-C_S} \qquad ...(6)$$

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
τ——elapsed time,h

The amount of CO_2produced by humans is related to the metabolism of human body[12],that is

$$q=1.44\times10^{-4}(MA_p) \qquad ...(7)$$

In the Equation (7)
q-amount of CO_2breathed 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:

$$A_p=0.202m_b^{0.425}H^{0.725} \qquad ...(8)$$

In the Equation (8),

m_b -weight, kg

H-height,m

For a normal Chinese,metabolism rate is about 70W/m^2 when he takes a little light exercise. According to Equation (8) and (7), human skin surface area is 1.69m^2 and one person breathing out CO_2 volume is about 0.02m^3/h.

In this study, the standard calculating volume of classroom was 308m^3. 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(0.3m^3/person, 30 students were assumed in the classroom) was considered, the actual calculating volume of classroom was 270 m^3.

The outline of measurement

For ease of comparison, four classrooms were measured in this study, the classroom wererepresented as A, B, C, D respectively. Measuring time was 90 minutes once.10:05-10:50was 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 2. Measuring results summary

Classroom	CO_2 concentration	Relative humidity	Temperature	Particulate matter ($PM_{2.5}$, PM_{10})
A	Autumn measuring 2 times			
	Winter measuring 4 times			-
B	Winter measuring 2 times			Winter measuring 2 times $PM_{2.5}$
C	Autumn measuring 1 times			-
D	-			Winter measuring 2 times PM_{10}

RESULTS AND DISCUSSION

The average CO_2 concentration and the fresh air volume during the class

The average CO_2 concentration and fresh air volume of classroom during the class timewere shown in Table 3. Table 3 showed the minimum value of average CO_2 concentration in Classroom Awas 553ppm in September 27. And during testing, only this time the CO_2 concentration was lower than the limit value 1000ppm of *Indoor Air Quality Standard*in China, and the CO_2 concentrations wereall out of limits in the other classrooms during the class time.The highest average CO_2 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 CO_2 concentration was increased obviously in classroom when entering the winter heating period in November. This was becauselong closure of the classroom window during the winter heating period caused poor indoor ventilation and the rising of average indoor CO_2 concentration. This behavior would decline the indoor air quality seriously and influencethe 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 30m^3/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 classroomsdidn't reach the standard in the measurement date. The per capita fresh air volume of Classroom A,B and C even did not reach 10m^3/h in some measurement dates,and far below the national standard. The air quality of classroomremains worrying.

Temperature, relative humidity and particulate matter content of Classroom

Table4 showed the temperature,relative humidity and particulate matter ($PM_{2.5}$,PM_{10}) of classrooms. Based on *Indoor Air Quality Standard*and*Ambient Air Quality Standard* (GB3095-2012)[13] in China,standard value for winter heating temperature is 16~24°C and standard value for relative humidity is 30~60% while the secondary

Table 3. Measurement of CO_2 concentration and fresh air volume in testing classroom during the class time

Classroom	Date	CO_2 concentration (ppm)	Number of people (number)	Fresh air volume (m^3/h)	Per capita fresh air volume ($m^3/h\cdot$ number)	Air change rate (h^{-1})
A	27-Sep	553	22	3171	144.0	10.6
	18-Oct	1389	25	1065	42.6	3.6
	8-Nov	1356	33	995	30.2	3.3
	15-Nov	1523	31	342	11.0	1.1
	22-Nov	1910	34	219	6.4	0.7
	6-Dec	1716	28	1426	50.9	4.8
B	13-Nov	2040	44	324	7.4	1.1
	20-Nov	1766	43	416	9.7	1.4
	4-Dec	2471	44	155	3.5	0.5
	5-Dec	2278	12	286	23.8	1
C	18-Oct	1648	26	243	9.4	0.8

standard value for particulate matter PM_{10} is 0.15 mg/m^3 and two trial standard value for particulate matter $PM_{2.5}$ is 0.075 mg/m^3 .Table 4 showed the indoor temperature and relative humidity reached the standards of China and the indoor particulate matter ($PM_{2.5}$, PM_{10}); measuring results were also under the standard value.

Concluded from analysis of Table 3 and Table 4,the poor college indoor air quality was related to high CO_2 concentration and less per capita fresh air volume.

Table 4. Concentrations of temperature, humidity and particulate matter in classroom

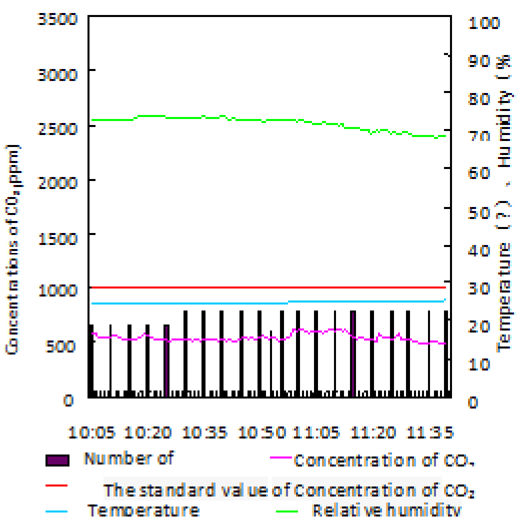
Classroom	Date	Temperature (°C)	Humidity (%)	Particulate matter(mg/m^3)
A	27-Sep	24.8	72	-
	18-Oct1	23.8	38	
	18-Oct2	21.8	45	
	8-Nov	22.8	37	
	15-Nov	21.7	36	
	22-Nov	21.6	41	
	6-Dec	18.8	32	
B	13-Nov	23.1	38	-
	20-Nov	22.5	40	-
	4-Dec	22.8	39	$PM_{2.5}$
	5-Dec	20.7	41	-
D	5-Dec	-	-	PM_{10}

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

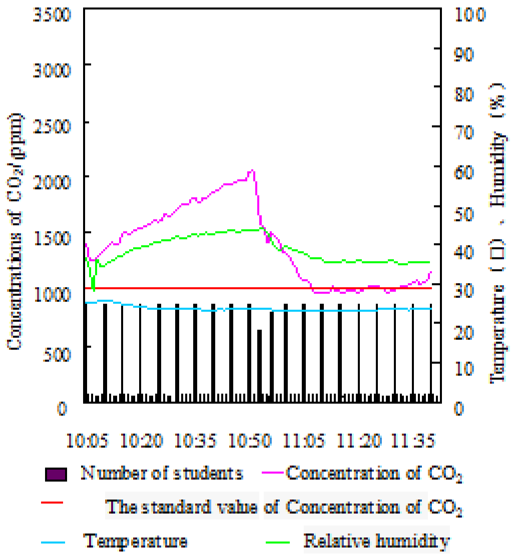
Figure 4 showed the CO_2 concentration, temperature, relative humidity changes of Classroom A on September 27 in autumn.From Figure4,it could be found thatthere was not much changesfor three indicatorsduring class time. Just CO_2 concentration fluctuated slightly, but it was still below the standard 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 5showed 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_2concentration reached 2,100ppm. During the



(Notes: The window of Classroom A was open during the class time)

Fig. 4. Concentrations of CO_2,temperature,humidity in Classroom A on 27-Sep

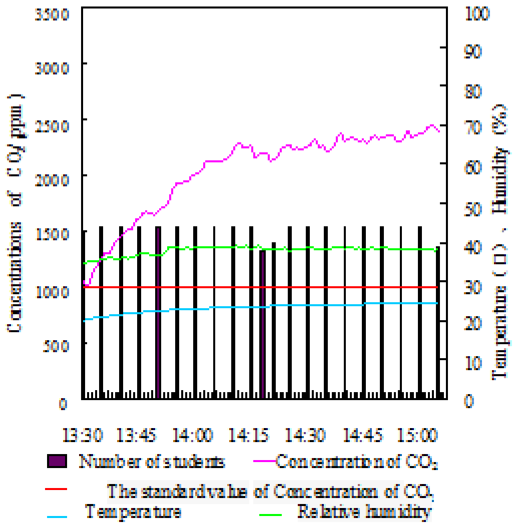


(Notes: The windows of Classroom Awere turned offduring the first class and opened after class at 10:50, keeping opened to 11:40)

Fig. 5. Concentrations of CO_2, temperature,humidity in Classroom A on 18-Oct

first class, CO_2 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 inwas reduced, therefore, CO_2 concentration began to decrease about 10:50, and then relative humidity began to decrease, which showed the relative humidity hysteresis than the CO_2 concentration changes. By 11, 05, the front and back doors wereclosed again during the class, CO_2 concentration and relative humidity stopped to reduce.At the same time, since the classroom windows were open at the second class, the indoor CO_2 concentration did not begin to rise again, maintained at around 1000ppm, relative humidity decreasedand finally maintained at about 35%.

Figure 6 showed the CO_2 concentration and temperature and relative humidity changes of Classroom B on November 13. From Figure 6, it could be found that the indoor CO_2 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 studentswho stayed inwas reduced after class, but the CO_2 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 tobe lack of air infiltration and unable to meet the needs

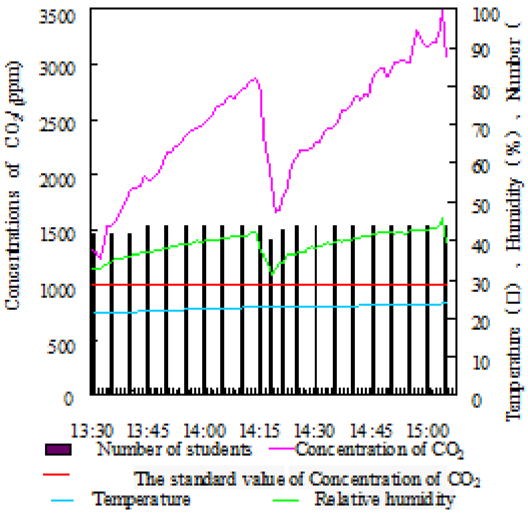


(Notes: The windows of Classroom B were always closed during class and after class)

Fig.6. Concentrations of CO_2, temperature, humidity in Classroom B on 13-Nov

of the people in the room.

Figure7 showed the CO_2 concentration, temperature and relative humidity changes of Classroom Bon 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_2 concentration changed obviously. The windows had been closed during the class in Figure 6, so the CO_2 concentration had been on the rise; the windows were opened after class in Figure 7, so the CO_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_2 concentration had affected student learning



(Notes: The windows of Classroom B were always closedduring class, while windows and front door were open for a short time after class)

Fig. 7. Concentrations of CO_2, temperature, humidity in Classroom B on 4-Dec

The concentration of indoor particulate matter ($PM_{2.5}$,PM_{10})

Figure8 was the mass concentration of particulate matter$PM_{2.5}$in Classroom B on December 4. Measurement points 1-9 weremeasured before class, measuring points 10-15were measuredat rest time and measuring points 16-27weremeasured afterclass. Figure 8 showed the trend of the mass concentration of $PM_{2.5}$was high before class, reducedat rest time and increased afterclass. This showed that the value of indoor particulate matter concentration was related to indoor activities of the people closely. Student did more activitiesbefore and afterclass, causing indoor particulate re-suspended. So the particle concentrationsin 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 waslower thanthe nationalstandard, so indoor particulate matterconcentration ($PM_{2.5}$, PM_{10}) had little effect about the quality of indoor air.

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

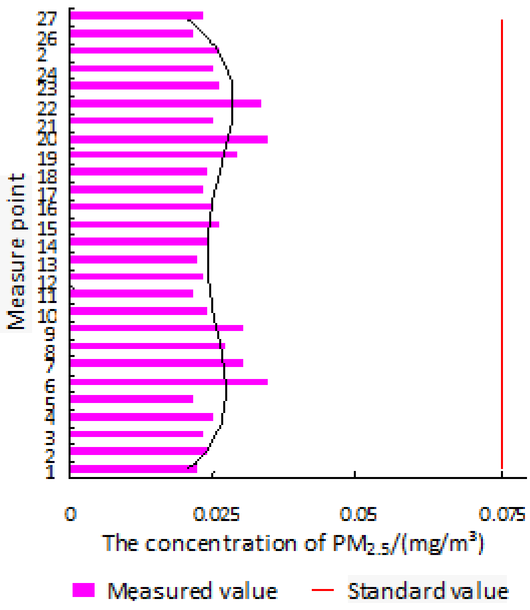


Fig. 8. Concentration of $PM_{2.5}$ in classroom B on 4-Dec

The CO_2concentration of different classrooms in the same season

Figure 9 showed the comparison of CO_2concentration of Classroom A and C in autumn, and Figure 10 showedcomparison of CO_2concentration of Classroom A and Bin winter. From these two figures, it could be seenthat

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

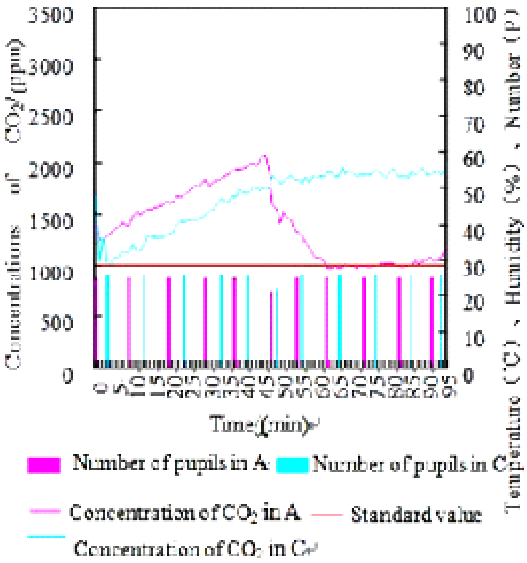
Measuring point	Average (mg/ m³)	Minimum (mg/m³)	Maximum (mg/m³)
1	0.074	0.059	0.109
2	0.074	0.051	0.138
3	0.079	0.054	0.441
4	0.067	0.002	0.195
5	0.055	0.04	0.093
6	0.053	0.037	0.238
7	0.042	0.035	0.049

different classrooms in the same season also had different CO_2concentration.

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 wasdeclined and the Classroom B had been on the rise, whichwas mainly related to the open windows. The trend of CO_2concentration in Classroom A wasthe same asClassroom B, but the CO_2concentration in Classroom B wassignificantly higher than the Classroom A. The reason of this phenomenonwasthat the person-density in Classroom B was much larger than Classroom A. The breathing was the main source of indoor CO_2 in winter heating period when the doors and windows wereclosed, andthe penetration of fresh air wasfar from meeting the demand for indoor fresh air, so itwas very likely to cause the CO_2 concentration exceeding the standard, and thus a threat to the health of teachers and students aswell as learning outcomes cannot be guaranteed.

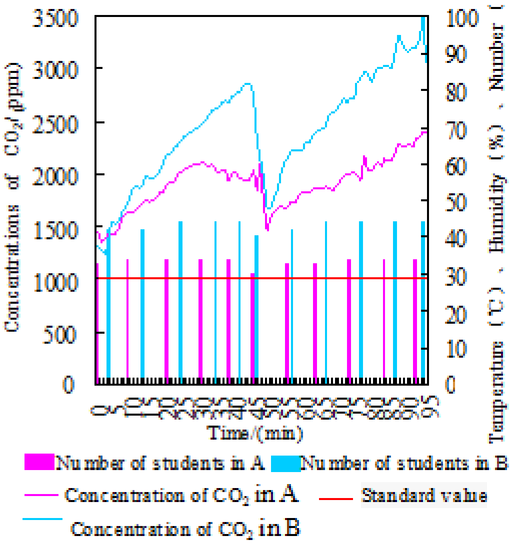
The CO_2concentrations of same classroom in the different seasons

Figure 11 was the comparison of CO_2concentrations of Classroom A between autumn and winter. It was found that the CO_2 concentrations of same classroom in the different



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

Fig. 9. Concentrations of CO_2 in Classroom A and Classroom B in autumn



(Notes: For it was in heating period, the windows were all closed)

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

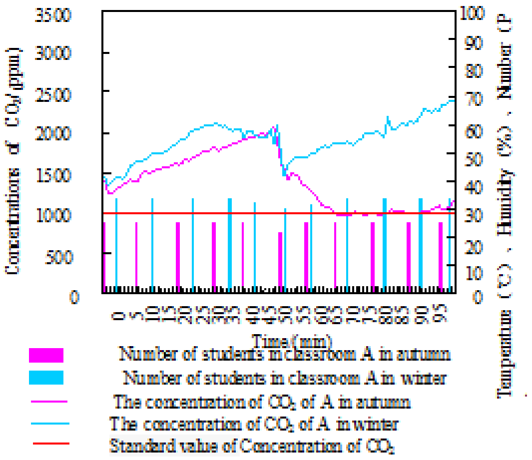
Table 6. Full rate in classroom

The name of room	Date	Number of people (person)	The concentration of CO_2 (ppm)	Full rate (%)
A	18-Oct	25	1389	35
	8-Nov	33	1356	46
	15-Nov	31	1523	43
	22-Nov	34	1910	47
B	13-Nov	44	2040	61
	20-Nov	43	1766	60
	4-Dec	44	2471	61

seasonswere also different. The CO_2 concentrations in winter heating period were significantly higher thanthose in autumn. The windows open state played a great role in the CO_2concentrations

The relationship between the full rate of the room and the CO_2 concentration

Table 6showed the full rate of Classroom A and Classroom B. From the table, it couldbe seenthat the full rate was also an important factoraffecting the CO_2concentration 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 outdoorsto do some activities, so that a large number of indoor oxygen was consumed and it caused the rise of theCO_2concentration 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_2concentrations 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_2concentration. On the other hand, if the indoor air quality was improved, it wouldmakea better learning environment and have a better effectiveness of student learning.



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

Fig. 11. Concentrations of CO_2 in Classroom A during autumn and winter

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 ° Cand the average relative humidity range was 32% to 72%.They were bothqualifiedwith the requirement of *Indoor Air Quality Standard* (GB/T1883-2002).The average concentration of CO_2in the room wasalso out of limitand the maximum concentration value was up to 2471ppm, which was nearly2.5 timesthan the standard. Meanwhile, the per capita fresh air wasless than 10m^3/h after several tests, which was far under the national standard. The average concentration of PM_{10}was0.042mg/

m^3 to 0.074 mg/m^3 and the average concentration of $PM_{2.5}$ was 0.025mg/m^3. Theywere bothqualifiedwith 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 CO_2 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 CO_2, 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) CO_2 adsorption material could be painted on the wall of the classroom.
4) Some CO_2 absorption plants are placed in the classroom.
5) Reasonable arrangements for school classrooms.
6) CO_2 alarm is placed in the classroom for monitoring the CO_2 concentration.

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