Experimental study on indoor environment quality in a naturally ventilated classroom of a university using natural ventilation and ventilation fan

Jie Zong¹, Wenjun He¹, Lingna Wang¹, Hongkai Chai¹, Yingying Zhao¹, and Jiying Liu^{1,2*}

¹School of Thermal Engineering, Shandong Jianzhu University, Jinan 250101, China

²Shandong Province Green Building Collaborative Innovation Center, Jinan 250101, China

Abstract. Strengthening indoor ventilation is an important measure to improve air quality. In transitional season between spring and summer, a university classroom in Jinan city was selected as the research object. Mechanical air supply is adopted to solve the problem of insufficient fresh air or excessive carbon dioxide concentration in the classroom. CO₂ concentration and air change rates are compared in natural ventilation and mechanical classrooms. The experiment shows that the indoor CO₂ concentration of mechanical ventilation classroom is relatively low. Under natural ventilation, mechanical ventilation and mixed ventilation, the average air change rates were 1.05 h⁻¹, 1.83 h⁻¹ and 2.7 h⁻¹, respectively. According to the statistics analysis of the questionnaire, 72.84% of the students hope to install the mechanical ventilation in the classroom.

1 Introduction

CO₂ concentration and outdoor air ventilation rate are two key indicators for indoor air environment assessment [1-4]. However, there is no clear standard of the minimum outdoor air rate and the maximum CO₂ concentration to satisfy students' comfort in Chinese university classrooms [5]. Domestic and foreign scholars have done some studies on indoor CO₂ concentration and outdoor air rates. Turanjanin et al. [6] measured ventilation rates in five naturally ventilated schools in Serbia with a conclusion that the ventilation is inadequate during the heating period. Bakó-Biró et al. [7] studied the effect of classroom ventilation on pupils' performance and found that the low ventilation rates in the classroom can significantly reduce pupils' attention and vigilance. Park et al. [8] studied the appropriate capacity of Korean classroom ventilation system based on air permeability to obtain the optimal design conditions of the ventilation system.

At present, most university classrooms only considered natural ventilation. Due to dense students, only natural ventilation cannot solve the problem of insufficient fresh air in the classroom [9]. Therefore, this study adopt the mechanical ventilation to pursuit the indoor environment quality of classroom. The CO₂ concentration, indoor air temperature and humidity in mechanically ventilated and naturally ventilated classrooms were compared. Meanwhile, the questionnaire surveys were conducted in classroom. The purpose of this study is to analyze the indoor environment quality of a university classroom in

transitional season between spring and summer in Jinan city.

2 Experimental methods

2.1. Experimental subjects

This experiment chosen the teaching building of Shandong Jianzhu University as the test object. There is no outdoor air system in this teaching building, and the main way of ventilation is to open windows. At the beginning of the test, the detailed usage of the classroom in the whole teaching building was investigated, and Room No. 213 classroom was selected as mechanical ventilation classrooms. The classroom can accommodate 90 people, and the students and teachers in the classroom are usually exposed to unacceptable bad air quality. The concentration of carbon dioxide is as high as 5000 ppm, which is much higher than the average recommended level of 1500 ppm and the preferred level of 1000 ppm. The test time was selected in April 2019. The monthly average temperature was 16.2°C. The main reason for selecting the test in the transition season is that fresh air can be directly introduced outdoors without heat treatment or cold treatment, so the supply air temperature is more suitable. Fig. 1 is the plan of the mechanical ventilation classroom.

2.2 Experiment introduction

The experiment includes indoor CO₂ concentration, temperature and humidity (including the temperature and

* Corresponding author: jxl83@sdjzu.edu.cn

humidity of the fan inlet and outlet), air velocity, black globe temperature, etc. The number of student in classroom, the opening area of doors and windows, and the starting time and stopping time of fans are recorded. The ventilation system is placed outdoors, and fresh air is directly supplied by a pipe system with a diameter of 150 mm. It enters the classroom through the opening of the window. The air supply outlet is arranged in the center of the classroom. The air supply is a square diffuser with a fan outlet of 300 X 300 mm. The air supply capacity is 313 m³/h in the form of the top-supplying. Table 1 is the test instruments details.

Fig. 1. Plan view of Room No. 213.

Table 1. Instruments used in the field survey.

Parameters	Instrument	Range	Accuracy
CO ₂	TSI	0~5000ppm	±50ppm
Air temperature	iButton	-20~85°C	±0.0625°C
Relative humidity	iButton	0~100%	±0.04%
Radiation Temperature	KIMO BN-150-45	0~60°C	±0.2°C
Regional air velocity	Swema 3000	0~100m/s	0.1 m/s

According to the requirements for indoor air sampling points in the Standard for Indoor Air Quality (GB/T1883-2002), the test instruments are placed on the bracket, three carbon dioxide sampling points are arranged in the classroom under test, and three sampling points are diagonally distributed in the classroom crowd. The height of sampling points is 1.1 m, that is, the position of human breathing belt under sitting posture. The iButton temperature sensors are directly attached to the air duct of the inlet and outlet to measure temperature and humidity accurately because of its compact and portable characteristics. The black globe thermometer and anemometer are also placed on the bracket and in the undisturbed classroom aisle. The data were recorded every 30 seconds. Instrument layout and indoor environment of the test room are shown in Fig. 2.

2.3 Questionnaire

In order to fully understand the students' satisfaction with the thermal environment in natural and mechanical ventilation classrooms, questionnaires were distributed to students in this teaching building. The undergraduate students' ages were 18-22. The main content of the questionnaire includes the students' satisfaction with the current classroom thermal sensation, air quality, relatively humidity and so on. Because the previous environment may affect students' subjective evaluation, subjects can fill in the questionnaire at least 30 minutes after sitting in the classroom. A total of 868 valid questionnaires were collected after removing the samples of physical discomfort.

Fig. 2. Instruments used in the experiment and indoor environment condition in the classroom

2.4 Air change rate calculation

Based on conservation of mass, the individual step increase of CO₂ concentration within time interval $\Delta\tau$ can be formulated as^[10]:

$$\Delta c = (\Delta\tau/V) \cdot [F10^6 - ACH \cdot V \cdot (C_1 - C_0)] \quad (1)$$

$$F = RQ \cdot 0.00201 \cdot H^{0.725} \cdot W^{0.425} M / (0.23 \cdot RQ + 0.77) \quad (2)$$

where ΔC is the unit concentration change (ppm), $\Delta\tau$ is the unit time interval (h), V is the volume of the zone (m³), F is the emission rate of CO₂ (m³/h), ACH is the air change rate (h⁻¹), C_1 is initial CO₂ concentration of time interval $\Delta\tau$ (ppm) and C_0 is outdoor CO₂ concentration (ppm). where F is the emission rate of CO₂ (m³/h), RQ is a respiratory quotient, which is generally assumed to be 0.83, H is the height of occupant(m), W is the weight (kg), M is the metabolic level (met).

3 Results

3.1 CO₂ concentration

Taking the CO₂ test data of April 16 as an example, as shown in Fig. 3, there was no fan at 7:30-17:00, and 18:20-21:00 was the time period of fan opening. It can be seen from the figure that the indoor CO₂

concentration can be significantly reduced when the fan is turned on in a comparable number of cases. About 7:30, people came in one after another, and the concentration of CO₂ rose from 500 ppm to 4230 ppm.

During the period from 9:25 to 9:40, the door of the classroom was opened and the flow of people was frequent, which caused the fluctuation of CO₂ concentration. In the afternoon, the concentration of CO₂ is low because of the small number of students attending classes. At 18:20, people began to enter one after another, and the concentration of CO₂ gradually increased. When windows were opened at 20:00 and mixed air supply was carried out, CO₂ concentration decreased gradually. The results show that the indoor CO₂ concentration of mechanical ventilation classroom is relatively low, and the improvement of indoor environmental quality is more obvious by mixed air supply.

Fig. 3. Variation of CO₂ concentration and population.

3.2 Indoor air temperature and humidity

Fig. 4 shows the temperature and humidity distribution curve in the classroom on April 27. The temperature distribution curve is shown in Fig. 4 (a). The overall temperature curve in the classroom shows an upward trend, with the highest temperature reaching 22.6 °C and the average temperature reaching 21.16 °C. Because of the dense population in the middle of the classroom, the temperature was relatively high. The temperature fluctuated between 9:25 and 9:45, which was caused by the movement of people after class. Because the temperature measurement button of the inlet was placed in the indoor ventilation duct, the temperature was too high before the fan was turned on.

After the fan was turned on, the temperature of the inlet decreased rapidly with the introduction of outdoor fresh air, but the temperature of the classroom and the temperature of the inlet were still about 2°C different due to the indoor environmental impact. The relative humidity distribution curve is shown in Fig. 4 (b). The relative humidity curve and the temperature curve show the opposite trend. The indoor average relative humidity is 38%. The day of April 27 was cloudy, so the relative humidity of the fan inlet was higher. After opening the fan, the air flow in the pipe accelerated, which reduced the relative humidity of the inlet and outlet.

Fig. 4. Indoor air temperature variation (a) and relative humidity variation (b).

3.3 CO₂ in classroom

Table 2 shows the air change rate calculated according to the actual situation of the classroom. The number of air change rate is the combined effect of fan, window opening and occupant density. For April 27, the smaller the density of personnel, the greater the number of air change rate. When mixing ventilation, air change rate is above 2 h⁻¹, and the number of air change rate depends on the windows opening time. The longer the window opening time is, the more the window opening is, and the greater the air change rate is. Under natural ventilation, mechanical ventilation and mixed ventilation, the average air change rate were 1.05 h⁻¹, 1.83 h⁻¹ and 2.7 h⁻¹, respectively. When the window was not opened on April 12, the air change rate was only 0.71 h⁻¹. It can be seen that mechanical ventilation can significantly increase indoor ventilation, so that students are not exposed to high CO₂ concentration.

Table 2. Air change rate in classroom

Date	Time	Fan /window	Student no.	Mode	ACH
Apr.12	9:30-11:10	Window on	60	NV	1.25
	11:30-12:00	No	60	NV	0.71
	13:30-16:15	Both on	80	MIV	2.71
Apr.14	13:30-15:00	Fan on , window 15min	40	MIV	2.56
	15:30-16:50	Fan on	39	MV	1.5
Apr.16	7:30-12:00	Window 15min	60	NV	1.18
	19:00-21:00	Fan on	59	MV	1.6
Apr.23	18:40-21:00	Fan on, window on	40	MIV	2.43
Apr.24	18:40-21:00	Fan on, window on	35	MV	3.1
Apr.27	7:40-9:25	Fan on	21	MV	2.28
	9:45-11:15	Fan on	41	MV	1.95

4 Analysis of questionnaire

4.1 Evaluation natural and fan ventilation

The evaluation of indoor air quality, temperature and thermal comfort in natural and mechanical ventilation classrooms is shown in Fig. 5. As can be seen, for the comparison of air freshness, most people in the mechanical ventilation classroom feel fresher. The number of people who feel sultry is less than 1/3 of the number in natural ventilation classroom. There is little difference between feeling fine and feeling a little stuffy. By contrast, the air in the mechanically ventilated classroom is fresher. For the comparison of indoor temperature, the number who feel moderate temperature in mechanical ventilation classroom is far greater than that in natural ventilation classroom, accounting for 50.5%.

Fewer people feel hot when the indoor temperature is slightly higher. Many people feel little hot or little cold. For the reasons, first, only one diffuser is arranged in the classroom, the indoor air blow is uneven, which cause a little cold near the air outlet and a little hot far off the air outlet. Second, due to individual differences, the evaluation standard for thermal sensation are different, causing some feeling cold and some feeling hot. For the comparison of indoor thermal comfort, the number in mechanical ventilation classroom feels more comfortable than the number in natural ventilation classroom, and the discomfort evaluation is relatively less.

Fig. 5. The subjects vote of indoor air quality (a), temperature (b) and thermal comfort (c) in natural and mechanical ventilation classrooms

4.2 Evaluation of natural and fan ventilation

In order to better understand the needs of students and provide students with a better and comfortable learning environment, a survey related to occupant feeling was conducted. According to the current situation of classroom ventilation, through the question "What factors will make you feel more comfortable in the room?" The survey results are shown in Fig. 6. 35.51% chose "the change of fresh air", and fewer chose "the

wind speed", "temperature and humidity". It shows that improving indoor air freshness (increasing air ventilation) during the transitional season is an urgent need of students. It also shows that there are serious ventilation problems in the existing classrooms. In addition, through willingness questionnaire for installing fan, 72.84% of students thought it important to install fan in classroom.

Fig. 6. Results for motion for looking forward to improvements in the classroom (a) and the willingness to install fans (b).

5 Conclusions

This study conducted an on-site experiment to investigate the indoor environment quality in a naturally ventilated classroom of a university using natural ventilation and ventilation fan. The CO₂ concentration, indoor air temperature and humidity in mechanically ventilated and naturally ventilated classrooms were compared. Meanwhile, the questionnaire surveys were conducted in classroom. The results show that once the fan is turned on, the growth rate of CO₂ concentration in classroom slows down but still exceeds 2000 ppm. Because the actual air volume of the fresh air fan can't meet the design requirements, and the indoor students' density is high, the mechanical ventilation is insufficient. The CO₂ concentration still exceeds the 2000ppm. Therefore, ventilation can be carried out in a mixed manner. The opening of fans and windows and the student number can affect air change rate. Under natural ventilation, mechanical ventilation and mixed ventilation, the average air change rates were 1.05 h⁻¹, 1.83 h⁻¹ and 2.7 h⁻¹, respectively. The longer the window opening time is, the larger air change rate is. According to the results of the questionnaire survey, 35.51% of the students want to improve the air freshness of the classroom, and 72.84% of the students hope to install fresh air fans in the classroom. Therefore, it is very necessary to use mechanical ventilation as an auxiliary tool of classroom ventilation in the universities classroom to provide comfortable environment and sufficient fresh air for students.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (51608310) and Support Plan for Outstanding Youth Innovation Team in Shandong Province (2019KJG005), Students' Research and Training Project of School of Thermal Engineering in Shandong Jianzhu University (SRTP-201810).

References

1. P Kapalo, P Siroczki, International Journal of Ventilation **13** 12 (2014)
2. J Liu, S Zhu, M K Kim, J Srebric, Sustainability **11** 4166 (2019)
3. Z Li, K Li, J Chang, H Wu, J Liu, IOP Conference Series: Materials Science and Engineering **609** 042016 (2019)
4. J Liu, D A Dalgo, S Zhu, H Li, L Zhang, J Srebric, Building Simulation **12** 905 (2019)
5. S Batterman, International Journal of Environmental Research and Public Health **14** 145 (2017)
6. V Turanjanin, B Vučićević, M Jovanović, N Mirkov, I Lazović, Energy **77** 290 (2014)
7. Z Bakó-Biró, D J Clements-Croome, N Kochhar, H B Awbi, M J Williams, Building and Environment **48** 215 (2012)
8. PARK, Jonghoon, JANG, Yongsung, AHN, Youngchull, CHEONG, Seongir, LEE, Jaekeun, Journal of Mechanical Science and Technology **22** 788 (2008)
9. P V Dorizas, M N Assimakopoulos, C Helmis, M Santamouris, Science of the Total Environment **502** 557 (2015)
10. J Hou, Y Zhang, Y Sun, W Pan, Q Zhang, X Kong, J Sundell, Building and Environment **132** 273 (2018)