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The Effect of Avoiding Closed Spaces on the Indoor Environment of Nursery School Rooms during COVID-19 winter

Ryosuke Ito [1*], *Tetsu* Aoki [2], *Sachiko* Taguchi [3], *Kosei* Honda [4]

[1] Advanced Course, National Institute of Technology, Gifu College, Gifu, Japan, 2022y03@stu.gifu-nct.ac.jp
[2] Department of Architecture, National Institute of Technology, Gifu College, Gifu, Japan, taoki@gifu-nct.ac.jp.
[3] Advanced Course, National Institute of Technology, Gifu College, Gifu, Japan, 2021y25@stu.gifu-nct.ac.jp
[4] Advanced Course, National Institute of Technology, Gifu College, Gifu, Japan, 2018a34@stu.gifu-nct.ac.jp

Abstract. This study aimed to clarify the effect of the policy of avoiding closed spaces with poor ventilation for preventing COVID-19 on the indoor environment of nursery school rooms during winter. The measurement survey was conducted in 23 rooms of nine nursery schools in the Tokai region of Japan. We measured the CO_2 concentration, temperature, and humidity in 10 min intervals during the winter in 2022. The data collected from 9 a.m. to 3 p.m. on weekdays when the rooms were occupied were analyzed. The results showed that the mean value of the CO_2 concentration in the nursery school rooms was below 1000 ppm in 22 of 23 rooms. Besides, we estimated the ventilation rate and found that most rooms exceeded the value per person required to keep the concentration below 1000ppm. The results suggest that the nursery school teachers actively used mechanical and window-opening ventilation. On the other hand, the mean temperature was below 18 °C in 12 rooms and the mean relative humidity was below 40% in 22 rooms. We found that increasing the ventilation volume to avoid closed spaces during winter significantly decreased the relative humidity in the nursery school rooms.

1 Introduction

In December 2019, COVID-19 infections began in Wuhan, China, and spread to many countries worldwide in the following February. The Omicron strain of infection increased in both children and adults. As of November 2022, certain schools and nurseries remain closed.

There has been some research on coronavirus infections and ventilation methods for improving the indoor air environment in schools. Rodriguez et al. [1] conducted a field survey on indoor CO_2 levels in secondary schools and universities during the COVID-19 pandemic. They found that controlled mechanical ventilation systems are essential in educational spaces, and that wearing a properly fitting FFP2–N95 mask indoors should also be strongly recommended to minimize the risk of airborne infection transmission. Barrio et al. [2] measured indoor temperatures and CO_2 concentrations to compare indoor environmental conditions before and during the COVID-19 pandemic in winter in public middle and high schools. The results showed that the mean CO_2 concentration decreased by 1,400 ppm, with a second term value of approximately 1,000 ppm, as the temperature decreased by nearly 2 °C, with a mean value of 18 °C.

In Japan, the New Coronavirus Infectious Disease Control Subcommittee summarized effective ventilation methods for preventing the spread of COVID-19 in buildings [3]. The Ministry of Health, Labor, and Welfare [4] has established guidelines for infectious disease control in nursery schools. However, few studies based on field surveys in nursery schools have been conducted.

Therefore, this study aimed to clarify the effect of the policy of avoiding closed spaces with poor ventilation for preventing COVID-19 on the indoor environment of nursery school rooms during winter.

2 Method

We selected nine nursery schools in the Tokai region of Japan for this study. A measurement survey was conducted in 23 rooms regularly used by the children. The indoor carbon dioxide (CO_2) concentration, temperature, and relative humidity was measured in 10 min intervals during winter for approximately 40 days from mid-January to late February 2022. A CO_2 logger (TR-76Ui; accuracy: ±50ppm, T&D Corp.) was used to measure the CO_2 concentration, and a temperature/humidity logger (TR-72U; accuracy: ±0.3°C, ±5%, T&D Corp.) was used to measure the temperature and relative humidity in each room. Table 1 lists the structure of the facilities, year in which they were built, number of children, floor space, and presence or absence of a humidifier in the room. The temperature and humidity of the outside air was obtained from the Automated Meteorological Data

* Corresponding author: 2022y03@stu.gifu-nct.ac.jp

Table 1. Outline of target nursery rooms in the survey

Address	Facility ID	Room ID	Age	Structure	Year of construction	Num. of children	Window specification	Floor space [m^2]	Heating appliance	Other appliances	Ventilating facilities
Aichi Prefecture Nagoya City	Ta	Ta1	3,4,5	Wood	2019	19	Single	38.0	※1	※6	※8
		Ta2	3,4,5			38		38.0	※1		※8
		Ta3	2			12		37.6	※1	-	※8
Aichi Prefecture Nagoya City	Tb	Tb1	1,2	RC	1983	20	Single	31.3	※1,2	※4,6,7	-
		Tb2	0			10		36.7	※1,2	※6,7	-
Aichi Prefecture Nagoya City	Tc	Tc1	5	Wood	2020	17	Double glazed	31.3	※1	※6	※8
		Tc2	2			12		28.9	※1	※4,6	※8
		Tc3	1			12		39.3	※1	※4,6	※8
Aichi Prefecture Nagoya City	Td	Td1	4	Steel	2010	26	Single	49.8	※1	※4	※8
		Td2	0,1,2			18		47.8	※1	※4,5	※8
Mie Prefecture Iga City	Te	Te1	4,5	Steel	1983	13	Single	42.0	※1	※6	-
		Te2	3			7		42.0	※1	※6	-
		Te3	0,1,2			18		48.0	※1	※6	-
Mie Prefecture Kuwana City	Tf	Tf1	5	Wood	2021	16	Single	55.3	※1	-	※8
		Tf2	4			18		45.9	※1	-	※8
		Tf3	3			18		45.9	※1	-	※8
Gifu Prefecture Ogaki City	Tg	Tg1	5	RC	1976	17	Single	58.3	※1	※6	-
		Tg2	3			23		48.0	※1	※6	-
		Tg3	2			20		58.3	※1,3	※6	-
Aichi Prefecture Toyota City	Th	Th1	3,4,5	Steel	1985	9	Double glazed	46.5	※1	※6	※8
Aichi Prefecture Toyohashi City	Ti	Ti1	5	RC	1975	28	Double glazed	58.3	※1,3	※6	-
		Ti2	3	Steel	2019	28		73.4	※1,3	※6	※8
		Ti3	0			15		40.9	※1,2	※6	※8

※1 Air conditioner
※2 Floor heating
※3 Gas heater

※4 Humidifier
※5 Air purifier
※6 Air purifier with humidification function
※7 Ion generator

※8 No heat exchange ventilation

Acquisition System (AMeDAS) weather data of the same city. According to the Japan Meteorological Agency, the standard climate values of temperature, humidity, and maximum snow accumulation in the prefectural capitals in this region are 5.3 °C, 62.3%, and 4.5 cm, respectively. Furthermore, nursery teachers were interviewed regarding the temperature settings, ventilation methods, and room occupation times. Based on these interviews, the data collected from 9 a.m. to 3 p.m. on weekdays when the rooms were regularly occupied were analyzed.

3 Results and discussion

3.1 CO_2 concentration

3.1.1 Box-and-whisker diagram

Japan's Ministry of Health, Labour and Welfare has indicated that if the concentration of carbon dioxide is 1000ppm or less, it is not a closed space with poor ventilation. All of the nursery rooms surveyed used air conditioners as heating equipment. Open stoves were used in some rooms as a supplement, but only temporarily in the morning.

Fig. 1 shows a box-and-whisker diagram of carbon dioxide concentrations. The notches on the box plots indicate a ~95% confidence interval of the median calculated, and the cross mark indicates the mean value. The mean value in nursery rooms was below 1000ppm in 22 out of 23 rooms except for Tc1. Furthermore, the third quartile values were below 1000 ppm in 22 rooms. In particular, Th1 had a small quartile range and was close to the outdoor air concentration. Mechanical ventilation equipment was installed in 12 of the 23 rooms, but they were not of the heat exchange type. In interviews with each facility, they answered that most rooms were ventilated by opening the windows. Therefore, we found that many rooms are sufficiently ventilated during winter regardless of whether they have ventilation equipment or not.

On the other hand, in Tc1, the mean value exceeded 1000 ppm and there was a wide range of scatter above and below the median. According to the interviewees, they could not open the windows in this room because the noise from inside the room could be heard through the open windows and disturbed the neighbors. However, the constant use of mechanical ventilation equipment suggested that the equipment lacked ventilation capacity.

3.1.2 Time of day when the concentration tends to increase

Next, we tried to reveal the times and activities at which CO_2 concentrations were likely to rise. Daily activities often include morning homeroom, indoor and outdoor play, lunch, nap, and afternoon meeting. The mean daily variation was determined by averaging each measurement at each time, and the peak time of concentration was calculated. The peak times for each room are shown in Fig. 2. The peak CO_2 concentration times varied: some rooms had peak times around 9 a.m. and some rooms had peak times after 1 p.m.

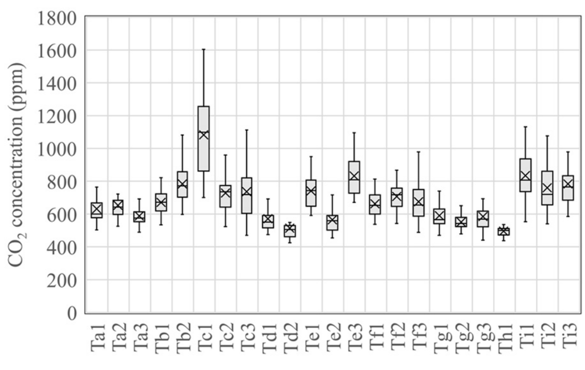

Fig. 1. Box plot of indoor CO_2 concentration.

Reasons given for peak CO_2 concentrations in the morning included the following

•Everyone was gathered in the room for the morning meeting.

• Temporary use of open oil stove due to low temperatures in the morning.

On the other hand, the following reasons were considered for rooms with peak concentrations in the afternoon.

• The concentration gradually increased from the morning and reached its peak before the children left the nursery school.

• Window opening ventilation was avoided during afternoon naps.

From the above, it was inferred that the time of day when the concentration tends to be high in each room is different and that the activity conditions are also different.

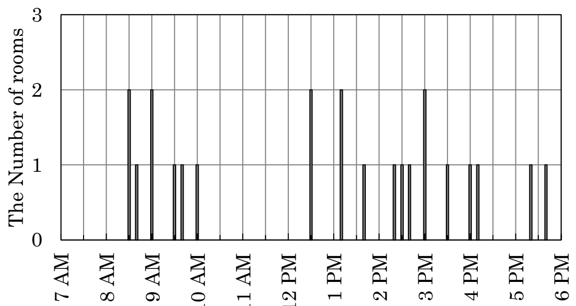

Fig. 2. Distribution of mean CO_2 concentration peak times

3.1.3 Ventilation rate

Furthermore, we regarded the time under consideration to be in a steady state and thus estimated the ventilation rate from actual measurements. The required ventilation rate needed to be maintained below a concentration of 1,000 ppm using the Seidel formula (Eq.1).

$$Q = \frac{k}{pi - po} \tag{1}$$

where (m^3/h) is the ventilation rate, k (m^3/h) is the pollutant emissions, pi (m^3/m^3) is the acceptable CO_2 concentration in the room, and po (m^3/m^3) is the outside CO_2 concentration. The CO_2 exhalation was set at 0.011 and 0.022 m^3/h for a child and nursery school teacher, respectively, based on the Standard for School Environmental Sanitation [5]. The outdoor CO_2 concentration was set at 423 ppm based on data from a meteorological observatory. This value is the mean value for January and February observed in Ayasato. Fig. 3 shows the estimated and required ventilation rates. Incidentally, the rates were not shown in terms of ventilation frequency because many ceiling shapes are difficult to calculate in terms of volume owing to the diversity of nursery room designs.

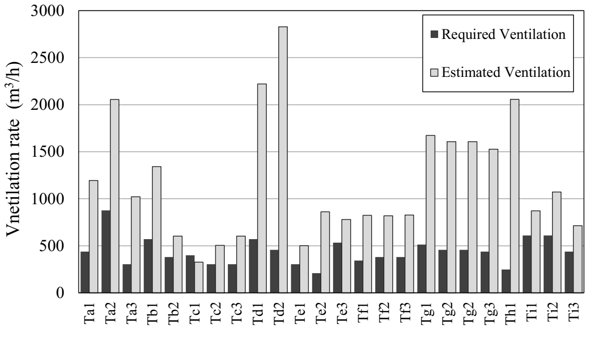

Fig. 3. Estimated and required ventilation rate in each room

As shown in Fig. 3, the minimum and maximum estimated ventilation rates were 326 and 2929 m^3/h in Tc1 and Td2, respectively. In contrast, the minimum and maximum ventilation requirements, which were below 1,000 ppm, were 210 m^3/h in and 877 m^3/h in Ta2 and Te2, respectively.

Fig. 4 shows the Fig. 3 results converted to an estimated ventilation rate per person (child). The Japanese Ministry of Health, Labor, and Welfare and HASS102 (SHASE of Japan) recommend a maximum ventilation rate of 30 m^3/h. This is the value for an adult. With the exception of Tc1 and Ti1, the rooms all exceeded 30 m^3/h. More than 60 m^3/h was observed in eight of the 23 rooms. This indicates that excessive ventilation by opening windows may have a significant impact on the indoor temperature and humidity during winter.

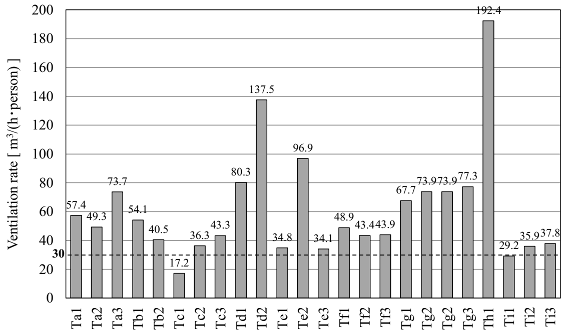

Fig. 4. Estimated ventilation rate per person

3.2 Temperature and Humidity

3.2.1 Box-and-whisker diagram

Box-and-whisker plots of the indoor temperatures are shown in Fig. 5. The mean temperature was below 18 °C in 12 of the 23 rooms. The temperature range recommended by the Guidelines for the Control of Infectious Diseases in Daycare Centers is 20–23 °C. The mean temperature was within this range in only 2 of the 23 rooms, and included Td, which had the highest CO_2 concentration.

Box-and-whisker plots of the indoor relative humidity are shown in Fig. 6. Only 1 of the 23 rooms had a mean temperature above 40% and 10 rooms had mean temperatures below 30%. These results indicate that the promotion of ventilation may result in a decrease in temperature and humidity.

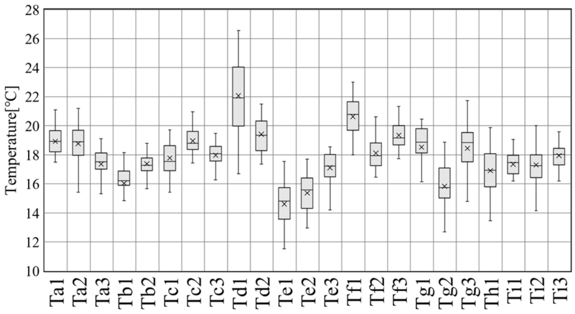

Fig. 5. Box plot of indoor temperature

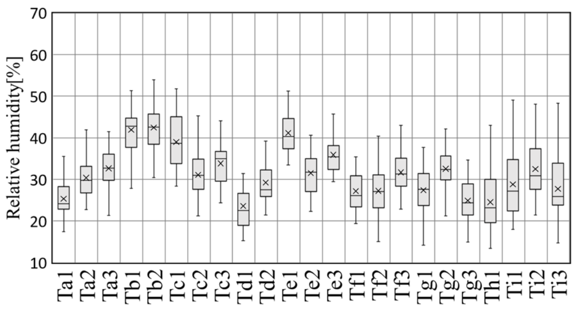

Fig. 6. Box plot of indoor relative humidity

3.2.2 Relationship between CO_2 concentration and temperature or humidity

Fig. 7 shows the relationship between the mean CO_2 concentration and mean indoor temperature. Although there was a slight tendency for the room temperature to decrease as the CO_2 concentration decreased, the correlation coefficient was as low as r = -0.14. We supposed that as the effect of ventilation was small in rooms with a high heating capacity, the indoor temperature could be maintained.

Fig. 8 shows the relationship between the mean CO_2 concentration and mean indoor relative humidity. As the CO_2 concentration decreased, the relative humidity also tended to decrease. The correlation coefficient was r = 0.51. The regression line shows that the relative humidity falls below 40% when the concentration falls below 1000 ppm. Moreover, the regression line also shows that the relative humidity was below 30% when the CO_2 concentration was lower than about 620 ppm. Similar results were obtained even when Tc1, which had a high concentration, was removed.

Fig. 9 shows the relationship between the mean CO_2 concentration and indoor/outdoor absolute humidity difference. From the whole regression line, the indoor absolute humidity tended to decrease as the CO_2 concentration decreased. In particular, in some rooms where the indoor/outdoor difference was approximately 0, the absolute humidity was almost the same as the outdoor air, thus dry. Besides, we conducted a t-test and found that only four rooms absent humidifiers showed no trend toward significantly higher absolute humidity.

Therefore, if the heating capacity of the room is high, the indoor temperature is not significantly reduced by ventilation. However, the indoor humidity is significantly reduced by ventilation, and this drying is concluded to be a problem.

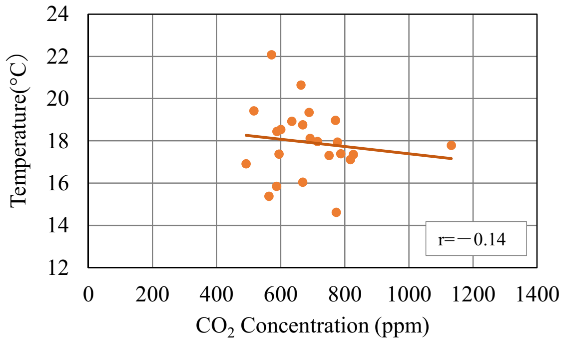

Fig. 7. Relationship between the mean CO_2 concentration and the indoor temperature

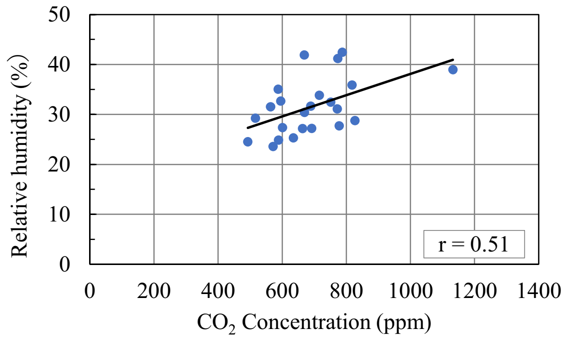

Fig. 8. Relationship between the mean CO_2 concentration and the indoor relative humidity

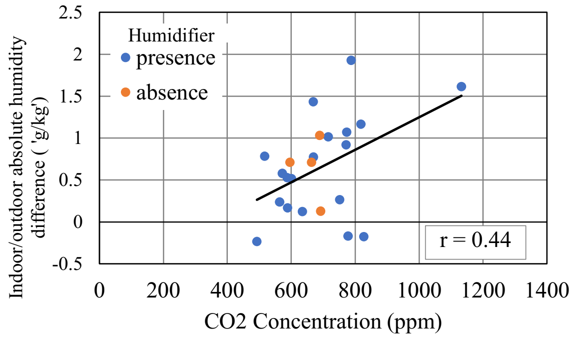

Fig. 9. Relationship between the mean CO_2 concentration and indoor/outdoor absolute humidity difference

4 Conclusion

CO_2 concentrations in most of the nursery rooms were below 1000 ppm during winter owing to ventilation promotion to prevent the spread of COVID 19. Besides, some rooms were significantly above the required ventilation rate per person to remain below 1000 ppm. We found that in nursery rooms, since opening windows are mainly used for ventilation and the ventilation equipment does not have a heat exchange, excessive ventilation leads to low temperature and humidity. Therefore, we considered that a ventilation facility having a total heat exchanger is effective, but excessive ventilation must be avoided first.

Moreover, since the Tokai region targeted for this survey belongs to the Pacific climate, we presume that the above results were influenced by a warm and dry climate. In the future, it is necessary to consider the existence of regionality.

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