Study on ventilation issues in urban nursery facilities: Long-term field survey in Yokohama, Japan

Shinya Taneichi 1*, Ineko Tanaka 2

1 Graduate School of Urban Innovation, Yokohama National University, Kanagawa, Japan
2 Institute of Urban Innovation, Yokohama National University, Kanagawa, Japan

Abstract. In many urban nursery facilities in Japan, daily ventilation behavior is restricted, and poor indoor air quality has been an issue of concern. However, the lack of specific common standards for indoor environments, including ventilation in nursery facilities, has left the issue unresolved in Japan. The purpose of this study is to clarify ventilation issues at nursery facilities in urban areas and indicate future measures. To this end, indoor air quality was analyzed using data from intermittent measurements taken between 2014 and 2022 at 21 nursery facilities in Yokohama City. As a result, the nursery facilities were classified into three categories based on nursery teachers’ ventilation behavior: “window-ventilation type,” “mechanical-ventilation type,” and “combined-ventilation type.” There was a significant difference (p-value <0.001) in the mean CO2 concentration between the window-ventilation type and the mechanical-ventilation type, and between the window-ventilation type and the combined-ventilation type, confirming the difference indoor air quality due to the difference in ventilation behavior. It was clear that the mechanical-ventilation type and combined-ventilation type had significantly lower compliance rates with the minimum ventilation rate required by the Japanese Building Standard Law (20 m3/h), which buildings must have at a minimum.

1 Introduction

In Japan, the criteria for establishing nursery facilities have been relaxed to allow outdoor spaces such as parks in the vicinity of nursery facilities to be accepted as substitutes for schoolyards. This measure was taken in response to an increasing demand for nursery facilities due to an increase in dual-income households and changes in working patterns [1]. Against this background, nursery facilities established as part of office buildings, commercial facilities, and residential complexes (hereinafter referred to as “complex-type” facilities) have become more common in urban areas. And the indoor air quality issues of nursery rooms have been pointed out [2-3]. Because, voluntary ventilation by opening windows is often more restricted in these facilities than those established independently (hereinafter referred to as “independent-type” facilities).

One of the reasons to focus on such issues is that there are no standards for the maintenance and management of the indoor air quality in nursery facilities. Although the “Infectious Disease Control Guidelines of Nursery Schools” [4] is available as a guide, it does not provide guideline values such as CO2 concentration or ventilation frequency. Thereby, leaving the indoor air quality of nursery rooms to the environmental control policies of the nursery facilities. Thus, the quality of the nursery environment in which children spend their time has not been properly evaluated. This is because priority has been given to the quantitative improvement of nursery facilities with the goal of reducing the number of children on waiting lists. Many studies have been conducted overseas on indoor air quality in urban nursery facilities, and these have been proposed issues and solutions [5-7].

However, there are few studies and no specific progress on this point in Japan. In light of the current COVID-19 pandemic and new infectious disease countermeasures to come, it is necessary to clarify the issues related to ventilation and provide solutions to these issues in Japan.

This paper aims to clarify the ventilation issues in urban nursery facilities in Japan. We analyzed the results of the measurement surveys [8-12] that have been conducted intermittently in Yokohama [S1] from 2011 to 2022.

2 Research summary

Table 1 shows an overview of 21 nursery facilities that the authors have intermittently surveyed in Yokohama City from 2011 to 2022. Data collected in Kamakura City are treated as reference values for the suburbs [S2]. As shown in Fig. 1, the general room layout of nursery facilities in Japan is the individual-room type. In urban areas, the one-room type shown in Fig. 2 is also common, accounting for about half of all nursery facilities in Yokohama City [3].

Temperature, relative humidity, and CO2 concentration were measured at 1-minute intervals in each nursery room for mainly 0-2 and 5 years old. Also, total volatile compounds (hereinafter referred to as TVOC) were measured in the 0- and 1-year-old rooms of some of the nursery facilities[S3]. The measuring devices were placed in locations where the direct influence of sunlight and air conditioning equipment was minimal, and the children could not reach them (90–120 cm high).
Table 1. Overview of 21 nursery facilities surveyed in Yokohama City

<table>
<thead>
<tr>
<th>ID</th>
<th>Facility type</th>
<th>Room type</th>
<th>Establishment year</th>
<th>Structure</th>
<th>Floor</th>
<th>Ventilation method</th>
<th>Room ID</th>
<th>Age</th>
<th>Number of nursery teachers**</th>
<th>Number of children**</th>
<th>Room area [m²]</th>
<th>Ceiling height [m]</th>
<th>Survey period</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Complex-type</td>
<td>One-room</td>
<td>2014</td>
<td>RC</td>
<td>1st</td>
<td>-</td>
<td>A1-2</td>
<td>1-2</td>
<td>23</td>
<td>8</td>
<td>89.6</td>
<td>2.5</td>
<td>Aug. 2018</td>
</tr>
<tr>
<td>B</td>
<td>Complex-type</td>
<td>Individual-room</td>
<td>2011</td>
<td>RC</td>
<td>1st</td>
<td>-</td>
<td>B0-1</td>
<td>0-1</td>
<td>8</td>
<td>4</td>
<td>38.2</td>
<td>2.5</td>
<td>Aug. 2018</td>
</tr>
<tr>
<td>C</td>
<td>Independent-type</td>
<td>Individual-room</td>
<td>2011</td>
<td>Wood</td>
<td>1st-2nd</td>
<td>Class 3</td>
<td>C0-1</td>
<td>0-1</td>
<td>18 (14)</td>
<td>6 (6)</td>
<td>69.8</td>
<td>2.5</td>
<td>1st: Dec. 2017</td>
</tr>
</tbody>
</table>

* This facility is located in Kamakura City, adjacent to Yokohama City, and is shown for reference.

** The numbers in parentheses are at the time of the second survey.

Fig. 1. Nursery room at facility Yi (Individual type)

Fig. 2. Nursery room at facility Ya (One-room type)
For the analysis, only the data measured from 10:00 to 16:00 (6 hours) were used, based on the flow of nursery schedules at each nursery facility, to consider only the common hours of attendance. For the outdoor air CO₂ concentration, the average value of 430 ppm obtained in these actual measurements was used as the standard outdoor air CO₂ concentration for all facilities.

3 Research results

3.1 Actual indoor air quality in nursery rooms

3.1.1 Temperature in the nursery facility

Fig. 3 shows that the lowest average indoor temperature was facility Ya1’s temperature in winter, and the highest was facility Yg1-2’s temperature in autumn. The highest value, Yg1-2, was above 30 °C despite the autumn. This was influenced by the facility’s policy of not using air conditioning and actively implementing window opening ventilation. Therefore, excessive window opening ventilation led to an increase in room temperature and a decrease in comfort.

The next step is to compare the measured values with the current indoor environmental standards in Japanese. The percentage of the measured temperature that complies with the Management Manual of School Environmental Sanitation (MEXT) [13] and the management standard of environmental sanitation for buildings (MHLW) is defined as the "compliance rate" and is shown in Table 2. As a result, more than 90 % fell within the standard values regardless of the season. It was seen that the indoor temperature was generally good, approximately 22-26 °C, although the outdoor temperature varied more than 25 °C depending on the season.

3.1.2 CO₂ concentration in the nursery facility

Fig. 4 shows that the lowest average indoor CO₂ concentration was 493 ppm at Yg0 in Autumn, and the highest was 2052 ppm at C0-1 in winter. Facility Yg, which exhibited the lowest value, had an environmental control policy that mainly relied on ventilation by window opening. Thus, the value was closest to the outdoor CO₂ concentration. On the other hand, the highest value was found at facility C in the suburbs during winter season. This was due to the fact that the ventilation equipment did not function adequately because the air supply port in the nursery room was blocked by furniture. Even in suburban areas where ventilation activities are not restricted in this way, proper use of ventilation equipment is important because window opening is less likely to occur during the winter. Facilities Yc and Yd are similar in aspect, as we also observed that ventilation equipment was not in use. Also, facility Yd, which exhibited high value during autumn season, used both ventilation by window opening and mechanical ventilation, but the means of ventilation differed depending on the nursery teacher in charge of the nursery room. Therefore, Yd2, which had the lowest frequency of window opening, used both ventilation by window opening and mechanical ventilation, but the means of ventilation differed depending on the nursery teacher in charge of the nursery room. Therefore, Yd2, which had the lowest frequency of window opening and only operated the ventilation intermittently, resulted in higher CO₂ concentration. In these individual-room type facilities, Yd, Ye, Yf, and Yi, the differences in CO₂
concentration among nursery rooms were larger than in the one-room type. The influence of the means of ventilation used by the different nursery teachers in charge was suggested.

The next step is to compare the measured CO₂ concentration values with the current indoor environmental standards in Japanese (Table 2). As a result, showed that the compliance rate of 1500 ppm, which was set to ensure a learning environment, was generally satisfactory, except during the summer season. On the other hand, the compliance rate of 1000 ppm, which was set to ensure a sanitary environment, was 68% in the autumn season, 7% in the summer season, and 53% in the winter season. Data counts are an issue, but were noticeably lower during the summer season when windows are opened less frequently. Also, compliance rate for only facility Ya surveyed after the COVID-19 epidemic was 60%, indicating a slight increase.

3.1.3 TVOC value in the nursery facility

Of the facilities where TVOC was measured, four facilities of Yf, Yh, Yi, and Yj were below the Ministry of Health, Labor, and Welfare’s guideline value of 400 μg/m³ (Fig. 4). However, at facility Yh, the CO₂ concentration exceeded 1000 ppm, suggesting that the ventilation was not sufficient and that there were fewer VOC emission sources, to begin with. At facilities Yd and Yk, where TVOC emissions significantly exceeded the guideline value, disinfectants with alcohol were frequently used for room cleaning. Another reason is that ventilation is not implemented after room cleaning. Therefore, it is necessary to exchange the air by window opening after using chemicals such as alcohol. This is especially important during periods when the use of alcohol and other chemicals becomes prominent as a measure against infectious diseases, such as the current COVID-19 pandemic.

### Table 2. Compliance rates of temperature, CO₂ concentration and TVOC value by Management Manual of School Environmental Sanitation (MEXT) and the management standard of environmental sanitation for buildings (MHLW)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Reference guideline and standard</th>
<th>Target value</th>
<th>Compliance rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Autumn</td>
</tr>
<tr>
<td>Temperature</td>
<td>The management standard of environmental sanitation for buildings (MHLW) and Management Manual of School Environmental Sanitation (MEXT)</td>
<td>18-28 °C</td>
<td>94%</td>
</tr>
<tr>
<td>CO₂ concentration</td>
<td>Management Manual of School Environmental Sanitation (MEXT)</td>
<td>≤ 1500 ppm</td>
<td>97%</td>
</tr>
<tr>
<td></td>
<td>The management standard of environmental sanitation for buildings (MHLW)</td>
<td>≤ 1000 ppm</td>
<td>68%</td>
</tr>
<tr>
<td>TVOC</td>
<td>Japanese provisional target value by MHLW</td>
<td>≤ 400 μg/m³</td>
<td>45%</td>
</tr>
</tbody>
</table>

* Results extracted only from surveys conducted before the COVID-19 epidemic.
** Only results from Ya facilities conducted after the COVID-19 epidemic were extracted.

Fig. 5. Mean CO₂ concentration (± standard deviation) by ventilation behavior of nursery teacher (*** p-value < 0.001)

### 3.2 Classification of nursery facilities by ventilation behavior

In the previous section, we found that the indoor air quality in a nursery room is affected by the means of ventilation used by the nursery teacher in charge of the room. Therefore, we categorized facilities that ventilated more than half of the time the children were in the nursery by window opening as the “window-ventilation type,” those that did not or could not use ventilation by window opening as the “mechanical-ventilation type,” and those that used both ventilation by window opening (less than half of the time) and mechanical ventilation as the “combined-ventilation type.” The mean indoor CO₂ concentration in the facility classified by this ventilation behavior is shown in Fig. 5. As a result, there was a significant difference (p-value < 0.001) in the mean CO₂ concentration between the window-ventilation type and the mechanical-ventilation type, and between the window-ventilation type and the combined-ventilation type, confirming the difference indoor air quality due to the difference in ventilation behavior.
3.3 Estimation of ventilation in urban nursery facilities

In Japan, the Building Standards Act is enforced as the minimum standard that buildings must satisfy, and the ventilation rate required in the Act is 20 m³/h. In addition, to meet the management standard of environmental sanitation for buildings (1000 ppm) based on the previous section, it is necessary to achieve a ventilation rate of 30 m³/h. Based on this, the MHLW recommends securing a similar ventilation rate for COVID-19 measures.

In order to confirm whether these required ventilation rates are satisfied in the actual environment, the ventilation rate in each nursery room was estimated using an

![Fig. 6. Estimated ventilation rates per person by ventilation behavior (above 50 m³/h indicates by number)](https://doi.org/10.1051/e3sconf/202339601084)

**Table 3. Compliance rates of ventilation rate by Building Standards Act and the management standard of environmental sanitation for buildings (MHLW)**

<table>
<thead>
<tr>
<th>Reference standard</th>
<th>Target value</th>
<th>Ventilation behavior</th>
<th>Compliance ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Standards Act</td>
<td>20 m³/h</td>
<td>Window-ventilation type</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical-ventilation type</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined-ventilation type</td>
<td>88%</td>
</tr>
<tr>
<td>The management standard of environmental sanitation for buildings (MHLW)</td>
<td>30 m³/h</td>
<td>Window-ventilation type</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical-ventilation type</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined-ventilation type</td>
<td>68%</td>
</tr>
</tbody>
</table>

For the estimated ventilation rate, the following equations are used:

\[
\bar{Q} = \left( \frac{m}{C_i - C_o} \right) + \frac{V_{emz}}{t_2 - t_1} \cdot \log_e \frac{C_i(t_2) - C_o}{C_i(t_1) - C_o}
\]

(1)

\[
\left( \frac{m}{C_i - C_o} \right) = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{m(t)}{C_i(t) - C_o} \, dt
\]

(2)

\( \bar{Q} \): Hourly mean ventilation rate [m³/h]  
\( m \): Estimated CO₂ emission [m³/h]  
\( C_i \): Indoor CO₂ concentration [m³/m³]  
\( C_o \): Outdoor CO₂ concentration [m³/m³]  
\( V_{emz} \): Effective volume [m³]  
\( t \): time [s]  
\( t_1 \): Start of measurement  
\( t_2 \): End of measurement
actual measurement of CO₂ concentration (hereafter referred to as the “estimated ventilation rate”). For the estimation, we used the concentration decay method, the only continuous generation method shown in SHASE-S 116-2020 [14] that allows for time variability in the estimation of the ventilation rate (Eq. 1 and 2) [S4].

Following the results of 3.2, the relationship between the required ventilation rate and estimated ventilation rate was also classified into the window-ventilation type, mechanical-ventilation type, and combined-ventilation type, and the results are shown in Fig. 6. The total estimated ventilation rate was divided by the number of people in the room to calculate the ventilation rate per person. The estimated ventilation rate for the window-ventilation type was 7 m³/h at the minimum and 612 m³/h at the maximum (Fi3. [A]). The distribution of the data suggests that the required ventilation rate is generally satisfied, but for the convenience, Table 3 shows the satisfaction rate. In the periods of class activities and lunch, all rooms met the requires ventilation rate, which decreased during the post-nap period. The decrease in the satisfaction rate during nap to snack times was influenced by facility Yj, where the windows were closed due to rainfall, and the CO₂ concentration temporarily increased. Therefore, it was confirmed that even in a window-ventilation-type nursery facility, the ventilation rate may be temporarily insufficient.

The estimated ventilation rate for the mechanical-ventilation type, excluding facility C in suburb, was 3 m³/h at the minimum and 64 m³/h at the maximum. These values are significantly lower than that for the window-ventilation type (Fig. 6[B]). In addition, the satisfaction rate in Table 3 dips below half in the period between lunch time and snack time. Therefore, it is clear that the mechanical-ventilation-type nursery facilities fall short of even the minimum standard for buildings. In particular, it is difficult to ensure 30 m³/h with only mechanical ventilation equipment in operation.

The estimated ventilation rate for the combined-ventilation type was 4 m³/h at the minimum and 348 m³/h at the maximum, indicating a wide distribution of over- and under-ventilation (Fig. 6[C]). The compliance rates in Table 3 also suggest that temporary window opening ventilation is recommended during lunch and nap times, especially because of the lack of ventilation rate. However, since it is also important to maintain a quiet sleeping environment, separate consideration should be given to the feasibility of temporarily opening windows during nap time.

This is due to the fact that the ventilation requirements of the Building Standard Law assume a resting state and cannot accommodate a variety of activities such as nursery activities.

4 Conclusion

This paper analyzed the ventilation issues in urban nursery facilities based on measurements data from Yokohama City, which has been surveyed on an ongoing basis. As a result, although there are issues with the number of data, CO₂ concentrations tended to be higher in summer and winter, when windows are opened less frequently. There were several facilities where issues were found in the use of ventilation equipment.

The characteristics of the indoor air quality in the nursery rooms differed according to the means of ventilation and were classified into the “window-ventilation type,” “mechanical-ventilation type,” and “combined-ventilation type.” In particular, the estimated ventilation rate for some of the “mechanical-ventilation type” nursery facilities were less than half of 20 m³/h, the value required by the Building Standards Act, clearly indicating that the ventilation rate intended at the time of design was not secured. Therefore, it is difficult to achieve the ventilation rate of 30 m³/h recommended by the MHLW when operating only mechanical ventilation equipment in nursery facilities with a wide range of activities.

From the above, the intensity of activities of nursery teachers and children in nursery facilities is high, it will be necessary to design ventilation in accordance with the actual conditions of these activities. Also, while window opening can be considered a temporary measure of ventilation, windows cannot be opened in some nursery facilities in urban areas, which is another future issue that needs to be addressed.

Acknowledgment

We would like to sincerely thank the staffs of the nursery facilities who cooperated in the surveys.

Supplementary data

S1. Yokohama is the capital of Kanagawa Prefecture and the most populous city in Japan [15].

S2. The results for Facility C show CO₂ concentrations and estimated ventilation rates (Figs. 4 to 6) as reference values for suburban areas, but are excluded from the analysis when discussing issues in urban areas (Tables 2 and 3, Fig. 5).

S3. The temperature/humidity logger (ESPEC, RS13) was used to measure temperature and relative humidity only, and the CO₂ temperature/humidity logger (T&D, TR-76Ui) was used to measure temperature, relative humidity, and CO₂ concentration. The PID-type VOC concentration meter (RIKEN KEIKI, TIGER) was also used to measure TVOC. The accuracy of the device is ±0.5°C for temperature, ±5% RH for relative humidity, ±50 ppm ±5% of reading for CO₂ concentration, and ±5% ±1 digit of reading for TVOC.

S4. The CO₂ emission required to calculate the estimated ventilation rate was calculated using the equation proposed by Tajima et al [16].

References


5. J. Park, J. Yoo and J. Jeong, Impact of ventilation methods on indoor particle concentrations in a daycare center, Indoor Air, 32, 1-10 (2022)

6. C. Kim, D. Choi, Y. Lee and K. Kim, Diagnosis of indoor air contaminants in a daycare center using a long-term monitoring, Building and Environment, 204, 1-16 (2021)


10. K. Miyajima, I. Tanaka and Q. Zhang, Research on indoor air pollution focused on VOC in nursery facilities in urban area, Summaries of Tech. Papers of annual meeting, AIJ, Env., 841-842 (2019)


