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Assessment of Indoor Climate for Infants in Nursery School Classrooms in Mild Climatic Areas in Japan

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Abstract: In Japan, the standard of indoor climate in nursery school classrooms has not been established, and the control and maintenance of indoor climate in the classrooms are entrusted to individual childminders. Therefore, indoor climate in nursery school classrooms was measured to prepare fundamental information for proper environmental design and environmental control, considering infants' comfort and health. The climate of 0-year-old and 1-year-old children's rooms in 15 nursery schools located in mild climatic areas in Japan were measured in the summer and winter over four years. Consequently, a lower average temperature was found during winter at lower heights at which infants spend time and indoor air quality was found to be poor in both summer and winter due to a lower ventilation rate in some classrooms with a smaller area per infant compared to the minimum standards for child welfare institutions. One classroom with an average CO_2 concentration of over 1500 ppm was found in both summer and winter due to less ventilation. Illumination less than 300 lx in one-third of the studied classrooms and high equivalent noise level in most classrooms were measured. The need for indoor environmental standards was indicated in terms of infants' comfort and health.

Keywords: nursery; classrooms; vertical temperature difference; humidity; CO_2; air stuffiness index; particle matter; illumination; noise level

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1. Introduction

In Japan, with the advancement of women in society, the number of children who use nursery schools is increasing, and the proportion of young children is increasing [1]. Infants exhibit less thermoregulatory function than adults and are more affected by the surrounding thermal environment. Childcare time increases up to 11 h, and children who go to the nursery spend most time in nursery schools' indoor environments. Therefore, the environmental improvement of the nursery school classrooms is becoming increasingly important in maintaining children's mental and physical health. Guidelines for the indoor environment have been defined by the school environmental health standard for kindergartens, which is under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology [2]. However, no specific guidelines have been developed for the classrooms in nursery schools, which fall under the jurisdiction of the Ministry of Health, Labor and Welfare. Consequently, control and maintenance of the indoor environment in nursery schools are entrusted to individual childminders. The indoor environments in nursery schools are controlled based on the sense of comfort for adults, and the comfort and health of infants who spend time at lower heights tend to be overlooked. If an indoor environment standard for the nursery school classrooms is prepared, childminders could adjust indoor environment appropriately to make the indoor climate in the classrooms more conducive to comfort and health. Infants are particularly susceptible to infectious diseases such as influenza; hence, controlling indoor temperature and humidity in nursery classrooms is necessary for infants' wellbeing. Additionally, ventilation is important to prevent the spread of coronavirus disease 2019 (COVID-19)—not only in office and school buildings but also in nursery schools. The infectious disease control

guidelines for nursery schools were established in 2018, which was before the COVID-19 pandemic; thus, the standards for thermal environment were demonstrated specifically for the first time [3]. According to the guidelines, the temperature should be set at 26–28 °C in the summer and at 20–23 °C in the winter, and relative humidity should be set to 60%. Although the basics of air infection control clearly include the isolation of the affected person and management of room ventilation, the guideline for indoor air environment is not clearly indicated. The aforementioned school environmental health standard provides the following guidelines: carbon dioxide concentration should be set to less than 1500 ppm as an index of ventilation; temperature should be set to more than 18 °C and less than 28 °C (the lower limit of the temperature standard was 17 °C until the end of March 2022) [2]; relative humidity should be set to more than 30% and less than 80%, illumination should be set to more than 300 lx; noise level should be set to less than 50 dBA when the window is closed and 55 dBA when the window is open. The humidity ratio (HR) is not specified in Japan; the current ASHRAE Standard 55-2017 [4] only specifies the upper limit of HR as 0.012 kg/kg (DA) and does not specify the lower limit. By contrast, recently, noise has been acknowledged as a social problem in nursery schools in Japan. Kawai et al. [5] investigated the conditions of the acoustic environment of six nursery schools of the Kanto area that were opened during 2005–2012 and conducted a review of overseas standards and guidelines. They revealed the problems of acoustic environment specific to nursery schools, such as the possibility of health effects by indoor high sound pressure level, securing quietness during nap time, and the importance of speech intelligibility for children in the developmental stage. On the contrary, in the United Kingdom, Building Bulletin 93 [6], published by the Institute of Acoustics and the Association of Noise Consultants in 2015, provided design criteria for acoustics and lighting design and guidance on fulfilling these criteria. The guidelines on ventilation, thermal comfort, and indoor air quality in schools have been updated in Building Bulletin 101 (BB101) in 2018 [7], wherein thermal comfort criteria are classified into four categories, and a higher level of expectation for thermal comfort may be needed for very young pupils. For example, the normal maintained operative temperature during the heating season is set at 25 °C, and the strictest draught criteria to provide thermal comfort are applied to the space utilized by young children less than 5 years of age. The control of the ventilation rate in nursery school classrooms is as important as that of the indoor thermal environment. In the case of natural and hybrid ventilation systems, the control set points on carbon dioxide concentration for the ventilation system in teaching spaces, which include opening windows, should be set to achieve less than 1000 ppm whenever possible; however, although carbon dioxide concentration in school classrooms should be kept below 1500 ppm according to the school environmental hygiene standards in Ministry of Education, Culture, Sports, Science and Technology, Japan (as mentioned earlier), no standards for carbon dioxide concentration have been established in Japanese nursery classrooms. The recommended illumination in nursery schools is 300 lx in BB101 [7], but no standards for illumination have been established in Japanese nursery classrooms.

Thus far, compared to the numerous studies on the indoor environment in school classrooms [8–21], few studies have been conducted on the indoor environment in nursery schools [22–26]. Particularly in Japan, research focusing on the environmental humidity in the winter has been conducted for kindergartens from the perspective of influenza prevention by Aoki et al. [27]; however, recently, Taneichi et al. [28] investigated the indoor environment of nursery schools. To date, however, few survey cases on indoor environment in nursery schools have been conducted. Therefore, for the present study, we have conducted questionnaire and measurement surveys focusing on the indoor environment of nursery schools since before the onset of the COVID-19 pandemic [29,30].

As mentioned earlier, except for the infectious disease control guidelines, there have not been any indoor environmental standards—particularly indoor air environmental standards—in nursery schools in Japan, until now [3]. Therefore, indoor climate in nursery school classrooms was measured to prepare fundamental information for proper environmental design and environmental control considering infants' comfort and health. Indoor environments

were measured and questionnaire surveys were administered in 15 different nursery schools in mild climatic areas in Japan during the summer and winter from 2016 to 2019. This paper summarizes the results of the measurements thus far and, further, proposes the indoor environmental standards that should be established for nursery school classrooms.

2. Materials and Methods

The survey was administered in 15 different nursery schools located in Nagasaki City, which has a population of around 400,000 inhabitants in 406 km^2 and is located in western Kyushu Island, with mild climate in Japan (32°45′ N, 129°53′ E). Tables 1 and 2 present the description of the investigated nursery school buildings. The investigated nursery schools included 14 authorized nursery schools—comprising four public schools (Nursery A, B, C, and D), 10 private nursery schools, and one unlicensed in-house nursery school (Nursery O). Thirteen nursery schools, excluding Nursery K and Nursery L, correspond to Certified Childcare Centers, which fall under the jurisdiction of the Cabinet Office and are supervised by the Ministry of Health, Labor and Welfare together with the Ministry of Education, Culture, Sports, Science and Technology. Nurseries K and L fall under the jurisdiction of the Ministry of Health, Labor and Welfare. The newest nursery is Nursery O, which was constructed in 2017, while Nursery A is an extremely old building, with a completion date in 1949. Three public nursery schools, excluding Nursery A, were completed around 1970. The airtightness values of observed buildings were unknown because the measurement of airtightness itself is not obligatory in Japan, although the value influences draught, CO_2 concentrations, and noise level. Air conditioners were installed in all the nurseries for space cooling and space heating. Along with air conditioners, floor heating was installed in Nursery I, J, and N. Ventilation systems were installed in 11 nursery schools, excluding three public schools and one private school. Humidifiers were used in 13 nursery schools, excluding Nurseries L and O, and air cleaners were used in 13 nursery schools, excluding Nurseries B and E. In the two nursery schools, Nurseries J and M, the floor area did not meet the standard of 1.65 m^2 per child, which was defined by the standards on facilities and operation of child welfare institutions [31], because, due to a shortage of nursery schools in Nagasaki City at the time of this research, it was supposed to accept children up to 120% of its capacity.

Thirteen nursery schools excluding A and F were evaluated in both summer and winter. Nursery A was evaluated during winter and nursery F was evaluated during summer. Each school was studied during one full school week—from Monday to Friday.

Table 3 shows the description of measurement items and measuring equipment used. We administered a survey on indoor thermal environment, indoor air environment, illumination environment, and acoustic environment for 0-year-old and 1-year-old children's rooms used by infants, and the outdoors. The vertical temperature was measured at the following four points: 0.1 m from the floor, which is the height at which infants crawl; 0.3 m from the floor surface, which is the height at which they sit on the floor; 0.6 m, which is the height of their head when they stand; and 1.1 m, which is the height of a head when adults sit in a chair. In Nurseries H and L, no partition exists between the 0-year-old and the 1-year-old children's rooms; hence, measurements were conducted at one point, considering the two spaces as one room. The measurement survey was administered for about two weeks in Nurseries A, B, C, E, F, and J and for about one week in the other nine nursery schools. The sensors continuously collected data while they were installed in the classroom. Additionally, measurements on the acoustic environment were conducted since the winter of 2016. $PM_{2.5}$ concentration and equivalent noise level were evaluated once by a 10 min measurement per classroom. Outdoor air temperature and relative humidity were obtained from the nearest meteorological station [32]. In addition to the measurement survey, a questionnaire survey on activities in the nursery classroom was also administered for each nursery classroom. In the questionnaire survey, investigated items included the following: the number of infants and nursery teachers in each nursery room, usage of cooling and heating equipment, usage of ventilation equipment, window opening, and the weekday and Saturday timeline.

Table 1. Description of the investigated nursery school buildings.

Name	Nursery A	Nursery B	Nursery C	Nursery D	Nursery E	Nursery F	Nursery G	Nursery H
Classification	public	public	public	public	private	private	private	private
Building form	single	composite	composite	composite	single	single	single	single
Completion	1949	1969	1970	1972	1972	1988	1999	2012
Structure [1,2]	RC	S	RC	RC	RC	RC	S	RC
Floor number	2 floors	2 floors	3 floors	1 floor	3 floors	2 floors	3 floors	2 floors
Gross floor area (m^2)	665.28	483.29	667.56	827.52	662.56	1014.18	408.67	763.68
Space cooling system [3]	AC	AC	AC	AC	AC	AC	AC	AC
Space heating system [3,4,5]	AC, KH	AC, EC	AC	AC, EC	AC	AC	AC	AC
Ventilation system	natural	natural	natural	mechanical	natural	mechanical	mechanical (not used)	mechanical
Other equipment	air cleaner, humidifier	humidifier	air cleaner, humidifier	air cleaner, humidifier	humidifier	air cleaner, humidifier	air cleaner, humidifier	air cleaner, humidifier
Lighting equipment [6,7]	FL	FL, IL	LED, FL	FL	LED, FL	LED	FL	FL
Opening time	7:30–18:00	7:30–18:00	7:30–18:00	7:00–18:00	7:00–19:00	7:00–18:00	7:00–18:00	7:00–18:00
Capacity	120	90	120	140	130	90	135	80
Area of infants' room (m^2/head) summer/winter [8]	0-year-old room:-/5.78 1-year-old room: -/3.20	0-year-old room:6.4/4.8 1-year-old room: 4.0/4.0	0-year-old room:5.3/4.0 1-year-old room:3.1/2.9	0-year-old room:4.5/4.5 1-year-old room:5.8/5.3	0-year-old room:5.5/3.6 1-year-old room:2.7/2.8	0-year-old room:6.8/- 1-year-old room:1.9/-	0-year-old room:4.3/4.1 1-year-old room:1.7/1.7	0- and 1-year-old room: 5.1/4.6
Survey year	2016	2017	2017	2019	2017	2017	2018	2018

[1] RC, reinforced concrete. [2] S, steel frame. [3] AC, air conditioner. [4] KH, kerosene fan heater. [5] EC, electric heating carpet. [6] FL, fluorescent light. [7] IL, incandescent lamp. [8] '-', 'not measured'.

Table 2. Description of the investigated nursery schools.

Name	Nursery I	Nursery J	Nursery K	Nursery L	Nursery M	Nursery N	Nursery O
Classification	private	private	private	private	private	private	unlicensed in-house
Building form	single	composite	single	single	single	composite	single
Completion	2013	2013	2013	2014	2015	2016	2017
Structure [1,2,3]	RC	RC	W	S	RC	RC	S
Floor number	2 floors	3 floors	2 floors	2 floors	2 floors	2 floors 1 basement	1 floor
Gross floor area	968.24	1310	unknown	1186.93	963.17	1233.41	252
Space cooling system [4]	AC	AC	AC	AC	AC	AC	AC
Space heating system [4,5,6,7]	AC, FH	AC, FH	AC, KH	AC	AC	AC, FH	AC
Ventilation system	mechanical	mechanical	mechanical	mechanical	mechanical	mechanical	mechanical
Other equipment	air cleaner, humidifier	humidifier	air cleaner, humidifier	air cleaner	air cleaner, humidifier	air cleaner, humidifier	air cleaner
Lighting equipment [8,9]	LED	LED	FL	LED, FL	LED	LED	LED
Opening time	7:00–18:00	7:00–18:00	7:00–19:00	7:00–20:00	7:00–19:00	7:00–18:00	7:00–18:00
Capacity	100	119	60	140	140	190	30
Area of infants' room (m^2/head) summer/winter	0-year-old room: 2.1/2.3 * 1-year-old room: 3.4/2.3 *	0-year-old room: 2.6/1.6 1-year-old room: 1.5/1.5	0-year-old room: 3.7/3.7 1-year-old room: 2.7/2.7	0- and 1-year-old room: 4.5/3.2	0-year-old room: 1.6/1.5 1-year-old room: 1.3/1.3	0-year-old room: 3.2/3.2 1-year-old room: 2.8/2.8	0-year-old room: 5.5/3.9 1-year-old room: 4.6/4.6
Survey year	2018	2016	2019	2019	2019	2018	2019

[1] RC, reinforced concrete. [2] W, wooden. [3] S, steel frame. [4] AC, air conditioner. [5] KH, kerosene fan heater. [6] EC, electric heating carpet. [7] FH, floor heating. [8] FL, fluorescent light. [9] IL, incandescent lamp. * 0- and 1-year-old room.

Table 3. Description of measurement items and measurement equipment used.

Measurement Items	Measurement Height (Number of Sensors)	Measurement Interval	Measurement Equipment	Range and Accuracy
Temperature	0.1, 0.3, and 0.6 m above the floor (1 for each height)	10 or 5 min (as for CO_2 measured in 2016 and 2017)	small data logger for temperature and humidity measurement (RSW-21S)	range: 0 to 55 °C, 10 to 95%RH
Humidity				accuracy: ±0.5 °C, ±5%RH
Carbon dioxide concentration, temperature, humidity	1.1 m above the floor (1)		data logger for carbon dioxide concentration, temperature, and humidity measurement (TR-76Ui)	range: 0 to 9999 ppm accuracy: ±50 ppm of range ± 5% of reading range: 0 to 55 °C, 10 to 95%RH accuracy: ±0.5 °C, ±5%RH
Globe temperature	1.1 m above the floor (1)		small data logger for temperature measurement (RTW-31S), globe thermometer with a diameter of 75 mm	range: −20 to 80 °C accuracy: ±0.3 °C
$PM_{2.5}$ concentration (particle number)	1.1 m above the floor (1)	1 min for 10 min measurement	air quality monitor (laser light scattering particle counter, DC170, sampling flow rate: 1.7 L/min)	particle size sensitivity: 0.5, 2.5 μm
Illumination	0.1–1.1 m above the floor (1)	10 min	data logger for illumination measurement (TR-74Ui)	range: 0 to 130 klx accuracy: ±5%
Equivalent noise level	1.1 m above the floor (1)	10 min measurement	normal noise level meter (NL-27)	range: 30 to 137 dB resolution: 0.1 dB (class 2)

An index called ICONE [22] was calculated from the measurement results of CO_2 concentration and used to evaluate indoor air quality (IAQ). The ICONE is an air stuffiness index used in the air quality evaluation of the classroom environment in France. Occupancy periods of less than 5 h are discarded. CO_2 values are classified according to their levels: n_0—values < 1000 ppm, n_1—values between 1000 and 1700 ppm, and n_2—values > 1700 ppm. The ICONE air stuffiness index is then calculated by applying Equation (1), where f_1 is the proportion of CO_2 values between 1000 and 1700 ppm ($f_1 = n_1/(n_0 + n_1 + n_2)$ and f_2 is the proportion of CO_2 values above 1700 ppm ($f_2 = n_2/(n_0 + n_1 + n_2)$).

$$\text{ICONE} = \left(\frac{2.5}{\log_{10}(2)}\right)\log_{10}(1 + f_1 + 3f_2), \quad (1)$$

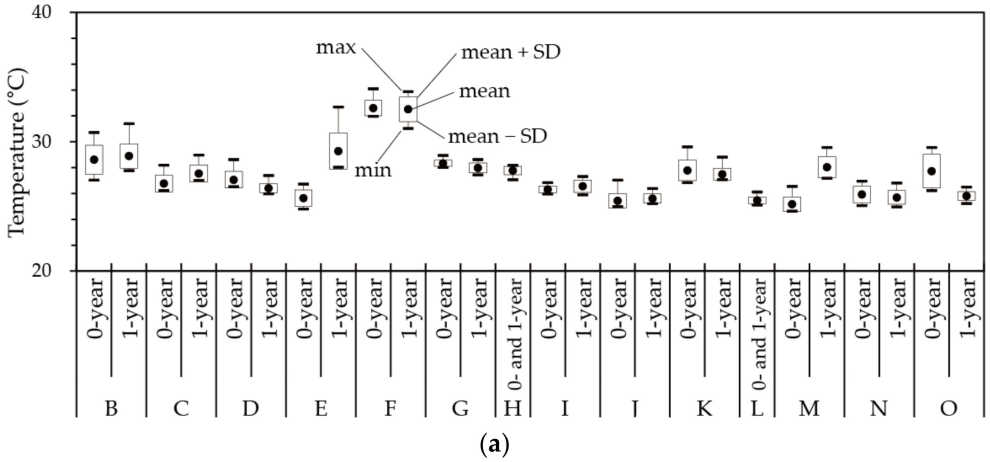
The final results are rounded to the nearest integer. The air stuffiness level of the room is then expressed by a score ranging from 0–5. ICONE scores from 0–5 correspond to an air stuffiness gradient: 0, none; 1, low; 2, average; 3, high; 4, very high; and 5, extreme stuffiness [22].

3. Results and Discussion

The median outdoor temperatures and relative humidity (RH) during the measuring period for the summer and winter were 27.8 °C and 80%, and 8.5 °C and 69%, respectively. The results are evaluated with reference to the infectious disease control guidelines for nursery schools established in 2018 [3]. Further, the school environmental health standard [2] and ASHRAE Standard 55-2017 [4] are referenced as needed.

3.1. Temperature and Humidity

Results of temperature at 1.1 m above the floor during opening hours in the summer and winter are presented in Figure 1. Figures 2 and 3 present a part of the vertical temperature distributions during the summer and winter opening hours. The temperature difference between 1.1 m above the floor and 0.1 m above the floor is termed the vertical temperature difference, and whether the temperature difference is above or below the comfortable range of 3 °C is evaluated [4]. Results of RH, HR, and globe temperature during opening hours in the summer and winter are presented in Figures 4–6, respectively. The mean values of temperature, globe temperature, RH, and HR during the measuring period were 27.4 °C, 26.5 °C, 62%, and 0.014 kg/kg (DA) in the summer; and 19.2 °C, 18.6 °C, 46%, and 0.006 kg/kg (DA) in the winter, respectively. Compared to the infectious disease control guideline mentioned above [3], the summer mean temperature was between 26 and 28 °C, but the winter mean temperature was lower than the lower limit of 20–23 °C. Mean RH was close to 60% of the standard in the summer, but lower than the standard in the winter.



(**a**)

Figure 1. *Cont.*

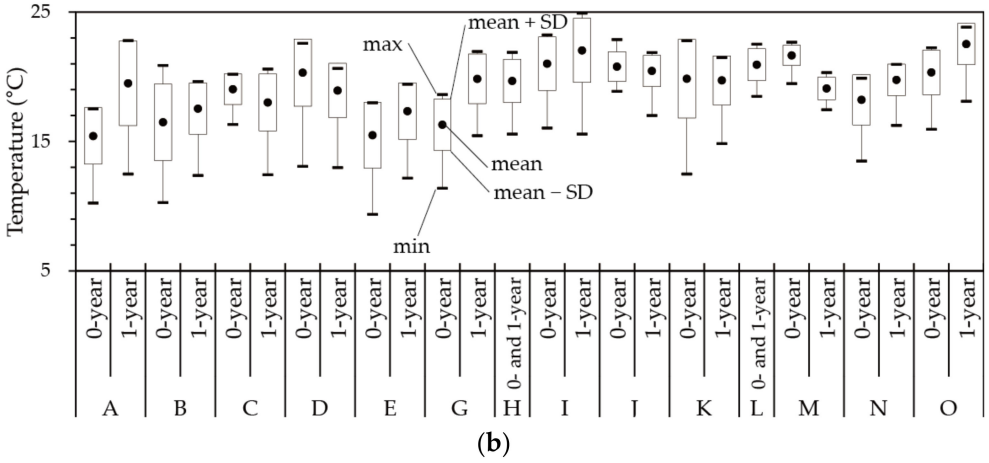


Figure 1. Temperature at 1.1 m from floor surface during opening hours in (**a**) summer and (**b**) winter.

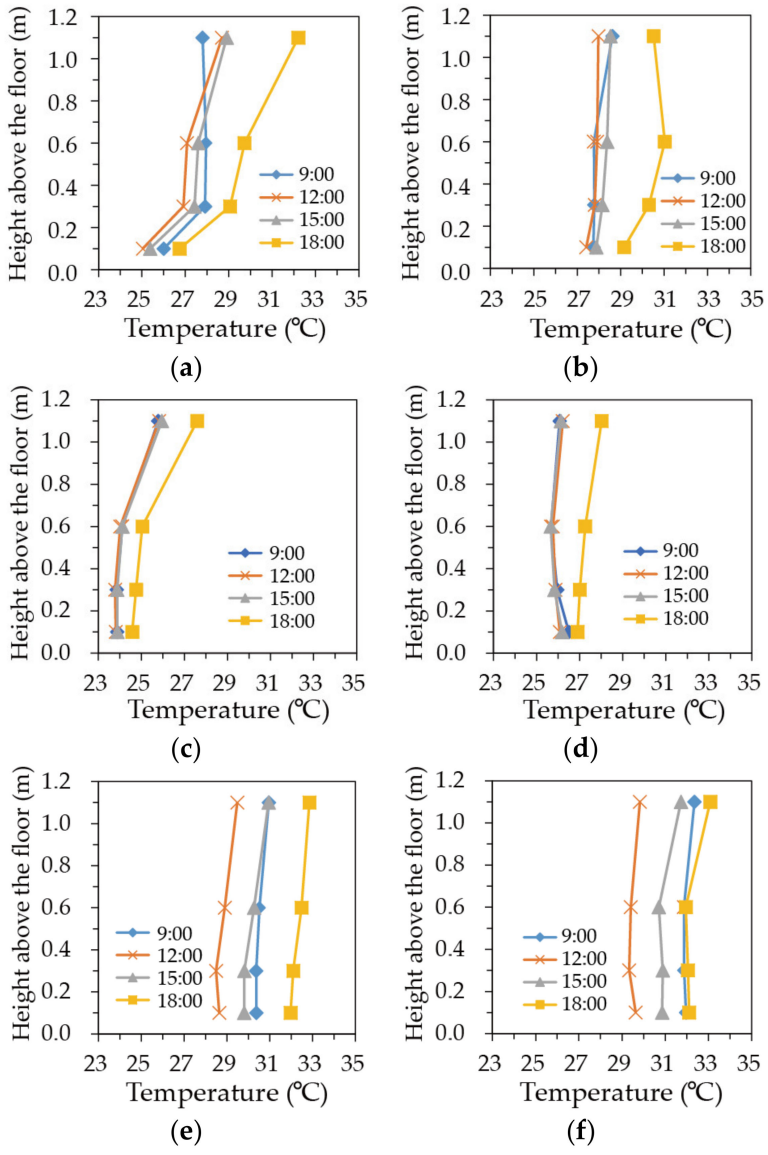


Figure 2. *Cont*.

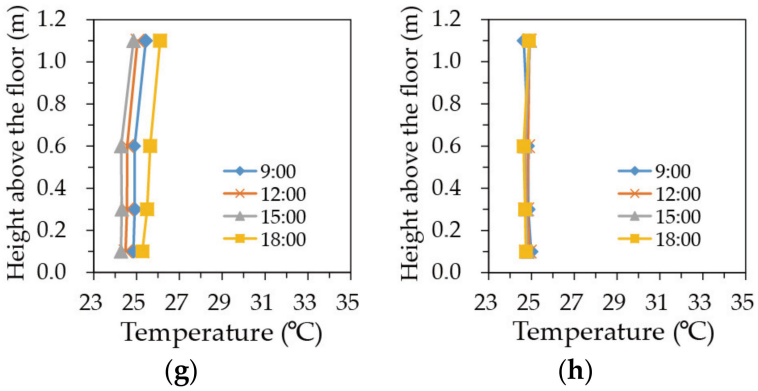


Figure 2. Vertical temperature distributions during opening hours in summer: (**a**) 0-year-old room in Nursery B; (**b**) 1-year-old room in Nursery B; (**c**) 0-year-old room in Nursery C; (**d**) 1-year-old room in Nursery C; (**e**) 0-year-old room in Nursery F; (**f**) 1-year-old room in Nursery F; (**g**) 0-year-old room in Nursery N; (**h**) 1-year-old room in Nursery N.

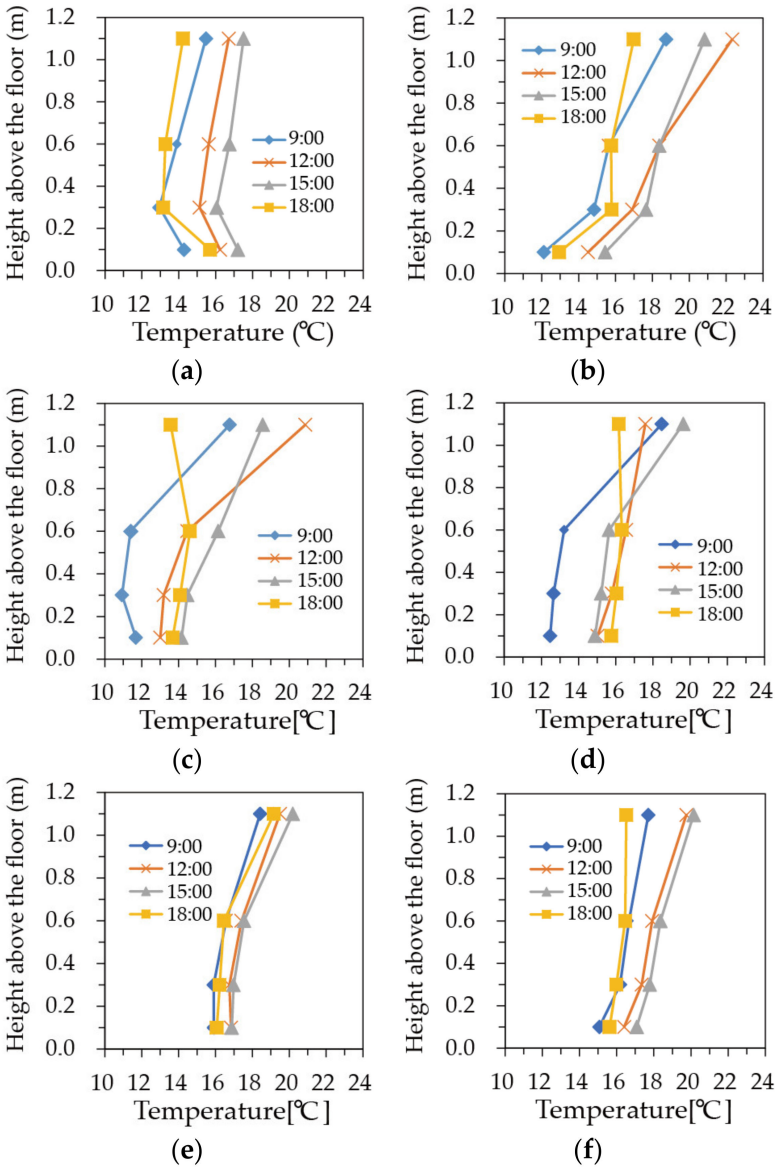


Figure 3. *Cont.*

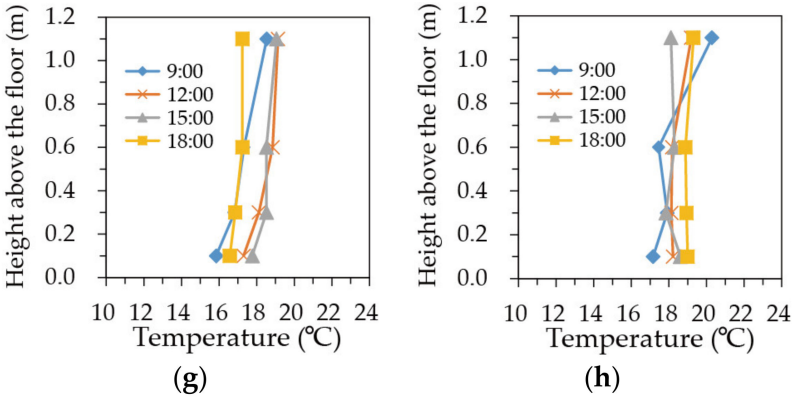


Figure 3. Vertical temperature distributions during opening hours in winter: (**a**) 0-year-old room in Nursery A; (**b**) 1-year-old room in Nursery A; (**c**) 0-year-old room in Nursery B; (**d**) 1-year-old room in Nursery B; (**e**) 0-year-old room in Nursery C; (**f**) 1-year-old room in Nursery C; (**g**) 0-year-old room in Nursery N; (**h**) 1-year-old room in Nursery N.

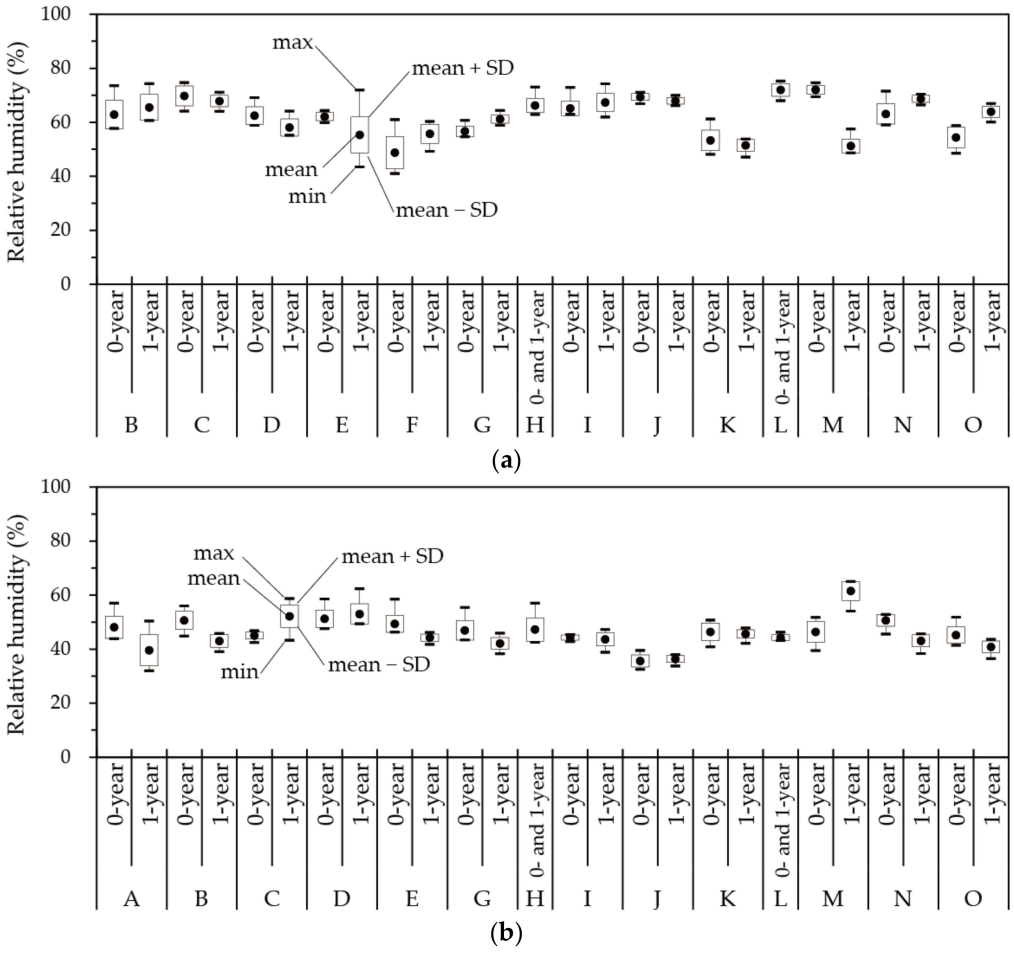


Figure 4. Relative humidity at 1.1 m from floor surface during opening hours in (**a**) summer and (**b**) winter.

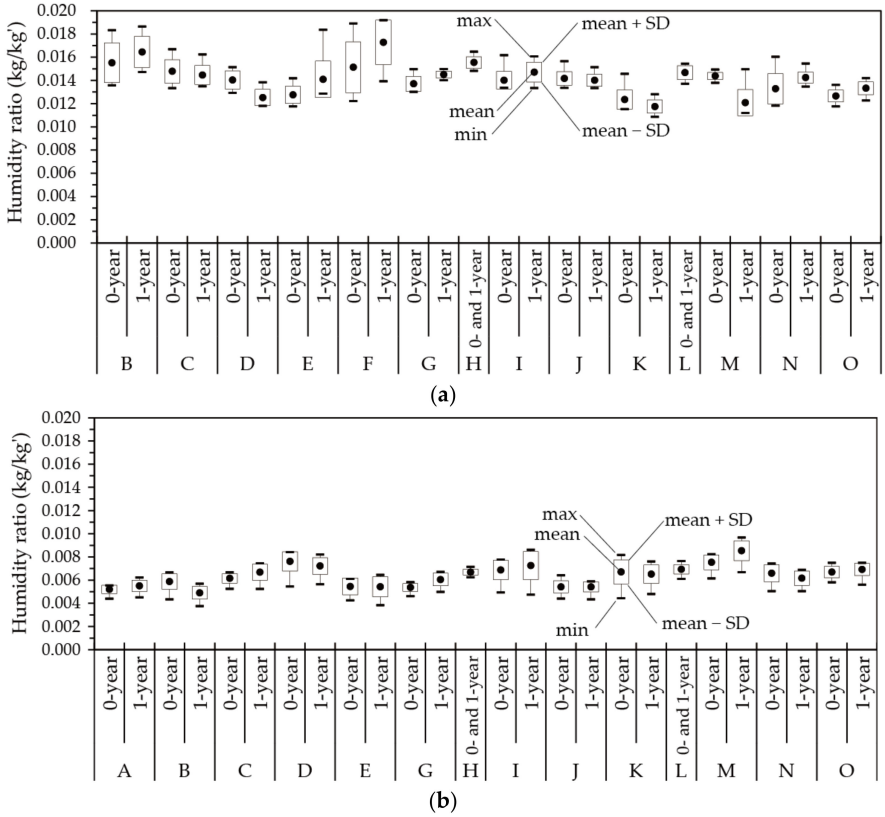


Figure 5. Humidity ratio at 1.1 m from floor surface during opening hours in (**a**) summer and (**b**) winter.

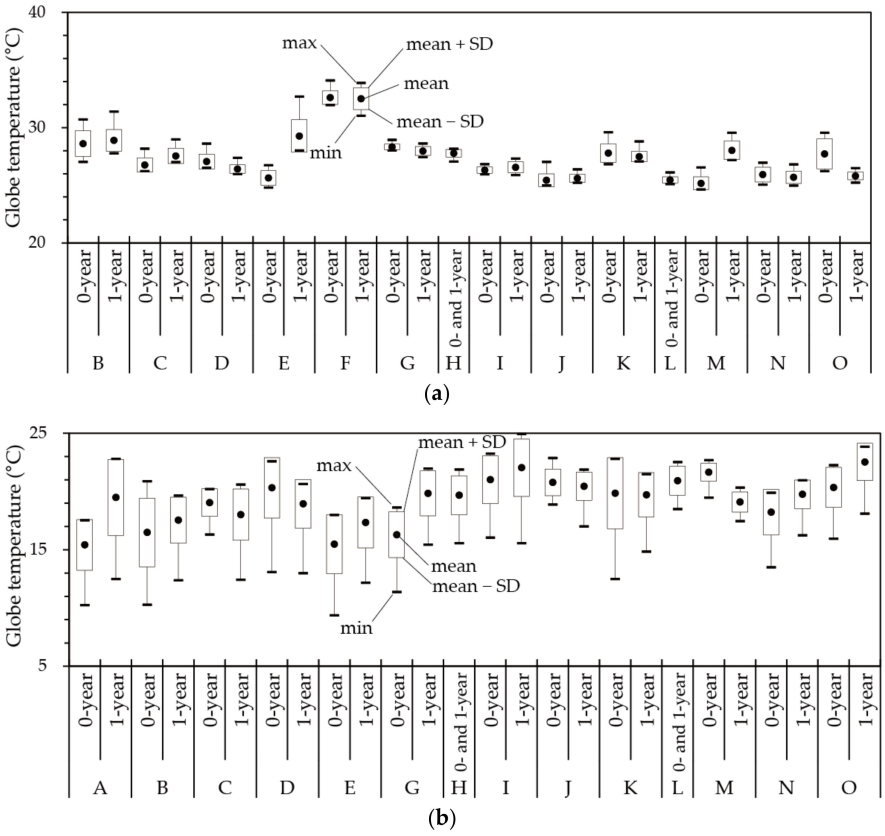


Figure 6. Globe temperature at 1.1 m from floor surface during opening hours in (**a**) summer and (**b**) winter.

In the summer, the temperatures of the following nursery classrooms nearly satisfied the above guideline [3]: both classrooms in nursery B, 0-year-old room in nursery E, both rooms in nursery G, 0-year-old room in nursery K, 1-year-old room in nursery M, and 0-year-old room in nursery O. In most other nursery rooms, the temperature was below the lower limit of the guideline and met the requirement except in Nursery F, where the temperature was too high and failed to fulfill the guidelines. Nursery F refrained from using an air conditioner in accordance with the policy of childcare regarding sweating, and thus, the temperature in the 1-year-old room at any height except at 12:00 was higher than 30 °C, as illustrated in Figure 2f [30]. From the perspective of preventing heat stroke, using air conditioning is necessary in this nursery school. Overall, the temperature was lower at a height of 0.1 m above the floor than that at 1.1 m above the floor in most nursery rooms, for example, in the 0- and 1-year-old room in nursery H, where cold air was circulated by a ceiling fan.

As shown in Table A2, in the winter, the temperature at 1.1 m above the floor generally meets the aforementioned standard [3] of 20–23 °C, except for some nursery schools, such as those that are older; however, the lower the height above the floor, the lower the temperature tended to be (Figure 3b–d) [29,30]. Therefore, the temperature at 0.1 m above the floor did not meet the standards in any nursery room. This may be due to poor insulation performance or poor air circulation, even in recently constructed nursery schools. In nursery schools I, J, and N, where floor heating was installed, the temperature at 0.1 m above the floor was kept relatively high; hence, the vertical temperature difference was within 3 °C, as is shown in Figure 3g,h. Since infants spend their time at a lower height than adults, raising the temperature at 0.1, 0.3, and 0.6 m above the floor in the winter is necessary to ensure infants' comfort and health.

Figures 2 and 3 show that the vertical temperature difference was over 3 °C in two (8% of the total) out of 26 rooms in the summer and 11 (42% of the total) out of 26 rooms in the winter. Reportedly, the vertical temperature difference was larger in the winter than in the summer. Except for the 1-year-old room in nursery E and 0-year-old room in nursery F in the summer, temperature was evaluated to be comfortable in terms of the vertical temperature difference because it was less than 1.0 °C. On the contrary, most nursery rooms studied in the winter were evaluated to be less comfortable. Figure 3b,c show that the largest and second largest vertical temperature differences were found to be 6.8 °C in the 0-year-old room in nursery B and 5.9 °C in the 1-year-old room in nursery A, respectively. As illustrated in Figure 3, compared to the vertical temperature distribution at 9:00, 12:00, 15:00, and 18:00 in each studied room, the largest vertical temperature difference was found at 9:00 in the morning in most nursery rooms. In the winter, the room temperature was under 17 °C in addition to the large vertical temperature difference; hence, numerous nursery rooms were evaluated to be less comfortable for both infants and childminders. The reason for this is the low insulation performance of the older buildings; thus, the temperature at 0.1 m above the floor did not rise easily even if the temperature at 1.1 m above the floor rose when heated. Most nursery schools heat the rooms only with air conditioners, but when nursery rooms are heated only with air conditioners, especially in old buildings, the temperature near the floor does not increase enough; hence, devising ways to ensure comfort is necessary, for example, through the use of auxiliary heating. Additionally, since the insulation performance in mild climatic areas in Japan is lower than that of Europe or the United States, efforts such as raising the insulation performance of buildings and repairing the insulation of existing buildings can also be considered necessary.

Figure 4 demonstrates that according to the infectious disease control guideline [3], mean RH did not satisfy the value of 60% in any nursery classrooms through the summer and winter measurements. However, according to the school environmental health standard [2], mean RH satisfied the value of 30–80% in all studied nursery classrooms. The mean RH ranged 49–72% in the summer and 36–62% in the winter, respectively. According to Tables A3 and A4, the 95th percentile RH exceeded the upper limit of 80% in three classrooms in the summer, and the 5th percentile RH was below the lower limit of 30% in six

rooms in the winter. Figure 5 shows that the mean HR in most studied nursery classrooms except one classroom (1-year-old room in nursery K) ranged from 0.012 to 0.017 kg/kg (DA) and did not satisfy the upper limit of 0.012 kg/kg (DA) specified by ASHRAE Standard 55-2017 [4] in the summer, though the mean HR in all studied nursery classrooms, which ranged from 0.005 to 0.009 kg/kg (DA), satisfied the standard value in the winter. Since it is hot and humid during the summer in Japan, humidity control from the viewpoint of microbial contamination is vital. On the contrary, the mean HR across eight classrooms (31% of the total) of 26 nursery classrooms in the winter was less than 0.006 kg/kg (DA), which was proposed by Shoji [33] as the index of influenza epidemic warning level despite using humidifiers. HR measured in the winter in this study was higher than that measured in the winter in Aoki et al.'s survey [27] for kindergartens in Gifu prefecture in the Tokai area, which is located in central Japan, with the range 0.004–0.005 kg/kg (DA). Indoor HR values studied in this survey in the winter were similar to the abovementioned survey [27].

From Figures 1 and 6, globe temperature difference obtained by subtracting the temperature at 1.1 m above the floor from the globe temperature of the same height in each nursery room ranged from −2.6 to 0.0 °C in the summer and −5.1 to 0.4 °C in the winter. Although the globe temperature differences were negative in all nursery classrooms except one classroom (0-year-old room in nursery B) in the summer, it was negative in the studied nursery classrooms in the winter except for some nursery classrooms (0-year-old room in nursery A, 1-year-old room in nursery D, 0-year-old-room in nursery K, and 0-year-old room in nursery M). The globe temperature differences were negative in most classrooms both in the summer and winter, and nursery classrooms were affected by cold radiation.

3.2. CO_2 Concentration

The results of the measurements of CO_2 concentration during opening hours in the summer and winter are presented in Figure 7. Tables A5 and A6 show that the median CO_2 concentrations calculated for opening hours on weekdays were 922 ppm in the summer and 990 ppm in the winter. According to the results of a survey of nursery schools in Denmark [23], the median CO_2 concentration during opening hours was 579 ppm, which was lower than that of the nursery classrooms in this study. On the other hand, according to the results of a survey of nursery schools in France [24], the mean CO_2 concentration during opening hours was 1200 ppm, which was higher than that of the nursery classroom in this study. In both summer and winter, the mean CO_2 concentration in one classroom was found to be over 1500 ppm, which was specified by the school environmental health standard [2]. The mean CO_2 concentration during opening hours in the summer exceeded 1500 ppm in the 0-year-old room in nursery K, probably because of a lower ventilation rate, despite meeting the area standard per infant, as shown in Table 2. The mean CO_2 concentrations during opening hours in the winter were over 1500 ppm in the 1-year-old room in nursery M, where the ventilation rate was probably low because it did not meet the area standard per infant as mentioned earlier.

Figure 7a shows that during opening hours in the summer, of the 26 measured classrooms, one classroom had a mean value of more than 1500 ppm, and the mean values exceeded 1000 ppm in six classrooms, which is 23% of the measured classrooms. Figure 7b shows that during opening hours in the winter, of the 26 measured classrooms, one classroom had a mean value of more than 1500 ppm, and the mean values exceeded 1000 ppm in eight classrooms, which is 31% of the measured classrooms. In this way, the CO_2 concentration in the nursery classrooms tended to be higher in the winter than in the summer. Additionally, except for some nursery schools (nursery I in summer and nursery D, I, and K in winter), there was a significant difference in CO_2 concentration between the 0-year-old room and 1-year-old room on weekdays in both the summer and winter. In the summer and winter (nurseries B and K), in the summer (nurseries E, F, and N), and in the winter (nursery J), the CO_2 concentration in the 0-year-old room was significantly higher than that in the 1-year-old room. In other nursery schools, the 1-year-old room was found to exhibit a significantly higher CO_2 concentration than the 0-year-old room (Tables A5 and A6). The

high concentrations of CO_2 occurred when numerous people gathered in one classroom at the time of pick-up or during activities according to its fluctuations (data not shown). However, there was no relationship between CO_2 concentration and the areas per infant for both classrooms (Tables 1 and 2).

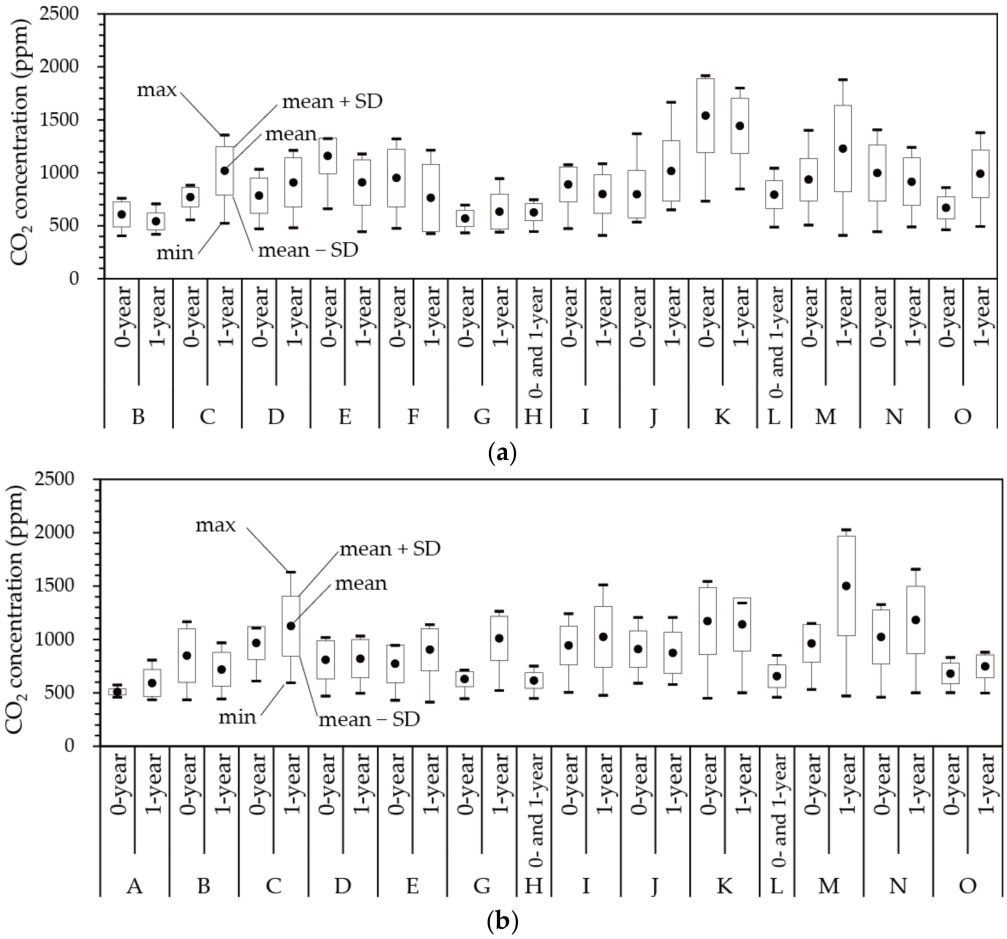


Figure 7. CO_2 concentrations in the nursery classrooms during opening hours in (**a**) summer and (**b**) winter.

Figure 8 shows the evaluation results of the IAQ during the opening hours for each nursery classroom in the summer and winter using ICONE [22]. No extreme air stuffiness (ICONE score = 5) was found in any of the nursery classrooms. Of 52 studied classrooms in the summer and winter, only one classroom (2%) had very high air stuffiness (ICONE score = 4), three (6%) had high air stuffiness (ICONE score = 3), 16 (31%) had average air stuffiness (ICONE score = 2), 20 (39%) had low air stuffiness (ICONE score = 1), and 12 (23%) had no air stuffiness (ICONE score = 0). With the exception of some nursery schools, the 0-year-old rooms and 1-year-old rooms had lower percentages (8%) of high air stuffiness (ICONE score $\geq$ 3) compared with that of nursery schools in France (38% [24]). Both 0-year-old and 1-year-old rooms in nursery K exhibited high or very high air stuffiness scores in both rooms in the summer, and the 1-year-old room in nursery M exhibited high scores in both summer and winter. Table 2 showed that in the 1-year-old room of nursery M, the area per infant did not meet the minimum standard, and the ventilation rate was insufficient due to the high density of the classroom. In nursery K, the small room volume contributed to the insufficient ventilation rate, even though the area per infant met the minimum standard.

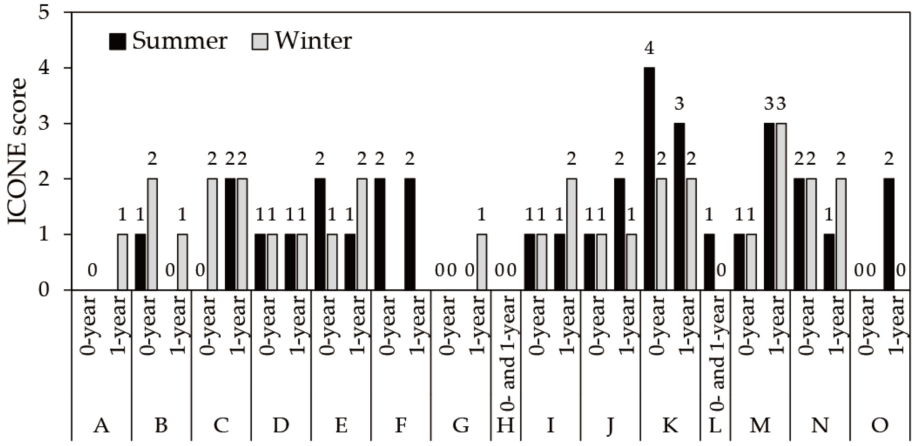
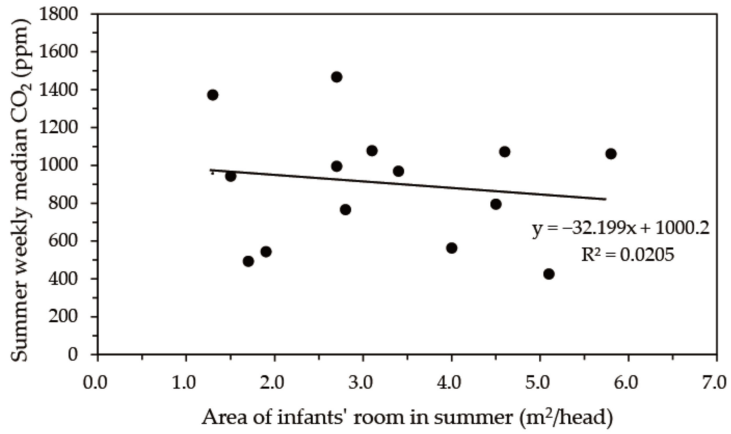
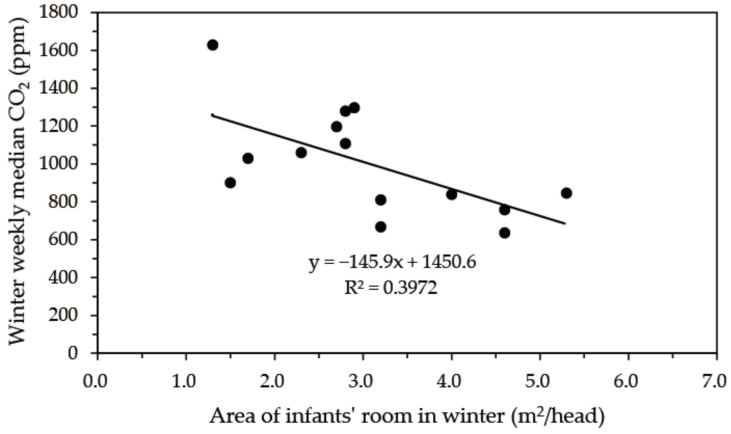


Figure 8. ICONE air stuffiness index scores in the studied nursery rooms during opening hours in summer and winter.

Figure 9 shows the relationship between the infants' room area and weekly median CO_2 concentration in the summer and winter. In the winter, there is a moderate correlation between the area per infant and the weekly median value of CO_2 concentration. It can be seen that in the winter, the larger the area per infant, the lower the weekly median CO_2 concentration, although there is no similar correlation in the summer.



(**a**)



(**b**)

Figure 9. Relationship between infants' room area and weekly median CO_2 concentration in (**a**) summer and (**b**) winter.

3.3. Particulate Matter

The results of $PM_{2.5}$ measurements during the 10 min spot measuring period in nursery classrooms and outside are presented in Table 4, which shows the number of small particles with a diameter of less than 0.5 μm, indoor-to-outdoor ratios (I/O ratios) that represent the ratios of the number of small particles between the indoor air and outdoor air, and IAQ determined based on the number of the small particles during measuring period in the summer and winter. I/O ratios can determine the impact of indoor/outdoor sources on indoor environments. The small particles were detected in all of the studied classrooms. IAQ in each nursery classroom was rated to be fair, poor, or very poor in most nursery schools, according to an IAQ judgment criteria based on the number of small particles. The air quality criteria were evaluated as follows on a five-point scale according to the number of small particles: 0–75, excellent; 75–150, very good; 150–300, good; 300–1050, fair, 1050–3000, poor; and >3000: very poor. Of the 24 classrooms measured in both summer and winter, 12 had a lower IAQ in the winter than in the summer, five had a lower IAQ in the summer than in the winter, and there was no change in IAQ between summer and winter in the other seven classrooms. The time that the windows are open tends to be shorter in the winter than in the summer, and the lack of ventilation affects the low IAQ result based on the number of small particles. I/O ratios ranged from 0.11 to 4.47 in 0-year-old rooms, and ranged from 0.10 to 2.01 in the 1-year old rooms, throughout the year. Compared by season, the I/O ratios ranged from 0.48 to 4.47 in 0-year-old rooms and ranged from 0.39 to 2.01 in 1-year old rooms in the summer, though the I/O ratios ranged from 0.11 to 1.89 in 0-year-old rooms and from 0.10 to 1.21 in 1-year-old rooms in the winter. In 1-year-old rooms, the I/O ratio was significantly higher in the summer than in the winter ($p < 0.05$), but there was no significant seasonal difference in the 0-year-old rooms. From the viewpoint of I/O ratio, the number of the small particles in the classroom was larger than outside in seven out of 26 classrooms (one-third of the measured rooms) measured in the summer and four out of 26 classrooms (one-sixth of the measured rooms) measured in the winter. In these 11 classrooms in both summer and winter, there is a source of small particles in the classroom. It is believed that small particles detected indoors were influenced by activities such as playing with sand in the garden. Children might come and go more frequently when playing outside in the playground in the summer than in the winter; hence, it may be easier to bring dust from the outside air into the classroom. In a Portuguese preschool environment, values of I/O ratios showed that a considerable part of small particle matter, including $PM_{2.5}$, originated indoors and carcinogenic risks due to exposure indoors were 10 and 4 times higher than for exposure outdoors, respectively, for younger (3 years) and older (4–5 years) pupils [25]. This was due to the fact that younger children tended to stay indoors for longer periods of time [25]. Therefore, focusing on the health effects of small particles in the classroom is necessary.

Table 4. Small particles (count/ft^3), I/O ratios, and IAQ during the summer and winter measurement periods.

Nursery, Room	0-Year-Old Room	1-Year-Old Room	Outdoor
A, in the summer	Not measured	Not measured	Not measured
A, in the winter	5107, 0.90, very poor	4580, 0.81, very poor	5673, very poor
B, in the summer	1302, 0.48, poor	1373, 0.51, poor	2685, poor
B, in the winter	1391, 0.31, poor	1529, 0.34, poor	4447, very poor
C, in the summer	6596, 1.37, very poor	6051, 1.25, very poor	4823, very poor
C, in the winter	2541, 1.40, poor	1299, 0.71, poor	1820, poor
D, in the summer	2562, 1.97, poor	2610, 2.01, poor	1301, poor
D, in the winter	1802, 0.25, poor	4700, 0.64, very poor	7340, very poor
E, in the summer	1005, 0.75, fair	872, 0.65, fair	1348, poor
E, in the winter	1005, 0.25, fair	1351, 0.34, poor	3992, very poor

Table 4. *Cont.*

Nursery, Room	0-Year-Old Room	1-Year-Old Room	Outdoor
F, in the summer	2813, 0.85, poor	4857, 1.47, very poor	3295, very poor
F, in the winter	Not measured	Not measured	Not measured
G, in the summer	1219, 1.04, poor	1275, 1.08, poor	1176, poor
G, in the winter	1347, 0.87, poor	1345, 0.87, poor	1543, poor
H, in the summer	2502, 4.47, poor		560, fair
H, in the winter	7515, 0.94, poor		7998, very poor
I, in the summer	776, 0.70, fair	944, 0.85, fair	1108, poor
I, in the winter	4907, 0.66, very poor	5778, 0.78, very poor	7450, very poor
J, in the summer	2863, N.A., poor	1645, N.A., poor	Not measured
J, in the winter	6805, 1.89, very poor	4375, 1.21, very poor	3610, very poor
K, in the summer	545, 0.84, fair	514, 0.80, fair	645, fair
K, in the winter	3448, 0.66, very poor	1647, 0.32, poor	5195, very poor
L, in the summer	5031, 0.79, very poor		6355, very poor
L, in the winter	1208, 1.07, poor		1133, poor
M, in the summer	797, 0.70, fair	445, 0.39, fair	1146, poor
M, in the winter	1292, 0.11, poor	1166, 0.10, poor	12,239, very poor
N, in the summer	820, 0.73, fair	1069, 0.95, poor	1121, poor
N, in the winter	2893, 0.54, poor	4070, 0.76, very poor	5375, very poor
O, in the summer	1469, N.A., poor	1374, N.A., poor	Not measured
O, in the winter	699, 0.48, fair	611, 0.42, fair	1444, poor

3.4. Illumination

Figure 10 shows the mean values of illumination in the studied nursery classrooms during opening hours in the summer and winter, including 95% confidence intervals. It shows a fluctuation from the lighting being temporarily turned off at any time from 12:00 to 14:00 due to the children napping in the nursery classroom, and the illumination is reduced to the minimum (results not shown). Notably, the measurement location may be partially affected by solar radiation due to the convenience of measurement installation. The numbers of the nursery classrooms where the average illumination during opening hours was less than the standard value of 300 lx established by the school environmental health standard [2] were eight (31% of the total) out of the 26 studied classrooms in the summer, and nine out of 26 (35% of the total) in the winter. There was no significant difference in the average illumination between summer and winter. The average illumination in the two classrooms was lower than 100 lx. In particular, the average illumination of the 1-year-old room in nursery F in the summer was under 77 lx, which was significantly lower because the lights were turned off to save energy for space cooling. Infants do not study as do school students, but in consideration for the needs of infant visual development, they do need to maintain minimal illumination for reading picture books and other indoor activities in the classrooms.

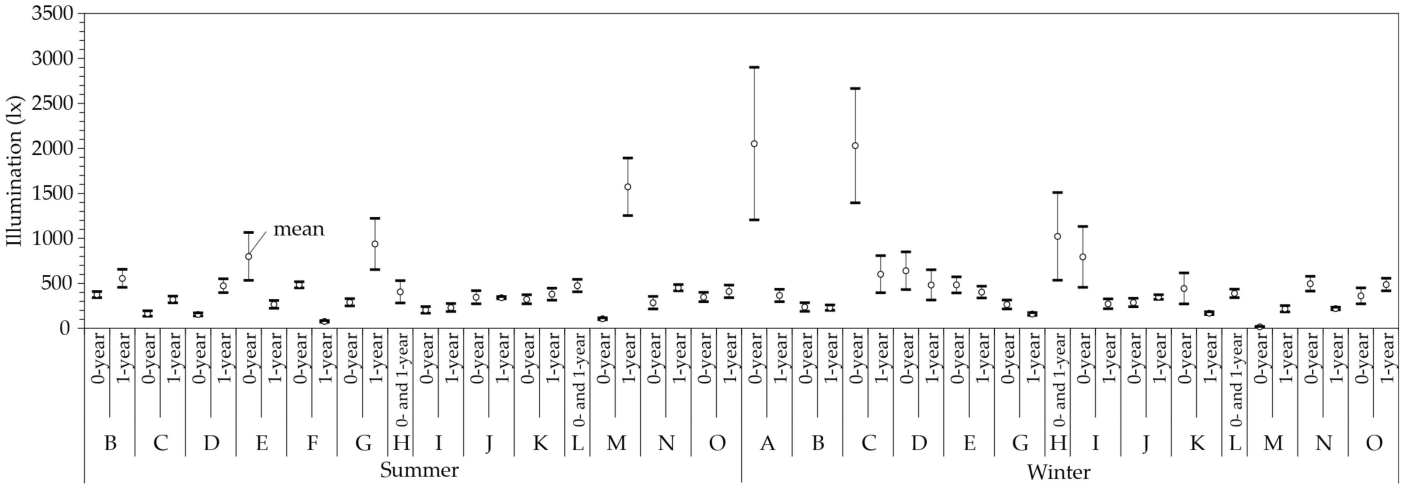


Figure 10. Mean values of illumination in the studied nursery rooms during opening hours in summer and winter, including 95% confidence intervals.

3.5. Noise Level

In this study, for nursery schools that could not be measured during naps, the noise levels during various activities were measured and treated as reference values. Results provide evidence showing how noisy it is; noise in the vicinity of nursery schools in Japan is considered to be a social problem. Strictly speaking, the noise level during nap time is not equal to the background noise level, but perhaps close to background noise and therefore useful. The equivalent noise level during various activities ranged from 50.4 to 70.6 dBA with an average of 60.1 dBA in 0-year-old rooms, and ranged from 48.9 to 84.3 dBA with an average of 64.1 dBA in 1-year-old rooms (results not shown). The equivalent noise level during the nap time ranged from 50.4 to 59.3 dBA with an average of 54.4 dBA in 0-year-old rooms and ranged from 49.3 to 58.5 dBA with an average of 53.1 dBA in 1-year-old rooms. According to the guidelines of WHO, the background equivalent noise level in classrooms of preschools should not exceed 35 dB Laeq during class [34]. Compared to this, the noise level in Japanese nursery classrooms is considerably higher even during naps. Considering the development of hearing of infants, establishing appropriate noise standards for nursery school classrooms is necessary.

3.6. Examination of Indoor Environmental Standards

Indoor environmental standards for nursery school classrooms where children are under 2 years old and who cannot easily wear a mask, cannot receive a COVID-19 vaccination, and spend a long time, will become increasingly necessary in Japan in the future. From the results of this study, first, concerning the thermal environment, the temperature should be 26–28 °C in the summer and 20–23 °C in the winter, as given in the infectious disease control guidelines for nursery schools [3]. Considering the time that children spend at lower heights close to the floor, this study's findings recommend assessing whether the temperatures at the heights of 0.1, 0.3, and 0.6 m above the floor meet the standard value. If the nursery school buildings are old, their insulation is also important.

Second, regarding relative humidity, the infectious disease control guideline only stipulates a relative humidity of 60% [3], but it is believed that the 40–70% standard with a range applied to office buildings under the Act on Maintenance of Sanitation in Buildings [35] should be applied to nursery school classrooms.

Third, regarding the indoor air environment, it became clear that the CO_2 concentrations in the nursery classrooms are high during activities or the waiting time for pick-up; hence, it is proposed that the daily average concentration of CO_2 should be less than 1000 ppm and the maximum concentration should not exceed 1500 ppm, with reference to BB101 established in the UK [7], though the infectious disease control guidelines do not set

ventilation standards [3]. Additionally, adhering to the standard for the area of the nursery classroom per infant, which is specified in the minimum standard for child-welfare-facility minimum criteria [28], will lead to satisfying the required ventilation rate per child, and provide a well-ventilated indoor air environment. As for $PM_{2.5}$ concentration, as mentioned earlier, the spot measurement was only for 10 min; hence, a concrete standard could not be proposed in this study.

Fourth, regarding the illumination environment, a minimum illumination of 300 lx, which is specified in BB101 [7], is required for infants' visual development. The nursery school classrooms are used by people of all ages, including infants' grandparents who pick-up the children instead of working parents. Older adults need twice as much illumination as adults [36]; hence, they need more than 300 lx from the viewpoint of universal design.

Fifth, regarding the acoustic environment, the indoor background noise level in the nursery school classrooms should ideally be restricted to 35 dBA, as determined by WHO. According to the results of inspections of nursery facilities in Munich, Germany, where regulations of acoustic design for daycare facilities exist, all the classrooms in the inspected facilities were equipped with sound absorptive material for sound insulation and the reduction in reverberation [37]. By contrast, in Japan, without any standards or regulations, meeting these strict requirements is difficult for nursery schools. Therefore, firstly, as stipulated in the school environmental health standard [2], fulfilling the minimum indoor background noise level of 50 dBA when windows are closed is necessary; however, establishing the indoor equivalent noise level slightly lower to consider the development of hearing in infants is also vital.

4. Conclusions

The measurements of indoor environments and questionnaire surveys in 15 different nursery schools in mild climatic areas in Japan were conducted in the summer and winter of 2016–2019. The results of the measurements were summarized and the indoor environmental standards that should be set in the nursery school classrooms were considered.

The study revealed that summer mean temperature was between 26 and 28 °C, but the winter mean temperature was lower than the lower limit of 20–23 °C. Mean RH was close to 60% of the standard in the summer, but lower than the standard in the winter, compared to the infectious disease control guideline. In addition, in the summer, there was one nursery school where the temperature in the 1-year-old room at any height was higher than 30 °C at almost time during the day in the summer, which was too high and did not meet the guidelines, although the temperature was lower compared to the lower limit of the guideline in most of the other nursery classrooms. It is necessary to use air conditioning in this nursery school to prevent heat stroke. In order to avoid an extremely hot indoor environment in the summer, the necessity of indoor environmental standards in the nursery classroom was shown. In the winter, it was found that the temperature at 1.1 m above the floor generally met the infectious disease control guidelines for nursery schools (20–23 °C), except for some nursery schools such as those in older buildings, in contrast, the temperature at 0.1 m above the floor in all of the nursery classrooms did not meet the standards (20–23 °C). This may be due to poor insulation performance or poor air circulation, even in nursery schools that were built more recently. Since infants spend their time at lower heights than adults, it is necessary to raise the temperatures at 0.1, 0.3, and 0.6 m from floor surface in the winter to ensure the comfort and health of infants. It can be said that efforts such as improving the insulation performance of buildings and repairing the insulation of existing buildings are also necessary to solve the problems of lower temperature at the lower height from the floor surface in the nursery classrooms during winter.

The mean RH satisfied the value of 30–80% specified by the school environmental health standard in all studied nursery classrooms both in the summer and winter. The mean HR in most of the studied nursery classrooms did not satisfy the upper limit of 0.012 kg/kg (DA) in the summer, specified by ASHRAE Standard 55-2017, although the

mean HR in all studied nursery classrooms satisfied the requirement in the winter. Since it is hot and humid during the summer in Japan, focusing on humidity control in the summer is important from the viewpoint of microbial contamination.

Nursery school classrooms were affected by cold radiation because the globe temperature differences were negative in most classrooms both in the summer and winter.

The mean CO_2 concentrations during opening hours exceeded 1500 ppm, specified by the school environmental health standard, in one classroom both in the summer and winter. The reasons for this were probably because of the low ventilation rate despite meeting the area standard per infant or insufficient ventilation rate because of not meeting the area standard per infant. The evaluation results of the IAQ during the opening hours of each nursery room in the summer and winter using ICONE showed that the 0-year-old and 1-year-old rooms, except some nursery schools, exhibit lower percentages (8%) of high air stuffiness (ICONE score ≥ 3).

Small particles with a diameter of less than 0.5 μm were detected in all studied classrooms. IAQ in each nursery classroom was rated to be fair, poor, or very poor in most nurseries, according to an IAQ judgment criteria based on the number of small particles. Half of the nursery school classrooms exhibited lower IAQ in the winter than the summer. The opening time of the windows is probably shorter in the winter than in the summer, and the lack of ventilation affects the low IAQ in the winter. As a result of I/O ratios, the number of small particles in the classrooms was larger than outside in one-third of the studied classrooms in the summer and one-sixth of the studied classrooms in the winter; therefore, sources of small particles may be present indoors. It is believed that small particles detected indoors were influenced by activities such as playing with sand in the garden.

The mean illumination during opening hours in one-third of the studied nursery classrooms was less than the standard value of 300 lx established by the school environmental health standard—both in the summer and winter. Considering the needs of infant visual development, minimal illumination for indoor activities for infants should be maintained.

The equivalent noise level by applying the A-weighting filter in studied nursery classrooms was considerably high even during nap times. Therefore, considering the development of infant hearing, the need for an acoustic standard for nursery school classrooms was shown.

To summarize, some nursery school classrooms were found to have large vertical temperature differences, while other classrooms had poor IAQ because they held more children than their capacities allowed. Compliance with the specified area per child would lead to the maintenance of a desirable IAQ. In this study, the need for indoor environmental standards in nursery schools was strongly indicated in terms of infants' comfort and health. It is necessary to continue to evaluate the actual conditions of indoor environment in nursery school classrooms and establish suitable indoor environment standards as soon as possible. Future indoor environmental standards for nursery classrooms—where children under 2 years old spend considerable time, who cannot wear a mask easily, and cannot receive COVID-19 vaccinations—will become increasingly necessary in Japan.

5. Limitations to the Study and Future Research

This study had the following limitations:

(1) The installation location of the measurement equipment tends to be restricted, especially in 1-year-old rooms, to ensure that children do not touch the measurement equipment.
(2) It is necessary to consider the metabolic rate of the children to set the temperature standard.
(3) In this study, particle matter and equivalent noise level were evaluated by the results of a spot measurement by sampling for only 10 min for each visit. Therefore, evaluating particle matter and equivalent noise level by lengthening the sampling time will be necessary in the future. Further, quantitatively evaluating $PM_{2.5}$ concentration and assessing its health risk to infants and childminders will be crucial.

(4) In this study, indoor air environment was evaluated by CO_2 concentration and particulate matter, but investigating the ventilation rate for each nursery classroom will be vital in the future.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Vertical temperature during opening hours in summer.

Nursery, Room	Temperature at 0.1 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 0.3 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 0.6 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
A, 0-year-old room A, 1-year-old room	Not measured	Not measured	Not measured	Not measured
B, 0-year-old room B, 1-year-old room	27.4 (25.1, 29.2) 27.7 (25.1, 29.7)	27.5 (24.8, 29.3) 27.8 (24.8, 30.4)	27.7 (24.6, 29.6) 27.9 (24.8, 30.9)	28.1 (25.0, 31.7) 27.9 (24.6, 31.1)
C, 0-year-old room C, 1-year-old room	25.6 (25.0, 26.7) 25.8 (24.9, 27.3)	25.5 (24.8, 26.7) 25.3 (24.0, 27.4)	25.8 (25.1, 27.1) 25.2 (23.7, 26.8)	26.4 (25.8, 28.0) 27.3 (26.3, 28.6)
D, 0-year-old room D, 1-year-old room	25.7 (23.8, 27.0) 25.9 (23.0, 26.6)	25.5 (23.8, 26.8) 25.8 (23.3, 26.7)	25.5 (24.0, 27.1) 25.8 (23.5, 26.8)	27.0 (24.6, 28.7) 26.3 (24.9, 27.9)
E, 0-year-old room E, 1-year-old room	26.8 (25.8, 28.8) 24.9 (23.8, 26.3)	26.5 (25.6, 28.8) 24.7 (23.5, 26.1)	26.4 (25.4, 28.9) 24.7 (23.6, 26.2)	25.6 (24.1, 27.1) 28.5 (27.0, 32.9)
F, 0-year-old room F, 1-year-old room	28.6 (27.1, 32.8) 31.2 (28.6, 32.9)	28.4 (26.9, 33.0) 31.1 (28.2, 32.9)	28.7 (27.0, 33.4) 31.0 (28.3, 32.8)	31.7 (29.6, 34.3) 31.9 (29.2, 34.8)
G, 0-year-old room G, 1-year-old room	27.8 (26.4, 29.7) 26.4 (24.1, 28.7)	27.7 (26.4, 29.7) 26.5 (24.2, 29.0)	27.6 (26.3, 29.6) 26.6 (24.6, 29.2)	28.2 (27.0, 30.0) 28.0 (26.1, 30.1)
H, 0- and 1-year-old room	26.6 (26.2, 27.4)	26.5 (26.0, 27.4)	26.6 (26.1, 27.6)	27.8 (26.9, 29.5)
I, 0-year-old room I, 1-year-old room	24.8 (24.4, 25.9) 25.1 (24.6, 26.1)	24.8 (24.4, 25.9) 25.2 (24.6, 26.3)	24.8 (24.4, 25.9) 25.2 (24.5, 26.5)	24.8 (24.3, 25.8) 25.2 (24.6, 26.8)
J, 0-year-old room J, 1-year-old room	25.0 (23.9, 26.7) 25.2 (24.0, 26.6)	24.8 (23.6, 26.3) 24.9 (23.6, 26.3)	24.7 (23.4, 26.4) 25.1 (23.8, 26.6)	25.2 (24.0, 27.5) 25.5 (24.2, 27.1)
K, 0-year-old room K, 1-year-old room	26.5 (25.6, 28.8) 25.3 (24.8, 26.3)	26.7 (25.8, 29.1) 25.3 (24.7, 26.4)	27.1 (25.9, 29.3) 25.5 (25.0, 26.7)	27.4 (26.1, 30.1) 27.3 (26.5, 28.4)
L, 0- and 1-year-old room	24.2 (23.2, 25.1)	24.4 (23.5, 25.3)	24.4 (23.5, 25.3)	25.5 (24.5, 26.3)
M, 0-year-old room M, 1-year-old room	24.6 (23.9, 26.1) 25.9 (25.1, 27.3)	24.7 (23.8, 26.2) 26.1 (25.2, 27.8)	24.7 (23.8, 27.5) 26.2 (25.3, 28.1)	24.9 (24.2, 26.6) 27.8 (26.7, 30.1)
N, 0-year-old room N, 1-year-old room	24.8 (23.9, 25.9) 24.8 (24.4, 25.9)	24.8 (23.9, 26.1) 24.7 (24.2, 25.9)	24.8 (23.9, 26.1) 24.7 (24.2, 25.9)	25.7 (24.7, 27.1) 25.3 (24.5, 28.0)
O, 0-year-old room O, 1-year-old room	27.0 (26.0, 29.5) 24.5 (23.7, 25.4)	25.9 (24.8, 29.4) 24.4 (23.6, 25.4)	26.4 (25.2, 29.7) 24.5 (23.7, 25.7)	26.9 (24.8, 31.5) 25.8 (24.6, 27.3)

Table A2. Vertical temperature during opening hours in winter.

Nursery, Room	Temperature at 0.1 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 0.3 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 0.6 m from Floor Surface (°C) Median (5th, 95th Percentile)	Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
A, 0-year-old room	16.0 (11.6, 18.4)	14.8 (8.4, 18.2)	15.3 (8.5, 19.1)	16.7 (9.1, 20.5)
A, 1-year-old room	14.1 (8.2, 17.4)	16.6 (11.5, 19.0)	17.6 (11.5, 20.1)	20.0 (12.3, 25.8)
B, 0-year-old room	13.7 (9.7, 16.0)	14.7 (9.9, 16.9)	16.8 (10.5, 18.7)	20.5 (12.0, 22.6)
B, 1-year-old room	15.7 (11.0, 17.3)	16.4 (11.0, 18.4)	17.1 (11.6, 19.5)	18.7 (14.0, 21.2)
C, 0-year-old room	17.1 (14.9, 18.3)	17.2 (14.8, 18.2)	17.9 (15.0, 19.5)	20.0 (16.6, 21.1)
C, 1-year-old room	17.5 (12.4, 20.0)	18.6 (13.1, 21.0)	19.2 (12.9, 22.6)	18.8 (14.5, 24.1)
D, 0-year-old room	18.6 (11.4, 21.2)	19.3 (12.3, 21.6)	20.0 (13.2, 22.5)	21.6 (15.3, 24.3)
D, 1-year-old room	16.8 (10.8, 19.9)	18.8 (13.6, 21.2)	19.6 (14.0, 21.9)	19.8 (13.5, 22.1)
E, 0-year-old room	11.8 (7.6, 15.2)	13.3 (8.6, 17.0)	16.0 (9.7, 19.1)	11.8 (10.9, 19.2)
E, 1-year-old room	14.6 (10.8, 18.0)	15.2 (11.2, 18.8)	16.1 (12.0, 19.7)	13.5 (12.9, 21.7)
F, 0-year-old room F, 1-year-old room	Not measured	Not measured	Not measured	Not measured
G, 0-year-old room	12.2 (10.8, 14.2)	13.4 (10.8, 16.4)	14.7 (10.9, 18.9)	16.5 (10.8, 20.2)
G, 1-year-old room	16.4 (12.4, 18.2)	17.1 (12.6, 19.4)	17.8 (12.6, 20.5)	20.5 (14.9, 22.7)
H, 0- and 1-year-old room	16.7 (14.5, 18.4)	16.8 (14.3, 18.9)	17.3 (14.4, 19.8)	19.7 (15.9, 24.2)
I, 0-year-old room	Not measured	Not measured	Not measured	21.6 (15.9, 23.9)
I, 1-year-old room	19.9 (14.2, 22.8)	20.8 (14.3, 23.6)	21.1 (14.2, 24.0)	22.7 (15.7, 25.5)
J, 0-year-old room	17.4 (15.1, 18.9)	17.8 (15.5, 20.2)	18.5 (15.9, 21.6)	20.4 (17.6, 24.0)
J, 1-year-old room	18.5 (15.4, 19.6)	19.1 (15.5, 20.9)	19.8 (15.8, 22.4)	20.7 (17.0, 24.2)
K, 0-year-old room	17.5 (10.5, 20.5)	18.3 (10.8, 21.5)	19.3 (11.5, 22.2)	20.8 (12.7, 23.7)
K, 1-year-old room	17.5 (12.9, 19.8)	18.1 (13.2, 20.1)	18.7 (13.9, 20.5)	20.3 (15.4, 22.0)
L, 0- and 1-year-old room	18.4 (15.2, 20.2)	19.3 (16.7, 20.9)	20.3 (17.6, 21.7)	20.8 (18.2, 23.1)
M, 0-year-old room	19.0 (16.7, 19.6)	20.2 (17.5, 22.0)	21.9 (18.7, 24.2)	22.2 (19.2, 24.0)
M, 1-year-old room	17.9 (15.3, 19.2)	18.0 (15.4, 19.3)	18.3 (15.9, 19.7)	19.2 (17.1, 21.5)
N, 0-year-old room	16.9 (13.2, 18.7)	17.6 (13.2, 19.5)	17.9 (13.1, 19.9)	19.4 (13.6, 21.4)
N, 1-year-old room	17.8 (14.8, 19.8)	17.9 (14.7, 20.1)	17.9 (14.3, 19.9)	20.1 (15.9, 21.8)
O, 0-year-old room	16.1 (11.9, 18.3)	17.1 (11.8, 19.3)	18.7 (12.3, 20.7)	20.9 (15.2, 23.3)
O, 1-year-old room	18.7 (12.3, 20.7)	20.4 (15.7, 21.9)	20.9 (15.8, 22.4)	23.1 (18.2, 24.3)

Table A3. Relative humidity, humidity ratio, and globe temperature during opening hours in summer.

Nursery, Room	Relative Humidity at 1.1 m from Floor Surface (%) Median (5th, 95th Percentile)	Humidity Ratio at 1.1 m from Floor Surface (kg/kg (DA)) Median (5th, 95th Percentile)	Globe Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
A, 0-year-old room A, 1-year-old room	Not measured	Not measured	Not measured
B, 0-year-old room	60 (50, 82)	0.015 (0.011, 0.020)	28.1 (25.0, 31.7)
B, 1-year-old room	66 (52, 82)	0.015 (0.012, 0.020)	27.9 (24.6, 31.1)
C, 0-year-old room	66 (56, 77)	0.014 (0.012, 0.017)	25.4 (24.6, 27.4)
C, 1-year-old room	59 (49, 69)	0.013 (0.011, 0.016)	25.6 (24.3, 27.4)
D, 0-year-old room	63 (47, 74)	0.014 (0.011, 0.017)	25.6 (24.1, 27.2)
D, 1-year-old room	59 (41, 70)	0.013 (0.009, 0.015)	26.3 (24.1, 28.1)

Table A3. *Cont.*

Nursery, Room	Relative Humidity at 1.1 m from Floor Surface (%) Median (5th, 95th Percentile)	Humidity Ratio at 1.1 m from Floor Surface (kg/kg (DA)) Median (5th, 95th Percentile)	Globe Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
E, 0-year-old room	61 (55, 72)	0.013 (0.011, 0.016)	25.1 (23.6, 26.7)
E, 1-year-old room	56 (40, 72)	0.013 (0.011, 0.018)	26.4 (25.4, 29.2)
F, 0-year-old room	46 (34, 62)	0.013 (0.010, 0.019)	29.5 (27.7, 33.6)
F, 1-year-old room	55 (47, 69)	0.017 (0.012, 0.021)	31.6 (28.5, 34.1)
G, 0-year-old room	56 (44, 66)	0.013 (0.010, 0.017)	27.5 (26.4, 29.3)
G, 1-year-old room	62 (50, 70)	0.015 (0.012, 0.018)	26.3 (24.3, 28.9)
H, 0- and 1-year-old room	65 (52, 76)	0.015 (0.013, 0.018)	26.8 (26.2, 28.1)
I, 0-year-old room	65 (57, 74)	0.013 (0.011, 0.015)	24.8 (24.3, 25.8)
I, 1-year-old room	67 (57, 78)	0.014 (0.012, 0.016)	25.2 (24.6, 26.8)
J, 0-year-old room	69 (63, 76)	0.014 (0.012, 0.016)	25.1 (24.1, 27.2)
J, 1-year-old room	68 (62, 75)	0.014 (0.012, 0.016)	25.4 (24.2, 26.9)
K, 0-year-old room	52 (41, 65)	0.012 (0.011, 0.016)	26.7 (25.6, 29.1)
K, 1-year-old room	52 (44, 60)	0.012 (0.010, 0.014)	26.1 (24.0, 29.1)
L, 0- and 1-year-old room	73 (64, 79)	0.015 (0.013, 0.017)	24.4 (23.5, 25.3)
M, 0-year-old room	73 (65, 77)	0.014 (0.013, 0.015)	24.8 (24.1, 26.3)
M, 1-year-old room	51 (43, 63)	0.012 (0.010, 0.016)	27.5 (26.0, 31.1)
N, 0-year-old room	62 (55, 73)	0.013 (0.011, 0.016)	25.3 (24.4, 26.7)
N, 1-year-old room	69 (54, 82)	0.014 (0.011, 0.017)	24.4 (23.7, 27.3)
O, 0-year-old room	55 (42, 63)	0.012 (0.011, 0.016)	26.1 (23.9, 31.0)
O, 1-year-old room	64 (57, 70)	0.013 (0.012, 0.015)	25.2 (23.8, 26.5)

Table A4. Relative humidity, humidity ratio, and globe temperature during opening hours in winter.

Nursery, Room	Relative Humidity at 1.1 m from Floor Surface (%) Median (5th, 95th Percentile)	Humidity Ratio at 1.1 m from Floor Surface (kg/kg (DA)) Median (5th, 95th Percentile)	Globe Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
A, 0-year-old room	48 (35, 58)	0.006 (0.003, 0.007)	16.6 (9.2, 20.5)
A, 1-year-old room	39 (25, 52)	0.005 (0.004, 0.007)	20.0 (12.3, 26.0)
B, 0-year-old room	48 (32, 56)	0.007 (0.004, 0.008)	20.5 (12.0, 22.6)
B, 1-year-old room	39 (32, 47)	0.005 (0.003, 0.007)	18.7 (14.0, 21.2)
C, 0-year-old room	44 (39, 49)	0.006 (0.005, 0.007)	19.4 (15.9, 21.1)
C, 1-year-old room	52 (40, 60)	0.007 (0.005, 0.008)	20.1 (14.6, 25.0)
D, 0-year-old room	49 (42, 66)	0.008 (0.006, 0.011)	20.5 (14.7, 23.1)
D, 1-year-old room	50 (40, 70)	0.007 (0.005, 0.011)	20.0 (15.3, 22.5)
E, 0-year-old room	59 (51, 67)	0.005 (0.004, 0.008)	18.5 (11.4, 20.7)
E, 1-year-old room	48 (38, 61)	0.005 (0.004, 0.007)	18.1 (13.9, 21.5)
F, 0-year-old room F, 1-year-old room	Not measured	Not measured	Not measured
G, 0-year-old room	46 (33, 64)	0.005 (0.004, 0.007)	16.5 (10.8, 20.2)
G, 1-year-old room	43 (32, 52)	0.006 (0.004, 0.008)	19.6 (14.1, 21.7)
H, 0- and 1-year-old room	46 (29, 66)	0.006 (0.004, 0.009)	18.2 (15.2, 22.2)
I, 0-year-old room	45 (35, 53)	0.007 (0.005, 0.009)	21.4 (14.6, 25.2)
I, 1-year-old room	44 (35, 52)	0.008 (0.005, 0.009)	22.0 (15.6, 24.8)

Table A4. *Cont.*

Nursery, Room	Relative Humidity at 1.1 m from Floor Surface (%) Median (5th, 95th Percentile)	Humidity Ratio at 1.1 m from Floor Surface (kg/kg (DA)) Median (5th, 95th Percentile)	Globe Temperature at 1.1 m from Floor Surface (°C) Median (5th, 95th Percentile)
J, 0-year-old room	36 (25, 45)	0.006 (0.004, 0.007)	19.8 (17.1, 23.7)
J, 1-year-old room	36 (27, 44)	0.005 (0.004, 0.007)	20.3 (16.3, 23.8)
K, 0-year-old room	47 (37, 53)	0.007 (0.005, 0.008)	20.1 (11.8, 31.9)
K, 1-year-old room	46 (36, 53)	0.007 (0.005, 0.008)	19.3 (14.5, 21.6)
L, 0- and 1-year-old room	41 (26, 64)	0.006 (0.004, 0.010)	21.0 (18.1, 22.4)
M, 0-year-old room	46 (29, 75)	0.007 (0.005, 0.011)	22.3 (19.0, 24.5)
M, 1-year-old room	63 (43, 79)	0.009 (0.006, 0.011)	19.1 (16.7, 21.3)
N, 0-year-old room	51 (41, 60)	0.007 (0.005, 0.009)	18.7 (13.4, 20.5)
N, 1-year-old room	44 (33, 51)	0.006 (0.004, 0.008)	19.4 (14.8, 21.4)
O, 0-year-old room	44 (37, 55)	0.007 (0.005, 0.009)	20.6 (15.3, 23.1)
O, 1-year-old room	41 (33, 51)	0.007 (0.005, 0.009)	22.5 (17.9, 23.6)

Table A5. CO_2 concentrations (ppm) in nursery classrooms during opening hours in summer.

Nursery, Room	Weekday Median (5th, 95th Percentile)	Saturday Median (5th, 95th Percentile)	Holiday Median (5th, 95th Percentile)
A, 0-year-old room A, 1-year-old room	Not measured	Not measured	Not measured
B, 0-year-old room	692 (394, 1424)	432 (378, 630)	388 (375, 411)
B, 1-year-old room	564 (417, 1126)	414 (402, 518)	407 (382, 437)
C, 0-year-old room	801 (515, 1000)	758 (493, 891)	503 (476, 554)
C, 1-year-old room	1078 (525, 1523)	993 (471, 1451)	486 (445, 556)
D, 0-year-old room	827 (464, 1210)	532 (480, 807)	527 (521, 532)
D, 1-year-old room	1061 (457, 1359)	536 (485, 808)	463 (451, 476)
E, 0-year-old room	1268 (669, 1758)	1080 (622, 1322)	429 (416, 467)
E, 1-year-old room	996 (441, 1518)	497 (424, 1108)	440 (417, 465)
F, 0-year-old room	1157 (426, 1815)	654 (411, 1894)	421 (404, 431)
F, 1-year-old room	545 (406, 1803)	455 (404, 1657)	411 (396, 428)
G, 0-year-old room	551 (419, 1163)	444 (421, 512)	410 (398, 414)
G, 1-year-old room	494 (407, 1208)	479 (434, 687)	430 (419, 432)
H, 0-year-old room	657 (444, 829)	457 (429, 850)	419 (409, 433)
H, 1-year-old room	426 (401, 448)	430 (408, 940)	406 (403, 419)
I, 0-year-old room	967 (454, 1268)	860 (463, 1097)	554 (533, 606)
I, 1-year-old room	969 (464, 1332)	876 (438, 1101)	473 (450, 495)
J, 0-year-old room	668 (408, 1282)	866 (494, 1490)	427 (404, 443)
J, 1-year-old room	944 (393, 1875)	913 (435, 1752)	406 (401, 422)
K, 0-year-old room	1708 (652, 2172)	1298 (800, 1791)	574 (521, 651)
K, 1-year-old room	1468 (843, 2003)	1293 (866, 1754)	585 (532, 669)
L, 0- and 1-year-old room	795 (469, 1121)	662 (505, 902)	412 (401, 422)
M, 0-year-old room	985 (495, 1306)	708 (534, 878)	398 (393, 407)
M, 1-year-old room	1373 (410, 2224)	843 (410, 1170)	370 (366, 382)
N, 0-year-old room	922 (439, 1790)	813 (698, 904)	425 (419, 456)
N, 1-year-old room	766 (455, 1689)	812 (615, 1015)	446 (441, 477)
O, 0-year-old room	675 (458, 1014)	492 (444, 569)	442 (438, 451)
O, 1-year-old room	1072 (490, 1836)	634 (495, 739)	430 (423, 448)

Table A6. CO_2 concentrations (ppm) in nursery classrooms during opening hours in winter.

Nursery, Room	Weekday Median (5th, 95th Percentile)	Saturday Median (5th, 95th Percentile)	Holiday Median (5th, 95th Percentile)
A, 0-year-old room	598 (429, 876)	457 (399, 691)	471 (458, 531)
A, 1-year-old room	810 (442, 1151)	687 (442, 1192)	421 (406, 458)
B, 0-year-old room	1144 (451, 1746)	N.A.	390 (381, 433)
B, 1-year-old room	839 (467, 1421)	N.A.	419 (404, 450)
C, 0-year-old room	1084 (585, 1303)	N.A.	543 (461, 672)
C, 1-year-old room	1296 (549, 1773)	N.A.	532 (440, 644)
D, 0-year-old room	880 (468, 1261)	592 (447, 788)	428 (422, 448)
D, 1-year-old room	845 (496, 1290)	677 (486, 920)	461 (457, 486)
E, 0-year-old room	950 (439, 1397)	733 (446, 890)	423 (411, 446)
E, 1-year-old room	1108 (660, 1436)	942 (516, 1222)	411 (406, 426)
F, 0-year-old room F, 1-year-old room	Not measured	Not measured	Not measured
G, 0-year-old room	665 (435, 879)	474 (419, 630)	418 (404, 428)
G, 1-year-old room	1029 (449, 1482)	1121 (470, 2388)	444 (429, 458)
H, 0- and 1-year-old room	635 (429, 850)	478 (395, 593)	416 (402, 427)
I, 0-year-old room	1033 (510, 1386)	814 (495, 946)	474 (459, 499)
I, 1-year-old room	1059 (455, 1585)	963 (466, 1298)	456 (448, 461)
J, 0-year-old room	943 (503, 1403)	719 (482, 1012)	404 (399, 418)
J, 1-year-old room	900 (539, 1394)	785 (482, 1116)	414 (403, 435)
K, 0-year-old room	1236 (452, 1885)	941 (440, 1304)	412 (408, 450)
K, 1-year-old room	1196 (509, 1926)	877 (472, 1213)	413 (408, 457)
L, 0- and 1-year-old room	667 (453, 964)	595 (432, 664)	380 (378, 390)
M, 0-year-old room	1042 (547, 1386)	716 (507, 1055)	405 (401, 429)
M, 1-year-old room	1629 (473, 2670)	1169 (478, 1817)	400 (393, 418)
N, 0-year-old room	1126 (449, 1685)	543 (431, 660)	415 (406, 438)
N, 1-year-old room	1279 (441, 1992)	1076 (420, 1468)	416 (410, 435)
O, 0-year-old room	692 (487, 1074)	529 (430, 566)	408 (404, 415)
O, 1-year-old room	757 (469, 1188)	693 (459, 830)	417 (415, 424)

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