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Comparison of Indoor Environment and Energy Consumption before and after Spread of COVID-19 in Schools in Japanese Cold-Climate Region

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Abstract: A report released by the WHO indicates that aerosols from infected people are one of the major sources of the spread of COVID-19. Therefore, as the COVID-19 infection caused by the SARS-CoV-2 virus spreads, it has become necessary to reconsider the design and operation of buildings. Inside school buildings in cold regions, not only is it not easy to increase ventilation during the winter, but it may also be difficult for students to attend classes while wearing masks during the summer because such buildings are not equipped with air-conditioning systems. In short, school buildings in cold climates have more problems than those in warm climates. We report on the results of indoor environmental measurement using our developed CO_2-concentration meters, a questionnaire survey on students' feeling of being hot or cold (i.e., 'thermal sensation'), and a comparison of energy consumption before and after the spread of COVID-19 infection in schools in Sapporo, Japan, a cold-climate area. The results indicate that (1) more than 70% of the students participated in window ventilation by the CO_2 meter, and (2) a relatively good indoor environment was maintained through the efforts of teachers and students. However, we also found that (1) 90% of the students felt hot in summer and (2) 40% felt cold in winter, (3) energy efficiency worsened by 7% due to increased ventilation, and (4) air quality was not as clean as desired during the coldest months of the year. Therefore, investment in insulation and air conditioning systems for school buildings is needed.

Keywords: COVID-19; ventilation; thermal sensation; heating energy consumption; primary energy consumption

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1. Introduction

The spread of COVID-19 caused by the SARS-CoV-2 virus has had a major impact on building operations. WHO published a report on ventilation systems in March 2021 and reported that aerosols from infected people are one of the major sources of COVID-19 infection [1]. Sousans et al. found the SARS-CoV-2 virus while sampling air in a university dormitory where the infection had spread [2]. Some reports indicate that the recommended infection-prevention measures vary greatly depending on the air conditioning system [3]. Although behavioral restrictions have been greatly relaxed since 1 November 2021, the Japanese government warned us to be careful in situations such as social gatherings with food and drink, eating and drinking in large groups or for long periods, having conversations without a mask, living together in a small space, and change of location, and ventilation is the most important means for reducing such risks [4]. The society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) [5], as well as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [6] and Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) [7] published several documents on the use of buildings under the spread of COVID-19 infection, in which the importance of improving ventilation systems and increasing the ventilation rate is mentioned. Zehng et al. [8], Pan et al. [9], Elsaid et al. [10], and Berry et al. [11] refer to the above reports by ASHRAE, RHEVA, SHASE, etc., and clarify the problems of the current air conditioning systems and suggest possible countermeasures and future design methods. In cold-climate regions with severely cold winters, increasing the ventilation rate by opening windows in winter increases the heating load for ventilation. It deteriorates the indoor climate since outdoor air directly enters the building, which can be more than 20 °C colder. Brian Pavilonis et al. studied schools in New York City with cold winters and used the Wells–Riley equation to determine the probability of infection. The results showed that the probability of infection increased during the heating season when ventilation was reduced [12]. When we have to stop an energy-saving system that may spread infection, such as a returned air system and rotor-type heat exchange ventilation system [7], the thermal load for air-conditioning may exceed the design capacity. Therefore, the indoor environment may become uncontrollable.

In school buildings, where the population density has remained high for a long time, indoor environments tend to be poor. The indoor environment of schools has traditionally not been given much attention in the design stage, and only the recommendations of wearing masks, ventilation, and suspension of attendance for students with the virus were implemented during the current pandemic. Teachers and students have been forced to open and close windows of the school to maintain a sufficient amount of the indoor environment. The defects in such buildings, such as inadequate insulation and a ventilation system with a heat exchanger, have been neglected. After the pandemic is under control, the situation will be the same as before, with many class closures due to influenza during the winter months, and the schools will be the source of the spread of infections in the region. It is important to document the current state and update the building to prepare for the next virus. In 2021, COP26 was held, and the goal of limiting global warming to 1.5 °C was discussed. Although CO_2 emissions during the COVID-19 diffusion period have been on a downward trend, the economy's recovery needs to be carried out in a green and smart way, rather than letting CO_2 emissions return to normal as the recovery progresses [13]. In some areas, new ventilation systems are already being proposed on the basis of measured data and simulations. Gil-Baez et al. introduced the tips of natural ventilation from measurements as well as this study [14]. Stabile et al. installed a ventilation system with heat exchange in the naturally ventilated school. They evaluated CO_2, VOCs, and Particle Matter (PM) to see the effect of improving indoor air quality [15]. As a slightly advanced example, Haddad S. et al. investigated Demand Control Ventilation (DCV) with natural ventilation in a warm climate zone in Australia and reported the improvement of the indoor environment [16]. The above studies were conducted in temperate climates. In cold climates, it is necessary to study the increase in energy consumption and deterioration of the indoor environment due to increased ventilation. Luigi Schibuola et al. reported on applying a system combining a heat exchange ventilator and a heat pump to a school [17]. Fabrizio Ascione et al. investigated several mechanical ventilation methods using CFD and concluded that the linear slot diffuser was effective in airflow distribution and comfort [18]. However, the implementation of these systems requires a significant investment. The government is not very willing to invest in school facilities in Japan due to the declining birth rate. The installation of such systems requires a significant cost-benefit. Of course, the best approach is to develop facilities that automatically provide a suitable environment without any effort by students and teachers, as described by Simanic, Branko et al. [19]. Some challenging research uses passive methods [20–22]. However, in school architecture, where various people use the building in diverse ways over a long period, the building should be tough. We should aim for a universal solution rather than an acrobatic solution that combines several elements.

In this paper, we report on the results of indoor environment measurements with our developed CO_2-concentration meters, a questionnaire survey on students' thermal sensation, and a comparison of energy consumption before and after the spread of the virus.

2. Infection Control in School Facilities

2.1. Characteristics of School Facilities

This report focuses on school buildings in Sapporo, the largest city in Hokkaido prefecture, Japan. Sapporo's winters are cold and harsh enough to provide a reference for the operation of schools in cold-climate regions. School facilities are used by an unspecified number of people at high densities, so infection-control measures are necessary. In the current COVID-19 pandemic, a study reported that schools are the source of the spread of infection [23]. However, the only countermeasures against infectious diseases have been to suspend the attendance of infected students in Japan. However, identifying all infected students is difficult. Every year, influenza outbreaks occur, and many schools and classes are closed. Figure 1 shows the seasonal coefficient of mortality (CSVM) for Tokyo and Hokkaido, based on the Vital Statistics Death Charts for 1972–2015. Since it takes time for the Vital Statistics to be published, the results are almost up-to-date, but the influence of COVID-19 is not included [24]. The CSVM [25] is an index that compares mortality rates in winter and other seasons by dividing the year into three four-month periods. A CSVM of 0 means no difference in the mortality rate between winter and other seasons, and a CSVM of 0.1 means that the mortality rate in winter is 10% higher than in other seasons. In Japan, as in other developed countries, the mortality rate in winter is higher than that in other seasons, and infectious diseases in the elderly are responsible for the rising death rate. In 1998, the CSVM was at its peak. Influenza vaccination for school children was liberalized in 1994, causing the spread of influenza in schools due to the increased mortality rate in the elderly. The most effective method of preventing the spread of infection by schools is a school closure. In the US, school closures for COVID-19 began in March 2019. Although the effects of school closure cannot be separated from other intervention methods, it has been reported that school closures resulted in a 62% reduction in COVID-19 cases [26]. There is an argument that the negative effects of school closures should be compared with their benefits. The reopening of schools led to the spread of COVID-19 infections in the US [27]. In the UK, an advisory was also issued before schools reopened to avoid schools becoming a source of infection [28]. However, outbreaks occurring after schools reopened in the UK and Israel have been reported [29,30]. In Sweden, the odds ratio for infection of a teacher's partner was significantly high in some cases, and protection measures for teachers are also needed [31]. Conversely, there have been cases of infected teachers spreading the infection in the classroom [32]. Fukumoto et al. reported that they did not find any evidence that school closures decreased the spread of COVID-19 in Japan [33]. Lessler et al. reported in a US study that school-based mitigation measures, such as daily symptom monitoring, teacher masking, and discontinuation of extracurricular activities, significantly reduced the risk of infection [34]. Outbreaks may have been suppressed in Japanese schools because these measures were followed. COVID-19 is expected to coexist with influenza in the future, and controlling infection in school facilities will be key to controlling the spread of the disease throughout Japan.

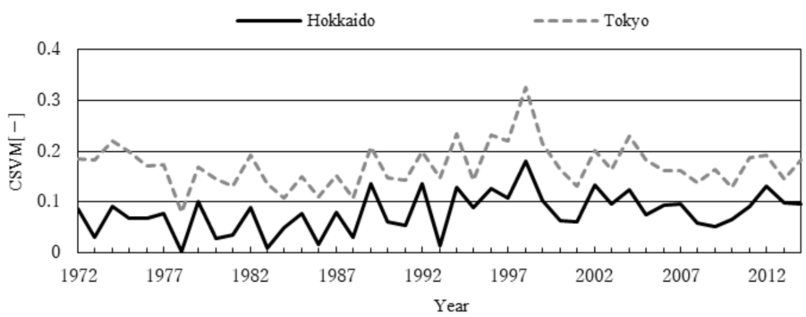

Figure 1. CSVM in Tokyo and Hokkaido.

2.2. Infection Control in School Facilities in Cold Regions

In the Japanese School Environmental Hygiene Standards [35], it is stated that "School founders shall maintain an appropriate environment in their schools about the School Environmental Hygiene Standards". It also states that carbon dioxide should be less than 1500 ppm as a standard for ventilation. On the other hand, the environmental health standard for normal office buildings should be less than 1000 ppm; thus, the ventilation standard for schools is more relaxed than that for general office buildings. This standard is between categories 2 and 3 in EN16798-1:2019, and it is not a high standard. The Architecture Institute of Japan (AIJ) studied current problems and countermeasures for thermal and air quality in schools [36] and found that concentrations exceeding 3000 ppm were found in several schools, compared with the standard concentration of 1500 ppm. They also reported that the percentage of ventilation systems installed in classrooms in school facilities in cold climates was about 30% in 2015, and they were rarely used. The Ministry of Education, Culture, Sports, Science, and Technology in Japan (MEXT) issued the following guidelines on ventilation after the spread of the COVID-19: (1) ventilation by opening windows should be used whenever possible; (2) open all windows for a few minutes at least once every 30 min; (3) open windows in opposite directions at the same time. Such an approach is relatively easy to implement in warmer climates [14]. In cold climates, however, the method will deteriorate the indoor environment. The Northern Building Research Institute, the research institute of the Hokkaido local government, published information on the web on "Ventilation methods for school in cold climate areas" [37]. This method recommends using heaters even in empty classrooms when ventilation systems with heat exchangers are not installed. It also recommends using partitions to prevent direct exposure of students to the cold outside air. Of course, using these methods would increase the amount of outdoor air introduced; thus, increasing heating-energy consumption.

2.3. Target Facilities

We report on (1) our development of CO_2-concentration meters with warning displays for school facilities, (2) the results of implementing the meters, and (3) the changes in thermal sensation of students and energy consumption before and after the spread of COVID-19. In (1), the CO_2 meter was first tested at Kushiro National College of Technology and then deployed at High School A in Sapporo, and (2) was also conducted at High School A. For point (3), daily changes were evaluated in the schools with electric heaters listed in Table 1 using the cloud-uploaded data. The monthly changes in primary energy consumption were evaluated in most schools in Sapporo. Figure 2 shows an interior view of High School A. Most of the schools in Sapporo were built in the 1970s and 1980s. The floor area ranges from 5000 to 10,000 square meters as shown in Table 1. The number of floors was three or four. High School A was also built during this period and is a typical building type. The classrooms have large openings on the south side for lighting and ventilation. Since the building has not been renovated since it was built, the windows are single-panel dual sash windows, resulting in significant heat loss. The large heating loads are heated by electric heaters located in the classrooms. There are also ventilation windows on the corridor side, which have been open most of the time during COVID19. There are no ventilation fans in the general classrooms, but exhaust ventilation fans were installed in the music and chemistry rooms.

Table 1. Target facilities.

School Name	Floor Area [m^2]	Heating System
A High School	12,255	Electric heater
B High School	10,541	Electric heater
C Junior High School	10,202	Electric heater
D Junior High School	9702	Heavy oil and kerosene oil boiler
E Elementary School	6346	Electric heater

Ventilation window on the corridor side

Electric heater

Classroom and windows

Some classrooms are equipped with ventilation fans

Figure 2. Picture of the classroom in High School A.

2.4. Development of CO_2-Concentration Meters with Warning Displays

We developed CO_2-concentration meters with warning displays by combining the microcomputers M5Stack and M5Atom with the CO_2 sensors SCD30 and MH-19C, which use near infra-red (NIR) for measurement. Figure 3 shows these devices. There have been several attempts to improve ventilation using these relatively inexpensive sensors, but there are few examples in cold regions where they are most effective [38].

Both devices are as accurate as the devices usually used. They also have an auto-calibration feature that sets the minimum daily concentration to 400 ppm and was placed in a well-ventilated room for at least a week before actual use. Both meters were being manufactured for 5000 to 10,000 JPY (43.7 to 87.4 USD). The displays of these devices were designed to change the background color according to the concentration: green for <800 ppm, yellow for <900 ppm, orange for <1000 ppm, and red for ≥1000 ppm. Since most Japanese schools are not equipped with mechanical ventilation, the opening of the windows must be adjusted by teachers and students. It is difficult to draw their attention and encourage them to take action with a regular LCD, so the LEDs and LCDs are illuminated with enough light to be visible from the classroom rear. Figure 4 shows the questionnaire survey results for testing the devices conducted at Kushiro National College of Technology. The notations 4A and 5A indicate the class names. "Yes" and "No" indicate the percentage of respondents who had or had not checked the warning signs and opened the windows or turned on the ventilation system, respectively. It shows that many students in both classes checked the LED indicators and carried out the ventilation procedure.

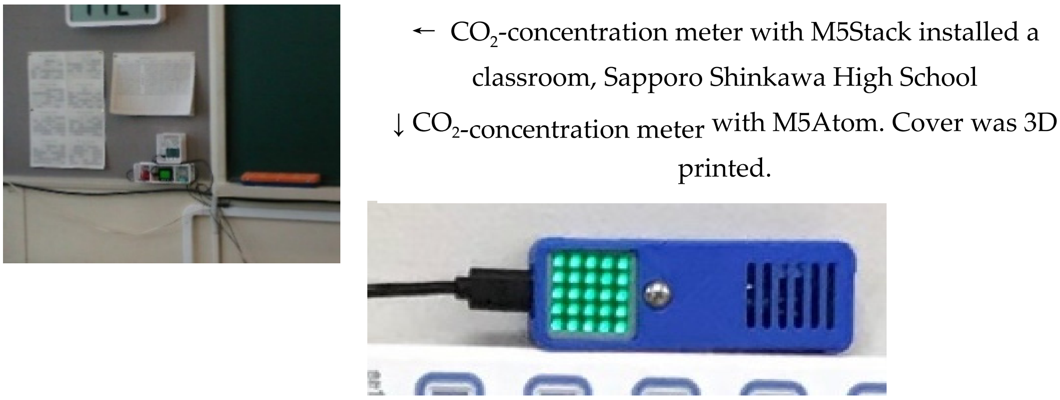

Figure 3. CO_2-concentration meters with a warning display.

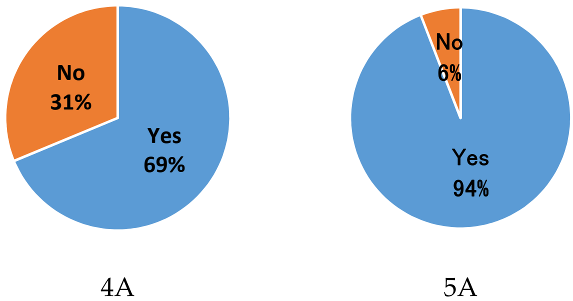

Figure 4. Results of questionnaire item "Did you open a window or turn on ventilation when the display alerted you?".

3. Indoor Environment of Classrooms

Figures 5 and 6 show the questionnaire results on the conditions of window-opening ventilation and thermal sensation, respectively, given to the students of Sapporo Shinkawa High School. Note that in Sapporo, schools were online from April 2020 to mid-June 2020. In the questionnaire about thermal sensation, we asked about their thermal sensation compared with last year. During the summer, the percentage of "the windows were fully opened" gradually increased, and the percentage of respondents who answered "hotter than last year" or "slightly hotter than last year" also increased. Figure 7 shows the results of the frequency of wearing masks. The percentage of respondents who wore masks at all times gradually decreased from June to August, with about half of the respondents not wearing masks for more than a few hours. The most common reason for this seems to be that it was too hot to wear masks. Similar results have been reported by Dragan Milošević [39]. Schools in Sapporo are equipped with fans, but few are equipped with air-conditioning systems. There is evidence that wearing masks in schools can prevent the spread of COVID-19 [40,41]. Other results indicate that mandatory mask-wearing is more effective than ventilation systems [42]. Many schools have been holding classes during the summer vacation; thus, installing air conditioning systems is expected to increase the percentage of students wearing masks in the summer, even in cold-climate areas.

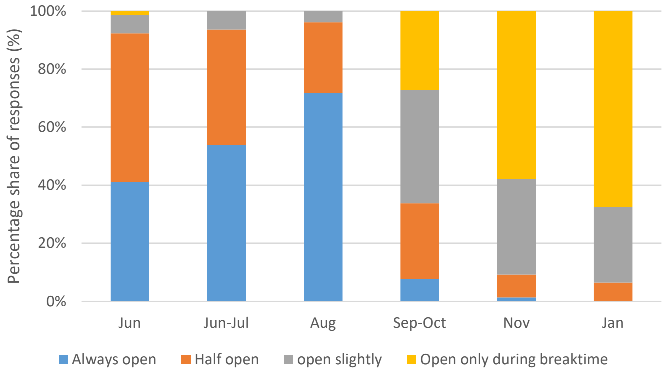

Figure 5. Results from window-opening ventilation.

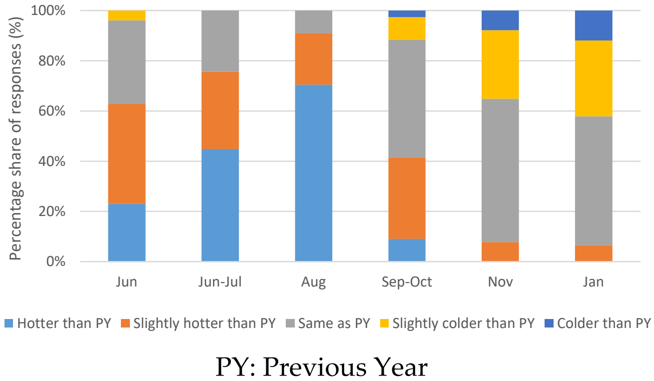

Figure 6. Comparison of students' thermal sensation in 2020 with that in 2019.

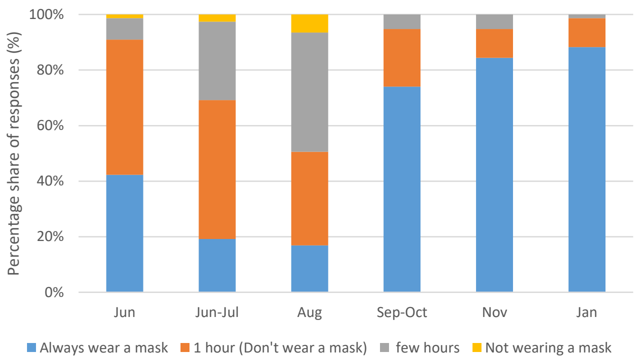

Figure 7. Wearing of masks.

As the outside temperature dropped from September to January, the open-window ventilation changed from "always open" to "open during the break between classes". In January, about 40% of the respondents answered that it was "slightly colder" or "colder" than last year. Although the room temperature in the classrooms was kept above 15 °C except on holidays, the increase in wind velocity and temperature distribution caused by open-window ventilation indicated that many students felt cold. Most students also wore masks after September. This suggests that proper room temperature control can improve the mask-wearing rate. It will be common for teachers and students to wear masks while teaching in most schools in Japan. It has been reported that the combination of masks and increased ventilation can reduce the final reproduction number considering the total exposure period (R_0) below 1.0 [17].

Figure 8 shows the cumulative frequency distribution of CO_2 concentration in the special (mathematics) and general classrooms of High School A from 8:00 to 15:00 on weekdays when classes were held. The period covered was two weeks from the date indicated in the legend. The 11-1 (11 November) data show that the concentrations in the classrooms increased as the outside temperature decreased and exceeded 1000 ppm in the special classroom for more than 60% of the usage time and in the general classroom for more than 80% of the usage time. We visited the high school on 15 November 2020 and suggested methods to improve ventilation based on the Northern Building Research Institute brochure and the measured data. As a result, the situation improved over the first half of November. The general and mathematics classrooms were used differently. The mathematics classroom was managed by a single teacher, while the general classroom was used by many teachers who took turns teaching. As a result, ventilation methods differed significantly among teachers. This measurement was conducted with the help of the teacher who used the mathematics classroom. He was familiar with the characteristics of the increase and decrease in CO_2 concentration in these classrooms by opening and closing the windows while monitoring the CO_2 display. He was able to keep the CO_2 concentration low by always opening the windows little by little and opening them fully once in the middle of the class (about 20–30 min). However, during the coldest months of January and February, students reported being cold. High School A had never reported any COVID-19 clusters.

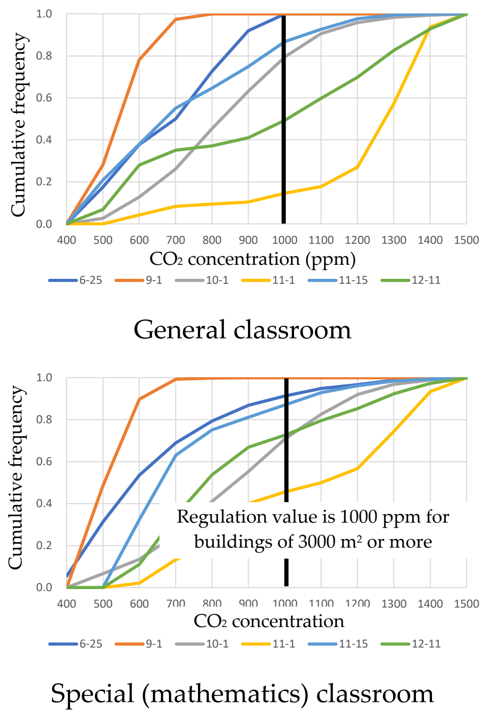

Figure 8. Cumulative frequency distribution of CO_2 concentration in special (mathematics) and general classrooms.

4. Changes in Energy Consumption before and after Spread of Novel Coronavirus Infection

4.1. Change in Daily Energy Consumption in Schools with Electric Heaters

Investigations into the impact of the pandemic on energy consumption are important. Schools generally belong to the local government and are sensitive to increases in energy consumption due to the local government's budget constraints and environmental policies. The current situation is an emergency, and it is not desirable for the local government to continue to ask schools to reduce their energy consumption under these circumstances. It is also important to document and analyze this situation for future renovations and retrofits. This has been applied in many residential buildings but should be performed in school buildings where the contribution to the spread of infection is greater [43].

Figures 9 and 10, respectively, show the relationship between daily energy consumption and outdoor temperature at High Schools A and B. Before and after the spread of COVID-19 infection are denoted as BC (April 2015–March 2020, blue), and AC (April 2020–February 2020, red), respectively, and the numbers in the figure represent months. High Schools A and B are about the same size (High School A is slightly larger), and both schools use electric heaters to heat their classrooms. The heating period for both BC and AC begins in October and ends in the first half of May. Base electricity consumption, which is consumed for lighting, etc., during the non-heating period, ranged from 1000 to 1300 kWh/day in both schools BC or AC. During the heating period, the power consumption of AC tended to increase compared with BC at the same outside temperature. The increase was more significant at High School A, probably due to the active ventilation of the entire school after November, as described in the previous section. When the daily average outside temperature was below 0 °C, the increase in electric consumption was saturated at both schools. The number of infected people increased in Sapporo from December to January, and the schools were instructed to ventilate. Still, the temperature in the classrooms dropped rapidly, so the priority was to maintain the room temperature by keeping ventilation to a minimum. In addition, when the windows in each classroom were opened for less time, the school building had less time when the windows on the other side of the building were open, so the opportunity for ventilation was lost. As a result, the CO_2 concentration was assumed to have increased, as shown in Figure 8. From the questionnaire survey, many students felt cold during the winter months, making it difficult to manage the classroom. Thus, it is unfair to place the responsibility of managing students' health on teachers in addition to their regular duties.

Particle matter measurements were also conducted during the winter, and the PM concentration in the classrooms was sometimes high. The installation of a ventilation system with an enthalpy heat exchanger is effective to ensure the amount of ventilation, but since maintenance of the filters is essential in this situation, it is necessary to install the systems in consideration of ease of maintenance. Additionally, it is necessary to consider installing air purifiers rather than humidifiers.

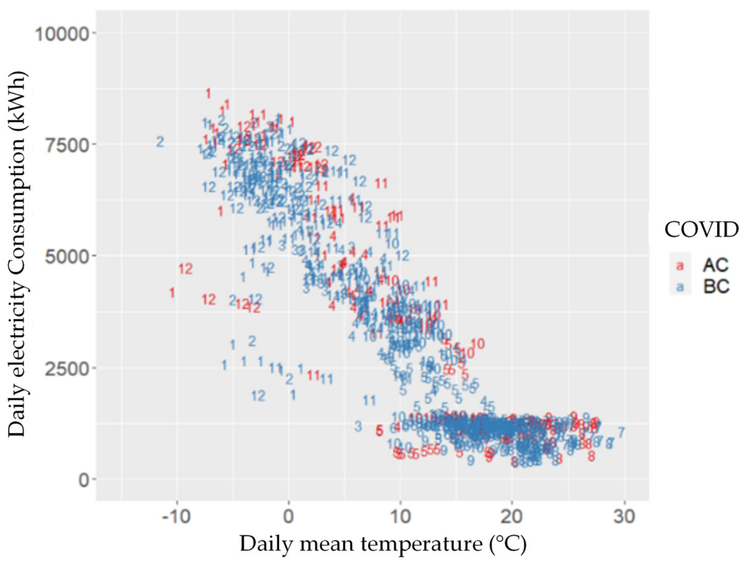

Figure 9. Relationship between daily energy consumption and outdoor temperature at High School A.

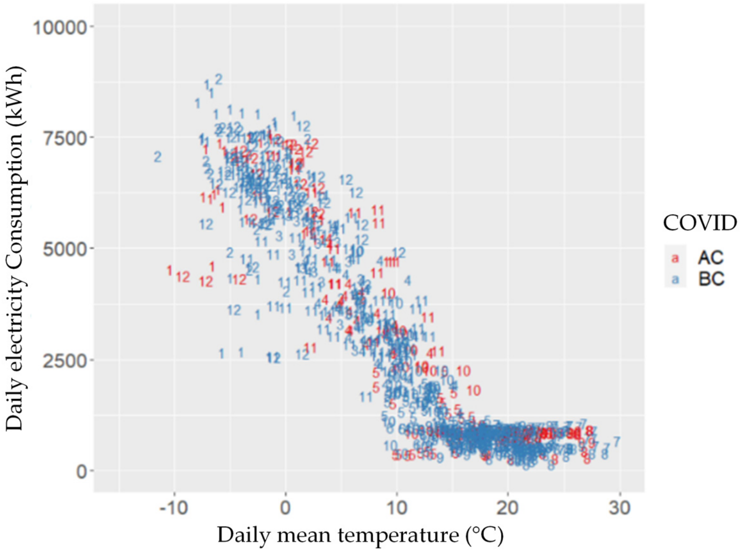

Figure 10. Relationship between daily energy consumption and outdoor temperature at High School B.

Figures 11 and 12, respectively, show the electricity consumption of Junior High School C and Elementary School E. In both schools, the heating system is an electric thermal storage heater. At Elementary School E, similarly to the high schools mentioned above, power consumption did not increase below 0 °C and tended to be the same or lower than the previous year. However, electricity consumption at Junior High School C continued to grow even below 0 °C, and at −5 °C, electricity consumption was 1.5 times the BC level. Thus, the management of the heating system from the start of heating until the average temperature reached 0 °C appeared to be the same in each school, but the management during the coldest period was different in each school. School administrators are always aware of energy costs, but in the current situation, they are comparing energy costs with the health of their students. While energy-wasting should be avoided, we recommend that adequate heating be provided for the school's period in operation. REHVA recommends at least one hour of ventilation before the building is used and after it finishes operation [7]. During the winter months, many extracurricular activities take place in classrooms and hallways after the school day, especially in schools in the colder regions of Japan. The spread of COVID-19 through extracurricular activities has been reported worldwide [44]. Ventilation should be recommended for a period after those activities are completed. Table 2 lists the results of applying an approximation line to the data during the heating period for all schools included in the study. Except for High School B, the slope of the approximation line for AC is more significant than that for BC. It indicates an increase in the heat loss coefficient due to the increase in ventilation. However, there was no substantial change in the intersection with the base consumption, representing the heating start temperature for AC and BC.

Table 2. Information of approximation lines.

School Name	Slope in BC	Slope in AC	ISC in BC	ISC in AC	R^2 BC	R^2 AC
A High School	−257	<−265	18.1	20.2	0.60	0.67
B High School	−335	>−318	14.3	15.8	0.72	0.68
C Junior High School	−225	<−259	13.9	15.4	0.66	0.52
E Elementary School	−124	<−172	14.5	15.8	0.57	0.58

ISC: Intersection with base consumption; R^2: coefficient of determination.

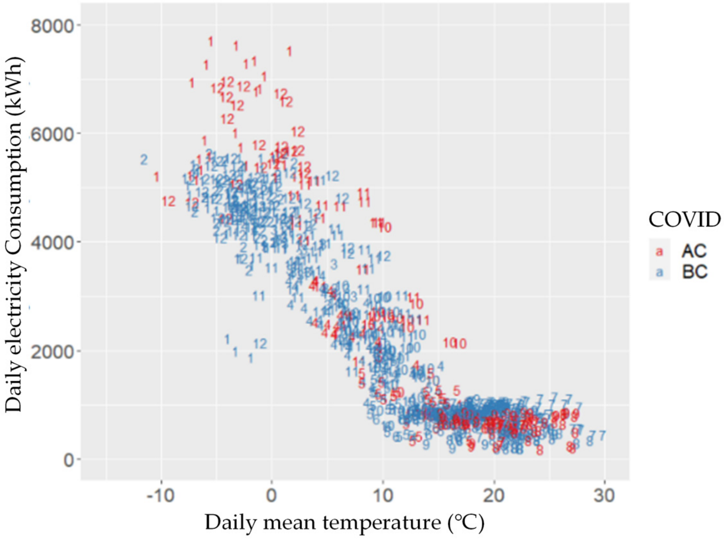

Figure 11. Relationship between daily energy consumption and outdoor temperature at Junior High School C.

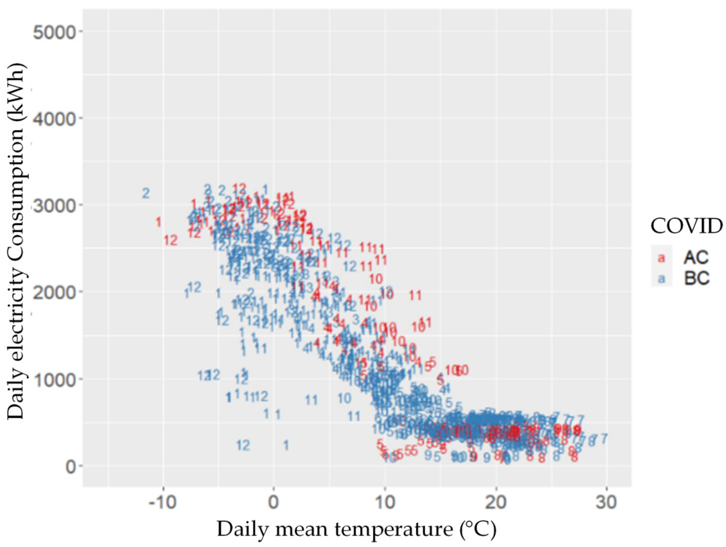

Figure 12. Relationship between daily energy consumption and outdoor temperature at Elementary School E.

4.2. Change of Monthly Primary Energy Consumption

There are 343 schools in Sapporo, which use not only electricity but also gas, kerosene, heavy oil, and other forms of energy. Kerosene and gas are the primary heat sources for schools in Sapporo, but the usage of these energy sources is not recorded daily as with electricity but when calculating the monthly bills. For example, the usage for February represents the usage from 15 January to 15 February. The relationship between primary energy consumption, which is calculated with these usages, and the monthly average temperature for the calculation period is shown in Figure 13. High School A uses electric heating, so the results are the same as daily heating consumption. Junior High School D uses kerosene and heavy oil for heating. As in the case of the school using electric heating, the primary energy consumption tended to increase when the outside temperature decreased. However, the primary energy consumption in January was lower than the previous three years. The reason for this was that the cold weather did not allow for active ventilation, and extracurricular activities were restricted from December to January 2021, resulting in shorter heating hours in schools. As with monthly electric heating consumption, the relationship between average temperature and primary energy consumption was linearly approximated, and the slopes, intercepts, and correlation coefficients were calculated. Figure 14 shows the slopes in BC and in AC. In about 75% of the schools, the absolute of slope was larger in AC than in BC. In other words, heating consumption expanded despite the reduction in extracurricular activities in winter 2021, indicating a decrease in active school hours. The remaining 25% also increased ventilation, but the increase in ventilation was offset by the shorter time of extracurricular activities. The slope of the approximate line was 1.07, which means that the energy efficiency of the school building decreased by about 7% due to the increase in ventilation. A similar study was conducted in Korea, which has a cold winter season. The report compared energy consumption in 2019 and 2020 in school facilities and found a significant decrease in 2020 [45]. In Japan, schools reopened in June 2020 due to the demand for guaranteed educational opportunities, but in Korea, schools did not reopen until 2021. Differences in school policies also had an impact on energy consumption.

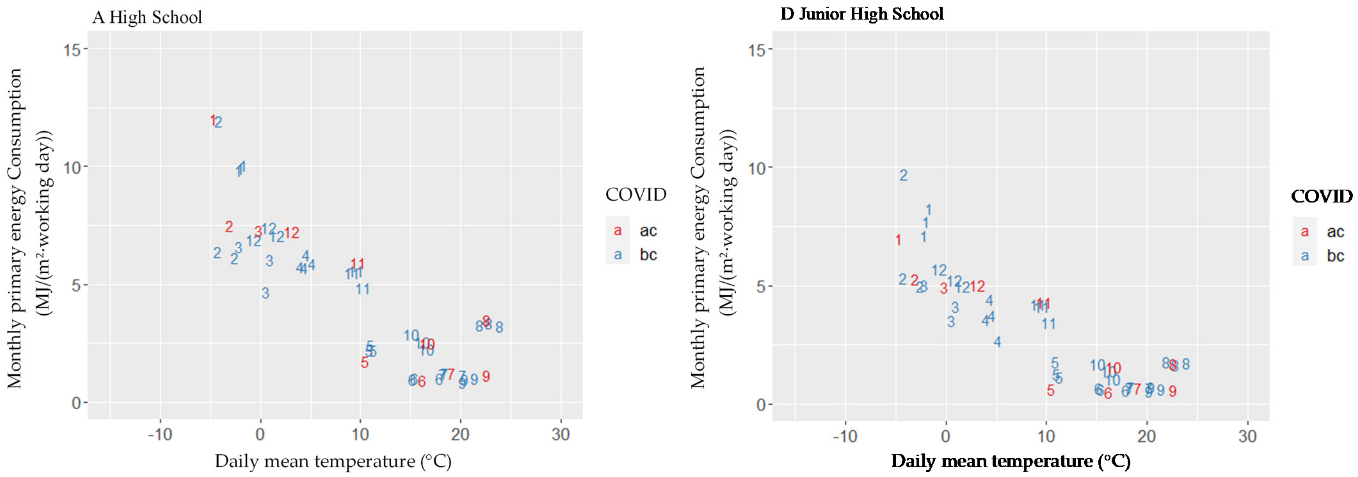

Figure 13. Relationship between monthly mean temperature and monthly primary energy consumption.

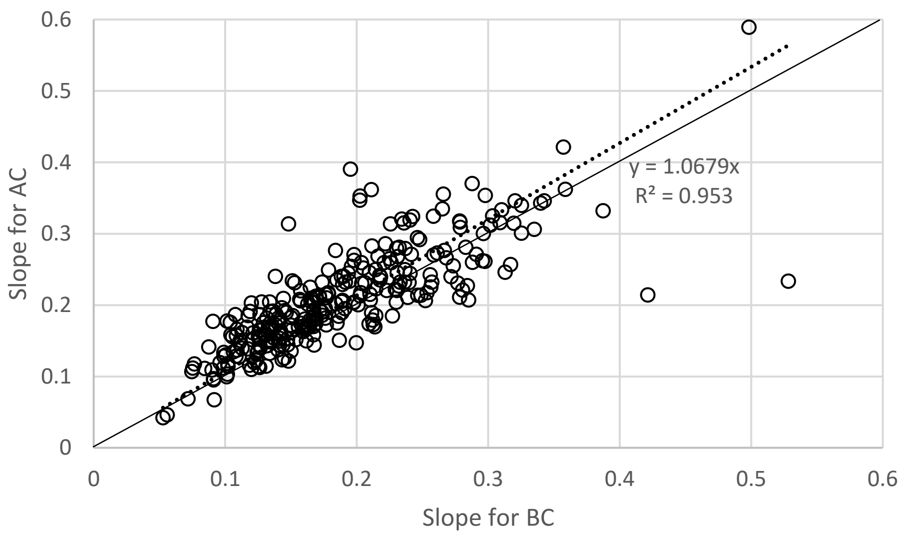

Figure 14. Comparison of absolute of slopes in BC and AC.

5. Conclusions

We reported how school buildings operated before and after an outbreak of COVID-19 in Sapporo, a city with a severely cold climate, and how these operations affected the indoor environment and energy consumption. A summary of the results is as follows.

1. Guidelines for infectious diseases in school buildings in cold regions of Japan were similar to those in warmer regions and inadequate for COVID-19. The problem was that the ventilation methods proposed by the national and local governments could not be continued because of the deterioration in the indoor environment caused by increased ventilation.
2. The CO_2-concentration meters with warning displays were effective in controlling open-window ventilation. More than 70% of the students participated in the open-window ventilation.
3. In total, 90% of students felt hotter than usual in summer, and 40% felt colder than average in winter.
4. In total, 40% of the students complained that it was cold, although the room temperature was kept above 18 °C. This is due to the distribution of room temperature and airflow.
5. The opening and closing of the windows to increase ventilation did not work well during the coldest months due to students' complaints of being cold.
6. In schools with electric heating, energy consumption increased due to increased ventilation, but not below 0 °C, as windows were closed due to the cold. It means that the ventilation rate did not increase; thus, the ventilation method needs to be improved.
7. Calculating the primary energy consumption of 343 schools in Sapporo, 75% showed an increase in the slope of primary energy consumption relative to outdoor temperature after a COVID-19 outbreak. In addition, the increase in slope was about 7%. In other words, the increase in ventilation resulted in a 7% deterioration in energy efficiency.

Since school buildings are the core facilities of the community, they are used not only by teachers and students. There is a need to invest more in insulation, ventilation, and air conditioning of school buildings to control infectious diseases in the community.

As a general premise, there has been almost no significant spread of infection throughout this pandemic through schools in Japan. Comprehensive measures such as ventilation, wearing masks, encouraging hand-washing, curbing extracurricular activities, etc., have been taken through the efforts of teachers and students to control the infection. Historically, however, school facilities in cold climates have been the cause of the spread of various infectious diseases. School facilities in Japan are also a place for environmental education, and there is a tendency to praise energy conservation through the patience and effort of teachers and students. We need to learn from this incident and consider measures to prevent the spread of infections through facilities and systems rather than actions. MEXT is promoting the eco-school project. Under this program, when a new school is built, it will be certified as an eco-school if it uses solar power, solar heating, biophilic design, wood, natural lighting, natural ventilation, and energy efficiency. Through this project, MEXT has also encouraged teachers and students to engage in energy-saving activities as part of their environmental education. The concept of eco-school should be changed from energy saving to a healthy environment with energy efficiency.

In addition, after the spread of COVID-19, the education system has been changing drastically. Tablets have been distributed to students, and classrooms are now equipped with high-security WiFi routers with dedicated lines. Even if students are suspended due to an infection, they can participate in class via a video conferencing system. Since those systems heat up indoors, it is necessary to consider installing air conditioning in classrooms, even in cold climates. On the other hand, schools are places that various people use for a long time, and school facilities must be hard to break and easy to use. Also, some of the diverse students may not participate in class calmly due to their high sensitivity to temperature changes. It is most important to focus on energy efficiency and achieve high IAQ, as in the Swedish example [19].

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References

1. World Health Organization. *Roadmap to Improve and Ensure Good Indoor Ventilation in the Context of COVID-19*; World Health Organization: Geneva, Switzerland, 2021.
2. Sousan, S.; Fan, M.; Outlaw, K.; Williams, S.; Roper, R.L. SARS-CoV-2 Detection in Air Samples from Inside Heating, Ventilation, and Air Conditioning (HVAC) Systems-COVID Surveillance in Student Dorms. *Am. J. Infect. Control* **2021**, *50*, 330–335. [CrossRef] [PubMed]
3. Correia, G.; Rodrigues, L.; Gameiro da Silva, M.; Gonçalves, T. Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission. *Med. Hypotheses* **2020**, *141*, 109781. [CrossRef] [PubMed]
4. Lipinski, T.; Ahmad, D.; Serey, N.; Jouhara, H. Review of ventilation strategies to reduce the risk of disease transmission in high occupancy buildings. *Int. J. Thermofluids* **2020**, *7–8*, 100045. [CrossRef]
5. Hayashi, M.; Yanagi, U.; Azuma, K.; Kagi, N.; Ogata, M.; Morimoto, S.; Hayama, H.; Mori, T.; Kikuta, K.; Tanabe, S.; et al. Measures against COVID-19 concerning Summer Indoor Environment in Japan. *Jpn. Archit. Rev.* **2020**, *3*, 423–434. [CrossRef]
6. Hoang, A. *Preparation in the Pandemic: How Schools Implemented Air Quality Measures to Protect Occupants from COVID-19*; World Health Organization: Geneva, Switzerland, 2021.
7. RHEVA. *REHVA COVID-19 Guidance Document How to Operate HVAC and Other Building Service Systems to Prevent the Spread of the Coronavirus (SARS-CoV-2) Disease (COVID-19) in Workplaces*; World Health Organization: Geneva, Switzerland, 2021.
8. Zheng, W.; Hu, J.; Wang, Z.; Li, J.; Fu, Z.; Li, H.; Jurasz, J.; Chou, S.K.; Yan, J. COVID-19 Impact on Operation and Energy Consumption of Heating, Ventilation and Air-Conditioning (HVAC) Systems. *Adv. Appl. Energy* **2021**, *3*, 100040. [CrossRef]
9. Pan, Y.; Du, C.; Fu, Z.; Fu, M. Re-thinking of engineering operation solutions to HVAC systems under the emerging COVID-19 pandemic. *J. Build. Eng.* **2021**, *43*, 102889. [CrossRef]
10. Elsaid, A.M.; Mohamed, H.A.; Abdelaziz, G.B.; Ahmed, M.S. A critical review of heating, ventilation, and air conditioning (HVAC) systems within the context of a global SARS-CoV-2 epidemic. *Process Saf. Environ. Prot.* **2021**, *155*, 230–261. [CrossRef]
11. Berry, G.; Parsons, A.; Morgan, M.; Rickert, J.; Cho, H. A review of methods to reduce the probability of the airborne spread of COVID-19 in ventilation systems and enclosed spaces. *Environ. Res.* **2022**, *203*, 111765. [CrossRef]
12. Pavilonis, B.; Ierardi, A.M.; Levine, L.; Mirer, F.; Kelvin, E.A. Estimating aerosol transmission risk of SARS-CoV-2 in New York City public schools during reopening. *Environ. Res.* **2021**, *195*, 110805. [CrossRef]
13. Rita, E.; Chizoo, E.; Cyril, U.S. Sustaining COVID-19 pandemic lockdown era air pollution impact through utilization of more renewable energy resources. *Heliyon* **2021**, *7*, e07455. [CrossRef]
14. Gil-Baez, M.; Lizana, J.; Becerra Villanueva, J.A.; Molina-Huelva, M.; Serrano-Jimenez, A.; Chacartegui, R. Natural ventilation in classrooms for healthy schools in the COVID era in Mediterranean climate. *Build. Environ.* **2021**, *206*, 108345. [CrossRef]
15. Stabile, L.; Buonanno, G.; Frattolillo, A.; Dell'Isola, M. The effect of the ventilation retrofit in a school on CO_2, airborne particles, and energy consumptions. *Build. Environ.* **2019**, *156*, 1–11. [CrossRef]
16. Haddad, S.; Synnefa, A.; Ángel Padilla Marcos, M.; Paolini, R.; Delrue, S.; Prasad, D.; Santamouris, M. On the potential of demand-contsrolled ventilation system to enhance indoor air quality and thermal condition in Australian school classrooms. *Energy Build.* **2021**, *238*, 110838. [CrossRef]
17. Schibuola, L.; Tambani, C. High energy efficiency ventilation to limit COVID-19 contagion in school environments. *Energy Build.* **2021**, *240*, 110882. [CrossRef]
18. Ascione, F.; De Masi, R.F.; Mastellone, M.; Vanoli, G.P. The design of safe classrooms of educational buildings for facing contagions and transmission of diseases: A novel approach combining audits, calibrated energy models, building performance (BPS) and computational fluid dynamic (CFD) simulations. *Energy Build.* **2021**, *230*, 110533. [CrossRef]

19. Simanic, B.; Nordquist, B.; Bagge, H.; Johansson, D. Indoor air temperatures, CO_2 concentrations and ventilation rates: Long-term measurements in newly built low-energy schools in Sweden. *J. Build. Eng.* **2019**, *25*, 100827. [CrossRef]
20. Bugenings, L.A.; Schaffer, M.; Larsen, O.K.; Zhang, C. A novel solution for school renovations: Combining diffuse ceiling ventilation with double skin facade. *J. Build. Eng.* **2022**, *49*, 104026. [CrossRef]
21. Peng, Z.; Deng, W.; Tenorio, R. An integrated low-energy ventilation system to improve indoor environment performance of school buildings in the cold climate zone of China. *Build. Environ.* **2020**, *182*, 107153. [CrossRef]
22. Li, X.; Zheng, S.; Tian, G.; Zhang, L.; Yao, W. A new energy saving ventilation system assisted by transpired solar air collectors for primary and secondary school classrooms in winter. *Build. Environ.* **2020**, *177*, 106895. [CrossRef]
23. Munday, J.D.; Sherratt, K.; Meakin, S.; Endo, A.; Pearson, C.A.B.; Hellewell, J.; Abbott, S.; Bosse, N.I.; Eggo, R.M.; Simons, D.; et al. Implications of the school-household network structure on SARS-CoV-2 transmission under school reopening strategies in England. *Nat. Commun.* **2021**, *12*, 1942. [CrossRef]
24. Mai, H.; Taro, M.; Hirofumi, H.; Motoya, H. Transitional analysis on seasonal dependence of death from disease using the vital statistics. *J. Environ. Eng.* **2021**, *86*, 557–566. [CrossRef]
25. REHVA. *REHVA_COVID-19_guidance_document_V3_03082020*; 2020. Available online: https://www.cdc.gov/vaccines/covid-19/covid19-vaccination-guidance.html (accessed on 6 July 2021).
26. Donohue, J.M.; Miller, E. COVID-19 and School Closures. *JAMA-J. Am. Med. Assoc.* **2020**, *324*, 845–847. [CrossRef]
27. Ertem, Z.; Schechter-Perkins, E.M.; Oster, E.; van den Berg, P.; Epshtein, I.; Chaiyakunapruk, N.; Wilson, F.A.; Perencevich, E.; Pettey, W.B.P.; Branch-Elliman, W.; et al. The impact of school opening model on SARS-CoV-2 community incidence and mortality. *Nat. Med.* **2021**, *27*, 2120–2126. [CrossRef]
28. Gurdasani, D.; Alwan, N.A.; Greenhalgh, T.; Hyde, Z.; Johnson, L.; McKee, M.; Michie, S.; Prather, K.A.; Rasmussen, S.D.; Reicher, S.; et al. School reopening without robust COVID-19 mitigation risks accelerating the pandemic. *Lancet* **2021**, *397*, 1177–1178. [CrossRef]
29. Aiano, F.; Mensah, A.A.; McOwat, K.; Obi, C.; Vusirikala, A.; Powell, A.A.; Flood, J.; Bosowski, J.; Letley, L.; Jones, S.; et al. COVID-19 outbreaks following full reopening of primary and secondary schools in England: Cross-sectional national surveillance, November 2020. *Lancet Reg. Health-Eur.* **2021**, *6*, 100120. [CrossRef] [PubMed]
30. Stein-Zamir, C.; Abramson, N.; Shoob, H.; Libal, E.; Bitan, M.; Cardash, T.; Cayam, R.; Miskin, I. A large COVID-19 outbreak in a high school 10 days after schools' reopening, Israel, May 2020. *Eurosurveillance* **2020**, *25*, 2001352. [CrossRef] [PubMed]
31. Vlachos, J.; Hertegård, E.; Hertegård, H.; Svaleryd, H.B. The effects of school closures on SARS-CoV-2 among parents and teachers. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2020834118. [CrossRef]
32. Lam-Hine, T.; Mccurdy, S.A.; Santora, L.; Duncan, L.; Corbett-Detig, R.; Kapusinszky, B.; Willis, M. *Morbidity and Mortality Weekly Report Outbreak Associated with SARS-CoV-2 B.1.617.2 (Delta) Variant in an Elementary School-Marin County, California, May–June 2021*; Centers for Disease Control and Prevention (U.S.): Atlanta, GA, USA, 2021.
33. Fukumoto, K.; McClean, C.T.; Nakagawa, K. No causal effect of school closures in Japan on the spread of COVID-19 in spring 2020. *Nat. Med.* **2021**, *27*, 2111–2119. [CrossRef]
34. Lessler, J.; Grabowski, M.K.; Grantz, K.H.; Badillo-Goicoechea, E.; Jessica, C.; Metcalf, E.; Lupton-Smith, C.; Azman, A.S.; Stuart, E.A. Household COVID-19 risk and in-person schooling. *Science* **2021**, *372*, 1092–1097. [CrossRef]
35. Ministry of Education, CSS and T. School Environmental Hygiene Management Manual Theory and Practice of School Environmental Hygiene Standards. Available online: https://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2018/07/31/1292465_01.pdf (accessed on 19 September 2021).
36. AIJ Thermal and Air Environment in Schools Current Problems and Countermeasures-to Create a Healthy and Comfortable Learning Environment for Children. Available online: http://news-sv.aij.or.jp/kankyo/s7/school_air_guide.pdf (accessed on 19 September 2021).
37. Hokkaido Research Organization Building Research Department. How to Ventilate Schools for the Cold Winter Months in Hokkaido. Available online: http://www.hro.or.jp/list/building/koho/develop/gakko_kannki.html (accessed on 19 September 2021).
38. McNeill, V.F.; Corsi, R.; Huffman, J.A.; King, C.; Klein, R.; Lamore, M.; Maeng, D.Y.; Miller, S.L.; Lee Ng, N.; Olsiewski, P.; et al. Room-level ventilation in schools and universities. *Atmos. Environ. X* **2022**, *13*, 100152. [CrossRef]
39. Milošević, D.; Middel, A.; Savić, S.; Dunjić, J.; Lau, K.; Stojsavljević, R. Mask wearing behavior in hot urban spaces of Novi Sad during the COVID-19 pandemic. *Sci. Total Environ.* **2022**, *815*, 152782. [CrossRef]
40. Budzyn, S.E.; Panaggio, M.J.; Parks, S.E.; Papazian, M.; Magid, J.; Barrios, L.C. Morbidity and Mortality Weekly Report Pediatric COVID-19 Cases in Counties with and without School Mask Requirements-United States, July 1–September 4, 2021. *MMWR Morb. Mortal. Wkly. Rep.* **2021**, *70*, 1377–1378. [CrossRef]
41. Theuring, S.; Thielecke, M.; Van Loon, W.; Hommes, F.; Hülso, C.; Von Der Haar, A.; Körner, J.; Schmidt, M.; Böhringer, F.; Mall, M.A.; et al. SARS-CoV-2 infection and transmission in school settings during the second COVID-19 wave: A crosssectional study, Berlin, Germany, November 2020. *Eurosurveillance* **2021**, *26*, 2100184. [CrossRef]
42. Zimmerman, K.O.; Brookhart, M.A.; Kalu, I.C.; Boutzoukas, A.E.; McGann, K.A.; Smith, M.J.; Panayotti, G.M.M.; Armstrong, S.C.; Weber, D.J.; Moorthy, G.S.; et al. Community SARS-CoV-2 surge and within-school transmission. *Pediatrics* **2021**, *148*, e2021052686. [CrossRef]

43. Kawka, E.; Cetin, K. Impacts of COVID-19 on residential building energy use and performance. *Build. Environ.* **2021**, *205*, 108200. [CrossRef]
44. Honein, M.A.; Barrios, L.C.; Brooks, J.T. Data and Policy to Guide Opening Schools Safely to Limit the Spread of SARS-CoV-2 Infection. *JAMA-J. Am. Med. Assoc.* **2021**, *325*, 823–824. [CrossRef]
45. Kang, H.; An, J.; Kim, H.; Ji, C.; Hong, T.; Lee, S. Changes in energy consumption according to building use type under COVID-19 pandemic in South Korea. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111294. [CrossRef]