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Trial of Building a Resilient Face-to-Face Classroom Based on CO₂-Based Risk Awareness

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Abstract. The COVID-19 pandemic forced many schools to switch to online classes. Although there has been a movement to return to face-to-face classes since then, many schools are still struggling to ensure safety during classes and subsequent examinations in a face-to-face environment. In this study, we attempted to visualize the relationship between class usage and building air conditioning management by installing CO₂ sensors at fixed points in classrooms and also applied them to environmental monitoring during examinations to grasp the risks in real time and provide a response.

Keywords: COVID-19, CO₂, Risk Awareness, Situation Awareness

1 Introduction

The novel coronavirus disease (COVID-19), which was first reported in Wuhan, China, at the end of 2019, caused a worldwide pandemic, and it is still difficult to determine when the pandemic will be over.

In Japan, the government issued a request for the temporary closure of elementary, junior high, and high schools in late February 2020 when the infection began to spread in the country. Although universities were not subject to the request, many of them responded by canceling graduation and entrance ceremonies and postponing the start of classes for the new semester. The pandemic continued to spread, leading to the declaration of a national state of emergency, and many universities were forced to close their campuses and shift to online classes.

Since late May 2020, when the state of emergency was lifted nationwide, there has been a gradual return to face-to-face classes, but with the outbreak of the second wave of infection soon after, full recovery has not been possible. Many universities tried face-to-face classes with staggered attendance or introduced hybrid (online and face-to-face) teaching.

The shift to online classes, which could be said to have been forced, brought about various adverse effects; however, the National Institute of Informatics promoted a cyber-symposium to share best practices and know-how about education online and at various universities promoted as “digital transformation (DX) for educational institutions” [1]. However, in classes that can only be conducted face-to-face, especially those that involve practical training and skills, face-to-face classes must be continued while

dealing with the fear of infection risk, causing great stress not only for students but also for school personnel.

The biggest problem is that the risk of infection is difficult to measure. Thanks to the efforts of the government's expert panel and others, the factors that increase the risk of COVID-19 infection were identified at an early stage and provided in the easy-to-understand phrase "Three Cs" (Closed spaces, Crowded places, and Close-contact settings) [2]. However, the level of environment we should be prepared to consider safe remains a matter of trial and error.

Initially, droplet and contact infections were considered the main routes of COVID-19 infection, but later, the possibility of infection by microdroplets (aerosols) with a diameter of 5 micrometers or less was pointed out [3]. Even if social distance is maintained, the risk of infection occurs when microdroplets drift around the room for a long time, so ventilation is more important. However, ventilation is difficult for people to sense physically, and it is difficult to know how much ventilation is being provided especially in high-rise buildings where windows cannot be opened for structural reasons.

In this paper, we report on an attempt to visualize the degree of ventilation in a university campus located in a high-rise building by measuring CO₂ concentrations and evaluating the extent of situation awareness [4] about the infection spread risk in face-to-face classes and examinations and to direct our responses against these infection risks.

2 Case Study and Issues

2.1 Case Study

The target university, the International Professional University of Technology in Tokyo (IPUT), to which the author belongs, has just been established in April 2020 as a new professional and vocational university in Japan. The major differences from conventional universities are the high percentage of full-time practitioner teachers (more than 40%), the high percentage of practical training classes in the curriculum (more than 33%), and the number of students per class is limited to 40 or fewer [5]. The campus is located in a high-rise building (50 floors above ground) in Shinjuku, Tokyo.

Due to the effects of the onset of the COVID-19 pandemic just before the establishment of IPUT, we had to take various emergency measures to maintain business as usual, although none of the previously planned on-campus events or classes was held. Table 1 is a summary of the typical response to addressing educational continuity taken since establishing IPUT.

To initiate classes to our first students as soon as possible, we established a communication tool *Slack* (<http://slack.com/>) to connect all students and the faculty and built an online classroom environment as soon as was practicable. By the end of the consecutive holidays in May, we were able to start online classes for all subjects based on the original timetable.

However, practical training and skills classes, which are characteristic of a "professional and vocational university," would be hindered by running online classes only, so

we also considered an immediate return to face-to-face classes in anticipation of the lifting of the emergency declaration. In addition, there was concern from an early stage that students' stress would increase due to the continuation of online classes and the fact that they would not be able to see their friends due to the continued self-restraint [6].

Table 1. Timetable of educational continuity response at International Professional University of Technology

| Timeline | Events |
|--------------------|--|
| Early March 2020 | End of general entrance examinations (as originally scheduled). |
| Mid-March 2020 | Decision to cancel the entrance ceremony (to be held online) and postpone the start of classes for 2 weeks. |
| Early April 2020 | The university started. The entrance ceremony and student orientations were conducted online. |
| Mid-April 2020 | Online classes began for parts of subjects with a special timetable. |
| Mid-May 2020 | Online classes began for all subjects with the original timetable. |
| Mid-June 2020 | Students attended the campus for the first time. Distributed attendance (2 days a week for each student), shifted to mixed online/face-to-face (hybrid) classes. |
| Early October 2020 | The second semester started, with one more face-to-face class day per week. |
| Early January 2021 | In response to the second emergency declaration, face-to-face class days were reduced by 1 day per week. |
| Early April 2021 | Second school year started. Five levels of hybrid classes were provided. Starting with level 1 (three face-to-face class days per week), it changed in response to the pandemic situation in Tokyo. |
| Late August 2021 | In response to the situation of a worsening infection spread (fifth wave) and the fourth emergency declaration, the level at the end of August 2020 was reduced to level 4 (full online classes each day). |

To resume face-to-face classes, the following measures were implemented to reduce the infection spread risk:

- Reducing the number of students on campus by staggering attendance
- Halving the capacity of classrooms
- Measuring body temperature at the entrance of the school building
- Setting up disinfectant (ethanol) on each floor
- Establishing rules for daily life, such as prohibiting lunch with more than three people gathered
- Reminding students frequently about safety measures at the beginning of classes and through administrative communications such as *Slack*

As a result of the above measures, fortunately, both faculty and students were able to get through the first year without causing any infection clusters.

In addition, there were many issues in ensuring the fairness and impartiality of the online entrance examinations and routine examinations, as well as the preparation and operation of the online examinations, so we abandoned online examinations and conducted all examinations face to face. For the entrance examinations in particular, unlike routine examinations, which are always conducted with the same members (current students), an unspecified number of examinees from all over the country visit the campus for the first time, so it was necessary to take stricter measures against infection in preparation for the possible introduction of viruses. On the other hand, the students who took the examinations were also anxious about going to Shinjuku, Tokyo (an area where many infections occur), and required an environment where they could take the examinations with peace of mind.

2.2 Ventilation Issues

However, the fact that the entire campus is located in a high-rise building makes it difficult to take countermeasures. Due to the structure of the building, it is not possible to open the windows, and there is no spontaneous ventilation. Even if the doors of classrooms are opened, the ventilating effect cannot be expected because the entire floor is a kind of sealed space. Air conditioning is managed centrally throughout the building, and since several other schools (vocational schools and universities) are housed in the same building, it is difficult to control the air conditioning according to the circumstances of a specific school or room. In addition, ventilation is more difficult for people to sense physically than heating and cooling, and it is difficult to grasp the operational status of the ventilation system.

The measurement of carbon dioxide (CO₂) concentration has been attracting attention as a means of visualizing ventilation. When people are in a room, CO₂ is rapidly generated by their breathing, and if the ventilation is inadequate, the CO₂ concentration in the room will increase. By measuring this, it is expected to determine how well ventilation is working.

High CO₂ concentrations are known to have adverse effects on the human body, such as headaches, dizziness, and nausea, and have also been linked to poor concentration and even falling asleep in class [7]. The Ministry of Education, Culture, Sports, Science and Technology recommends that the concentration of CO₂ in classrooms should be 1,500 ppm or less [8], and the Ministry of Health, Labor and Welfare stipulates that the concentration should be 1,000 ppm or less [9]. Therefore, in buildings of a certain size, CO₂ concentration is monitored, and ventilation control is considered to be based on it. However, this criterion is not based on the presence or absence of ventilation, but on the extent of the CO₂ concentration, and is intended to prevent health hazards caused by high CO₂ concentrations. On the other hand, when focusing on ventilation, the increase or decrease in CO₂ concentration is more important than the increase or decrease in concentration, and ventilation control has not been implemented from this perspective. In addition, the increase or decrease of CO₂ depends on the movement of people

in and out of the room, and ventilation is affected by temperature and humidity, making uniform control difficult.

Therefore, in this study, we decided to start by placing CO₂ measurement devices in classrooms to capture the daily increase and decrease patterns. Then, we identified the problems and risks of the current ventilation system to realize more effective ventilation in the face-to-face environment. In addition, we conducted short-term monitoring of events and studied how we could apply this information to individual responses.

Figure 1 shows schematically the relationship between ventilation and CO₂ concentration. When there are people in the room, the amount of CO₂ emitted by breathing increases with time, but it reaches equilibrium at a certain concentration when ventilation is provided to some extent. As the number of people in the room increases, the amount of CO₂ emitted increases and the concentration also rises, but if sufficient ventilation is provided, the concentration soon reaches equilibrium or decreases as in the upper row. On the other hand, if the number of people in the room is small but ventilation is inadequate, the CO₂ emitted by people is not discharged outside the room, and the concentration continues to increase. The right case is the most problematic because microdroplets contained in exhaled air remain in the room for a long time even if the number of people is small, and the risk of infection is considered to be high if there are infected people present. However, with conventional building air conditioning control, the problem will not be noticed until it reaches the environmental hygiene management standard (1,000 ppm), and there is a strong possibility that ventilation will not occur. On the other hand, it is not practical to forcibly ventilate all rooms. A large amount of outside air will affect the temperature and humidity in the room, and the power consumption of the air conditioning system, including heating, cooling, and humidification, may significantly increase.

As described above, an air conditioning control that balances infection control (ventilation), maintenance of the building environment (temperature and humidity), and economic efficiency (reduction of electricity consumption) is not an easy task, and the solution will require observation of actual room usage and air conditioning circumstance to establish a pattern.

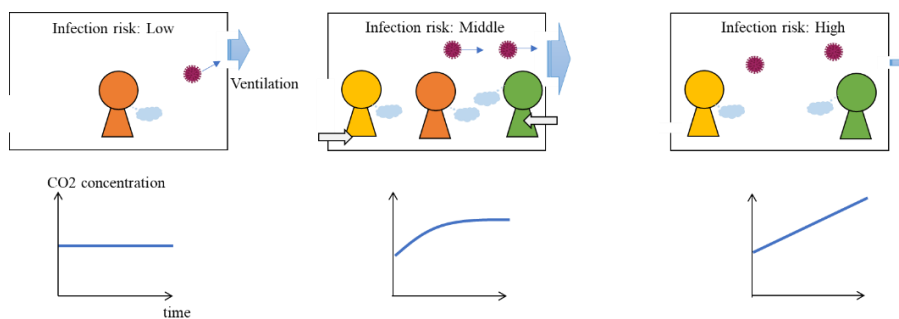


Fig. 1. Relationship between CO₂ and ventilation

3 Measurement System

The non-dispersive infrared (NDIR) method is a typical method of CO₂ detection, but the measuring instruments are relatively expensive. Some inexpensive measuring instruments estimate and calculate the equivalent CO₂ from the concentration of volatile organic compounds (VOCs) (especially ethanol concentration), which poses a problem with accuracy [10]. In addition, most of the measuring instruments on the market do not have a log function and only display the measured value at the time, making it difficult to capture the trend of increase or decrease. Therefore, we decided to build a prototype measuring instrument using an NDIR CO₂ sensor device. We obtained sensor devices, *SCD30* (<https://www.sensirion.com/jp/environmental-sensors/carbon-dioxide-sensors/carbon-dioxide-sensors-scd30/>), which is also able to measure temperature and humidity simultaneously.

We used the *M5StickC Plus* (https://docs.m5stack.com/en/core/m5stickc_plus) microcontroller for the sensor gateway. *M5StickC Plus* is an IoT development board using *ESP32* as the microcontroller chip and has a small LCD screen and Wi-Fi communication functions. We also use *Ambient* (<https://ambidata.io/>) as an IoT cloud network service to gather and visualize sensor data.

The system configuration is shown in Figure 2. *SCD30* sensor data is measured by *M5StickC Plus* via I2C interfaces, periodically sent to *Ambient* via Wi-Fi, and displayed as a graph on a web browser.

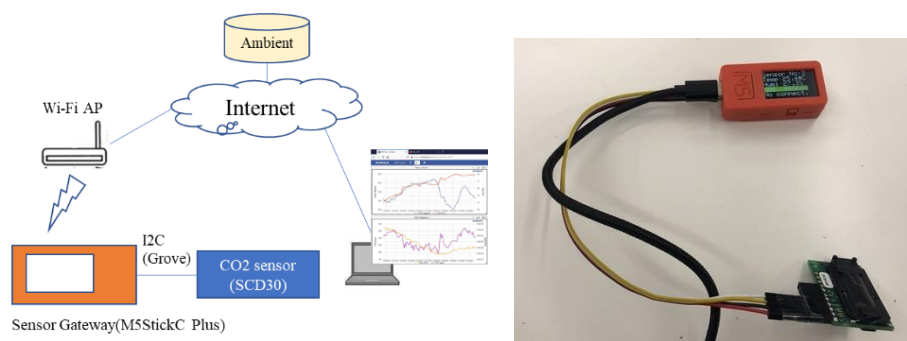


Fig. 2. System configuration and overview

4 Experiments

4.1 Measurement at an Event

Since it is necessary to find the best solution for air conditioning control of classrooms in regular use while considering the economic efficiency of the entire building, it is not easy to respond to individual cases. Therefore, we conducted a trial of CO₂ monitoring and response during events targeting the entrance examinations (for candidate students) and routine examinations (for current students), which are major events at universities.

Figure 3 shows the overall examination implementation system for entrance examination: three prototype measuring instruments were installed at the examination sites (paper test room, interview test room, and anteroom), and the measurement results were monitored and displayed centrally in the examination office. In the case of the routine examinations, two paper test rooms were used simultaneously although there were no interview tests.

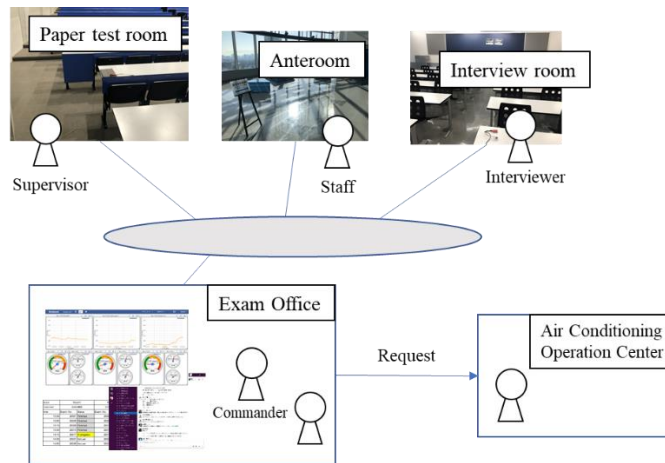


Fig. 3. Response structure for exams

The examination office and the staff at the examination site (supervisors, interviewers, guidance staff, etc.) used *Slack* to communicate, and a system was created in which the examination office and staff could share the progress of the test and changes in CO₂ concentration. If there was a problem, the commander could identify it immediately and take appropriate action (such as contacting the air conditioning operation center). An example of comments in *Slack* is shown in Figure 4.

The instruments were installed on the morning of the examination day to stabilize the measurement values. The measurement interval was set to 30 seconds. The measurement results of three instruments were shown in a single browser window using graphs and meters. An example of the measurement view is shown in Figure 5.

The total view design in the examination office is constructed by referring to the emergency management concept of “Plan/Do/See,” which was implemented to the emergency management support system “KADAN.” [11] The *Slack* acts as the “Do” screen, and the CO₂ view acts as the “See” screen. The “Plan” screen is also implemented, but on a simple Excel sheet as a program progress list.

The experiment was conducted on the entrance examinations (one comprehensive selection, four general selection) and the routine examinations held from January to March, 2021. Table 2 shows the number of comments on *Slack* during the examinations and the number of comments on the topic of CO₂ concentration. The number of com-

ments divided into threads is counted for each comment. The number of responses indicates the number of requests for increasing ventilation to the air conditioning control center of the building.

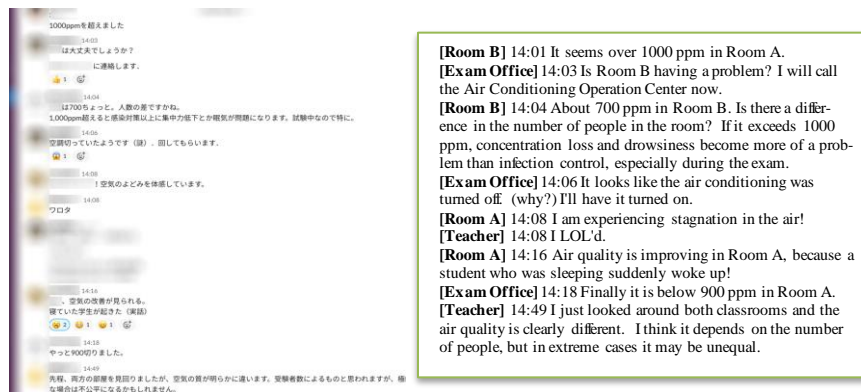


Fig. 4. Example of comments in *Slack* (English translations are shown on the right)

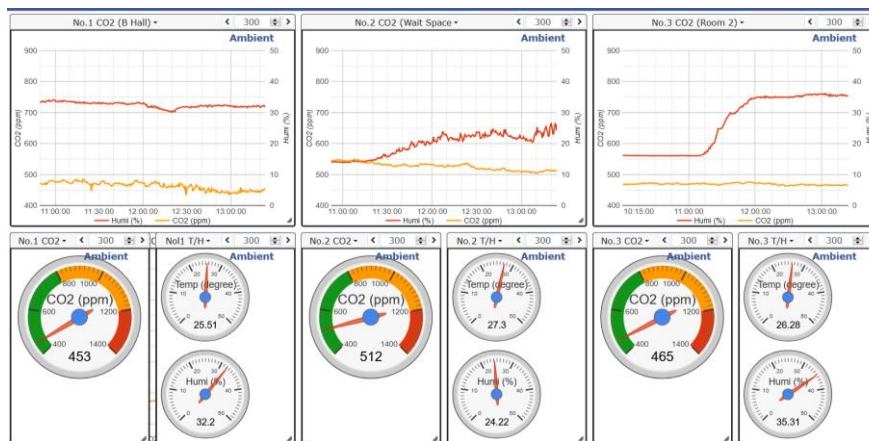


Fig. 5. Example of the CO₂ view in the examination office

For the entrance examinations, *Slack* was divided into two channels: one for the overall management and the other for the interview rooms, but only the data from the overall management channel is counted because the latter was specialized for managing the progress of the interviews. For the routine exam, we also had two separate channels, one for general management and the other for the exam room, but since this was only a written exam, the exam room channel was also used for general management, so only the data from the exam room channel is counted. For the entrance exam, CO₂-related comments accounted for 27.6% and 21.8%, respectively, of the data for the routine exam, suggesting that CO₂-related comments made a significant contribution to the management of the exam.

Table 2. Number of comments in *Slack*

| Exam type | Total comments | CO ₂ -related comments | Number of responses for ventilations |
|---------------|----------------|-----------------------------------|--------------------------------------|
| Comprehensive | 39 | 13 | 3 |
| General 1 | 31 | 8 | 1 |
| General 2 | 49 | 13 | 1 |
| General 3 | 24 | 4 | 0 |
| General 4 | 20 | 7 | 1 |
| Routine 1 | 113 | 27 | 1 |
| Routine 2 | 74 | 13 | 1 |
| Routine 3 | 5 | 2 | 0 |

During the entrance examination on January 30, the CO₂ concentration in the paper test room was slightly high before the examination began, so we asked the air conditioning control center to increase ventilation. As a result, the CO₂ concentration improved, but the classroom suddenly began to dry out, and the humidity dropped below 10% during the test. The air conditioning control center was urgently requested to operate the humidifier. This was a valuable lesson that monitoring ventilation alone is not enough. In subsequent examinations, the balance with humidity was maintained, and the need for monitoring each individually in the written examination room was almost eliminated.

However, another problem arose in the interview room. There were two interviewers in a classroom with a capacity of about 40 people, and the number of examinees was few (one examinee for the comprehensive selection and five for the general selection). However, when the interviewer entered the test room, the CO₂ concentration began to rise and continued to rise throughout the interview test, which means a higher-risk situation, as shown in Figure 1. As a result, the increase in CO₂ concentration was noticed during the first set of interviews and enhanced ventilation was requested, and the CO₂ concentration finally leveled off or started to decrease after the second set of interviews (Figure 6, left). It is highly possible that the students were so relieved by the sufficiently low concentration that they did not increase ventilation, and it is necessary to review the operation of the room by consciously starting ventilation just before the start of the examination.

For the routine exam, since it was a routine event for current students only, the exam office did not take any special measures at first; however, the increase in CO₂ concentration was more pronounced than for the entrance exam, and the commander had to request the air conditioning control center to take action urgently (Figure 9, right). In addition to the report of the increase in concentration, there were mentions of the stagnant air and the degree of concentration of the students.

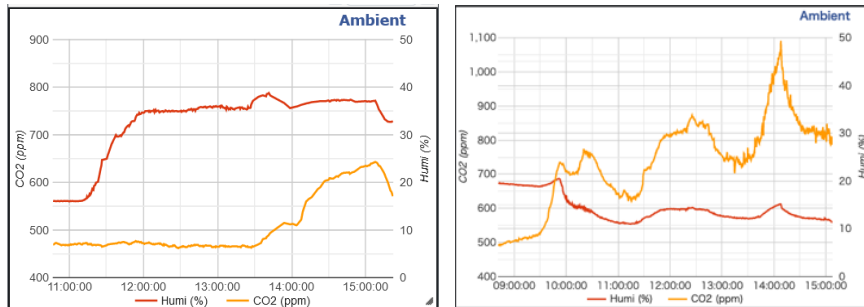


Fig. 6. Example of CO₂ measurement during exams

4.2 Measurement of the Whole Campus

Under normal circumstances, classes are held in many classrooms at the same time, and it is difficult to request ventilation measures for each classroom as described above. Therefore, we aimed to familiarize ourselves with the overall situation of ventilation in the building by observing changes in CO₂ concentration in multiple classrooms at the same time, to enable us to get risk awareness and to take appropriate measures.

As an experiment, CO₂ measurement instruments were installed in six classrooms (two classrooms on each of three floors), and an example of how the situation can be monitored is shown in Figure 7. Measurements were taken at 2-minute intervals, and bar graphs were displayed to make it easier to notice any sharp increase in CO₂ concentration (which means increased infection risk). This graph can be viewed online at any time by faculty members, and when ventilation is insufficient, they can see the overall situation, including the situation in surrounding rooms, and take measures such as switching the priority of ventilation between classrooms or temporarily evacuating to another classroom.

We have started to evaluate the operation of the system; however, due to the spread of cases of infection in Tokyo, the number of hybrid classes has been down, which means the frequency of face-to-face classes has been reduced. Therefore, we have not yet had a chance to take specific actions.

As another means of getting risk awareness, we have begun to experiment with the use of electronic bulletin board displays (LED matrix arrays), which are expected to enable faculty and students to notice risks by viewing them in classrooms and corridors without having to open their PCs or smartphones, especially since web-based viewing takes up a large area of the PC screen and interferes with classes. The figure shows an example of the display, with arrows indicating the increase or decrease in addition to the CO₂ concentration in the room.



Fig. 7. Risk visualization on multiple classrooms. The capacity of rooms 371, 374, 361, and 351 is about 100 seats, while 364 and 354 are laboratory-style rooms with about 40 seats



Fig. 8. Risk visualization using an LED matrix array

5 Conclusion

By measuring CO₂ concentrations during classes and examinations on a university campus in a high-rise building, we attempted to understand the risk of COVID-19 infection from the viewpoint of ventilation and to actively utilize the results for responses. Through the measurement, it became clear that the pattern of increase and decrease in CO₂ concentration is not so simple to evaluate, and visualization showed that it can be used for risk situation awareness and proactive response to ventilation control.

In the future, by installing sensors in a wider area, we will construct an environment in which we can grasp the risk situation from both an aspectual and temporal perspective and study the possibility of realizing an environment in which students can take face-to-face classes and examinations safely.

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