

A Usage and Analysis of Measured CO_2 Levels in Japanese Community Buses with IoT Sensors

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Abstract. Since 2020, COVID-19 has raged throughout the world, and with recommendations to open windows and ventilate enclosed spaces, such as buses and trains, attention has been drawn to the issue of indoor environmental pollution. Therefore, it was hypothesized that measuring and reporting the air quality inside buses would allow passengers peace of mind. In this research, Internet of Things (IoT) sensors were installed inside buses, and the measured data were analyzed. With the cooperation of Sue Town in Japan, IoT sensors were installed in regional public transportation systems (i.e., Japanese Community Buses) and data that temperature, humidity, CO_2, noise, and pressure were collected. The measured data were displayed in real-time on signage inside the bus. As a preliminary step to predict the ability of the buses to maintain normal air quality inside the vehicles at all times, data accumulated on three buses over a six-month period were analyzed.

Keywords: Community Bus · Regional Public Transportation · CO_2 · IoT Sensor · Analysis · Usage

1 Introduction

Buses play a central role in public transportation systems in the regional cities of Japan, particularly those that primarily consist of buses operating within specific regions. However, the number of regional public transportation service users is on the decline due to competition with private cars. This is particularly true for buses that primarily operate within a given region, as opposed to buses that link cities. Even given this competition, there are expectations that buses will continue to play a central role in regional public transportation, as a means to address environmental issues and cater to an aging society. In particular, community buses and demand-driven transportation, which are operated mainly by local governments, play a vital role in Japan [1], where over 40% of the population is expected to consist of elderly citizens, over 65 years old, by 2050. Thus, buses operated primarily by local governments are highly important for social welfare.

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Since 2020, when the COVID-19 pandemic first started, the spread of a new approach was seen, which differs from conventional wisdom. There have been recommendations [2] to open windows and ventilate the confined spaces in buses and railways, and this has drawn attention to indoor environmental pollution. In particular, the concentration of CO_2 emitted by humans has been used as a barometer for measuring indoor environmental pollution. Many recommendations and studies have used this metric, due to the widespread use of sensors and the ease of measurement.

This research team collaborated with more than 10 local authorities within Fukuoka Prefecture in Japan and carried out activities to support regional public transportation on buses and ferries. The support activities included posting route information on Google Maps, through the maintenance of General Transit Feed Specification (GTFS), a system for collecting and displaying location information on buses in real-time, as well as the summary and analysis of a passenger survey application [3–6]. Community buses operated by local governments often have a capacity of 30 or fewer people, and there are concerns about the risk of pollution to the indoor environment. It was considered necessary, therefore, to collect environmental information within the bus in real-time, and communicate this both to passengers who have already boarded and those who are about to board.

In this paper, as a preliminary step to determining how to maintain normal air conditions inside the vehicle at all times, the measured data from inside the bus were analyzed. With the cooperation of the Sue Town, in Kasuya-gun, Fukuoka Prefecture, Internet of Things (IoT) sensors were installed for periods of up to six months, collecting data on the environment inside community buses, and said data were analyzed. In Sect. 2, related research is introduced. In Sect. 3, in addition to providing an overview of the Sue Town and the community buses, an explanation is given regarding the installation of the IoT sensors. In Sect. 4, the data collected by the IoT sensors are analyzed, and a summary is provided in Sect. 5.

2 Related Works

Chun-Fu Chiu et al. [7] investigated whether the accident ratio increased as the concentration of CO_2 within the bus increased. Verification was performed by measuring the CO_2 concentrations and temperature within three tour buses with a passenger capacity of 43 people during a three-day/two-night school excursion. The results of the verification indicated that the CO_2 concentration greatly exceeded the standard values. As the air in the air conditioners within the tour buses circulated, there was a significant lack of air being exchanged with the outside air, and the researchers warned that this may have a negative effect on transportation safety. This suggests that increasing the opportunities for ventilation within tour buses would maintain safety during travel, and would be extremely beneficial for increasing the quality of the trip.

Kevin Weekly et al. [8] developed data-driven partial differential equations and ordinary differential equation models to predict the respective CO_2 concentrations in conference rooms resulting from a human presence or user-controlled

ambient CO_2. Three cases were considered, and an actual conference room was used for the simulation. For the estimation of exogenous inputs, CO_2 concentrations were measured at two indoor locations, and these were used for the design and validation of a model-based observer.

Andrzej Gajewski [9] discussed the quality of air inside a bus. An experiment was performed in which 24 passengers and one driver boarded a bus, and the CO_2 concentration was measured on the outbound and inbound routes. On the outbound route, the concentration of CO_2 exceeded the allowable limit of 1,000 ppm, whereas, on the inbound route, a maximum of 2,400 ppm was measured. Based on the result of the experiment, an analysis was performed, calculating the ratio of fresh air required to satisfy the standard allowable limit.

3 Measurement Environment

The measurements of environmental data within a regional public transportation service were taken on Sue Town community buses. Therefore, Sue Town, the community bus, and the IoT sensors used for measurement will be introduced in this section.

3.1 Sue Town

Sue Town [10] is located slightly northwest of the central region of Fukuoka Prefecture, approximately 10 km east of Fukuoka City. It is bordered by towns on all four sides. It has a total area of 16.31 km^2 comprised of 7.1 km east to west, and 4 km north to south. The Sue River flows from east to west through the center of town, and the central region is in the southwest part of town. In the western region of the town is Mt. Bota, which straddles the towns of Kasuya and Shime. The northwestern and southwestern parts of Sue Town have been increasingly developed in recent years as a bedroom community for Fukuoka City. The population, as of April 2022, was 28,840, and three prefectural roads pass through the town, functioning as arterial roads. The Kyushu Expressway was established to run through the town, and the Sue parking area was established on both the inbound and outbound roads. In the parking area, a national social experiment called the Sue Smart Interchange (limited to mini and standard-sized vehicles equipped with ETC on board equipment) was conducted and is now in full operation following the experiment's completion in October 2006. This Sue Smart Interchange has become entrenched in the community and is viewed as an important facility essential for life in the region. In addition, three JR railway lines pass through the town, and there are three stations in town: JR Sue-Chuo Station, JR Shimbaru Station, and JR Sue Station. Three bus routes are operated by the main transportation company in the prefecture, Nishi-Nippon Railroad Bus, and these connect Fukuoka Airport and Fukuoka City. Furthermore, the community bus operation started in February 2010, which aimed to supplement regional transportation in areas through which the railway or bus routes did not pass.

3.2 Community Bus

Community buses in Japan are planned for and operated by local governments in order to eliminate transportation gaps and inconvenience. Unlike bus routes operated by corporations, which are the mainstay of public transportation in metropolitan areas and core regional cities, community buses are not intended to make profits. The main objectives are to fill the blank areas or areas where buses are not convenient, to provide an alternative to commuting by car, to support the elderly and disabled in areas lacking welfare bus services, and to connect and revitalize commercial facilities in the city center.

In Sue Town, five buses, including one held in reserve, operate from the base point of Sue Town Hall (Fig. 1). The passenger capacity ranges from nine to 28 people depending on the bus (Table 1). The number of bus runs is a maximum of 10 per day, and the buses run every day except for weekends and public holidays, as well as the period at the end/start of the year. Rather than being operated by Sue Town directly, all operations are outsourced by Sue Town to taxi operators within the town. There are seven routes in total, including routes running from the central region of the town to the outskirts, and routes confined to the central region (Table 2). In terms of the number of bus stops, route 1 has 20, route 2 has 13, route 3 has 15, route 4 has 14, route 5 has 20, route 6 has 10, and route 7 also has 10. All buses start from the welfare center in the center of the town, and after visiting the designated bus stops, return to the welfare center (Fig. 2). The Sue Town community buses are operated such that one bus straddles multiple routes. For example, the PINK bus follows a fixed route order every day: $3 \rightarrow 3 \rightarrow 7 \rightarrow 3 \rightarrow 3 \rightarrow 3 \rightarrow 7 \rightarrow 3 \rightarrow 7 \rightarrow 3 \rightarrow 3$.

The Toyota HIACE buses are allocated to route 6, where there are many narrow streets, because of the ability to turn in a small radius. The fare is fixed at 100 yen per person, and the charge is reduced for children of elementary school age and below, those 65 years old and above, and users with disabilities. Furthermore, the driver records on paper the number of people boarding and alighting from the bus at each bus stop.

Table 1. Summary of Sue Town community buses.

Bus name	Bus type	Passenger capacity
PINK	Pon'cho	24
BLUE	Pon'cho	26
GREEN	Pon'cho	26
SILVER	HIACE	9
(Reserve bus)	(Reserve bus)	28

3.3 IoT Sensors

IoT sensors were installed in three of the Hino Pon'cho community buses (PINK, BLUE, and GREEN), which had a comparatively high degree of spare capacity



Fig. 1. Sue Town community bus vehicles.

Table 2. Operating routes.

Route No.	Route name	No. of bus stops
1	Ichibanda-Kami-Sue route	20
2	Otsuueki-Sue-Shiroyama route	13
3	Tabiishi-Yamanokami-Shimbaru route	15
4	Satani-Kawago route	14
5	Satani-Kenshoji route	20
6	Hirabaru-Oma route	10
7	Central circulation route	10

in terms of space and electricity. The sensors were installed on top of the front and rear handrails within the vehicles so that the passengers would not touch them by accident. Netatmo [11] IoT sensors were used, which come in a pair con-

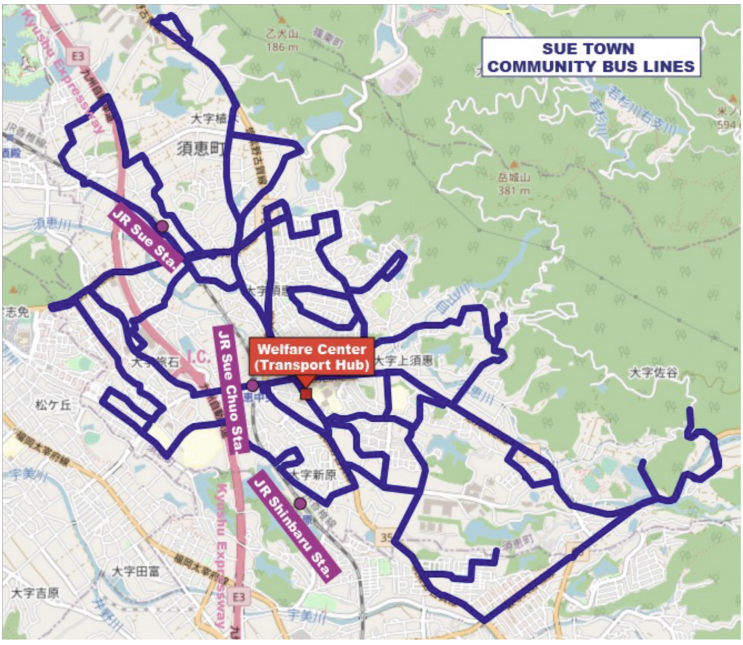

Fig. 2. Route map that includes seven lines.

sisting of a main unit supplied with electricity via USB, and a battery-powered handset. The main unit is able to measure temperature, humidity, CO_2, noise, and pressure, whereas the handset can only measure temperature, humidity, and CO_2. The measured data were uploaded and stored on the Netatmo Cloud every 10 minutes. In addition to being able to confirm the accumulated data through graphs and figures using a dedicated application or website, it is also possible to download the accumulated data through the prepared API. The main unit was installed at the front of the bus and the handset was installed at the back. The bus installation locations and images of the installed sensors are shown in Fig. 3. In addition, an in-vehicle Wi-Fi router [12] was installed inside the bus to facilitate automatically sending the data to the Netatmo Cloud via the Internet. The installation periods for the IoT sensors were March 2021, November 2020, and September 2021 for the PINK, BLUE, and GREEN buses, respectively. As all buses undergo repairs several times a year, data could not be acquired during those periods.

4 Usage and Analysis of IoT Sensor Data

4.1 Data Usage

A prototype of the digital signage was installed on the GREEN bus. An image of the actual digital signage is shown in Fig. 4. Within the digital signage, the

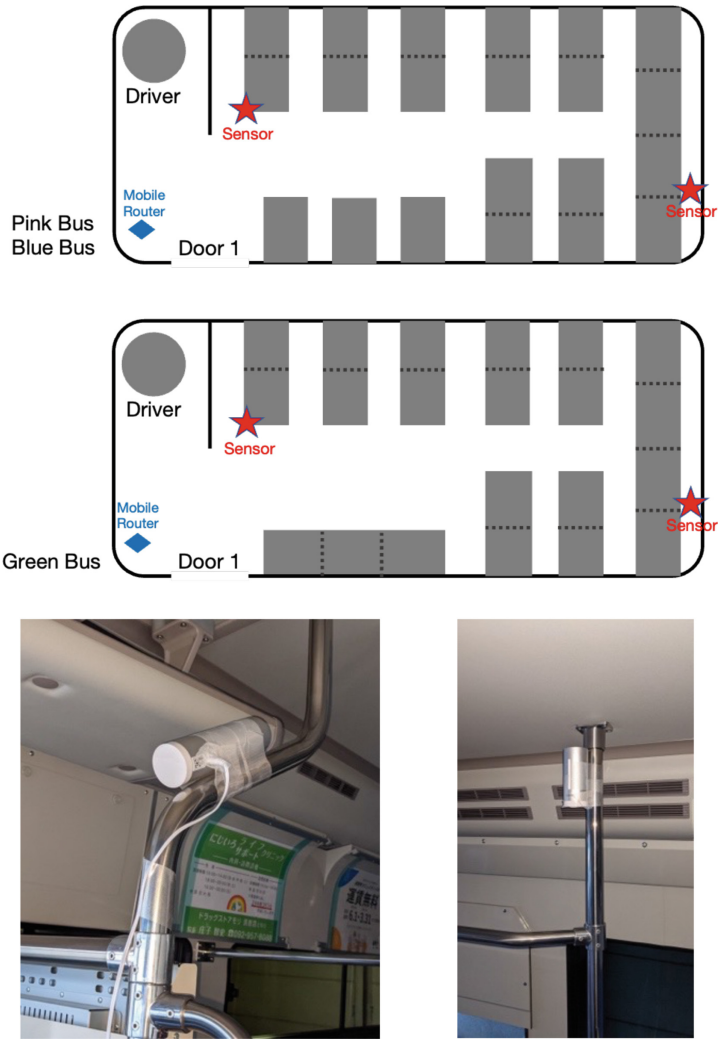

Fig. 3. IoT sensor installation locations and images.

current location is derived from location information obtained separately from the bus location system, and the bus stop guidance and delay information are updated and displayed in real-time. As part of this, the temperature within the bus and the CO_2 value from the Netatmo sensor are displayed in real-time to communicate the state of the environment inside the bus to the passengers. The passengers, by looking at this value and opening or closing the windows, can regulate the CO_2 concentration within the bus. Moving forward, by predicting CO_2 concentration based on the analyzed results, the researchers believe that advance warning can be provided.



Fig. 4. Digital signage monitor within the GREEN bus.

4.2 Data Analysis

An analysis was performed on the data measured using the IoT sensors installed on the Sue Town community buses. Among the measured data, the analysis mainly focused on the CO_2 concentration values.

In Japan, the recommendation of the Ministry of Health, Labor, and Welfare for indoor CO_2 concentration is that it be kept below 1,000 ppm [13]. The European Federation of Air Conditioning Associations [14] has stated the importance of confirming that indoor CO_2 concentration does not exceed the standard value of 1,000 ppm (with a recommended value of 800 ppm). The air environment guidelines for the Hong Kong Environmental Protection Agency [15] recommend an indoor CO_2 concentration of 2500 ppm or below.

Figure 5 shows the measured CO_2 concentration values. The values from the IoT sensors at the front of each bus from the date of installation to March 2022 were rounded and plotted on a line graph in five-minute intervals. The areas where the data is blank are the intervals during which data could not be acquired due to difficulties connecting to the IoT sensors or the Internet, or periods during which the bus was being repaired. In addition, as the values were not stable during the initial phase after installation, the valid periods used were July 1, 2021 to March 30, 2022 for the PINK bus, April 2021 to March 30, 2022 for the BLUE bus, and September 2021 to March 30, 2022 for the GREEN bus. The number of valid data items for the PINK bus was 9,316, with the mean in-vehicle temperature being 24.3% and the mean humidity being 50.7% (maximum 43.7% and 90%, minimum 17.5% and 33%) across all processes. The mean and median values for CO_2 concentration were 967.3 ppm and 335 ppm, respectively, with a maximum value of 2,112 ppm and a minimum value of 555 ppm. The number of valid data items for the BLUE bus was 17,355, with the mean in-vehicle temperature being 24.2% and the mean humidity being 47.4% (maximum 36.6% and 89%, minimum 19.4% and 23%) across all processes. The mean and median values for CO_2 concentration were 923.1 ppm and 335.8 ppm, respectively, with a maximum value of 3,409 ppm and a minimum value of 264.2 ppm. The number of valid data items for the GREEN bus was 16,346, with the mean in-vehicle temperature being 23.1% and the mean humidity being 38.6% (maximum 35.7% and 81%, minimum 1.3% and 19%) across all processes. The mean and median values for CO_2 concentration were 582.7 ppm and 256.3 ppm, respectively, with a maximum value of 1,700 ppm and a minimum value of 0 ppm. Although the CO_2 reference value of 1,000 ppm recommended by the Japanese guidelines and the European Federation of Air Conditioning Associations are exceeded, some of the buses are within the air conditioning environment guidelines of 2500 ppm set by the Hong Kong Environmental Protection Agency. The fact that the periods and number of data items are not proportionate is due to the periods during which the buses were being repaired. As the data volume for the GREEN bus is insufficient, and the blank areas are conspicuous, for this paper, only the data measured from the PINK and BLUE buses were analyzed.

Next, to investigate the transition in CO_2 concentration over time, the CO_2 concentrations for the valid period were wrapped in five-minute intervals and plotted on a heat map (Fig. 6). The reason that there are blank periods during the PINK lunch breaks is that, as the power to the bus was cut, the power to the sensors was also cut, meaning that the data could not be measured. It appears that the CO_2 concentration increases linearly as the number of passengers increases but decreases linearly in a smooth manner when the doors are opened or when the number of passengers decreases. Furthermore, in areas where the values are exceptionally low, this is likely when the doors were left open during the gaps when changing routes. During the period as a whole, the PINK bus had a CO_2 concentration of 2,500 ppm in specific timeframes three or four

times in the mornings and four times in the afternoons, and these are seen as the peak values. The BLUE bus had a CO_2 concentration of around 3,000 ppm once each in the morning and afternoon (09:00-11:00, 13:00-16:00), which was the peak value. Thus, routine multiple increases in CO_2 concentration followed by decreases during a single day of operation is the cycle repeated throughout the seasons, though there may be some seasonal variation. The route each bus takes throughout the day is fixed, and so this is thought to be related to whether there are boarding or alighting passengers at specific bus stops.

Therefore, to consider the relationship between the season, CO_2 concentration, and temperature within the vehicle, a scatter diagram plotting the relationship between CO_2 concentration and vehicle temperature for the summer (July) and winter (January) is shown (Fig. 7). The mean and median temperatures within the PINK bus in the summer were 24.6 °C and 24.8 °C, respectively. In contrast, in the winter the respective mean and median temperatures were 23.2 °C and 23.7 °C. Furthermore, the mean CO_2 concentration in the summer was 971.3 ppm and the median was 940 ppm, whereas in the winter the mean was 746 ppm and the median was 664 ppm. The mean and median temperatures within the BLUE bus in the summer were 24.6 °C and 23.9 °C, respectively, whereas in the winter the respective mean and median temperatures were 24.4 °C and 24.8 °C. The mean CO_2 concentration in the summer was 1,026.6 ppm and the median was 1037 ppm, whereas in the winter the mean was 860 ppm and the median was 793 ppm. Although the distribution trends were the same regardless of the season, both temperature and CO_2 concentration tended to be higher in the winter than in the summer. These characteristics were similar for both the PINK and BLUE buses.

Thus, although the values varied according to the season, the distribution trends between in-vehicle temperature and CO_2 concentration were extremely similar. The variation in the CO_2 concentration measured during one day of operation was verified. When confirming the variation, by comparing this with the number of passengers, for which there is considered to be an extremely close relationship with CO_2 concentration variation, it was possible to analyze the relationship. When performing the analysis, Sue Town Hall provided the summary data for the number of passengers boarding and alighting the PINK and BLUE buses from March 2020 to September 2021. This summary data contains the number of boarding and alighting passengers recorded by the bus driver at each bus stop. The number of passengers on board the bus was calculated for each bus stop based on the number of boarding and alighting passengers. It was assumed that if the bus arrived at the bus stop at a fixed time and there were no passengers there, the doors were not opened. The CO_2 passenger data for August 29, 2021 is shown in Fig. 8. The mean CO_2 concentration and passenger numbers for every five-minute interval were output and plotted. Service started t 08:20, and the CO_2 concentration gradually increased from that time. The CO_2 concentration was near zero around 12:30 because this was the lunch break

period in which the bus was not in operation. The graph shows that the CO_2 concentration and passenger numbers are linked, with a delay of approximately 1020 minutes. The reason for the error in the transition of CO_2 concentration and passenger numbers is thought to be because, contrary to the number of passengers, which is in non-linear form, the linear CO_2 concentration values are gradually increasing and decreasing. Thus, the increase and decrease in values when boarding or alighting means that the doors were opened and closed and that the CO_2 concentration fell at that time, regardless of the number of passengers. However, if a bus departs with one or more passengers on board, the CO_2 concentration will increase again. The speed of increase in the CO_2 concentration toward the upper limit is faster the more passengers are aboard. Furthermore, the fact that the CO_2 concentration never went below 500 ppm is due to the fact that the driver was always present.

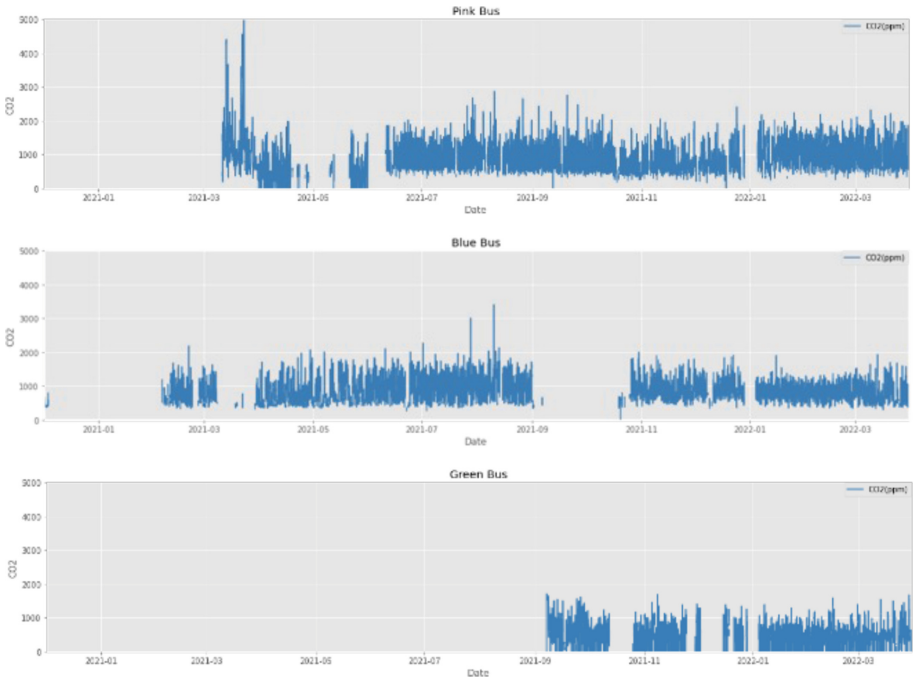

Fig. 5. Measured CO_2 concentration data.

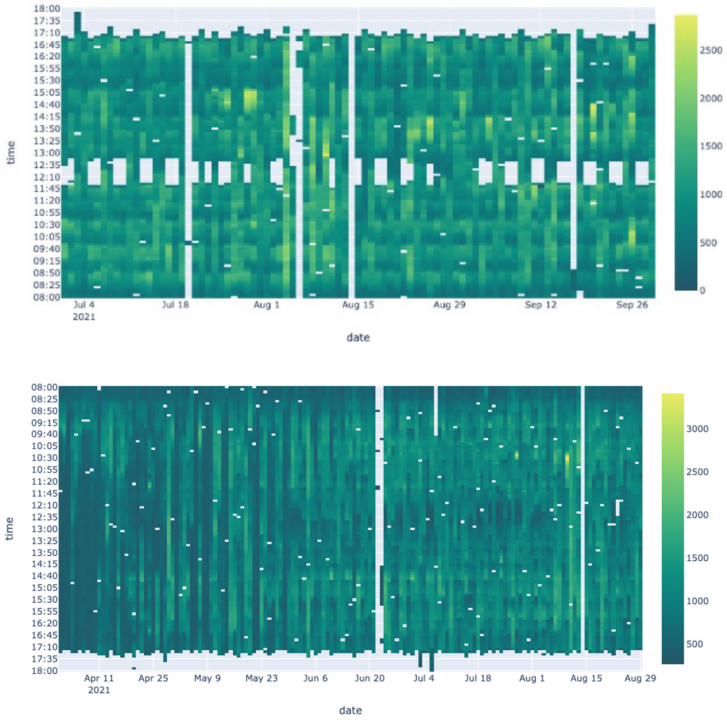

Fig. 6. Five-minute interval heat map.

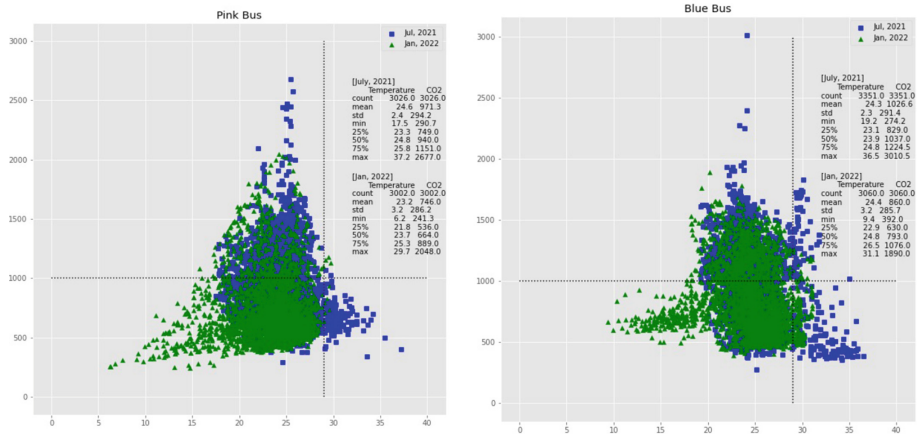

Fig. 7. Relationship between CO_2 concentration and temperature.

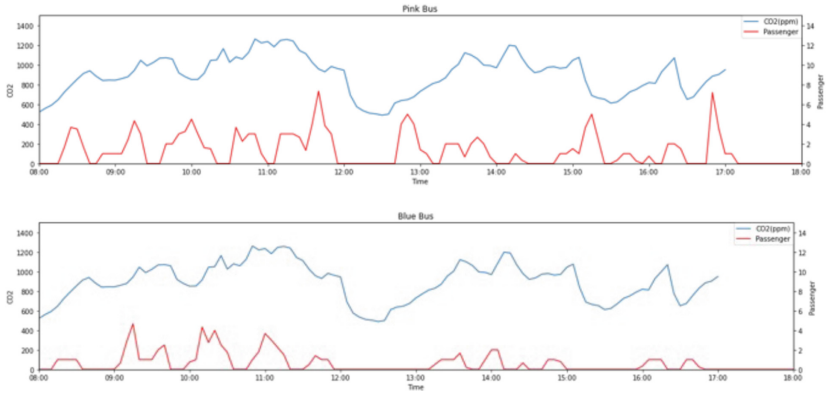

Fig. 8. CO_2 concentration and number of passengers (August 29, 2021).

5 Conclusion

In this study, IoT sensors were installed on three Sue Town community buses to measure environmental data. The CO_2 concentration data are displayed in real-time on a digital signage monitor inside the bus to encourage passengers to ventilate. By analyzing the environmental data measured within the bus, the nature of variations and relationships between the vehicle environment parameters and the number of passengers were derived. In addition, the installed monitor can aid in the avoidance of congestion within the vehicle environment. As a result of analyzing the measured CO_2 concentration data, it was found that the CO_2 concentration increased and decreased based on the season, but in the fixed cycle within one day of operation, variation in the CO_2 concentration clearly occurred. As factors in the variation, the opening and closing of doors with the boarding and alighting of passengers, and the number of passengers who had boarded the bus were identified. Moving forward, the design of an algorithm is being considered to predict CO_2 concentration based on the analyzed results with the aim to publish the predicted CO_2 concentration to passengers in advance.

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