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Health Hazard of Carbon Dioxide

Researchers from various countries, including Japan, Germany, the United States, Sweden, France, and Denmark, have reported evidence on the health hazards of CO_2. When summarised, it has been shown that when the CO_2 concentration exceeds 1,000 ppm, symptoms such as fatigue, headaches, tinnitus, and shortness of breath increase, and the degree of fatigue significantly increases. Additionally, the relationship between the increase in CO_2 concentration in the low concentration range of around 1,000 ppm and in physiological changes in humans (partial pressure of CO_2 in blood, heart rate, etc.) and also in symptoms related to Sick Building Syndrome (SBS) has been demonstrated. The physiological changes in humans are considered to be due to CO_2. However, further verification is needed to determine whether SBS symptoms are due to CO_2 or mixed exposure to other pollutants, particularly in cases of long-term exposure. Nevertheless, these negative health effects can be prevented by keeping indoor CO_2 concentrations in buildings below 1,000 ppm.[1]

A paper that systematically analysed the results of multiple studies on the relationship between CO_2 concentration in elementary school classrooms and students' academic performance, achievement, and absenteeism has been reported by the AIVC,[2] which is an International Information Center on building ventilation and air conditioning technology. The study mainly targeted students from 4th to 6th grades and used various methods. The results showed that cognitive abilities measured by means of psychological tests were better with lower CO_2 concentrations in the range of 889 ppm to 2,000 ppm. When CO_2 concentration decreased from 2,000 ppm to 1,000 ppm, it was estimated that the speed of completing school tasks increased by 12%, mistakes decreased by 3%, and the number of students passing end-of-year promotion exams increased by 12%. This resulted in getting good grades in a six-student per 100 students.

The effect of CO_2 concentration of around 1,000 ppm on labour productivity (decision-making and problem-solving abilities) has also been highlighted by researchers from Harvard University and others in 2016. In that study, the CO_2 concentration in a room was set to 945 ppm or 1,400 ppm, and the higher-order decision-making abilities of participants in a managerial position were compared, using computer software. The results showed that participants in the room with a CO_2 concentration of 1,400 ppm had lower ability in the following situations – "complex thinking", "using information", "paying attention to the situation in hand" and "formulating strategies in emergency situations", compared to those in the room with a CO_2 concentration of 945 ppm.[3]

With the advent of the New Coronavirus pandemic, unprecedented efforts are being made worldwide to make indoor air safer. It is clear that retrofitting existing buildings can be a costly endeavour, but the benefits outweigh the costs. This is discussed in Practical Process for CAP in PointPath-CAP, from the viewpoint of technology (ventilation methods, etc.) and equipment (CO_2 monitors, air conditioners, air purifiers, etc.). (https://pointpath.jp/cap/)

References

1. Kenichi Azuma, 2016. Health Effects of Acute and Prolonged CO2 Exposure in Normal and Sensitive Populations. Indoor Environment 21, 113–121.
2. Pawel Wargocki, José Alí Porras-Salazar and William P. Bahnfleth, 2017. Quantitative relationships between classroom CO_2 concentration and learning in elementary schools: 38th AIVC Conference VENTILATING HEALTHY LOW-ENERGY BUILDINGS, Nottingham, UK, 13–14 September.
3. Joseph G. Allen, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino, and John D. Spengler, 2016. Associations of Cognitive Function Scores for CO_2, Ventilation, and Volatile Organic Compound Exposures in Office Workers. Environ Health Perspectives 124, 805–12.

Pay attention to the changes in indoor CO_2 concentration

Comparing the three infection routes of respiratory infection, the airborne route via the aerosols exhaled by infected person has the highest risk of infection, while droplet and contact transmission are rather low and limited in their situations (see "Guidebook on How to Prevent Respiratory Infections", PointPath-Guide https://pointpath.jp/guide/) . Therefore, to prevent the airborne transmission, maintaining indoor CO_2 concentrations below 1,000 ppm is unlikely to result in anyone being infected.

The risk of infection with the pathogen (virus and bacteria) is thus reduced if ventilation is kept below 1,000 ppm CO_2 concentration. However, when people gather together to converse, or to sleep in a closed room with two or more people, CO_2 emissions can easily exceed 1,000 ppm. If there is an infected person in the room, everyone is at high risk of becoming infected: CO_2 concentration in a sealed room is much higher than you might realise.

Be aware that high levels of CO_2 even in a house with a 24-hour ventilation system because CO_2 can frequently exceed 1,000 ppm when, as mentioned before, two or more people are sleeping in the same room. You can find an example illustrating this in Figure 1.

It is common in certain situations, such as on trains, buses and airplanes, in day-care centres, schools, workplaces, restaurants, etc. that CO_2 concentrations can quickly exceed 1,000 ppm (see Table 1, Figure 2 and 3).

Ventilation becomes inadequate without any of the occupants noticing it. The risk of airborne infection can hide, anywhere, at any time. Therefore, it is important to make sure that everyone knows what the CO_2 concentration is. Monitoring of CO_2 concentration is recommended.

In addition, newly developed APP, CAP-AI, help you know your infection risk intensity from the CO_2 concentration or ventilation rate (see CAP-AI site, PointPath-Land https://pointpath.jp/cap-ai/).

Ventilation must be controlled when the number exceeds 1,000 ppm. If we do this successfully, we will no longer be exposed to unnecessary increase of infection risk.

Examples of CO_2 Concentration Measurement

Here we introduce examples of measuring CO_2 concentration using a CO_2 monitor in various locations, at various times, and in different environments. The methods and accuracy of measurements may differ. Please refer to them as examples of indicators of CO_2 concentration changes. You will see how easily the CO_2 concentration fluctuates and how often it leads to unnoticed insufficient ventilation. To prevent insufficient ventilation, it becomes obvious that the installation of CO_2 monitors is necessary wherever people get together, including homes, workplaces, all means of transport, shops, and community facilities.

Bedroom

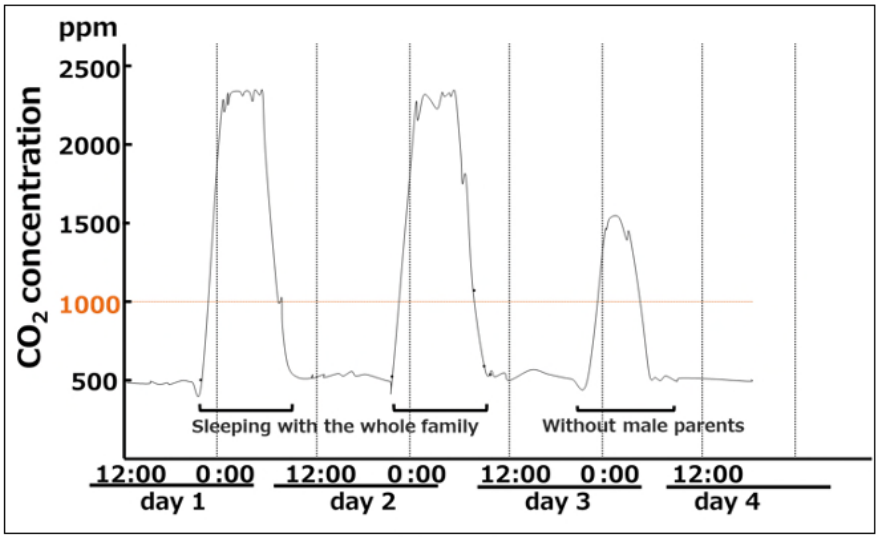

Figure 1 Changes in CO_2 concentration in a bedroom: Example of Family A with parents and two children

Family A lives in a two-storey house with 24-hour ventilation. In a 20 m^2 bedroom, a family of four usually sleeps. A CO_2 monitor is placed in the bedroom to measure CO_2 concentration for four consecutive days.

1) Day 1 and Day 2: On the 1st and 2nd day, four family members go to bed around 10 o'clock. The CO_2 value, which was initially about 500 ppm, surged to about 1,800 ppm at midnight, to about 2,300 ppm at 1 o'clock, and to around 2,300 ppm by 6 o'clock. It drops sharply as the parents wake up and leave the bedroom. The others get up and the CO_2 value drops to 500 ppm when everyone has left.

2) Day 3 and Day 4: On the third day, one parent is absent, and the peak value is 1,500 ppm. Other values fluctuate in the same pattern as Days 1−2.

(Adapted and modified from Figure 11: Change of carbon dioxide levels during sleep, Yoshihiro Sugiyama, Marushichi House)

Table 1 Changes in CO_2 concentration inside trains, Shinkansen (bullet trains), and aeroplanes are as follows

TP	Type	No. of passengers	Conditions	CO_2 ppm
T	Com	on a two-person seat	Occupying half of the area	696
	Com	on a long seat	Occupying one-fifth of the area	479
	Com	20 passengers	1/2 of the seats occupied	660
	Exp	15 passengers	1/2 of the seats occupied	600
	Com	Full occupancy	Not close together – spaced	1417
	SX	12 passengers	1/4 of the seats occupied	797
	SX	35 passengers	2/3 of the seats occupied	1010
B	Bullet	40 passengers	2/5 of the seats occupied	723
	Bullet	5 passengers on the 1st train to depart	1/20 of the seats occupied	483
A	A1	Approximately 150 passengers on the aircraft (fully occupied)	Just after boarding	1548
			Before takeoff	2107
			Seatbelt sign turned off	1244
			In level flight	957
			In level flight	943
			Seatbelt sign illuminated before landing	1097
			After landing	1440
			5 minutes after landing	2738
	A2	Approximately 50 passengers on the aircraft (⅓ occupied)	Just after boarding	700
			Before takeoff	1231
			Seatbelt sign turned off	959
			In level flight	740
			In level flight	709
			Seatbelt sign illuminated before landing	845
			After landing	909
			5 minutes after landing	1073

TP = Transportation, T = Train, B = Bullet train, A = Airplane,
Com = Commuter train, Exp = Express train, SX = Super Express train,
A1 = Airplane 1, A2 = Airplane 2.
(Adopted and modified from CO_2 Monitor Dissemination Association Website https://CO_2.theshop.jp/)

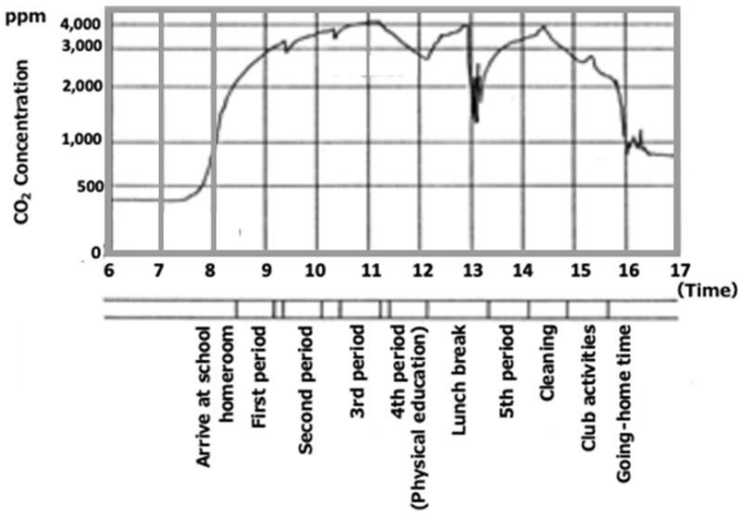

Figure 2 The changes in window ventilation and CO_2 concentration in elementary school classrooms

This presents the measurement results of CO_2 concentration in an elementary school C classroom which is heated by electric radiators. When students enter the classroom in the morning, the CO_2 concentration rises, reaching a peak of approximately 4,000 ppm. Opening the windows during break time helps reduce the concentration, but it does not go below 1,000 ppm. [Issues and measures regarding thermal and air environment in schools – Creating an environment for children to learn comfortably and stay healthy – by Motohisa Hayashi: Ventilation and Air Conditioning Sub-Committee, Environmental Engineering Committee, Architectural Institute of Japan (March 2015)]

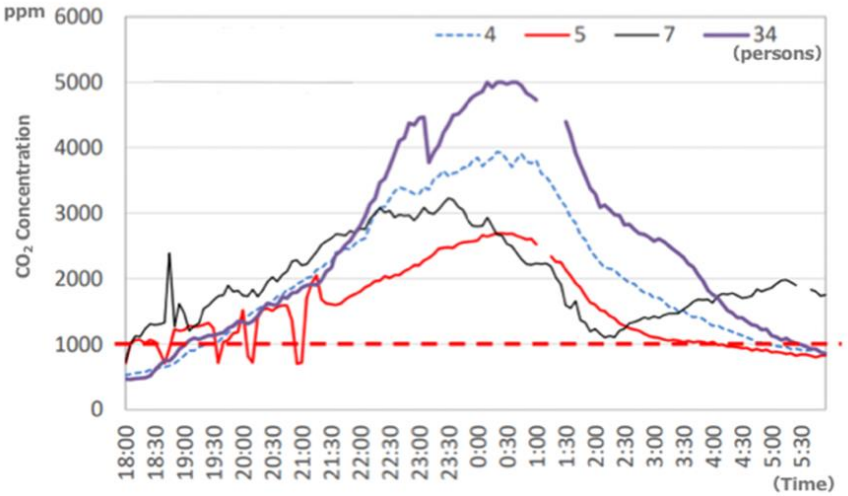

Figure 3 The changes in CO_2 concentration in a nightclub in Japan

In nightclubs located in major cities in Japan, there were dining receptions with four to 34 people. The CO_2 concentration in each room was measured, and its variations were examined. The peak of CO_2 concentration occurred around midnight to 2 am, reaching levels of 3,000 to 5,000 ppm.
[Adopted from Survey on ventilation, indoor environment, and measurement against COVID-19 in clubs and bars (Part 1): Overview of building facilities, ventilation condition and infection status, Kim, H., *et al. J Environ Eng, AIJ*, Vol. 88, No. 806, pp 300–306 (April 2023)]