Practical Process for CAP

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Wherever there are indoor spaces in which people come together, and there is good ventilation through constant fresh air, the COVID-19 pandemic will end. In such an environment, it will always be possible to live without worrying about COVID-19.

By maintaining this setting, not only can COVID-19 be overcome, but it will also be possible to conquer respiratory infections such as influenza, colds, and pneumonia, as well as tuberculosis and measles etc. Concerns about these illnesses will be a thing of the past.

The movement towards measuring CO_2 concentration as an indicator of how much fresh outdoor air replaces indoor air, and how to manage ventilation, has gained worldwide momentum.[2]

Originally, procedures to maintain fresh air ventilation were carried out in each country as measures solely against indoor air pollution and its negative health effects. However, with the arrival of the COVID-19 pandemic, many countries such as Belgium, the UK, the United States, and Japan started to implement them also as measures to prevent infection.

The practical process of carrying out CAP will involve a system of *ventilation* for introducing fresh air indoors and emitting the pollutants outside. How to achieve this involves installing CO_2 systems or constructing buildings with adequately equipped operational CO_2 *monitors* which can detect insufficient ventilation and regulate it.

In carrying out the CAP procedures, the necessary equipment, devices, and operating systems will be backed up and supported by advanced science and technology. Such back-up has already been developed. Given that the procedures have previously been put in place and are in operation on many building sites, adding a CO_2 concentration monitoring and ventilation control system to existing systems makes CAP extremely feasible (Figure 1).

Therefore, it is possible to initiate a process that starts at the individual level, which then gradually improves the current situation, in accordance with the regional conditions. This can then ultimately lead on to a much wider successful CAP program. Many challenges to improving ventilation systems and to improving buildings lie ahead. In many cases, existing buildings need to be updated. This can be a costly undertaking. However, the benefits obtained from such efforts greatly outweigh the costs.

To take this example, the UK spent an average of £2.3 billion (US$2.7 billion, 324 billion yen) per year in response to the outbreaks of the COVID-19 pandemic and seasonal influenza. It is estimated that improving building ventilation could save £17.4 billion (US$20.4 billion, 2.45 trillion yen) over 60 years[2].

This calculation does not take into account the financial outlay in the aftermath of the pandemic. Therefore, with hindsight, if the pandemic had been brought to an end through the implementation of CAP, the economic benefits would have been much greater, and the benefits to society, culture, as well as the health and safety of people would be immeasurably significant.

Gradually, as this process towards the implementation of CAP extends from individuals to groups, from buildings to regions, and from local governments to whole countries, corresponding measures will be required, according to the size or area of each unit. However, the operating system is basically the same, regardless of scale.

At each level a responsible manager is designated to carry out a CAP project, perhaps beginning with quite a simple structure. Projects at a municipal level will follow on a slightly larger scale. These will draw together other small projects in the same region. That will be followed by even larger projects at the prefectural level. Finally, national large-scale projects, bringing together all of these, will be developed.

In order to progress this work rapidly, it will be necessary to set up investment in facilities and equipment, as well as funding support. There will be a need to develop laws and regulations related to ventilation, CO_2 monitoring and buildings. It will also be important to standardise equipment such as CO_2 monitors and monitoring systems. However, since the basic unit system is the same across the board, these actions could be implemented and brought into force anywhere, and on any scale. The sooner we reach our goals, the more we will be able to enjoy a safe and healthy life, free from infection.

Now is the time to face our goal of delivering CAP everywhere

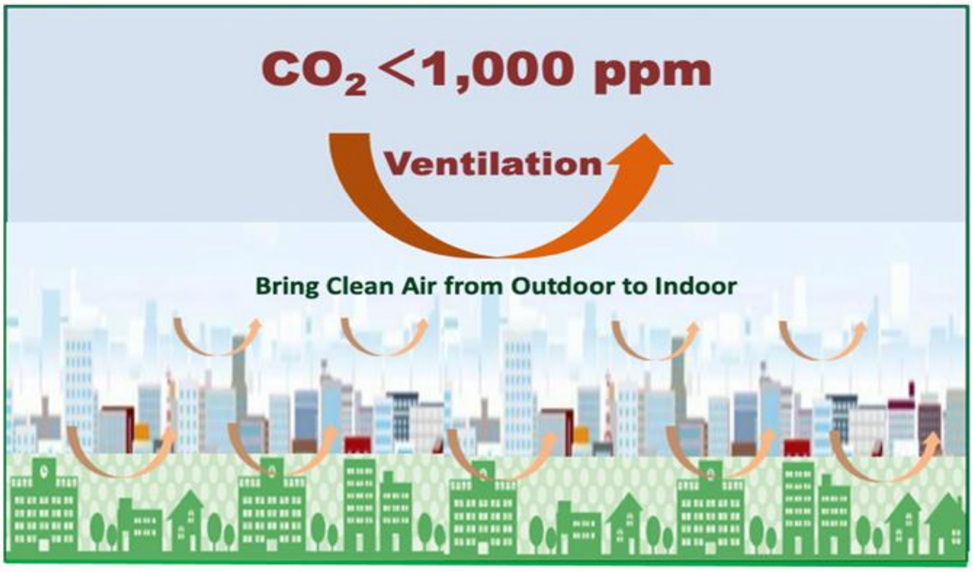

Figure 1

CAP (Clean Air Practice):
Practice of ensuring fresh indoor air[1]

CAP is an action that brings about the possibility of living in an environment with constant fresh air everywhere by allowing outdoor air to enter indoor spaces throughout an entire area. By maintaining indoor CO_2 levels below 1,000 ppm through ventilation, the indoor air contaminated with aerosols and CO_2 is replaced with fresh outdoor air. If CAP is practised everywhere, the COVID-19 pandemic will come to an end, and a healthy life without infections will be realised.

This grand project opens up the way to fulfil our positive dream of bringing about the sustained end of infection. By building a system utilising internet of things (IoT) and artificial intelligence (AI), the burden on individuals can be minimised. If we all share the goal and pursue it in a partnership of enthusiastic cooperation, this dream will surely come true.

CO_2 monitors are essential for healthy daily lives

People spend an average of 85% of their days indoors. Therefore, in addition to comfortable indoor temperature and humidity, healthy indoor air is very important.

Temperature and humidity can be sensed by our body, and we also react to them through sweating, shivering, and other responses. Additionally, we can quantitatively measure them using thermometers and hygrometers, and evaluate them accurately. For that reason, tools and devices have been developed to make levels of temperature and humidity comfortable. They have been installed in many indoor spaces. Thanks to this, even in hot and humid summers or cold and dry winters, we can spend most of our day comfortably indoors.

To improve indoor air quality, Equipment and devices to promote ventilation have been developed and installed in buildings. However, the fact is, that people cannot perceive the quality of the air. As a result therefore, they may spend time in polluted air without even noticing any change in air quality. This situation can lead to health problems and even severe illness. People unconsciously inhale polluted air contaminated with aerosols generated through normal breathing (refer to “Group Infection Control for Ending Pandemics” https://pointpath.jp/guide/). If the aerosols contain viruses, people can become infected, resulting in the creation of a tragic situation like a pandemic.

All of this is the result of unnoticed insufficient ventilation. Whether or not there is insufficient ventilation can be determined by a CO_2 monitor.

The only remaining challenge for realising a healthy indoor environment is that of air quality and the elimination of ventilation deficiencies in all indoor spaces. Solving this challenge, which is crucial for the survival of humankind, will stop pandemics and bring them to an end.

The question of the survival of humankind can be resolved by permanently installing CO_2 monitors everywhere indoors and ensuring that fresh air constantly circulates indoors by means of ventilation.

CO_2 monitors are extremely efficient

They are essential tools to eliminate the problem of insufficient ventilation in any indoor environment. It is important to take into account that the construction, ventilation, operation, and occupancy of buildings vary significantly. Even in identical houses on the same street, the objects and settings in each room differ. Furthermore, there are variations in the number and duration and in the activities of occupants. The types of combustion by-products from appliances like stoves, also vary. This poses a challenge in the task of improving indoor air quality.

CO_2 monitors play a crucial role in addressing this significant variation. Merely fixing and installing CO_2 monitors cannot adequately handle such diversity. An essential feature of CO_2 monitors is their capability of measuring and assessing CO_2 levels in multiple locations within a room. By strategically placing monitors in areas susceptible to inadequate ventilation based on CO_2 level assessments, it becomes possible to effectively monitor and mitigate ventilation insufficiencies throughout the entire room.

What is even more remarkable is that *the MK model*[3] *has validated its capacity to manage and control ventilation and infection risks by establishing a tailored CO_2 threshold of 1,000 ppm, which considers the variations present.*

Let us have a look at using a CO_2 monitor

Firstly, it is important for everyone to become familiar with the functions of CO_2 monitors. Once you get used to having a CO_2 monitor around and are able to pay attention to changes in indoor air quality, you will start to see a path towards achieving a comfortable life without worrying about getting infected.

Just like using a thermometer or a body temperature monitor to measure temperature, we can measure the concentration of CO_2 in places around us and in places we regularly use. By doing this, we can begin to understand how much CO_2 we exhale when we breathe, as well as how much CO_2 is exhaled by other people in the same room. We can also become aware of the fact that we share air with aerosols which are present in the room where we are.

CO_2 monitors visibly show the degree of aerosol contamination in terms of CO_2 concentration. This makes them indispensable for carrying out infection prevention methods which will, in the end, bring an end to the COVID-19 pandemic. It is important to recognise that being aware of the CO_2 concentration at all times in rooms or indoor spaces where two or more people gather can lead to taking action which will reduce the risk of infection.

The reference value for CO_2 is 1,000 ppm

The threshold for CO_2 concentration, which determines whether there is insufficient or sufficient ventilation, is 1,000 ppm. Let us explain why the standard value is 1,000 ppm and why it varies depending on the country or region.

In *Japan*, to reduce the risk of COVID-19 outbreaks, the Ministry of Health, Labour, and Welfare's expert panel on COVID-19 measures (March 2020) recommended avoiding the "three Cs"[1]closed spaces with poor ventilation, 2) crowded places with many people, and 3) close-contact settings with normal conversations or with strong vocal articulation. Ventilation in enclosed spaces is calculated based on the CO_2 emitted from humans, and also on maintaining indoor CO_2 levels at 1,000 ppm. This is equivalent to securing approximately 30 cubic meters of ventilation per person per hour. Therefore, measuring CO_2 concentration is an effective way to identify the existence of insufficient ventilation in a room. If the ventilation rate per person is maintained at 30 cubic m per hour, it is considered to comply with the air environment adjustment standards under the Building Standards Law (Law concerning the Ensuring of Hygienic Living Environment in Buildings). In this case, the area is not considered to be a "poorly ventilated space".

On the other hand, in schools, a CO_2 concentration of less than 1,500 ppm is desirable according to the School Health and Safety Act. This is a standard set to improve air quality in schools, although the recommended standard for infection prevention measures is 1,000 ppm, as recommended by the Ministry of Health, Labour, and Welfare.

The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA)[6] sets a standard of 1,000 ppm for CO_2 concentration in spaces (such as classrooms, conference rooms, and restaurants) that are occupied by groups of people for more than one hour. However, during the COVID-19 pandemic, they recommended setting a maximum line of 800 ppm to trigger rapid action to deal with inadequate ventilation, even in situations where the occupancy rate was low. Nevertheless, in general REHVA still advocates the standard of 1,000 ppm.

In many European countries, the standard for indoor CO_2 concentration is set at 1,000 ppm, but there are also countries that have their own policies. For example, in Belgium, a law was passed mandating the installation of CO_2 monitors by 2025 in all cultural and event sectors, including bars, restaurants, catering centres, discos, dance halls, sports centres, and cinemas.[4] The standard for CO_2 concentration is set at Level A, which is less than 900 ppm (40m^3/h per person ventilation rate), and Level B, which is less than 1200 ppm (25m^3/h per person ventilation rate), with either level being mandatory for each facility.

The US Centers for Disease Control and Prevention (CDC) and the UK's Environmental Modelling Group and Scientific Pandemic Insights Group on Behaviours (EMG/SPI-B 2021) both recommend a standard of 1,000 ppm for CO_2[9].

In the United States[2] a Clean Air in Buildings Challenge was established in March 2022, calling on building owners and operators to improve ventilation for indoor air quality. In October of the same year, California enacted a law requiring fresh air to be supplied to all school buildings. In December of that year, the White House issued a statement requiring fresh air supply for all federal government buildings, numbering about 1,500 in total. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)[7] issued a statement, on December 22, that there were still outstanding issues to determine the control threshold for airborne infection risks. They stated that by July 2023, having considered infection risks, they would develop ventilation standards (i.e., CO_2 concentration standards).

There is no particular problem with the fact that the standard value of CO_2 concentration varies depending on the country or region. However, in order to promote CAP globally, it is desirable to have a global standard. This is especially important in today's international society where human movement and interaction are more prevalent than ever before.

MK-model[3] that clarifies the relationship between CO_2 concentration and infection risk suggests that a *standard of 1,000 ppm for CO_2 concentration can be considered the gold standard*.

Setting up CO_2 monitors

To reduce the risk of airborne transmission properly, it is necessary to follow these steps. 1) select an accurate CO_2 monitor, 2) instal it in the appropriate location, 3) take the detailed record of the CO_2 concentration status in real-time and implement ventilation measures to manage it. Let us now explain each step.

1. **Choosing an accurate CO_2 monitor**

Although various products are available on the market, there are different guidelines for selecting suitable equipment in various countries. According to the guidelines from the Ministry of Economy, Trade, and Industry in Japan, it is recommended that the equipment utilises optical methods, such as NDIR (nondispersive infrared) or photoacoustic methods, and is equipped with a calibration function.

2. **Setting up the installation location[4, 6, 9]**

CO_2 monitors are not large pieces of equipment, and are easy to use. Measuring the CO_2 concentration level is a simple process. They can be installed anywhere indoors, and the CO_2 concentration can be checked in real-time, at any moment.

In addition to real-time monitoring, CO_2 monitors can carry out important evaluations in order to ensure adequate ventilation. Even in buildings designed to ensure sufficient ventilation, the efficiency of ventilation can decrease if people or objects obstruct the airflow. To ensure proper circulation of air, it is necessary to consider the placement of both people and objects. CO_2 monitors can be effectively used for such evaluations.

To give an example of this potential problem: partitions, curtain dividers, acrylic dividers, etc. that were installed as infection control measures during the COVID-19 pandemic, often created spaces that trapped CO_2 and aerosols, reducing the effectiveness of ventilation. As a result, the infection risk in these spaces may have been increased. While partitions and dividers can prevent droplet transmission and reduce the risk of droplet infection, they have no effect on airborne infections caused by aerosols and may even increase the risk of infection by creating pockets of stagnant air.

By utilising CO_2 monitors, it is possible to check in advance for areas where air may get trapped and then make adjustments in the installation or orientation of objects that could obstruct ventilation.

CO_2 monitors can be placed anywhere in a room, whether in the centre or at the edge, as long as they are not placed near doors or windows. The height of the monitor can also be adjusted to a better position. Typically, one monitor per room is sufficient, but in particularly large rooms, it is recommended to measure the CO_2 concentration at several locations before deciding on their position. If there are significant differences in CO_2 concentrations, it is important to select the area where air accumulation is most likely to occur and place the monitor there[9].

3. **Making CO_2 Monitors easily visible. Keeping records of CO_2 Monitor readings[5]**

CO_2 monitors should be made clearly visible to everyone. Also, the habit of checking the CO_2 readings on a daily basis should be cultivated. In this way, it will be possible to keep control of inadequate ventilation. Therefore, it is recommended that administrators or staff make precise plans to make sure that this is done.

1) For about a week at the outset, the manager should keep a record of the room intended for a CO_2 monitor in order to identify the CO_2 deviations and the different components in the room. The obstacles to ventilation efficiency caused by people and objects should be checked with a monitor and the placing of objects should be adjusted. It is recommended that the monitors be installed in places where CO_2 concentration is high. In some cases, it may be necessary to use multiple monitors to record the data. For this purpose, CO_2 monitors with graphing functions as well as monitors that automatically record CO_2 levels should be chosen.

2) A member of staff must check the data regularly and adjust the ventilation each time, based on a CO_2 concentration of 1,000 ppm. It is useful to have a device that buzzes or sends an e-mail notification when the CO_2 concentration exceeds a certain level. There is also equipment that automatically activates room ventilation when necessary.

3) A member of staff should show the position of the CO_2 monitor to residents and visitors. It is a good idea to demonstrate how the CO_2 concentration is always maintained below 1,000 ppm to promote ventilation and infection control measures. Everyone should be encouraged to participate in checking and practising infection control measures with the monitor. In fact, visible demonstrations of how CO_2 monitors work have been shown to be more effective in improving ventilation than simply pointing out their position.[8, 9]

4. Systematising CO_2 monitoring

Some models of CO_2 monitors are smartphone-linked. Ventilation status can be checked from anywhere. In the summer of 2023, Tokyo's Chiyoda Ward will lend 200 smartphone-linked CO_2 monitors to ordinary households, free of charge. This was decided as an emergency response to the Omicron 7th Wave, which was followed by the 8th Wave. This decision was based on the recommendation made at the Tokyo Metropolitan Government review meeting which concluded that the continued hot weather and air-conditioned rooms were a contributing factor to the spread of infection. Their data also showed that about 70% (68.9%) of the infection routes at that time were home infections.

A system has also been developed that allows CO_2 monitors to be linked via IoT and monitored with a smartphone. This system can be used for infection risk and air quality assessment and maintenance, management, and also when organising community activities. If such a system becomes widespread and established, people will be able to monitor CO_2 levels with their smartphones at work, while shopping, on business trips, and on vacations, enabling them to practise infection-free living using the monitors wherever they go.

Ventilation

Ventilation works by replacing contaminated indoor air with fresh outdoor air. These replacement methods include *natural ventilation* and *mechanical ventilation*.
Let us keep in mind that the key to terminating and creating a permanent end to the New Coronavirus is to *ensure that ventilation exists in the area and that it is maintained at an indoor CO_2 concentration of 1,000 ppm.*

Natural ventilation
This is a method of ventilation that does not use mechanical power, but uses natural forces such as air temperature differences, wind pressure, and air flow.

It operates by opening and adjusting windows and doors so that CO_2 does not exceed 1,000 ppm.

As a first step, use windows and other openings in buildings to create ventilation. In buildings without mechanical ventilation systems, openable windows are actively used. Natural ventilation with opening windows generally has a much higher ventilation rate, although much depends on the location of the windows and the direction of the wind. Opening windows and doors in both directions to allow airflow is an effective method of ventilation. If there is only one window, ventilation can be made more effective by using a fan, circulator, or exhaust fan in combination. If other people are going to occupy a room, make sure that ventilation conditions are appropriate by checking the CO_2 concentration beforehand. If it exceeds 1,000 ppm, open a window to improve conditions to the desired recommended level.

Mechanical ventilation
This is a method of ventilation using mechanical power such as ventilation fans and blowers. In Japan, the revised Building Standard Law of 2003 mandated 24-hour mechanical ventilation. This was in response to the movement towards achieving higher heat insulation which could result in airless unventilated houses and workplaces. This could, in turn, result in sick house syndrome. The question of sick house prevention also needed to be taken into account. According to the Law, such buildings should be equipped with a mechanical ventilation system (24-hour ventilation system) with a ventilation frequency of 0.5 times/h or more (every two hours or more frequently).

There are three types of air supply system (inlet) and exhaust system (outlet), each with or without a machine. Class 1 and Class 3 are mainly used in residences.

Class 1 Mechanical Ventilation: Both air supply and extraction are carried out by machines (fans).
Class 2 Mechanical Ventilation: Supply of fresh air is mechanically introduced, and exhaust air is naturally extracted. Forced air supply causes the air pressure inside the room to be higher than outside. This naturally promotes exhaust of used air.
Class 3 Mechanical Ventilation: Supplies air naturally, and extracts air mechanically. Forced exhaust air causes the air pressure inside the room to be lower than outside air pressure This naturally promotes outdoor fresh air supply.

In order to achieve greater comfort in a highly insulated and airtight energy-efficient home, *the use of a heat exchange ventilation system with a Class 1 mechanical ventilation is effective* (refer to Chapter 2, reference 6). During heating and cooling, conventional ventilation fans bring in cold outside air in winter and hot outside air in summer. This results in the loss of desired room temperature (hot or cold, respectively) in the room. Heat exchange ventilation equipment brings in outside air that is close to room temperature, reducing the load on the respective heating and cooling equipment, saving energy, and reducing temperature fluctuations in the room, without compromising comfort.

The HVAC (Heating, Ventilation, and Air Conditioning) system, which controls temperature, humidity, and air quality in addition to ventilation, regulates comfort (temperature and humidity), energy efficiency, and air quality.

To end the spread of COVID-19, it is necessary to create indoor air environments through ventilation over a wide area, where mechanical ventilation plays a major role. The challenge is to achieve air quality with CO_2 concentrations below 1,000 ppm throughout the indoor space, while ensuring comfort through temperature and humidity control that is not affected by ventilation, but at the same time maintaining energy efficiency.

To solve this challenge, HVAC is the optimal system.

HVAC /BAS/BEMS/Automatic control

The central control unit of the HVAC system can usually be programmed from the operational terminal. This means that it is possible to directly edit the programme according to the intended use, and the HVAC system can be digitally controlled. It is possible to schedule operation, set target temperatures, and incorporate control, logic, timers, trend logs, and alarms into the programme [Direct Digital Control (DDC)].

The HVAC system is connected to the Building Automation System (BAS). Various equipment such as air conditioning, lighting, and surveillance cameras are installed in the building and BAS controls the operation the equipment. The BAS monitors temperature and humidity and automatically maintains set parameters. Furthermore, by linking with the Building Energy Management System (BEMS), which manages and analyses energy consumption using data managed by BAS, *various energy-related goals such as conserving electricity can ultimately support the fight against global warming*.

Building managers can monitor the system and respond to system alarms on the site or remote locations and change settings from the BAS. The BAS itself can directly control equipment in the HVAC system. HVAC can have various interfaces depending on the specifications of the BAS.

The HVAC/BAS/BEMS/automatic control system has evolved to include a web server function in the central monitoring device. Internet and web technologies, and cloud technologies are also being utilised. This allows for a system where optimal monitoring and operation can be carried out from any client PC on the network, which has become more and more common.

Nowadays, it is possible to achieve energy savings by automatically maintaining various spaces within a building in a comfortable state while operating heating and air conditioning equipment with minimal energy consumption. Therefore, by *adding a CO_2 concentration monitoring system to the HVAC/BAS/BEMS/automatic control system, it is possible for an individual to monitor and control HVAC automatically, based on a CO_2 concentration of 1,000 ppm in any area including one's own personal space*.[8]

HVAC systems are expensive, so as a result, many people do not have them in their homes. However, in the long term, the benefits of energy savings by automatically maintaining each room at a comfortable state while operating the heat source and air conditioning equipment at a minimum level of energy consumption will outweigh the costs. Upgrade to heat insulting airtight and high-performance ventilation of both new-build houses and existing high/medium density housing will be required to improve the indoor environment.[10]

On 20 March 2023, the Japanese Ministry of the Environment began soliciting proposals for the "Support Project for the Introduction of High-Functioning Ventilation Equipment to Reduce Large-Scale Infection Risks"[11]. This public solicitation, which amounts to a budget of 75 million yen (approx. US$545,000) is part of the Ministry of the Environment's "Support Project for the Introduction of High-Functioning Ventilation Equipment and ZEB Conversion to Decarbonise and Strengthen the Resilience of Buildings and other areas". It aims to support the introduction of high-efficiency heat-exchange ventilation equipment that has a high ventilation capacity and contributes to the promotion of CO_2 reduction in buildings and in facilities such as restaurants that are used by a large number of unspecified people in order to prevent the space from becoming sealed and airtight. The target locations include a wide range of workplaces such as general supermarkets, retail stores, restaurants, hotels, bars, dining halls, fitness clubs, barber shops, theatres, hospitals, nursing homes, kindergartens, and schools. Heat-exchange ventilation, which uses fans for both intake and exhaust (Class 1 mechanical ventilation), can provide reliable ventilation and suppress temperature changes through heat exchange, creating a comfortable air environment. In CAP, heat-exchange ventilation under super-insulated conditions is recommended as the ventilation system of the future. While adding a CO_2 monitoring system is necessary, *such government measures create a process towards the living environment that CAP aims to achieve, and finally, make it reality.*

The Concept of Ventilation

The ultimate challenge remaining with respect to indoor environments is to ensure good air quality. This can be solved by installation of permanent CO_2 monitors throughout indoor spaces and circulating fresh air through ventilation. *While this is an extremely technical solution, it is the result of the history of human technology which has created the current global environment. We must find a solution in order to rescue the environment from its apparent irreversible state.*

The issue of ventilation is a common one, together with that of our environmental destruction, global warming, zero carbon. SDGs (Sustainable Development Goals) aim to solve these issues. However, the COVID-19 pandemic has further increased this heavy burden by adding on the problem of spread infectious diseases.

However, it has been found that the COVID-19 pandemic can successfully be addressed through the use of CO_2 monitors and HVAC systems.

On the other hand, people's awareness of air quality and ventilation issues is very superficial. The fact that we do not notice air quality is not surprising. It is invisible and intangible.

Although there are differences in perception among countries, regions, and the people who live there, the idea that natural ventilation through open windows is the best and sufficient method, remains deeply rooted and prevalent. Many people actually use this method. However, *in today's environment, it is almost impossible to ensure good air quality at all times through natural ventilation alone. The situation has been pushed to the brink of collapse.*

One example of this phenomenon that can be experienced first-hand is the occurrence of extreme heatwaves that are affecting the world. These are meteorological disasters caused by climate change. A heatwave is defined as a day where the highest temperature recorded is 35°C or higher, and it poses a threat not only to humans but also to many other living organisms. Heatwaves have been increasing since 1994, and in 2018, Japan experienced more than seven heatwave days in a year, with a record high temperature of 41℃ in July[12]. Morocco in North

Africa recorded 43.3°C, while California, USA, recorded 48.9°C[13]. In 2019, Germany experienced a record high temperature of 42.6°C, Belgium 41.8°C, and the Netherlands 40.7°C[13]. These events led to a situation where each country's highest temperature record was broken. In 2004, France had an estimated 14,802 heat-related deaths, with Italy at 3,134, Portugal at 2,106, and Wales, UK at 2,045 deaths, making it clear that all countries experienced significant fatalities.

In such an environment, unless an indoor comfortable environment is maintained by mechanical ventilation systems, the body cannot withstand it, and the deterioration of indoor air quality is unavoidable.

In the future, *we will enter an era where everyone can be assured of a comfortable living environment and high-quality air environment indoors by relying on mechanical ventilation in highly air-deprived indoor spaces without relying on natural ventilation*[10].

Unless we do so, pandemics will be repeated, many people will suffer from health problems, lose their comfortable environment.

The Construction Process of a Mechanical Ventilation System

There is an urgent need to achieve an infection-free environment by ensuring the use of indoor CO_2 concentration of 1,000 ppm with the aid of HVAC systems. In order to move steadily towards this goal, it is necessary to improve the operation of existing buildings and their ventilation facilities. Efforts to update general construction plans for new buildings and the renovation of existing buildings will need to be increased if we want to achieve the goal of creating an infection-free environment.

Improvement of building facility operation [6]

In REHVA's guidance[6] on building facility operation provides 15 recommendations for the operation of buildings equipped with mechanical ventilation systems during epidemic periods. The building manager must maintain the heating, ventilation, and air conditioning systems in accordance with the manufacturer's current operating instructions, particularly with regard to filter cleaning and replacement. There is no advantage or necessity to add anything related to COVID-19 to the maintenance cycle.

It is necessary to consider extending the operation time of the HVAC system beyond regular opening hours (before and after). Organisers and managers responsible for gatherings and important infrastructures, with the support of technical/maintenance teams, need to consider options to avoid air recirculation. Based on the information provided by the manufacturer, they should explain the procedure for using air recirculation in the HVAC system or if this is not possible, consider seeking advice from the manufacturer.

Improvements to the ventilation system of a building

Improving the ventilation system based on the structure of the building is an effective and undemanding process. This process reduces the aerosols in the air that all residents are sharing and breathing, without requiring any one person to regularly take any ventilation action.
Individuals can, of course, also limit infection by checking CO_2 monitors and opening windows or doors, turning on fans or vents, and using portable air purifiers if necessary.

A system that reduces the concentration of aerosols throughout the entire building enables more people to prevent airborne infections with less individual effort.

Most of the existing buildings can be structurally adapted to prevent airborne transmission of SARS-CoV-2 through relatively inexpensive improvements to their HVAC systems.[6]

The EU Environmental Protection Agency (EEA) has issued guidance to building owners and operators as part of its efforts to maintain fresh air in buildings through ventilation[14]. Similarly, the Centers for Disease Control and Prevention (CDC) in the United States, in its five guidelines, highlights the proven preventive measures to improve ventilation in buildings[15]. The CDC also provides interactive tools for homes and schools to assess the impact of improvements on indoor air quality, such as opening windows, replacing HEPA filters, and using HEPA air purifiers[2]. Adding a CO_2-ventilation system is a prerequisite for CAP compliance in accordance with all of these guidelines.

Renovation and reconstruction of buildings

The most costly improvements in addressing respiratory infections, including COVID-19, are those of large-scale building structures. An example of this is the reconstruction or renovation of public buildings. However, such structural improvements can improve indoor air quality for many people, in a fair manner, as well as generating huge energy cost savings[16].

Improvement of HVAC[17]

Investing in HVAC improvements in schools can ensure a healthy and safe environment for all students and staff. Companies that improve their HVAC systems can create a safer and infection-free environment for their employees while also achieving energy efficiency and future cost savings. HVAC improvements can make the work and living environment more comfortable, safe, and infection-free for all workers, customers, healthcare professionals, and the general public.[5] Hospitals with an excellent ventilation rate of 12 ACH (12 Air Changes per Hour) can effectively prevent airborne transmission of infections even in difficult conditions.

CO_2 monitors are essential to evaluate the functioning of any improvements made, and also to check that these improvements are working properly. The ideal system is one that provides a setup which automatically adjusts the ventilation volume based on a standard value of 1,000 ppm measured by CO_2 monitors, and managed by building managers responsible for its operation, maintenance, and management.

CO_2 monitors are effective when installed in visible locations, accessible to anyone. It may also be beneficial to link a CO_2 visibility system to social media and share the ventilation system parameters with building managers and other users online.

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