博士学位論文

Study on Factors Affecting the Quality of Life Based on a Closed Air-flow System

（クローズドエアフローシステムに基づく生活の質に作用する要因に関する研究）

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I. Background

Since the birth of human civilization, birth, old age, sickness and death have accompanied every human being throughout their lives. For life, health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. It is important to life because it is the basis for the proper functioning and enjoyment of all that life has to offer. From the polished stone axes of the farmers in the Neolithic Age to the first whistle of the Industrial Revolution[1], human societies have undergone several significant changes that have affected health care in different ways.

Before written records, our ancestors relied on an intimate relationship with the natural world. Healing practices were intertwined with spiritual beliefs, often overseen by shamans or tribal leaders. These early healers used a combination of herbs, rituals and physical therapies, drawing on accumulated tribal knowledge and spiritual insights. Excavations have found evidence of trepanation - the practice of drilling holes in the skull - dating back to the Neolithic period[2]. This procedure, probably carried out to treat various ailments or even to exorcise evil spirits, demonstrates early man's attempts at surgical intervention. Herbal remedies played an important role. Many of the plants used during this period, such as willow bark (a natural precursor to aspirin) or opium poppy, laid the foundations for modern pharmacology.

Ancient civilizations laid the cornerstone of medical knowledge when appeared on Earth. Often hailed as the cradle of civilization, Mesopotamia has some of the earliest written records of medical practice. Cuneiform inscriptions on clay tablets detail various treatments, surgical procedures, and medicinal herbs. In particular, the Code of Hammurabi, one of the earliest sets of laws, included sections on medical practice and fees, emphasizing the importance of health care in society. The Nile Valley civilization was a beacon of medical knowledge. Papyrus scrolls, such as the Ebers and Edwin Smith papyri, provide detailed insights into Egyptian medicine. They recognized ailments ranging from dental problems to tumors, and used a range of treatments - surgical procedures, ointments, and a vast pharmacopoeia of herbal remedies. Ancient Chinese medicine took a holistic approach. The basic concepts of yin and yang, representing balance and harmony, were central. Practices such as acupuncture, cupping, and moxibustion became popular, and herbal remedies were extensively catalogued. Books such as the “Huangdi Neijing” provided a comprehensive insight into these practices. Greece is often considered the birthplace of Western medicine. It brought a more systematic and analytical approach. The Hippocratic Corpus, a collection of texts, codified medical knowledge, emphasizing patient observation and the belief that diseases had natural causes. The famous Hippocratic Oath, a code of ethics for physicians, is still relevant today.

During the Middle Ages, the development of hospitals and medical schools in Europe led to advances in medical knowledge and treatment. After the fall of the

Roman Empire, Europe entered a period often referred to as the Dark Ages. But even in this period, medicine found bastions. Christian monasteries became repositories of medical knowledge. Monks, well versed in Greek and Roman medicine, also used local herbs and set up infirmaries on monastery grounds. At the same time, the Islamic world was experiencing a "golden age" of knowledge. Cities such as Baghdad and Cordoba became centers of learning. Greek medical texts were translated, preserved, and expanded. Scholars such as Avicenna (Ibn Sina) and Averroes (Ibn Rushd) wrote extensive medical treatises, and hospital-like institutions, "bimaristans," provided organized care. But the era wasn't without its challenges. The Black Plague, which decimated nearly a third of Europe's population, underscored the importance of public health and quarantine measures. The Renaissance, which spanned the 14th to 17th centuries, marked a revival in art, culture, and science. This period of rejuvenation had a profound effect on medicine, bringing it back into the limelight.

During the transformative period of the Industrial Revolution, healthcare underwent profound changes that reflected the broader societal and technological shifts of the era. As urban centers grew due to the lure of better economic opportunities in factories, cities faced the challenges of rapid population growth, which led to cramped living conditions in tenements and took a significant toll on urban health. Diseases such as cholera, typhoid, and tuberculosis became rampant, exacerbated by a lack of clean water and proper sewage systems. Recognizing the need for a healthy workforce in the factories, some industrialists introduced rudimentary health services, ranging from basic first aid to employing full-time physicians for their workers, laying the groundwork for modern occupational health services. Hospitals, once considered a last resort primarily for the destitute, began to evolve into structured institutions essential for providing organized medical care to the burgeoning urban population. At the same time, the growing demand for medical professionals to meet the health needs of the growing urban population led to the establishment of numerous medical schools that aimed to provide standardized medical training and move away from the older apprenticeship models of learning. In the United Kingdom, the Medical Act of 1858 was a landmark piece of legislation that established a standardized system of medical licensing and ensured that the practice of medicine was restricted to qualified individuals. Amid the challenges of disease outbreaks and public health crises, there was a growing recognition of the importance of organized public health systems. Edwin Chadwick's influential reports highlighted the appalling living conditions of urban workers and drew attention to the link between poor sanitation and the spread of disease. This spurred a series of public health reforms, with cities investing in comprehensive sewage systems, ensuring clean water supplies, and implementing regulations to improve housing standards. Despite these advances, access to health care during the Industrial Revolution remained sharply divided along socioeconomic lines. While the wealthy had the means to afford private care and often employed personal physicians, the working class, burdened by financial constraints, faced limited access to essential medical services. In reflecting on the Industrial Revolution's impact on health care, it becomes evident that the period was not just a testament to human technological ingenuity but also a pivotal chapter that reshaped health care's trajectory, laying the foundations for many aspects of modern medical practice.

The 20th century was a pivotal era for the global economy and social structures, and during this transformative period, the healthcare sector underwent significant evolution that can be insightfully analyzed using the three-sector model.

The primary industry to which agriculture belongs forms the basis of human society and civilization. Historically, agriculture has been a major source of food, raw materials, and livelihoods for communities, shaping settlement patterns, social structures, and cultural practices. The development of agriculture has enabled human societies to settle in one place, establish permanent settlements, and generate food surpluses to support population growth and social development. Agriculture also affected social organization, with the emergence of professional roles, trade, and exchange, leading to the development of complex societies and civilizations.

The secondary sector, including manufacturing, plays an important role in promoting industrialization and economic development and has important social implications. Manufacturing has created employment opportunities, shaped urbanization, transformed production processes, and brought about changes in living standards, lifestyles, and social structures. Manufacturing growth is often associated with urbanization, migration, and the rise of industrial cities and towns, leading to changes in population density, settlement patterns, and labor markets. Manufacturing also impacts social mobility, offering opportunities for skill development, entrepreneurship, and upward mobility. With technological advances, the concept of smart farming has emerged as a more sustainable and efficient approach to farming practices. Smart agriculture includes innovative technologies such as the Internet of Things (IoT), big data, drones, and sensors to optimize agricultural processes, reduce environmental impact, and increase productivity. The use of intelligent technology can revolutionize farming practices and enable more efficient, accurate, and data-driven farming. For example, IoT-based sensors can monitor soil moisture, temperature, and nutrient levels, allowing farmers to optimize irrigation and fertilization methods. Drones can be used for aerial photography, crop monitoring, and pest detection, helping farmers make informed and timely decisions. Big data analytics provide valuable insights into crop management, weather forecasting, and market analysis, helping farmers make data-driven decisions. These smart technologies can significantly increase agricultural productivity, reduce resource waste and make the primary sector more sustainable. Sustainable agriculture focuses on environmentally and socially fair agricultural practices that promote long-term sustainability. It emphasizes practices such as crop rotation, soil conservation, integrated pest management, and water management to minimize the use of harmful chemicals, reduce soil erosion, conserve water and protect biodiversity. Sustainable agriculture also encourages the use of organic and natural farming methods that can result in healthier soils, improved crop quality, and reduced pollution. By adopting sustainable agricultural practices, the primary sector can contribute to a more resilient and sustainable food production system while conserving natural resources in agriculture and promoting biodiversity-conserving herbicides. increase. These technologies include biological control, biopesticides, and bioengineered solutions that target pests and diseases without harming beneficial organisms or damaging the environment. Antibiotics technology helps reduce the negative environmental impacts of conventional chemical-based agriculture, including soil degradation, water pollution, and damage to non-target organisms. By adopting Antibiotics technologies, primary industries can reduce their reliance on harmful chemicals while promoting more sustainable and environmentally friendly agricultural practices. The second sector, particularly manufacturing industries such as electronics and semiconductors, often requires advanced processes and techniques to produce quality products. Large-scale integration (LSI) refers to the integration of many electronic components or circuits onto a single semiconductor chip or integrated circuit (IC). This has revolutionized the electronics industry, enabling the production of smaller, more powerful, and more complex devices such as microprocessors, memory chips, and other electronic components. A cleanroom is an environment controlled by strict standards of cleanliness, temperature, humidity, and other parameters to prevent contamination of the manufacturing process. Cleanrooms are essential in semiconductor manufacturing to prevent dust, particles, and other contaminants from interfering with the delicate processes involved in making microchips. The manufacture of hardware, including electronic components and semiconductor devices, often requires a high level of cleanliness to prevent dust, particles, and other contaminants from affecting the quality and performance of the final product. Cleanroom facilities are designed to maintain a controlled environment that minimizes the presence of contaminants during the manufacturing process. Semiconductor manufacturing is a key component of the electronics industry and involves the production of semiconductor devices such as microchips, transistors, diodes, and other electronic components. This process requires a high level of precision and control, including a cleanroom environment, to ensure the quality and reliability of the final product.

Tertiary industries, including information and artificial intelligence (AI) related industries, play a pivotal role in shaping modern society. The tertiary sector is often focused on providing services and technologies that improve the quality of life (QoL) of individuals and communities. This includes areas such as healthcare, education, entertainment, communications, and other services that contribute to well-being and human development. Software applications and platforms are also developed and used in the tertiary sector to process, analyze and interpret data and create innovative solutions in various fields. Machine learning, a subset of AI, uses algorithms and models to enable systems to learn from data and improve performance over time, helping to improve areas such as natural language processing, computer vision, and recommender systems. Promote progress. Especially in the areas of information and AI, they can play an important role in achieving the United Nations Sustainable Development Goals (SDGs). This includes using technologies such as AI, big data, and analytics to address social, economic, and environmental challenges, as well as drive digital transformation (DX) in various economic sectors. DX includes the use of digital technologies to drive innovation, efficiency, and growth, which can have a positive impact in areas such as healthcare, education, and incubation (creating companies). Meanwhile, the tertiary sector is having a major impact on education and healthcare, using information and AI technology to enhance learning experiences, enable telemedicine, and improve patient outcomes. Furthermore, through innovative business models such as e-commerce, digital platforms, and online marketplaces, the tertiary industry can generate entrepreneurial opportunities and create opportunities for employment and economic growth. Tertiary industries, including services, have become a dominant force in modern society, shaping social development and human civilization. The growth of services such as communications, education, healthcare, finance, and information technology has changed the way people live, work, and interact. Services have become essential to fostering a knowledge-based economy where the exchange of information, skills, and expertise is central to economic growth and development. The tertiary sector has also impacted social and cultural aspects such as lifestyles, consumer behavior, and social interactions through digital platforms and social media. In addition to these direct effects, the three-sector model also reveals cross-sectoral interdependencies. For example, advances in agriculture and manufacturing often lead to increased productivity and surpluses, which can support growth in the tertiary sector. Likewise, advances in technology and services will drive innovation in agriculture and manufacturing, leading to increased productivity and efficiency. In addition, social development and human civilization are closely intertwined with economic development. Economic growth and development can create opportunities for social mobility, poverty reduction, and access to education, health care, and other social services. Conversely, social development, such as improving education, health, and social care, can contribute to economic growth by fostering a skilled workforce, healthy populations, and inclusive societies.

A part of these will be discussed next. The QoL refers to the overall well-being and satisfaction that a person experiences in various aspects of life, including physical, mental, social, and emotional. It is a subjective measure that reflects an individual's perception of life and can vary greatly between people and cultures. It is influenced by many factors such as education, income, social relationships, and environmental conditions. Health is an important factor affecting the QoL. Good physical health, including access to medical care, nutrition, and physical fitness, contributes to a better QoL. Physical health affects your ability to perform daily activities, engage in recreational activities, and maintain general health. Mental health is also an important factor in determining the QoL. Good mental health, including emotional well-being, cognitive function, and psychological resilience, can positively impact a person's QoL. Access to mental health services, social support, and stress management skills are important factors influencing mental health and QoL. Social relationships and social support are important aspects of QoL. Positive relationships with family, friends, and community contribute to emotional well-being, belonging, and social connection. Social support networks provide emotional, instrumental, and informational support during difficult times and improve an individual's QoL. Education is strongly tied to QoL. Access to quality education provides individuals with the knowledge, skills, and opportunities for personal growth and development. Education is associated with better job prospects, higher incomes, and improved social inclusion, all of which have a positive impact on QoL. Income and financial well-being play an important role in determining the QoL. Adequate income provides resources to meet basic needs such as food, housing, clothing, and health care, contributing to a sense of security and stability. Higher incomes are associated with better access to education, health care, and other opportunities that affect the QoL. Environmental factors such as access to clean air, clean water, and safe living conditions also affect the QoL. A clean and healthy environment promotes physical health, mental health, and overall QoL. Environmental degradation, pollution, and inadequate infrastructure can affect physical and mental health and adversely affect the QoL. Achieving a work-life balance is important to the QoL. Work-related stress, long working hours, and lack of flexibility in work organization can negatively affect the QoL. A healthy work-life balance, on the other hand, allows you to pursue personal activities, spend time with loved ones, and pursue hobbies, contributing to a better QoL. QoL is also affected by cultural and social factors. Cultural values, norms, and beliefs shape an individual's perception of what constitutes a good life and influence overall well-being. Social factors such as discrimination, inequality, and social cohesion also influence the QoL by influencing a person's social integration and sense of belonging. QoL is also influenced by cultural and social factors. Cultural values, norms and beliefs shape an individual's perception of what constitutes a good life and influence their overall well-being. Social factors such as discrimination, inequality and social cohesion also influence QoL by influencing a person's social integration and sense of belonging.

In summary, QoL is a multidimensional concept encompassing various aspects of a person's life. This is influenced by factors such as health, psychological well-being, social relationships, education, income, environmental conditions, work-life balance, cultural and social background. Improving the QoL requires physical and mental health, social well-being, education, income equity, environmental sustainability, and work-life balance while respecting cultural and social diversity. These multiple factors need to be addressed comprehensively through facilitating policies and interventions.

The 20th century, a period of rapid industrialization and technological innovation, brought about significant societal transformations. Central to these changes was the evolving understanding of health care and its undeniable link to the quality of life (QoL). However, while medical advancements promised enhanced life expectancy and better health outcomes, the century also grappled with the dark shadow of increasing air pollution, underscoring a complex interplay between health care, QoL, and environmental challenges. Air, an essential element for life, has become laden with pollutants from various sources such as vehicular emissions, industrial processes, agricultural activities, and more. This compromised air quality doesn't just mar our environment but has dire consequences for human health. Breathing in polluted air can lead to a host of respiratory ailments, with fine particulate matter penetrating deep into lung tissues and causing inflammation. This exacerbates conditions like asthma and chronic bronchitis, and also poses risks of more severe diseases like chronic obstructive pulmonary diseases. Beyond the respiratory system, air pollutants imperil the cardiovascular system, leading to heart attacks and other circulatory diseases.

Moreover, the carcinogens floating in the polluted air heighten the risk of lung cancer. Recent research even unveils links between polluted air and compromised cognitive functions, potentially playing a role in neurodegenerative diseases like Alzheimer's.[3] As the century progressed, the importance of health care became increasingly evident. Nations worldwide began to recognize that a robust health care system wasn't just a luxury but a fundamental right for their citizens. The establishment of health care institutions, research centers, and public health initiatives reflected a global commitment to improving overall health outcomes. This focus on health wasn't just about combating diseases but also about enhancing the QoL. Improved medical treatments meant that conditions once deemed fatal or debilitating could now be managed or cured, allowing individuals to lead fuller, more productive lives. The QoL framework extended beyond mere physical well-being to encompass mental, emotional, and social facets, painting a holistic picture of human health.

Coronavirus disease 2019 (Covid-19) is a contagious disease caused by the coronavirus SARS-CoV-2. On January 30, 2020, the World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern (PHEIC), which was lifted on May 5, 2023. On March 11, 2020, the WHO determined that the characteristics of the disease indicated that it was a pandemic. United Nations Secretary-General Guterres asserted that the novel coronavirus outbreak represents the most significant crisis since World War II.

The transmission of the virus occurs when infectious particles are inhaled or come into contact with the eyes, nose, or mouth. The risk of transmission is highest when individuals are in close proximity; however, small airborne particles containing the virus can remain suspended in the air and travel over longer distances, particularly indoors. Furthermore, transmission can occur when individuals touch their eyes, nose, or mouth after coming into contact with contaminated surfaces or objects. Individuals remain contagious for up to 20 days and may disseminate the virus even in the absence of overt symptoms.[4]

The global spread of the virus has had a profound impact on society, overwhelming healthcare systems and altering daily life worldwide. Given that the virus primarily spreads through respiratory droplets and airborne particles, the importance of indoor air quality was identified as a crucial factor in controlling its transmission.[5] As a result of the extended periods spent indoors due to the implementation of lockdown measures, the necessity for well-ventilated and hygienic indoor environments became evident, not only for the purpose of curbing the spread of viral infections but also to enhance the overall quality of life (QoL).

The ongoing pandemic has highlighted the vital importance of maintaining optimal indoor air quality in order to effectively control the spread of infectious diseases and protect public health. As societies begin to recover and reflect on the lessons learned from this crisis, it is imperative to prioritize clean air in indoor environments as a means of promoting safer conditions, enhancing well-being, and strengthening the resilience of communities against future health crises.

II. Introduction

II.I History of traditional ventilation

When people brought fires into their dwellings, they found that they needed openings in the roof to let the smoke escape and to let air in to keep the fire burning. was the first incentive for Thermal comfort was closely related to ventilation, as the fire heated the room to a more comfortable temperature. The ancient Egyptians observed that masons working indoors experienced shortness of breath more frequently than those working outdoors. They attributed this to higher levels of dust in their indoor work areas. Therefore, dust control was the second identified need for ventilation.[6] The Romans denied the need for indoor fires when they invented radiant heating. Hollow tiles under the floor of the building channeled combustion products from furnaces around the building through the floor tiles and into the chimney. They have developed window-to-floor ratios that are good for daylight. Oiled parchment on window openings provided high penetration. The Venetians then developed a process to produce flat glass for windows. [7]

When Joseph Black proposed “fixed air”, carbon dioxide was gradually understood by people. Lavoisier began studying oxygen and carbon dioxide in the air in crowded spaces in 1777. He concluded that his excess CO_2 caused suffocation and bad air, not oxygen depletion. The hypothesis was that excess CO_2 in his lungs impairs his ability to absorb CO_2 from the blood. The debate has been going on for years about whether bad air is caused by a lack of oxygen or an excess of carbon dioxide. However, nowadays bad air quality is widely known to be caused by the presence of various pollutants, including industrial emissions, transportation emissions, agricultural activities, residential and commercial emissions, natural sources, climate change and indoor sources. Industrial processes, such as fossil fuel combustion, manufacturing, and other industrial activities, emit various pollutants such as particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), and heavy metals. May be released into the atmosphere. These emissions can contribute to air pollution, especially in and around industrial areas. Emissions from vehicles such as cars, trucks, and buses are a significant source of urban air pollution. Burning fossil fuels in car engines releases pollutants such as particulate matter, nitrogen oxides, carbon monoxide (CO), and volatile organic compounds, reducing air quality, especially in congested metropolitan areas. To do. Agricultural practices such as burning crop residues, raising livestock, and using fertilizers and pesticides release pollutants into the air such as ammonia, methane, dust, and agricultural combustion emissions that contribute to air pollution in rural and agricultural areas. may release. The use of solid fuels such as wood, coal, and biomass for heating and cooking in residential and commercial environments releases smoke and other pollutants into the air, which can lead to indoor and outdoor air pollution. Other sources of emissions in residential and commercial areas are emissions from energy production, construction, and the use of consumer goods such as paints, cleaning products, and cigarette smoke. Natural sources of air pollution include dust and smoke from wildfires, volcanic eruptions, and windblown dust. These can contribute to local and regional air pollution, especially during periods of increased natural activity and events. Climate change can also contribute to deteriorating air quality. Rising temperatures and changes in weather patterns affect the formation and distribution of air pollutants such as surface ozone, particulate matter, and allergens, which can degrade air quality in some regions. Indoor air pollution can also contribute to poor air quality, as various pollutants can be released from sources such as cooking, cleaning, smoking, and inadequate indoor ventilation. Poor indoor air quality can have a significant impact on health as people spend a significant amount of time indoors, especially in residential and commercial buildings.

Open air-flow ventilation, also known as natural or passive ventilation, has been used by people for thousands of years to bring fresh outdoor air into buildings and remove stale indoor air. Early human civilizations such as Mesopotamia, Egypt, and Ancient Greece designed buildings with openings such as windows, doors, and vents to allow natural airflow for ventilation. The stomata are strategically placed to take advantage of prevailing wind and temperature differences between indoor and outdoor environments. Throughout history, traditional indigenous buildings in various regions of the world have incorporated open air-flow ventilation techniques adapted to local climate and environmental conditions. For example, in hot, dry regions, buildings may have central courtyards or wind towers (as in Middle Eastern countries) to facilitate natural air circulation and provide cooling. In tropical regions, buildings may have high roofs, large windows, and elevated floors (as in Southeast Asian countries) to allow natural ventilation and reduce humidity. Many historic buildings such as castles, churches and palaces are designed with outdoor ventilation in mind. These buildings often had high ceilings, large windows, and strategically placed vents or vents to allow for natural airflow and exchange of indoor and outdoor air. During the 18th century and 19th century industrial revolution, mechanical ventilation systems became popular due to the invention of fans and other ventilation devices. However, many buildings continued to use open air-flow ventilation, especially in residential areas where fresh air exchange relied on natural ventilation. In recent years, there has been renewed interest in outdoor airflow as part of sustainable building design. Passive design strategies that use natural ventilation such as chimney effect, wind ventilation, and cross-ventilation ventilation technologies improve indoor air quality, reduce energy consumption, and promote environmental sustainability Because of this, they are increasingly being incorporated into modern building design.

II.II What is Clean Unit System Platform

Conventional air purifiers alone are not enough to create a healthy indoor environment. Being kind to the body means having good air quality (IAQ) in activity rooms and spaces. That is, 1) the number of dusts and bacteria in the indoor air is low, and 2) the concentrations of various gas molecules of interest are controlled within reasonable limits for the maintenance and activity of living organisms. We show that CUSP works very well, referring to criteria 1) and 2) above. Figure 1 shows a conventional clean room (or clean booth) and his CUSP system. The conventional cleaning system was equipped with a fan filter unit (FFU) consisting of a fan with a ventilation function and a dust removal filter. FFU is located at the boundary between indoors (clean room) and outdoors. The number of dust and microorganisms in the air, including bacteria and viruses, is reduced by filtering the air from outside and pushing it into the room with FFU. Finally, dust and microorganisms in indoor air are pushed out of the room by clean air. Filtration efficiency decreases over time. A very bad thing about conventional systems is that the FFU continues to clog even after the room itself is sufficiently clean. The conventional clean system is equipped with a fan filter unit (FFU), which is composed of a fan with air blowing ability and a filter. The FFU is located at the interface between the room (clean space) and the outside. The numbers of airborne dusts and/or microbes, including bacteria and viruses, are reduced by filtrating the air from outside and pushing it into the room with FFU. Eventually, the airborne dusts and microbes in the room is pushed out of the room by the clean air. The effectiveness of filters in removing airborne contaminants depends on their efficiency and maintenance. Filters may not be as effective at trapping pollutants, reducing their overall effectiveness in improving indoor air quality. In addition, regular maintenance such as cleaning and replacement is required to maintain the effectiveness of the filter. If filters are not properly maintained, they can become clogged and dirty, reducing their ability to trap airborne contaminants, and affecting indoor air quality. This may allow outside noise and odors to enter. This can affect the comfort and health of building occupants, especially in areas with high noise and odor levels. Effectiveness can also be affected by climate and seasonal variations. For example, during extreme weather conditions such as heavy rain or high winds, natural ventilation may need to be suspended or reduced, which can affect indoor air quality and ventilation rates. Also, in order to ensure a constant flow of air, the fan must be kept energized without interruption, which brings with it some additional power consumption.

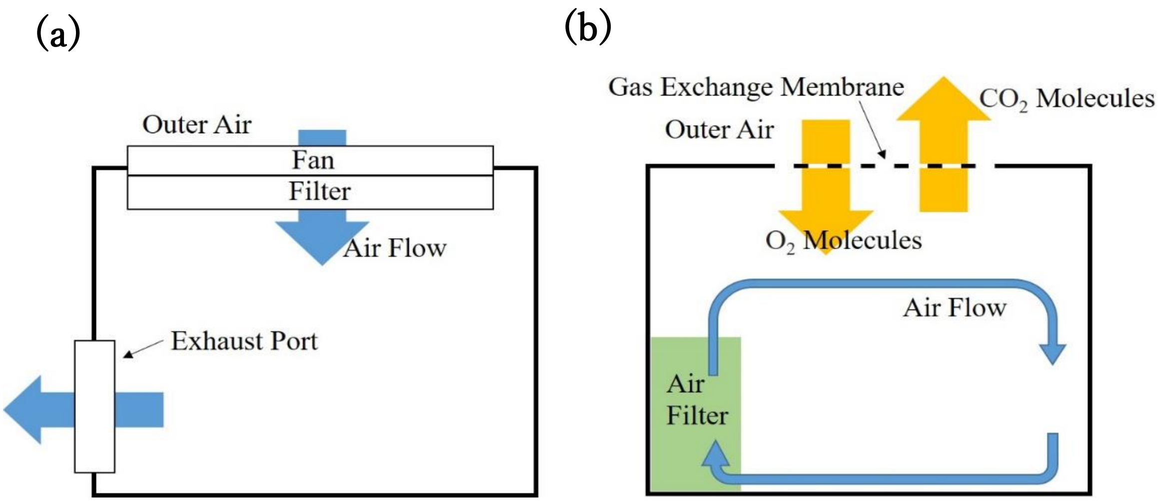

Fig.1. a) a conventional cleaning system, b) clean unit system platform (CUSP)

The clean unit system platform, CUSP, represents a 100% feedback system, as shown in Figure 1b, where the entire volume of air exiting the FFU returns to the inlet, resulting in a closed airflow system and because the indoor and outdoor air pressures are the same, there is no airflow between the interior and exterior of the room. In CUSP, the FFU is isolated from the outside. This is in marked contrast to conventional systems where the FFU is located at the boundary between the inner and outer sides, as shown in Fig. 1a. Furthermore, it is an active filtration system where the FFU directly captures dust and microbes inside, in sharp contrast to traditional systems where the FFU filters the outside air and this clean air pushes the particles inside and the microbes out. On the other hand, thanks to the closed airflow system that allows isolation from the outside, the people inside are completely free from the risk of intrusion of airborne microorganisms into the room from the outside, or of airborne microorganisms in the room going out of the room. be released. In CUSP, filter clogging is negligible because the FFUs that filter the room air operate with virtually no load as soon as the room is cleaned.

An isolated system plays a pivotal role in combating the SARS-CoV-2 virus by establishing a controlled setting where exposure to the virus can be meticulously minimized, thereby markedly reducing the risk of airborne transmission. In these systems, the precise management of air circulation, filtration, and gas exchange allows for the control and removal of infectious particles from the air. Advanced filtration technologies, including high-efficiency particulate air (HEPA) filters and ultraviolet (UV) light-based purifiers, are frequently utilized in isolated systems to reduce the concentration of viral particles, preventing their accumulation and ensuring the continued safety of occupants. Such systems are of particular utility in settings where there is a high risk of infection, including healthcare facilities, quarantine zones, and workplaces where essential services are provided. In these locations, it is of paramount importance to maintain low transmission rates to ensure the safety of the general public and of those on the frontline of the response.

In addition to regulating air quality, isolated systems permit the implementation of structured cleaning and disinfection protocols, which are more readily manageable within confined spaces. This containment strategy facilitates routine surface sanitation and disinfection of high-touch areas, thereby reducing the risk of surface-based transmission in addition to airborne spread. By confining viral exposure to a single, controlled area, isolated systems enhance the ability to identify, trace, and contain potential cases, thereby facilitating efficient contact-tracing efforts. If an individual within the system becomes infected, their interactions and potential transmission points are already limited by the isolated environment, thereby minimizing the likelihood of broader outbreaks.

The efficacy of isolated systems in controlling the spread of viruses has implications that extend beyond the immediate context of the pandemic. It has important implications for public health resilience. Their design and structure facilitate the implementation of both prevention and response measures, thereby reinforcing pandemic preparedness by ensuring the maintenance of safer environments during infectious disease outbreaks. In conclusion, isolated systems provide a robust framework for minimizing airborne transmission, thereby enabling proactive and targeted responses to infectious threats. As society continues to adapt to the realities of global health risks, the significance of isolated systems becomes increasingly evident, underscoring their role in shaping resilient public health strategies against both present and future airborne infectious diseases.

III. Theoretical analysis

III.I Particles

III.I.I Air-borne Particles/Microbes in conventional open air-flow system

Let's start by analyzing the conventional system shown on the left side of Figure 1. There is enough airflow so that the particle/bacteria density n is independent of the position in the cleanroom because the airflow through the ceiling is nearly uniform. Approximating that airflow through the ceiling is uniform and thus then the particles/microbe's density n is not dependent on the position in the clean space due to sufficient air flow, the dust density *n* at *t*=*t*+*dt* is given by

$$Vn(t+\delta t) = Vn(t) + S\sigma\delta t + (1-\gamma)N_0F\delta t - n(t)F\delta t \qquad (1)$$

The dust/microbe density inside increases in two ways: one is with these coming out of the inner surface and/or exhaled air of those who are in the room (the second term in the right-hand side of Eq. 1) and the other is those coming inside penetrating through the filter in the incoming airflow (the third term there) and decreases with being contained with density *n* in the outgoing air (the fourth term). Here S is area of the inner surface of the room shown in Fig. 1(a), V the volume of the room, σ the rate of dust particles coming out of the surface of the room (and people etc., inside, if any) per unit area per unit time, N_0 the particles/microbes' density outside, F the airflow rate out of FFU, and γ the dust filtration efficiency of the filter in FFU. Equation 1 directly reads to the differential equation:

$$V\frac{dn(t)}{d(t)} = S\sigma + (1-\gamma)N_0F - n(t)F \qquad (2)$$

The solution to Eq. 2 is

$$n(t) = S\sigma/F + (1-\gamma)\,N_0 + \left[N_0 - \left[\frac{\delta\sigma}{F} + (1-\gamma)N_0\right]\right]e^{-\frac{F}{V}t} \qquad (3)$$

with the boundary condition $n(0)$= N_0, i.e., the dust density inside is equal to the ambient dust density at t=0, the time when FFU is turned on. When we express the time-dependence of *n* using the characteristic time, t, as

$$\eta(t) \sim e^{-\frac{t}{\tau}},$$

τ is given, from Eq. 3, as follows:

$$\tau = \frac{V}{F} \qquad (4)$$

From Eq. 3, we understand the presence of a scaling rule which says that even if the size of a room is different, if you increase or decrease F in proportion to V, the identical time-dependence of n can be obtained with the same characteristic time t. Note that no matter how long time passes, the first two terms in the right-hand side of Eq. 3 remain in the conventional system, meaning that the conventional open airflow system is subject to the ambient particle/microbe density N_0 forever. Of course, if a high-end filter with the filtration efficiency γ being quite close to 1 is used, the influence from outside can be made very small (i.e., (1- γ) times N_0), but we must remember that the finer the filter, the sooner the filter gets clogged.[28] The filter life time is shorter.

III.I.II Air-borne Particles/Microbes in CUSP closed air-flow system

To overcome hindrances of old systems, we have been developing proposed CUSP for decades, and the problems could be solved. The CUSP, as shown in Fig. 1b, constitutes a 100% feed-back system in which the entire amount of air outflowing from the FFU returns to the inlet of the FFU resulting in a closed air-flow system and the equal pressure between inside and outside, because of which no air flow exists between the inside and outside of the room. As shown in Fig. 1(b), in our system, FFU is isolated from the outside, which is in marked contrast to the conventional system in which FFU is located at the interface between the inside and outside, as depicted in Fig. 1a. In addition, it is an active filtrating system in which the FFU traps the inside dusts and/or microbes directly, which is again in marked contrast to the conventional system in which the FFU filtrates outside air and this clean air pushes out the inside particles and microbes out of the room, as shown in Fig. 1a. This is very risky way to have a clean room to treat Covid-19 patients, since the inside airborne particles and microbes including SARS-COV-2 can go into the room because of γ not equal to 1.

In our CUSP, on the other hand, thanks to the closed air-flow system enabling isolation from outside, people inside are completely free from the risk that the outdoor airborne microbes come into the room from outside as well as that the in-room airborne microbes go outside of the room. In CUSP, the FFU, being filtrating the inside air, operates virtually load-free once the room gets clean, and the filter clogging accordingly becomes negligibly small. As mentioned before, there being no air-flow between inside and outside of the room, the SARS-COV-2 that floats in air cannot come inside from outside nor go outside from inside, which make CUSP an ideal clean space to protect and treat Covid-19 patients staying inside, while keeping the people who stay outside quite safe from air-borne COV-SARS2 inside.

Let’s analyze in detail quantitatively. In CUSP, the variation of dust/microbe density n with respect to time is

$$V\frac{dn(t)}{dt} = S\sigma + (1-\gamma)n(t)F \;\; - n(t)F \qquad (5)$$

Thanks to the fact that CUSP is 100% feedback closed air system, we can obtain Eq. 1

by just replacing N_0 with $n(t)$ in Eq. 1. Equation 3 has the solution:

$$n(t) = \frac{S\sigma}{\gamma F} + \left[N_0 - \frac{S\sigma}{\gamma F}\right] e^{-\frac{\gamma F}{V}t} \qquad (6)$$

with the boundary condition $n(0) = N_0$. For the closed airflow system of CUSP, the characteristic time is given by

$$\tau = \frac{V}{\gamma F} \qquad (7)$$

Because t is close to unity, the characteristic time for a closed airflow system is almost the same as that of an open airflow system with identical *V* and *F*.

In CUSP systems, when sufficient time passes, i.e., around t ~ 5×*V*/*F* (typically t ~10 min.), the first term in right side of Eq. 5 becomes almost zero and the steady state dust density:

$$n = \frac{S\sigma}{\gamma F} \qquad (8)$$

is reached.

In CUSP, the key parameter governing cleanliness is completely different from that in conventional clean systems (rooms or booths). As Eq. 1 shows, the most important factor in the conventional clean room is g, the filtrating efficiency, which, of course, should be as close to 1 as possible for the sake of cleanliness. For this purpose, ultra-low particulate air (ULPA) and high-efficiency particulate air (HEPA) filters are used, but since one side of the filter is always exposed to the outdoor air, the main filter has to be replaced in about 1 to 2 years (even with the pre-filter) because of clogging. For CUSP, on the other hand, the filtrating efficiency γ is not important at all, since γ, for example, as low as 0.9 still can give only 10% worse cleanliness than the best cleanliness obtained with γ=1, as seen from Eq. 6, The most important issue for CUSP is to minimize s as low as possible. For treating Covid-19, disinfection of the inner surface of what is inside of the CUSP room is important.

III.II Gas Exchange

III.II.I Gas concentration in conventional in conventional open air-flow system

In addition to the cleanliness, it is necessary to properly control the concentration of gas molecules of interest in a living space (room) with volume *V*. In the conventional clean system, ventilation is performed mechanically with FFU that push the outdoor air into the room after filtration. As shown in Fig. 1a. Here, the air in the room is replaced with the outdoor fresh air by FFU, which results in mechanical ventilation. The conventional system is expressed quantitatively as follows. When oxygen consuming activities (for example, burning of fire or breathing of people) is taking place at a rate of *B* [m^3/s] in this room with volume *V*, letting $\eta(t)$ and η_0 be, respectively, the oxygen concentration inside the room at time t and the oxygen concentration outside (the initial value of the indoor oxygen concentration), the volume of oxygen in the room at time $t = t + \delta t$ is written as

$$V\eta(t + \delta t) = V\eta(t) + \big(\eta_0 - \eta(t)\big)F\delta t - B\delta t \quad (9)$$

The first term in the right-hand side is the oxygen volume at time t, the second term the oxygen consumption, and the third term the increase in oxygen due to the ventilation with air flow F, in the time interval $(t, t + \delta t)$. From Eq.8, with transposing the first term on the right side to the left side and dividing both sides by δt. we have the differential equation

$$V\frac{d\eta(t)}{dt} = F\big(\eta_0 - \eta(t)\big) - B \qquad (10)$$

Because at $t = 0$ the oxygen concentration is equal to η_0, the solution of Eq. 9 is given by

$$\eta(t) = \eta_0 - \frac{B}{F}\left(1 - e^{\frac{-Ft}{V}}\right) \qquad (11)$$

From Eq. 11, we find that the characteristic time τ for controlling gas concentration in the open airflow system is given by the same equation as Eq. 4. After sufficient time passes (around t ~ 5×*V*/*F*), the system reaches the steady state and the exponential part of Eq. 11 becomes almost zero and the internal oxygen concentration converges to a constant value:

$$\eta(t) = \eta_0 - \frac{B}{F} \qquad (12)$$

Note that we can obtain the same result for the steady state just by letting *Vdh*(*t*)/*dt*=0 in Eq. 9, taking advantage of being a steady state).

III.II.II Gas concentration in CUSP closed airflow system

For the CUSP system, on the other hand, since it is an isolated closed system of equal internal and external pressures, as mentioned above, there is no air flow between inside and outside. For introducing fresh air into the room, we make a part of the wall of the room to be made of gas exchange membrane (GEM), which is thus located at the interface between the inside and outside of the room, as shown in Fig. 1b. Letting A be the area of this membrane, L the thickness, and D the diffusion coefficient of gas molecules across GEM, the volume of oxygen in the CUSP room at time $t = t + \delta t$ is given by

$$V\eta(t+\delta t) = V\eta(t) - B\delta t + \frac{jAC\delta t}{N_A} \qquad (13)$$

where B [m^3/s] is the oxygen consumption rate, N_A the Avogadro's number, C the gas volume per mole at the system pressure (~ 1 atm.), j the oxygen flux coming into the room through GEM. We now have the differential equation:

$$V\frac{d\eta(t)}{dt} = \frac{jAC}{N_A} - B \qquad (14)$$

Note that since the air in the CUSP is well stirred by the independent parameter of air flow F generated by the FFU, position-dependence of $\eta(t)$ can be neglected to a much better approximation than that in the conventional system for which F is directly connected to ventilation as seen in Eq. 9 In CUSP, F is indeed a ruling parameter for reducing rate of the particle counts, but not that for gas molecule diffusion. The third term on the right side in Eq. 13 is the volume of oxygen diffusing into the room due to the concentration gradient across the GEM (concentration difference between in- and out-side of CUSP). The flux j is given by

$$j = D\nabla\phi \qquad (15)$$

where ϕ is the number of gas molecules of interest (here oxygens) per unit volume inside the enclosure, D is the diffusion constant of the gas molecule across the GEM, and ∇ is the differential operator in the direction perpendicular to GEM.

Since the thickness of GEM, being extremely thin, is three or more orders of magnitude smaller than the size of the room, the derivative
in Eq. 15 can be replaced, to a good approximation, by the difference in η divided by thicknessand Eq. 12 leads to the differential equation

$$V\frac{d\eta(t)}{dt} = AD\frac{(\eta_0 - \eta(t))}{L} - B \qquad (16)$$

where η_0 is the ambient gas concentration, which is about 20.9% for oxygen. With the same boundary condition as for solving Eq. 9, the solution for Eq. 16 is

$$\eta(t) = \eta_o - \frac{BL}{AD}\left(1 - e^{-\frac{AD}{VL}t}\right) \qquad (17)$$

Now we understand the characteristic time τ for controlling gas concentration in the closed airflow system is expressed as

$$\tau = \frac{VL}{AD}\,. \qquad (18)$$

After a sufficient time, the gas molecule concentration is given by

$$\eta(t) = \eta_0 - \frac{BL}{AD} \qquad (19)$$

Comparing Eq. 12 and Eq. 19, we have a very important equation of correspondence between the old-fashioned mechanical ventilation system and our new diffusion ventilation system:

$$F = \frac{AD}{L} \qquad (20)$$

This, once a GEM with thickness L, and a diffusion coefficient D for the gas-molecule of interest is given, by adjusting the area of GEM, we can realize any diffusion-based, fresh-air-introducing system that has the same ability/performance of ventilation as any conventional system with air-flow F, thanks to Eq. 19. It is usual that there are plural gas-molecules of interest, and/or needed F is different for those gasses, and in these cases, of course, A is set to be large enough to be compatible with the largest F based on Eq. 19.

IV. Applications for Closed Air-flow system

IV.I Tent-type CUSP

Since the theoretical analysis is done above, we now implement CUSP/GEM systems based on the theory and check the performance. Thus, a tent-type CUSP (T-CUSP), shown in Fig. 2, is fabricated as one of the CUSP systems in which the closed space is completely covered by GEM[8]).Here, a large area of GEM (~8 m^2) is used for an airtight tent with a volume of ~2 m^3 in Fig. 2. The FFU (Panasonic F-PDF35) inside has three adjustable flow rates: ~1.0, ~2.0, and ~3.5 m^3/min and γ of 0.95~0.98. For medical systems, especially for the treatment of Covid-19, a highly clean environment is essential. However, in some underdeveloped countries or in some rural/suburban areas even in developed countries, hospitals may not have such clean environment [9][10]. For these cases, the CUSP could be the first choice, because the tent-type CUSP, which is very easy to set up, does not need to consume too many resources, it can meet the requirements of cleanliness and low power consumption. In the near future, when the CUSP is covered with flexible solar cells, the net power consumption of the whole CUSP system could be set close to zero. Due to the global pandemic of Sars-Cov-2 and its sub-strains, an effective and good diagnostic environment that protects not only patients but also medical staff is essential. According to the regulations of the Ministry of Health, Labor and Welfare of Japan, the carbon dioxide concentration in the room should be kept below 1500 ppm to ensure people's normal daily life, for which Eq. 19 and 20 help us to build a suitable CUSP/GEM system. The gas exchange unit (GEU) is composed of multiple GEMs stacked in a rectangular box, and it can provide uninterrupted ventilation throughout the day by molecular diffusion driven by thermal energy of room temperature, thus without turning on FFU. As for the FFU in CUSP systems, since it does not exchange the air flow inside with that outside, the indoor air environment is always cleaner

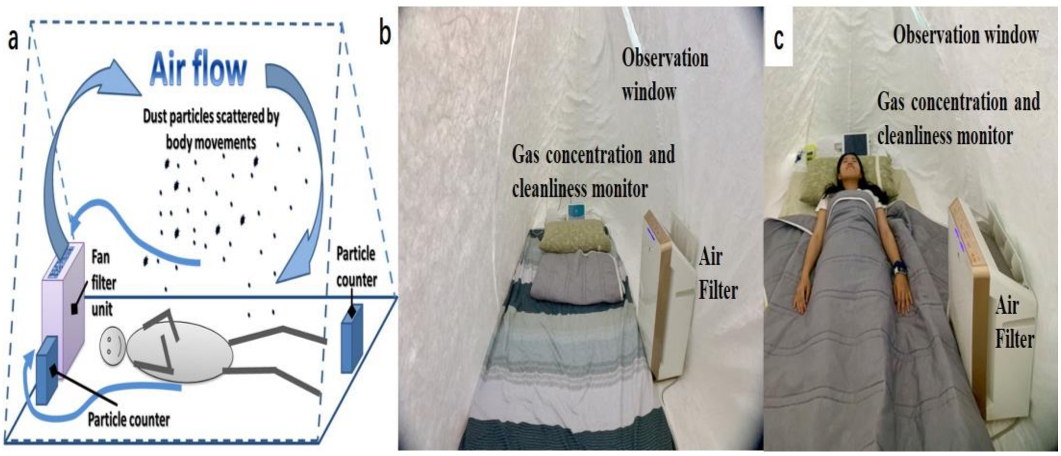

Fig.2. a) Conceptual diagram of T-CUSP; b) Inside view of T-CUSP, the air purifier works uninterrupted when there are people, gradually reducing the amount of particle matters. The observation window provides experimental personnel with conditions for medical observation and the real-time cleanliness and gas concentration can be seen. C) Object in T-CUSP

under 100% recirculation with closed air circulation. The particulate matter in the air is quite small in number and will have an almost negligible effect on the lungs, cardiovascular and cerebrovascular systems of humans.

The following experimental procedures are designed to verify the purification and gas exchange capability of the CUSP T-CUSP shown in Figure 2. 1) Completely mix the air inside and outside the tent to allow particles to completely enter the interior space. Turn on the FFU and record the number of particles (one part per cubic feet) to verify the internal cleaning capability of the T-CUSP. 2) Ignite the cassette furnace in a compact CUSP with approximately the same volume, GEM area, and FFU as the T-CUSP, turn it off after burning for a period of time, and measure the oxygen and carbon dioxide concentrations in the CUSP as a function of time. The gas concentration control capability of the GEM can be examined by monitoring the internal air conditions.(Zhou: Paper 1; Zhou: Symposium 4)

IV.II Nap-Box

Quality of Life (QoL) is a comprehensive measure that incorporates a multitude of elements that collectively influence an individual's perception of well-being and satisfaction. Among these factors, sleep efficiency is of particular importance, as it has a direct impact on physical health, mental clarity, and emotional balance. Sleep efficiency, defined as the ratio of time spent asleep to time spent in bed, is a critical determinant of feelings of rest and restoration. When sleep efficiency is high, individuals experience enhanced physical recovery, improved immune function, and a more stable mood—all of which are essential for a good quality of life. Conversely, poor sleep efficiency, often caused by factors like stress, noise, or poor air quality, leads to fatigue, irritability, and an increased risk of chronic conditions, all of which diminish QoL.[9][11] In the tapestry of life's daily rhythms, the act of napping weaves a crucial thread of rest and rejuvenation. Over time, with the onslaught of industrialization and the 24/7 demands of modern life, napping has often been relegated to the sidelines, sometimes even stigmatized as a sign of laziness or inefficiency. A closer look, however, reveals that the simple act of closing one's eyes and drifting into a brief slumber during the day has profound implications for our health, cognition, and overall well-being.

Sleep is essential for the repair and recovery of our bodies. While a good night's sleep is crucial, short naps during the day can also provide restorative benefits. A short period of rest can act as a reset button, reducing stress and lowering cortisol levels[12]. By providing a break, naps can help with emotional regulation, ensuring that you don't get overwhelmed by the challenges of the day. Even a short nap can recharge the mind, increase alertness, and improve overall mood. This can be especially beneficial for people who experience afternoon slumps, characterized by decreased concentration and increased sleepiness.

Most importantly, napping serves as a remedy for sleep deprivation. A short nap can mitigate the effects of sleep deprivation by reducing fatigue and increasing alertness. This increase in alertness is not just a matter of feeling more alert, it translates into improved task performance, improved reaction times, and better decision-making skills. In addition to combating fatigue, napping can also improve cognitive function. Memory benefits immensely from daytime slumber, as researchers delve into the intricacies of sleep, they've discovered that memory consolidation-the process by which the brain processes, organizes, and stores new knowledge-is enhanced during sleep. This suggests that students or professionals seeking to assimilate new information could benefit from a strategic post-learning nap to ensure that the newly acquired data is more firmly anchored in their neural networks.

In essence, napping is a testament to the body's innate wisdom. It signals the need for rest, for a momentary pause in the relentless march of time. As science continues to unravel the mysteries of sleep, the nap, in all its humble glory, is emerging as a powerful tool for health and wellness. Embracing this ancient practice is not just about surrendering to sleep, it is about honoring the body's rhythms, optimizing cognitive performance, and nurturing emotional well-being. In the symphony of life, the nap offers a restorative interlude that harmonizes health and happiness.

Furthermore, in indoor environments where individuals spend a considerable amount of time, maintaining optimal air quality is crucial for creating a comfortable and secure environment. Air quality is of paramount importance in environments such as hospitals, workplaces, and schools, where individuals are particularly susceptible to health risks associated with inadequate ventilation or airborne pathogens. For example, in hospital settings, the presence of clean air reduces the risk of infection transmission, which is of particular importance for individuals with compromised immune systems. In workplaces and schools, optimal air quality enhances productivity and focus, facilitating enhanced learning outcomes and work performance, which are integral to quality of life (QoL) for students and workers alike.

In conclusion, sleep efficiency and air quality are both essential elements of QoL, with each contributing to the maintenance of physical, mental, and emotional health. High sleep efficiency results in a well-rested and resilient individual, whereas good air quality ensures that people breathe more easily, think more clearly, and stay healthier. Collectively, they form the foundation for a high quality of life, enabling individuals to function optimally, feel better, and engage more fully in life's activities. Maintaining clean air and good sleep efficiency is not just a matter of comfort; it is an essential practice for achieving a fulfilling, healthy, and balanced life.

We have developed a new compact CUSP-GEM system named Nap Box, shown in Fig. 3, which allows the compact CUSP/Nap-Box to serve as a highly versatile PCe. Shown in Fig.4, employing the closed air-flow system to its advantage, we conducted a sleep assessment experiment using the Nap Box. (Zhou: Academic conference 1)

Fig.3. NAP BOX's exterior, interior, and experimental environment

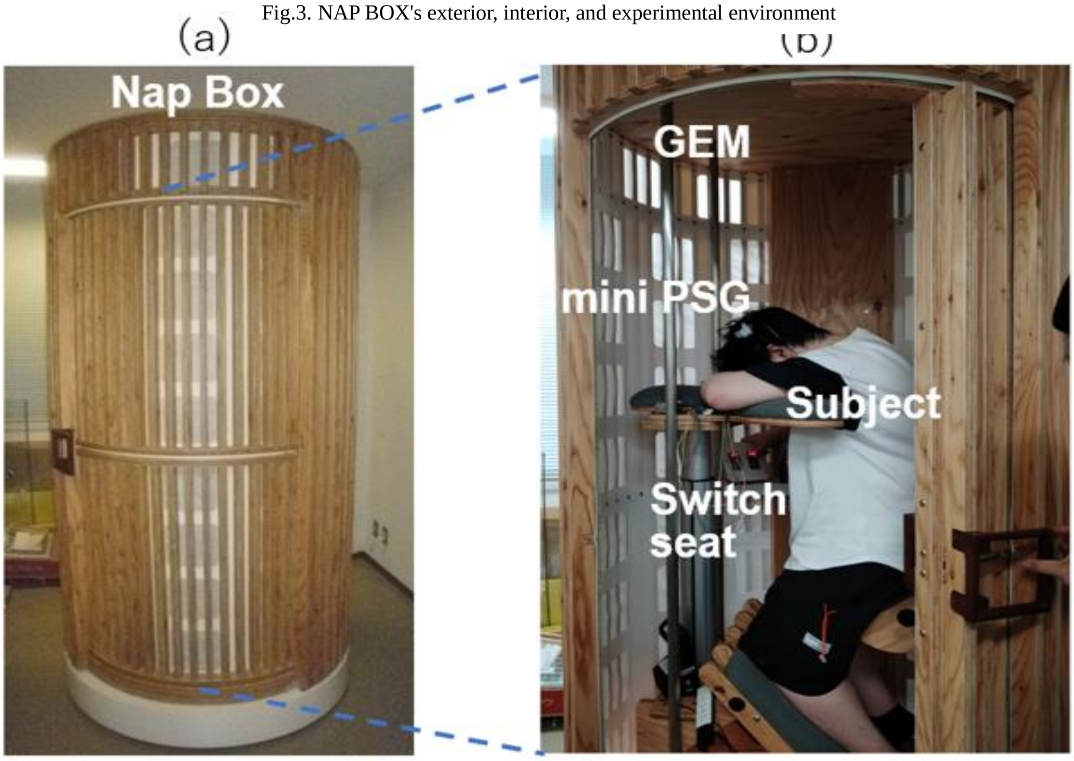

Fig.4. a) Outlook and b) inside, with a subject taking a nap, of a high air-quality Nap-Box based on CUSP. The subject's body is supported at 4 points, i.e., feet, knees, waist, and arms/elbows.

IV.III CCB

The Connected CUSP Booth (CCB) is a testament to this adaptability and innovation. At a time when safety and healthcare must coexist seamlessly, the CCB provides a solution that prioritizes both. It represents a fusion of design, function and medical necessity, ensuring that health assessments can be performed without compromising the safety of both the clinician and the patient.

The CCB is essentially an isolated space, carefully designed to ensure the safety of both the patient and the physician, especially in situations where contagious diseases may be involved. The booth is divided into two sections: the doctor's booth (DB) and the patient's booth (PB). These two booths are separated by a transparent sheet that allows visual communication between the doctor and the patient. Two holes have been made in this transparent partition. These holes play a crucial role in allowing the doctor to perform his diagnostic procedures without any physical contact with the patient. Whether it's checking the pulse, examining the throat or even taking blood, these holes ensure that doctors can perform their tasks without compromising their safety or that of the patient.

Another innovative feature of the CCB is the inclusion of a gas exchange membrane. Positioned on the side, this membrane covers portions of both the DB and PB shown in Fig.5. At its core, the membrane's primary function is to ensure that there's a safe exchange of gases, such as oxygen and carbon dioxide, between the two chambers. This is particularly important in scenarios where the patient may be carrying a respiratory infection. The membrane ensures that the air inside the booths remains fresh and any pathogens are effectively filtered out, reducing the risk of transmission.

The introduction of the CCB into healthcare environments can have a profound

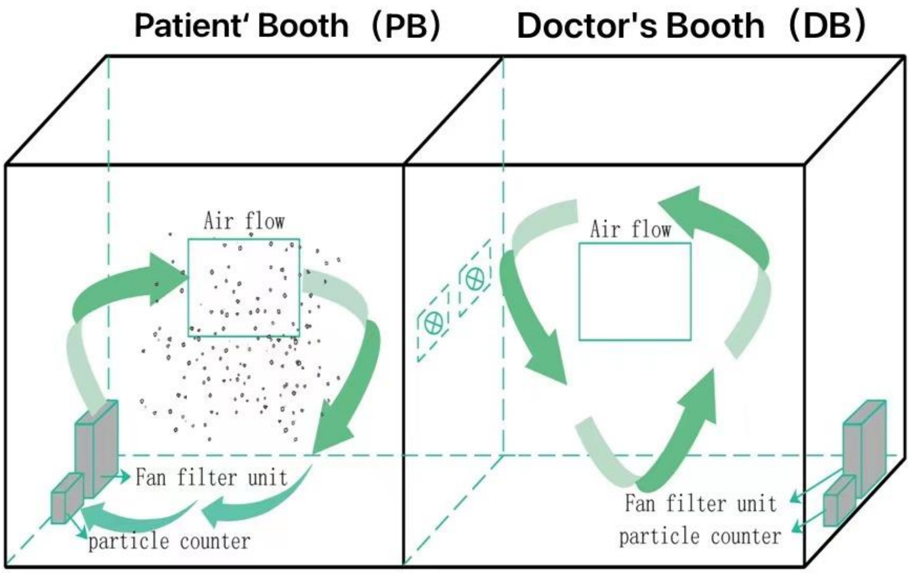

Fig.5. Conceptual image of CCB

impact. It can significantly reduce the transmission of infectious diseases, ensuring that healthcare professionals can perform their duties without risk. This is particularly important in the wake of global health crises such as the COVID-19 pandemic.

In addition, the CCB can be an excellent tool in high-traffic areas, allowing clinicians to see more patients without compromising safety. It can also be used in remote or war-torn regions where it may be difficult to establish full-fledged hospitals.

The CCB represents a significant leap forward in healthcare, fusing technology and design to create a safe space for both doctors and patients. As the world continues to grapple with health challenges, innovations like the CCB will undoubtedly play a pivotal role in shaping the future of healthcare. (Zhou: Academic conference 5) In Fig.6, we verified the particle transmittance of CCB, two FFU placed at both sides and two particle counters set on the middle of space in PB and DB.

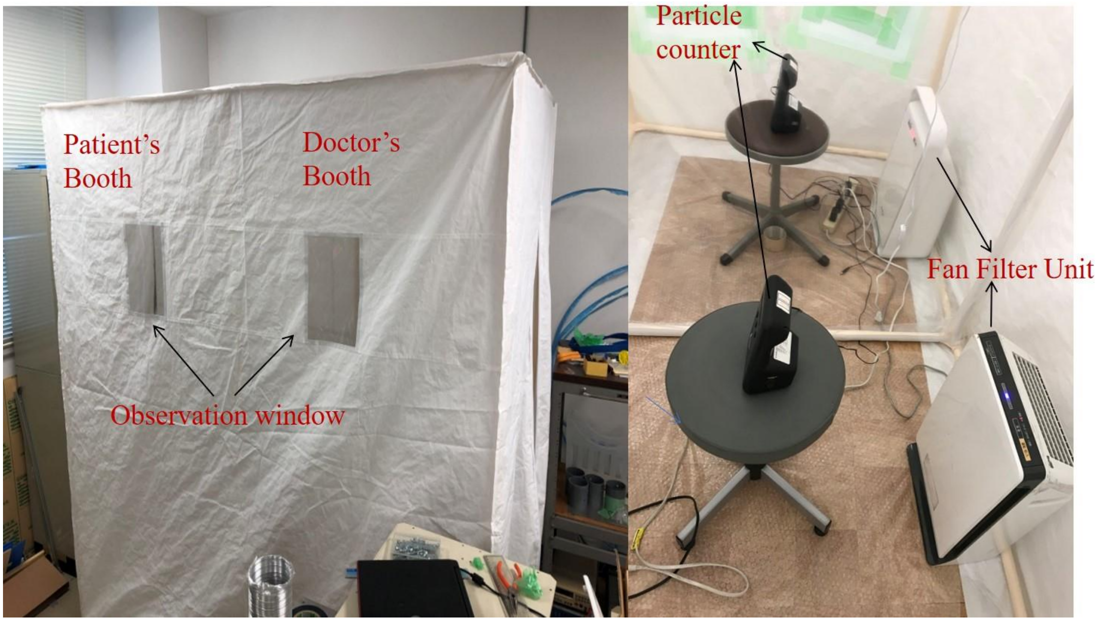

Fig.6. Actual photos of CCB and its interior

IV.IV Smart Agriculture

In the domain of agriculture, a foundational aspect of human civilization, technological advancements have facilitated the emergence of "smart agriculture," a paradigm where traditional practices and modern innovations converge in a seamless manner. Among these innovations, the closed-air flow system stands out, particularly in the context of mushroom cultivation. At its core, this system represents a delicate balance between creating an optimal growth environment and safeguarding against external factors that could hinder growth. In contrast to the majority of plants, mushrooms flourish not through photosynthesis but through the decomposition of organic matter, necessitating specific environmental conditions for optimal growth. It is evident that temperature, humidity, and air quality play a pivotal role in ensuring the successful cultivation of mushrooms. The closed airflow system, which employs advanced technology, enables the precise regulation of these factors within a controlled environment. One can envisage a space where temperature, humidity, and air quality are meticulously maintained, thereby creating an optimal environment for mushroom growth.

For example, the cultivation of Bunashimeji mushrooms exemplifies the agricultural and nutritional benefits of smart agriculture practices. These mushrooms exhibit rapid growth and thrive in stacked shelves or small containers, rendering them optimal for urban farming and the optimal utilization of available space. Bunashimeji mushrooms are a rich source of protein, dietary fiber, vitamins, and minerals. They contribute to improved immune function and provide anti-inflammatory properties. The cultivation of Bunashimeji mushrooms is contingent upon the maintenance of optimal CO_2 levels, which vary throughout each growth phase.[13]

During the initial mycelium growth phase, it is recommended that higher CO_2 concentrations be employed in order to prevent premature pinning and to promote the development of a robust mycelial network. As the mycelium colonizes the substrate and mushrooms begin to fruit, it is necessary to decrease the CO_2 concentration in order to facilitate cap development. The deployment of Internet of Things (IoT) monitors and devices plays a pivotal role in the creation of an optimal environment for the cultivation of Bunashimeji mushrooms. These devices are capable of monitoring air quality and gas concentrations in real time, thereby facilitating the optimization of the cultivation environment. By promptly responding to fluctuations in environmental conditions, these technologies enable precise control over mushroom growth, which in turn leads to increased economic value.(Zhou: academic conference 3, Zhou: Symposium 2)

In conjunction with gas exchange units, smart agriculture applications are essential in mushroom cultivation for the prevention of gas accidents. These units monitor and regulate the concentration of gases within the growing environment, thereby ensuring the safety of the mushrooms by preventing the accumulation of harmful gases that could lead to accidents such as asphyxiation or fires. By maintaining optimal gas levels, these applications promote healthy mushroom growth, maximize yields, and enhance overall efficiency in cultivation practices. Furthermore, they mitigate the risks associated with crop and facility damage, offering early warning systems for potential issues and enabling prompt corrective actions. The integration of smart agriculture technologies into mushroom cultivation not only enhances safety but also fosters sustainability and productivity in farming operations.

IV.V CAQLEA

A next-generation handy jump-up CUSP (CAQLEA) that is based on the CUSP technology and is designed to be easily set up and deployed rapidly has recently been released shown in Fig.7 [14]. The CAQLEA may be utilized as the primary chamber, capitalizing on its superior closed airflow and gas exchange membrane (GEM) or gas exchange unit (GEU), which comprises stacked multiple GEMs.[15][16] This self-supporting tent's elastic metal frame structure allows for expeditious installation in a matter of seconds. Subsequently, the ceiling component is attached to the mainframe through zipping, thereby completing the system in a brief period.

The rapid maintenance of elevated cleanliness levels renders CAQLEA invaluable for medical scenarios such as the treatment of SARS-CoV-2 and sleep assessments. Furthermore, CAQLEA displays exceptional capability in removing airborne particles, thereby demonstrating its effectiveness in reducing particulate matter (PM). The closed airflow design and energy-efficient diffusion processes of CAQLEA facilitate the creation of a personalized clean environment (PCe), while also enabling the monitoring of metabolic information and respiratory functions. This has the potential to lead to advancements in overall health conditions and quality of life.(Zhou: Symposium 1)

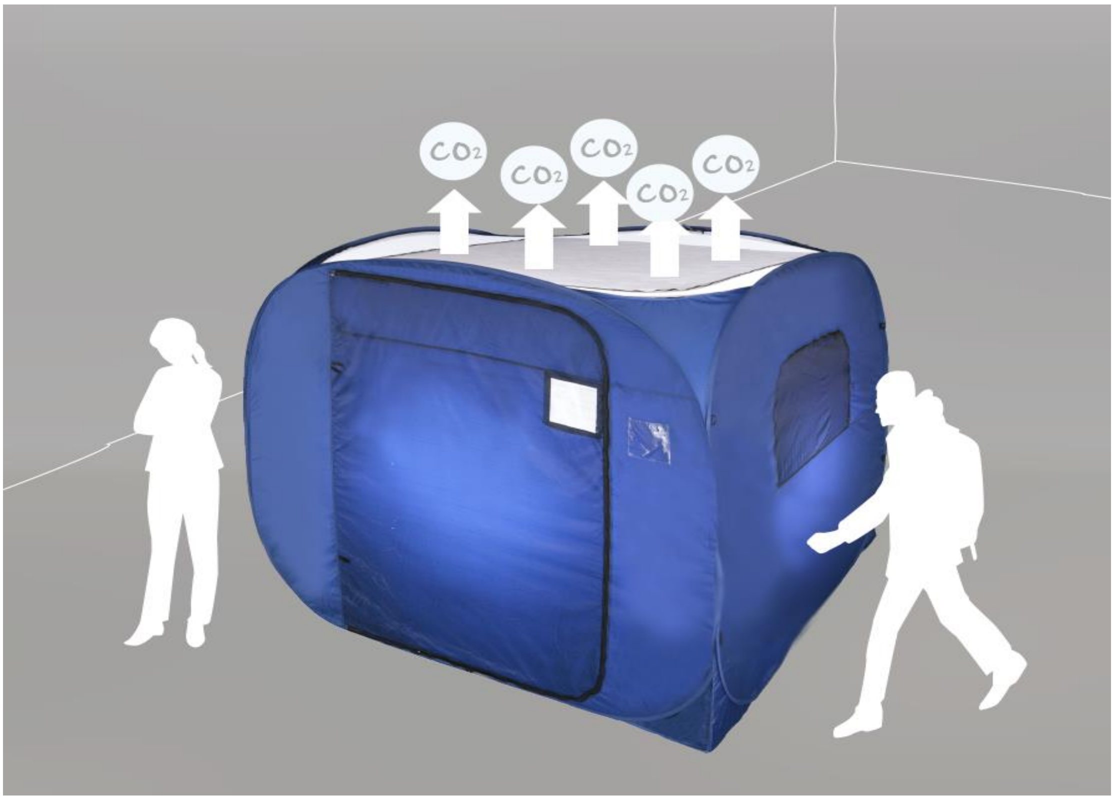

Fig.7. CAQLEA

V. Results and Conclusion

V.I Results

V.I.I Tent-type CUSP

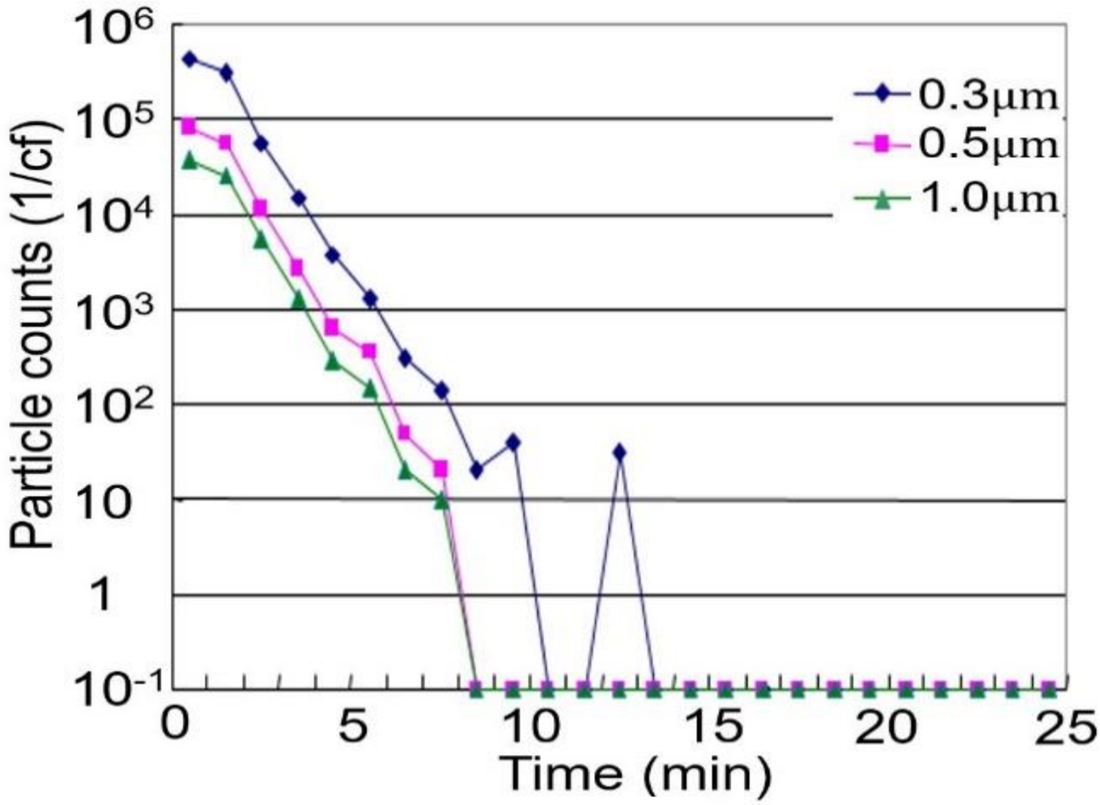

Fig.8. CUSP cleaning result

As illustrated in Fig. 8, following the activation of the FFU, the concentration of PM0.5 and PM1 particles exhibited a notable decline, stabilising at a minimal level within 10 minutes. Although the number of PM0.3 occasionally fluctuated, the dust/microbe density decreased to zero (it should be noted that the data point at 0.1/cf is plotted for the sake of clarity, as zero goes to $-\infty$ in the logarithmic plot). It takes approximately ten minutes for the particles and microbes to be reduced by one-tenth of their original concentration, reaching the US FED STD 209E class 10, equivalent to ISO 4, as illustrated by the pink line in Fig. 8. This indicates that the particle count decays exponentially with a time constant of approximately one minute, which is consistent with the theoretical prediction of Eq. (4).

$$\frac{V}{\gamma F} = \frac{2m^3}{0.95 \times 2m^3\ /\ min} \sim 1min$$

as V and F are both 2 m^3 and 2 m^3/min, respectively, with γ approximately equal to 1 as previously mentioned, it can be observed that particle counts reach a steady state at approximately 10 times the volume of V divided by F, as discussed. The number of PM0.3 particles, which are approximately 2–5 times the diameter of SARS-CoV-2, depending on their type, declines in T-CUSP to one hundredth of the initial value in approximately three minutes. Similarly, the number of smoke particles also decreases in a similar manner. Based on the reports indicating that virus-containing particles originating from the human body, transported by respiration, typically have a size of a few microns,[17].we can anticipate a higher filtration efficiency for SARS-CoV-2 viruses. Consequently, the CUSP can provide an optimal environment for the treatment of Covid-19 and other respiratory diseases.

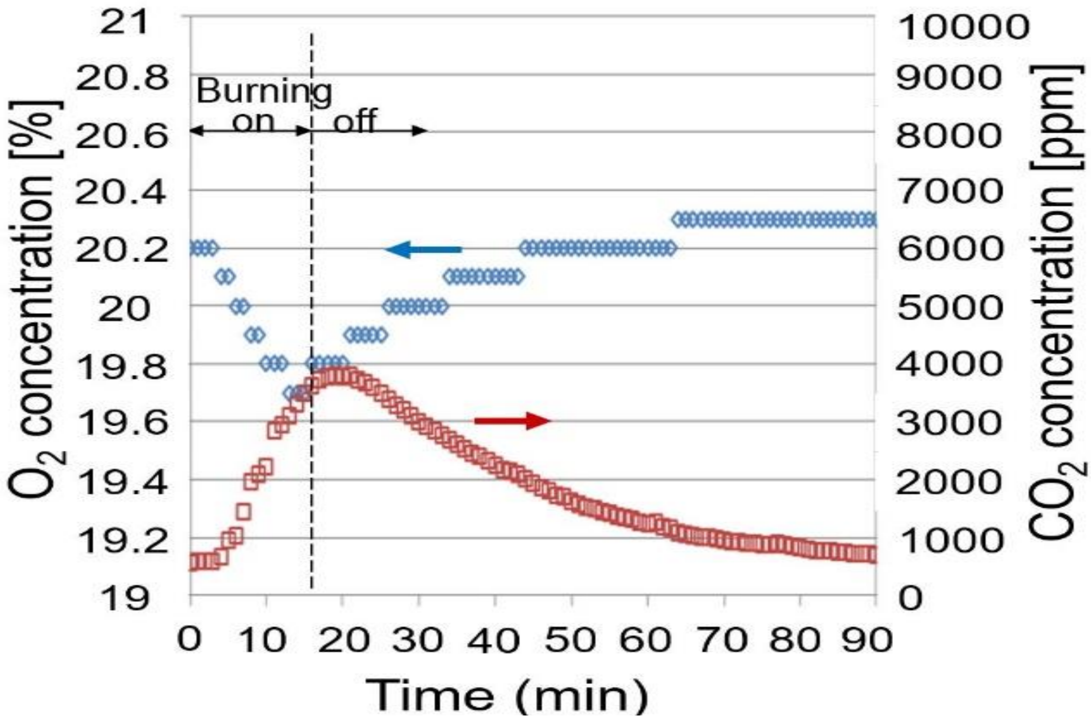

Fig.9. CUSP gas exchanging result

In the gas molecule concentration control experiment, oxygen and carbon dioxide concentrations are monitored over time in the compact CUSP, which has a volume (approximately 2.5 m^3) comparable to that of the T-CUSP mentioned before. The compact CUSP employs a GEU with a GEM of approximately 3 m^2 for gas exchange. As illustrated in Fig. 9, the concentrations are effectively controlled in the CUSP following a 16-minute combustion process. At the conclusion of combustion, oxygen levels rapidly begin to recover. It can be presumed that the latent time of the cooling of the air inside the CUSP after combustion is the cause of the gradual increase in carbon dioxide concentration for a period of time before it begins to decrease. The carbon dioxide concentration reduces from 4000 ppm down to below 1500 ppm, and the oxygen concentration is restored to that of the ambient air within 30 minutes. The time constant for O_2 and CO_2 is approximately 15 minutes, although it is slightly longer for CO_2 than for O_2. This is due to the fact that the masses of CO_2 and O_2 molecules are, respectively, approximately 44 and 32 times the proton mass. From the time constant, using Eq. (18), the diffusion constant can be estimated to be

$$D = \frac{VL}{A\tau} = \frac{2.5m^3 \times 160\mu m}{3m^2 \times 15min} \sim 1 \times 10^{-7} m^2 / s$$

given that *V*, *L*, and *A* are 2.5 m^3, 160 mm, and 3 m^2, respectively, as previously stated. This is believed to be the first experimental determination of the diffusion coefficient for a sheet of unwoven fabric used as the GEM. The diffusion coefficient of oxygen in air is estimated to be on the order of 10-5 cm^2/s.[18]. Consequently, the diffusion coefficient *D* estimated for oxygen molecules in the GEM is approximately two orders of magnitude smaller than that in air, which is a reasonable assumption given the significantly higher density of the thin sheet of unwoven fabric compared to the air.

V.I.II Nap-Box

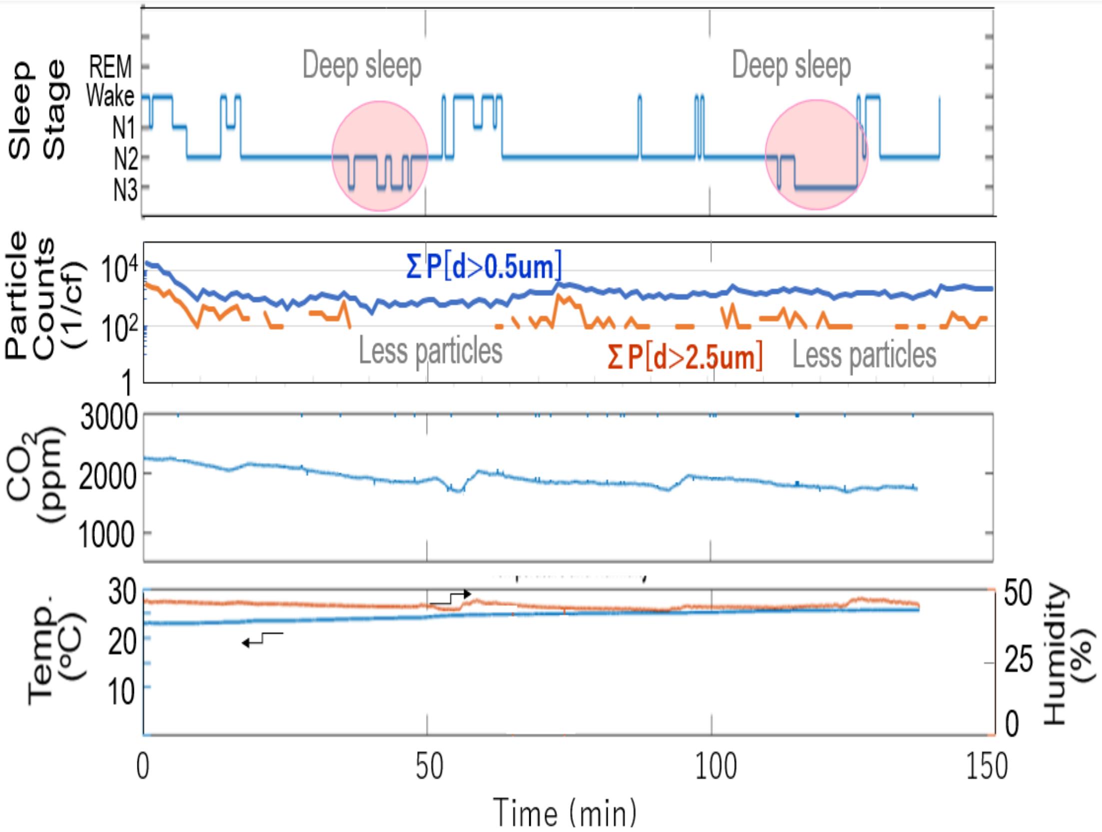

Fig.10. Sleep assessment experiment performed in Nap Box: Sleep stages; particle counts; CO_2 concentration; temperature and humidity are shown from top to bottom.

As depicted in Fig. 10, we recorded the sleep stages, particle counts, CO_2 concentration, temperature, and humidity during the experiment with the subject napping inside the Nap Box. Utilizing the sleep stage analysis protocol from Ref. [7][19], and thanks to the Nap Box's 4-point-supporting configuration (Fig. 4(b)), we achieved a world-first experiment measuring the sleep stage of a subject in a standing position. The results at the top of Fig. 10 indicate the subject remained in the N_2 sleep stage for a considerable period, which aligns with the probability of an optimal nap as demonstrated. [20] Additionally, the deep sleep stage corresponded with low particle counts and CO_2 levels, suggesting a state of restful sleep. However in this experiment, the level of CO_2 was around 2000 ppm, it can be decreased by using MOFs or alkali metal carbonates. MOFs are highly porous materials that can be designed to attract CO_2 molecules. They have the ability to capture CO_2 through physisorption which is reversible and can take place at room temperature. Moreover, sodium carbonate-based compounds can absorb CO_2 to create bicarbonates even at room temperature, notwithstanding the reaction being slower and less effective at standard atmospheric conditions than at higher pressures.[21] The sleep assessment by the Nap Box suggests that short naps within this environment may decrease sleepiness and aid in alertness restoration. The metabolic information and signals gleaned from the closed airflow system can be integrated with consumer electronics to provide health condition data, potentially improving the QoL. This technology represents a significant stride towards our vision of "The PCe for all of us," offering personalized environmental control for enhanced well-being.

V.I.III CCB

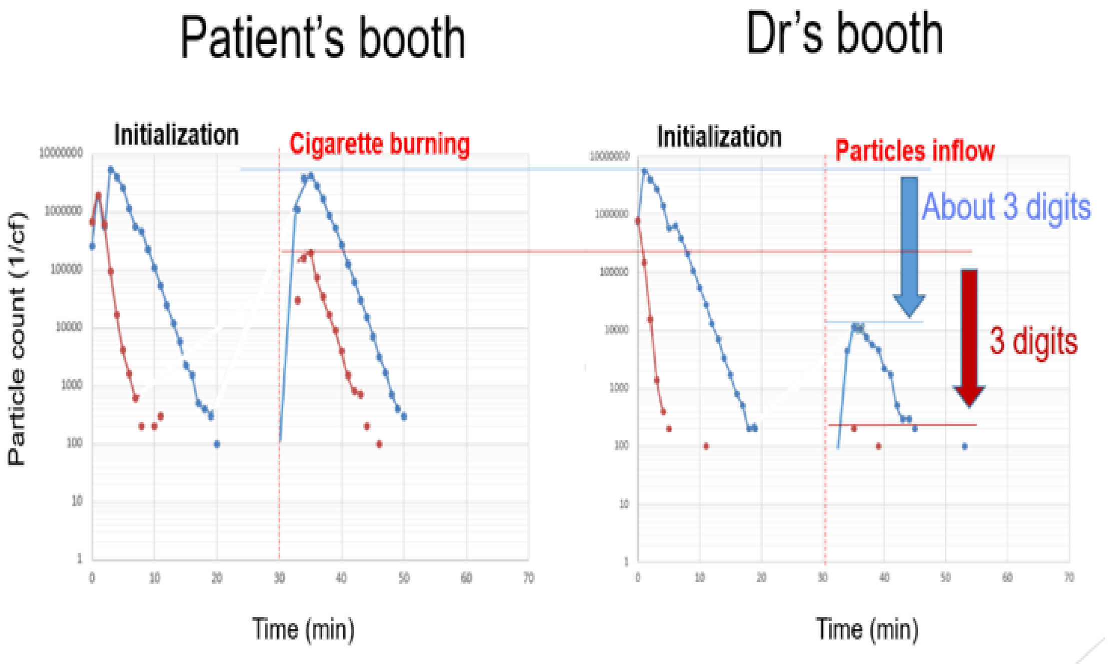

Fig.11. Results of particles in CCB

In the case of CCB, we employed the burning cigarette experiment to measure the diffusion coefficient of molecules through the exchange membrane. Our findings indicate that even with a substantial quantity of particulate matter (PM) present in PB, the PM density in DB remains remarkably low shown in Fig.11. Consequently, CCB will prove to be an invaluable asset in our response to the ongoing pandemic. The outcomes of these experiments will inform our investigation into the relationship between dust density on the PB and DB sides over time, thereby facilitating the development of more effective strategies for improving the DB environment. Furthermore, experimental data has demonstrated the feasibility of integrating air quality measurement functions into a lightweight device for applications related to sleep quality. This integration will be optimized to enhance usability, and the correlation between environmental factors and sleep quality will be studied to improve users' sleep quality. Consequently, CCB represents a highly efficacious instrument for combating the current pandemic and improving environmental conditions in medical settings and sleep quality applications.

V.I.IV Smart Agriculture

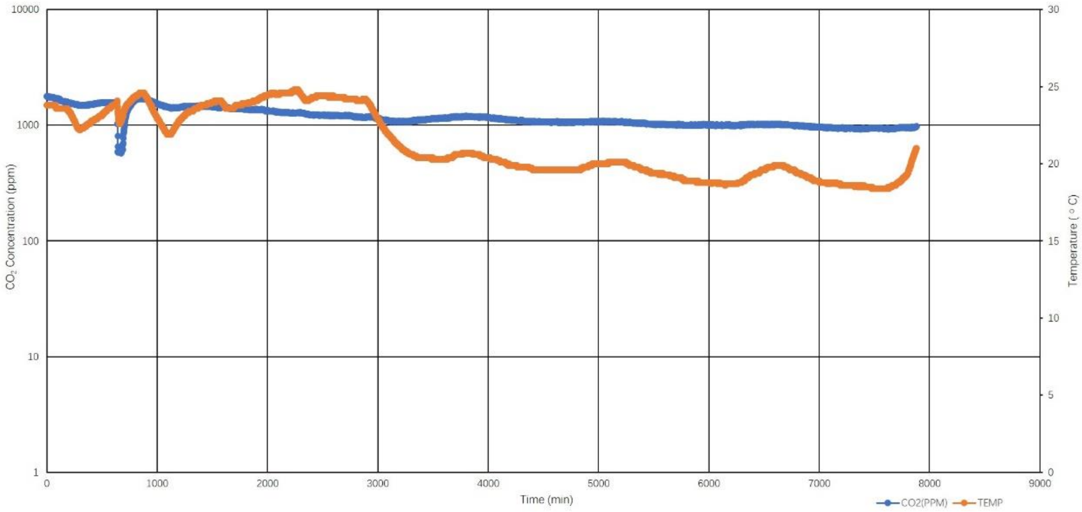

Fig.12. Gas concentration change in Mushroom box

The respiration rate of the mushrooms may have slowed down after the experiment began, resulting in a decrease in the release of carbon dioxide in Fig.12. At the same time, the chemicals released by the mushrooms may react with components in the air. For example, some volatile organic compounds (VOCs) may react with carbon dioxide in the air, resulting in changes in carbon dioxide concentration. Therefore, the carbon dioxide concentration dropped rapidly at 700 minutes and then gradually stabilized at around 1000ppm.

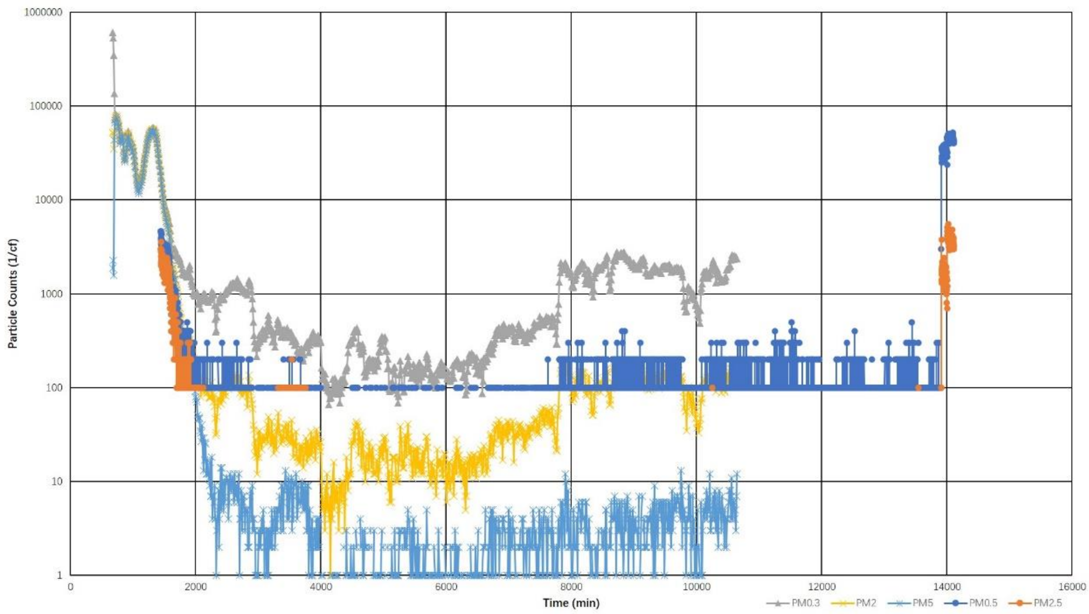

Fig.13. Particle density change in Mushroom box

After 33 hours, the concentration of particles was stabilized below 1000 class due to the gradual dehydration of the mushrooms, and most of the particle concentrations were even below 100 class shown in Fig.13.

V.I.V CAQLEA

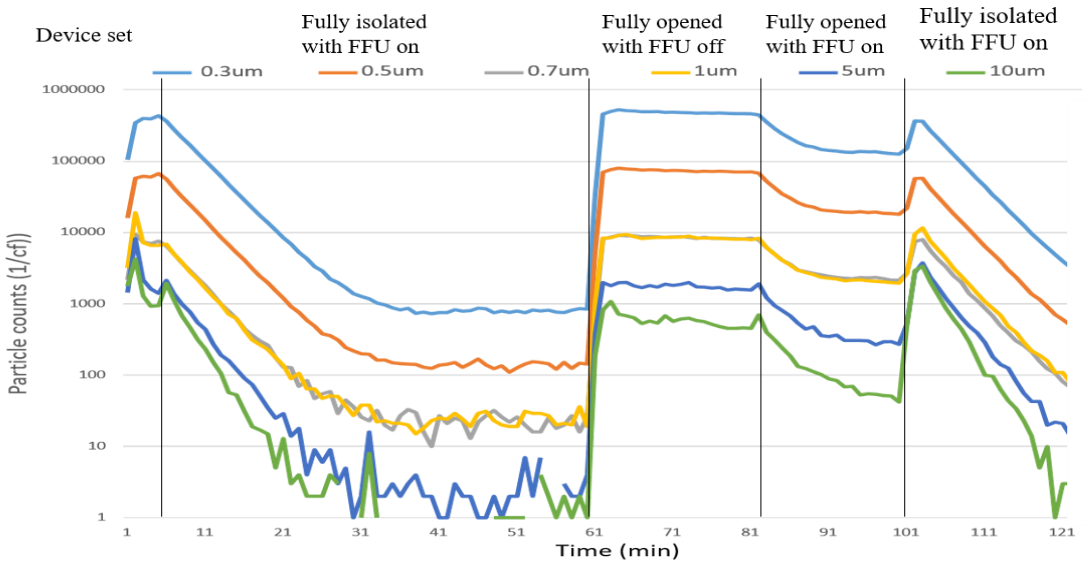

Fig.14. Results of particles in CAQLEA

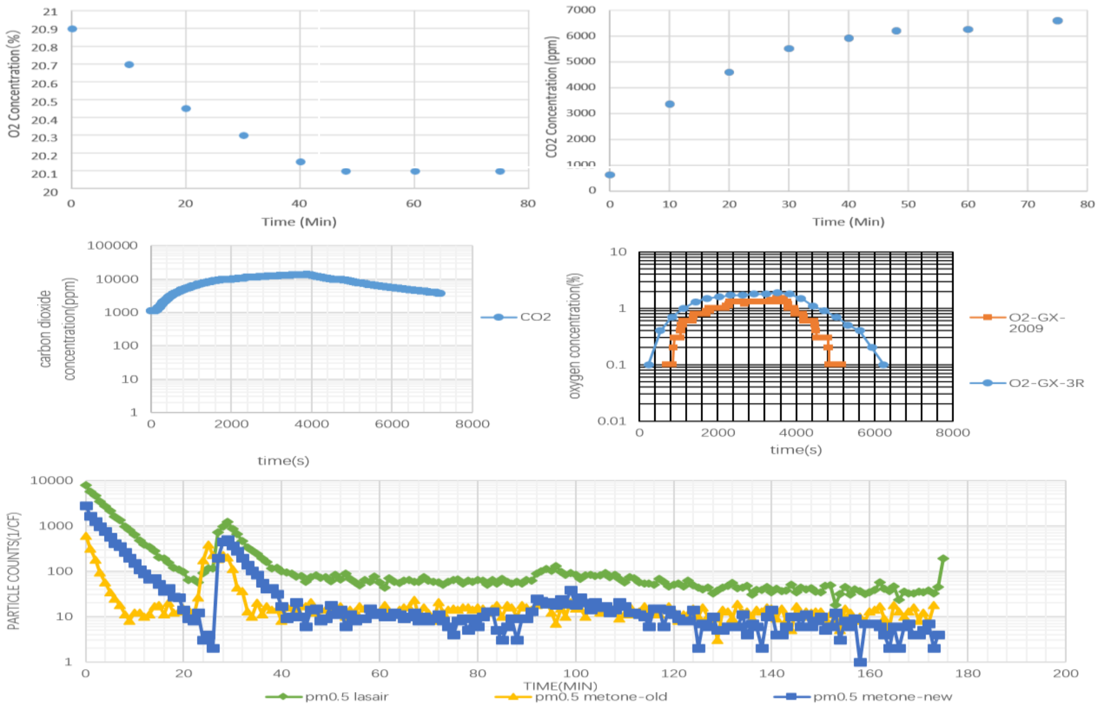

Fig.15. Results of 4-person stay in CAQLEA and Cassette furnace combustion experiment

Prior to commencing the study, a preliminary cleanliness test was conducted. Following the cleanliness test, a gas exchange capability test was conducted. In order to achieve the product goals of CAQLEA, the test was conducted using a cassette furnace for oxygen consumption and carbon dioxide generation, rather than using materials such as candles that produce products that are difficult to clean. Subsequently, the diffusion coefficient of GEM was quantified by having four test subjects remain within the CAQLEA apparatus and measuring the quantity of gas consumed or produced by human metabolism in comparison to the results obtained through the use of a cassette oven. Subsequently, a similar test was conducted to assess the influence of the GEM area on the results. With the GEM area doubled, it was folded to maintain a side length of 1.8 meters and mounted on top of the CAQLEA. The carbon dioxide concentration was quantified by burning a small quantity of alcohol and calculating the diffusion efficiency.(Zhou: Symposium 1)

It can be concluded that the FFU purification rate inside the CAQLEA is constant and reaches the Class 200 standard in the cleanliness performance experiment. However, upon reaching a steady state, the number of particles within the system increases significantly upon opening the system and entering the particles. This increase is approximately 500 times greater than the initial particle concentration. Even when the windows on three sides are opened, particles will enter the room at a rapid rate. Nevertheless, when the FFU is activated, even if the windows on three sides are opened, the number of particles will remain at a relatively low level. Consequently, it can be posited that the FFU exhibits a superior purification efficacy for particles with a larger diameter.

While the CAQLEA system is a combined, isolated system, the cleanliness is fully guaranteed, and the reading of Lasair is maintained at class 100 when the environment reaches a steady state. Given that the measurement sensitivity differs, Metone remained at class 100 in CAQLEA, whereas it is slightly lower. Upon entering the CCB and CAQLEA, due to the volume being approximately twice that of a single booth, the increase in particulate matter will be detected with a delay of approximately one minute. Furthermore, the increase will be approximately 100 times lower than that observed in a single CAQLEA in Fig.14.

Figure 15 shows a comparison of the data obtained in the four-person retention experiment and the gas combustion experiment indicates that the amount of oxygen consumed by the combustion of a cassette furnace and the amount of carbon dioxide produced is approximately equivalent to the consumption/production amount of 6-8 adults.

V.II CONCLUSION

The isolated closed system and high level of cleanliness could contribute significantly to the prevention of infectious diseases such as SARS-CoV-2. Following this, research and development proceeded apace, resulting in the successful development and verification of the system. During the pandemic, maintaining clean air was of paramount importance, particularly in hospitals, public spaces, and other high-traffic areas, where airborne transmission posed a significant health risk. The closed-loop design of CUSP allows for precise control over internal air quality through the continuous filtering and recirculation of air, thereby significantly reducing the risk of contaminants entering from the outside. The global pandemic has highlighted the critical importance of systems such as CUSP and GEM, which provide effective strategies for managing air quality and containment. The advancements driven by these systems lay the groundwork for more resilient public health infrastructures, better equipped to combat future airborne infectious diseases.

This high filtration capability is coupled with an advanced contaminant containment mechanism, whereby the same volume of air passes through CUSP's filters repeatedly, capturing increasingly smaller particles. This feature serves to both obstruct pathogens and actively diminish their concentration over time. CUSP has demonstrated superior efficiency in maintaining ultra-clean air compared to conventional filters such as HEPA and ULPA. Additionally, CUSP employs a diffusion-based gas exchange membrane that permits the permeation of gas molecules into the enclosed environment. This process enables the concentration of gases within the room to be regulated in a manner analogous to open systems at a specified airflow rate F, thereby facilitating precise and consistent control of the internal air composition.

Moreover, the innovative design of CUSP allows for adaptability to a multitude of environments, including medical isolation rooms, laboratories, and public buildings, where infection control is of paramount importance. The system is scalable, allowing for its deployment in both small, portable units and larger, centralized facilities. This flexibility and effectiveness have established CUSP as a reliable platform for enhancing public health and safety, providing a controlled environment that protects people, sensitive equipment, and research spaces alike from airborne contamination.

In addition to its immediate impact on health and safety, CUSP's efficient design reduces maintenance demands. By eliminating the need for constant air exchange with external sources, it decreases reliance on frequent filter replacements while maintaining a consistently clean environment. This makes it a cost-effective choice for long-term use in high-purity applications.

VI. Discussion and Outlook

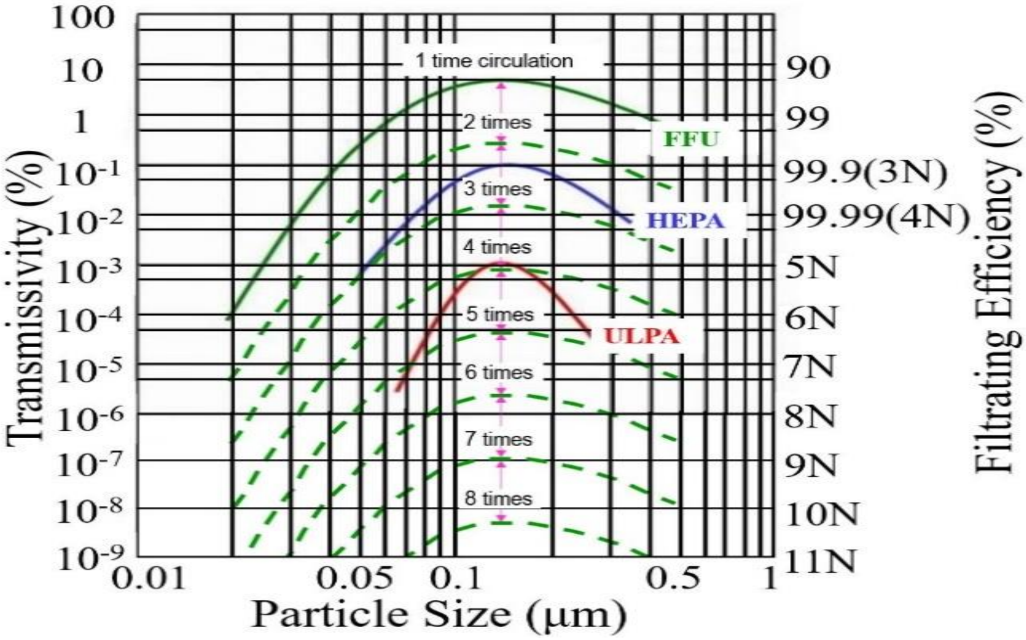

Fig.16. The difference between normal FFU, HEPA and ULPA

As illustrated in Fig. 16, ULPA exhibits the highest purification efficiency, followed by HEPA, and ordinary masks or medium-efficiency filters in commercially available home use. FFUs are found to have an insufficient filtration efficiency; however, low-efficiency filters have the potential to outperform high-quality filters once they are embedded in our CUSP system. For the sake of simplicity, let us assume that γ of the low-efficiency filter is 0.9 for the purposes of this discussion. In a single pass, 10% of the particles/microbes pass through the filter unfiltered. However, when the air passes through the filter N times, the probability that the particles go through the filter is as low as 10-N. This is because CUSP is a closed airflow system, and the same inside air goes through the filter repeatedly many times ($N \gg 1$). To illustrate, in the system depicted in Fig. 8, the air within the CUSP is filtered every 2–3 minutes. As illustrated in Fig. 16, the filtration efficiency may be even superior to that of HPEA (blue line) or ULPA (red line) when $N > 5$ or 6. It is noteworthy that the filtration efficiency is not affected by the presence of particles in the air, as evidenced by the zero count observed in 10 minutes in Fig. 8. As illustrated in Fig. 16, particles with a diameter of approximately 0.15 μm (between 0.1 and 0.3 μm) are the most challenging to filter. However, the SARS-CoV-2 virus in aerosol form is considerably smaller than that, and is relatively easy to filter due to the Brownian motion of the particles caused by collisions with, as well as scattering by, gas molecules comprising the air. [22]

Semiconductor industries

The semiconductor manufacturing industry is fundamentally dependent on the ability to create and maintain ultra-clean environments. This need stems from the industry's core requirement for precision at the microscopic level, where even the smallest particle of dust can disrupt the manufacturing process and lead to defects in the final product. Good cleaning systems are therefore integral to the operation of semiconductor manufacturing facilities, as they can achieve and maintain the ultra-high levels of cleanliness required. At the heart of the closed air flow system is a carefully designed process of air filtration, recirculation and control that effectively removes contaminants from the production environment. The closed nature of the system ensures that the air within the cleanroom can be continuously monitored and cleaned without the interference of external contaminants. This is critical because semiconductor manufacturing often involves the use of nanometer-scale materials, where even a single particle can interfere with the conductive pathways of a microchip. Another aspect of closed air flow system is environmental control. This includes controlling temperature and humidity, both of which can affect particle behavior and filtration efficiency. Semiconductor manufacturing often involves processes that are sensitive to these environmental factors, such as photolithography, where precise control of temperature and humidity is critical to the quality of the final product.

The future of closed air flow system in semiconductor manufacturing is likely to involve even more sophisticated technologies. This may include integrating sensors and IoT devices that can monitor and adjust cleanroom conditions in real-time. In addition, advances in materials science may lead to the development of new types of filters that can capture even smaller particles more efficiently. The role of closed air flow system in achieving ultra-high cleanliness is critical to the semiconductor industry's ability to produce reliable, high-performance products. As the industry continues to evolve and the size of semiconductor devices continues to shrink, the demand for more advanced closed airflow systems that can ensure a virtually contaminant-free environment will undoubtedly increase. This presents both a challenge and an opportunity for innovation in cleanroom design and operation. The continued evolution of these systems will be a critical factor in the semiconductor industry's ability to meet the growing demands of technology consumers and push the boundaries of what is electronically possible.

In school

Good air quality in educational environments is not only a matter of comfort but also a critical determinant of health for both students and educators. Recognition of the effects of poor IAQ in classrooms is not new. Studies have consistently shown that suboptimal air quality can lead to chronic illness, reduced cognitive performance, fatigue, and increased absenteeism. Given that students and teachers spend approximately half of their waking hours in educational facilities, the need to prioritize indoor air quality is clear. While the health effects of outdoor pollution are well known, research by the U.S. Environmental Protection Agency (EPA) has shown that indoor pollutants often exceed outdoor levels by up to five times.[23] This is especially concerning for children, whose developing respiratory systems are particularly vulnerable to polluted air. High indoor CO_2 levels, often accompanied by dust, mold, and airborne pathogens, can exacerbate respiratory illness, fatigue, and lack of concentration.

The effects of CO_2 levels on health are manifold. Normal outdoor air contains about 400 ppm of CO_2, while indoor levels typically range from 400 to 1000 ppm. When indoor levels reach 1000 to 2000 ppm, fatigue becomes common. Above 2000 ppm, more serious effects such as headaches, fatigue, and difficulty concentrating occur, with levels above 5000 ppm potentially leading to toxicity and oxygen deprivation.[24] To mitigate the risks posed by poor IAQ, it is recommended that CO_2 levels be measured to ensure that they remain within recommended limits.

Regulatory agencies and health organizations, including the CDC and WHO, providing the guidance on maintaining adequate ventilation in common areas. For example, the EPA emphasizes that "proper ventilation is key to preventing the spread of airborne viruses.[25] The CDC recommends increasing fresh air in classrooms, inspecting and repairing HVAC systems, using portable HEPA filters, and installing air quality monitors. However, the prevalence of poor IAQ and elevated CO_2 levels in schools remains a concern. Ensuring good IAQ in schools is a complex but essential task that affects the health, cognitive function, and well-being of children and adults alike. As research continues to illuminate the impact of IAQ on health and learning outcomes, it is becoming increasingly clear that investing in air quality measures is not just a matter of regulatory compliance, but also a proactive step toward fostering a resilient public health infrastructure within educational institutions.

This is where closed air flow system offers a significant opportunity to revolutionize air quality management in schools. Unlike traditional open air flow systems, one of the advantages of the closed air flow system is the ability to efficiently reduce indoor particulate matter. In areas with high levels of outdoor air pollution, such as urban centers or near industrial sites, closed systems can provide a sanctuary of clean air, free from the smog and particulates that can permeate the outdoor environment. Another benefit is the ability to control CO_2 levels. By continuously exchanging air, the system can prevent the buildup of CO_2 produced by students and staff throughout the school day. This ensures that the air remains fresh, mimicking the natural exchange that occurs with ventilation. The closed system may also allow for the integration of gas-phase filtration (currently, the GEM only allows molecules to pass through by diffusion, toxic gas molecules are able to enter the atmosphere), which can remove gaseous pollutants such as volatile organic compounds (VOCs) emitted from paints, cleaning products, and building materials. This level of filtration is critical to creating an indoor environment that is free of not only particulate matter, but also gases that can contribute to long-term health problems.

While schools face persistent challenges in managing indoor air quality, closed air flow systems offer a forward-thinking solution capable of providing clean, safe, and controlled air for educational environments. As awareness grows and technology advances, the adoption of closed air flow systems in schools has the potential to become a new standard, safeguarding the well-being of future generations and fostering optimal learning conditions.

ZEB and ZEH

A Zero-Energy Building (ZEB), also referred to as a Net Zero-Energy (NZE) building, utilizes renewable energy sources to generate the same amount of energy that it consumes on an annual basis. This is achieved through the implementation of technologies such as heat pumps, high-efficiency windows and insulation, and solar panels both on-site and offsite with renewable energy sources.[28]

The objective is for these buildings to have a lower overall greenhouse gas impact on the environment during operation when compared to non-ZNE buildings. Although they may use non-renewable energy and produce greenhouse gases at times, they also reduce energy consumption and greenhouse gas production elsewhere by an equal amount.

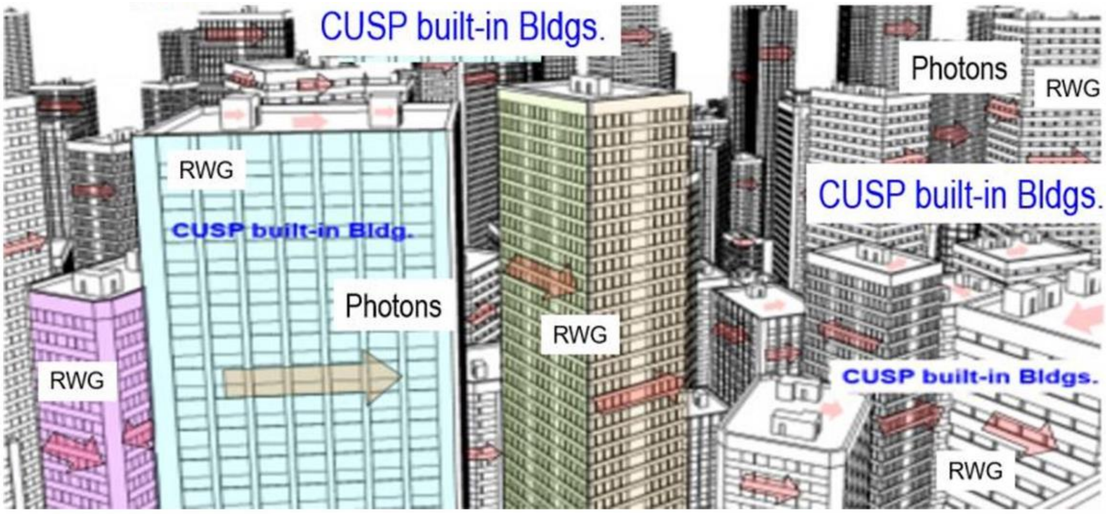

Fig.17. How to realize ZEB/ZEH in daily lives by the CUSP

Using the 2D-PhotoRecepto-Conversion scheme (2DPRCs) and integrating all the new ideas liberated by the concept of removing the old-fashioned spatial degeneracy of photo harvesting (photoreception) and photo-electro conversion can enable the establishment of a mega-solar power plant in metropolitan areas as depicted in Fig.17. Based on the 2DPRCs, which is not only applicable for solar power generation but also for OWPT or laser power beaming, it can serve as a critical lifeline for hospitals and/or nuclear power plants during emergency situations resulting from disruptions in electrical power lines caused by earthquakes, floods, tsunamis, or other disasters. With the CUSP in buildings, cities could not only realize zero energy consumption but also support a better area for people to QoL.[29]

Bubble OT

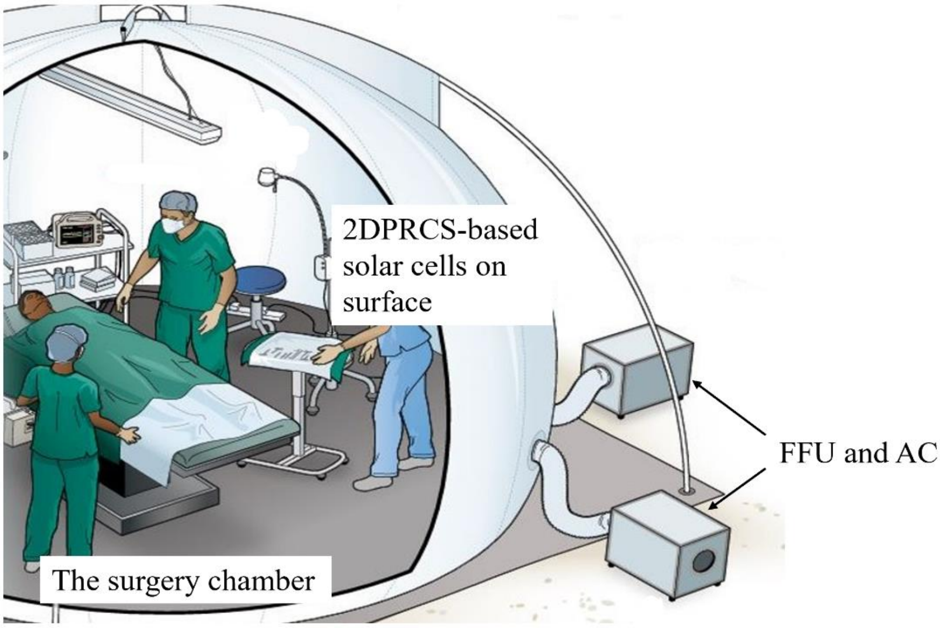

Fig.18. The bubble operating theatre is a portable surgical unit equipped with an air filter that provides sterile conditions for surgery, we propose to put 2DPRCS-based solar cells as the power supply on surface.

The Médecins Sans Frontières (MSF) constructed a portable operating theater in Kabala Hospital, Sierra Leone in Fig.18.[26] This mobile surgical space has the potential to revolutionize surgery in conflict zones and post-emergency settings. Equipped with an air filter that ensures sterile conditions, it is easy to assemble and can be utilized multiple times. The temporary bubble operating theater was utilized during the renovation process of the permanent one, and from April to November 2016, 90 surgeries were successfully performed in it. However, the bubble operating theater had its own difficulties. Its limited space of only nine square meters allowed for accommodating only four staff members at a time, with no additional room for neonatal resuscitation or other equipment. The extreme temperature inside can be challenging during long or complex surgeries, even with air conditioning. The use of zip doors instead of traditional swing doors requires assistance from outside to operate, which could pose problems during emergencies. Although the lighting is sufficient during the day, it is inadequate for night surgeries.

However, the closed air flow system has the advantage. The closed air flow system can also provide a high cleanliness for surgeries, with a good control on gas exchange(like oxygen and carbon dioxide). The bubble OT has the limit of space but closed air flow system will not. Besides, if aerogel is used as GEM the temperature can be well controlled while ensuring the exchange of gas molecules.[27]

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Reference

[1] Iversen, J. (1956). Forest clearance in the Stone Age. *Scientific American, 194*(3), 36-41.

[2] Faria, M. A. (2015). Neolithic trepanation decoded-A unifying hypothesis: Has the mystery as to why primitive surgeons performed cranial surgery been solved?, *Surgical neurology international*, *6*.

[3] Attademo, L., & Bernardini, F. Air pollution and urbanicity: common risk factors for dementia and schizophrenia?, *The Lancet Planetary Health*, *1*(3), e90-e91. (2017)

[4] "Coronavirus disease (COVID-19): How is it transmitted?". World Health Organization (WHO). (Retrieved 13 April, 2023).

[5] Li, Y., Nazaroff, W. W., Bahnfleth, W., Wargocki, P., & Zhang, Y. The COVID-19 pandemic is a global indoor air crisis that should lead to change: A message commemorating 30 years of Indoor Air. *Indoor air*, 31(6), 1683. (2021).

[6] Woods, J.E., Air Quality – Encyclopedia of Architecture: Design engineering and Construction, V.1. Wiley and Sons. (1988)

[7] Janssen, J. E. The history of ventilation and temperature control: The first century of air conditioning. *Ashrae Journal*, *41*(10), 48. (1999)

[8] A. Ishibashi, M. Yasutake, US Pat. 10,172,547, "System and method using information of involuntary body movement during sleep; and sleeping state detection system and method"

[9] Ogunsola, F. T., & Mehtar, S. (2020). Challenges regarding the control of environmental sources of contamination in healthcare settings in low-and middle-income countries-a narrative review. *Antimicrobial Resistance & Infection Control*, 9, 1-9.

[10] W. E. Scheckler, D. Brimhall, A. S. Buck, B. M. Farr, C. Friedman, R. A. Garibaldi, and S. L. Solomon, *Infect. Cont. Hospital Epidemiology*. 19, 114. (1998)

[11] Liao, C., Delghust, M., & Laverge, J. Association between indoor air quality and sleep quality. (2019)

[12] Faraut, Brice, et al. "Benefits of napping and an extended duration of recovery sleep on alertness and immune cells after acute sleep restriction." *Brain, behavior, and immunity* 25.1: 16-24. (2011)

[13] Monitoring CO_2 Levels Critical for Mushroom Farm Success, https://www.co2meter.com/en-jp/blogs/news/co2-mushroom-farming#:~:text=All%20must%20be%20tightly%20controlled,than%201%2C000%20ppm%20during, accessed May 03, (2023)

[14] CAQLEA. Available online: https://caqlea.com/ (accessed on 16 November 2022).

[15] Ishibashi, A., Noguchi, N., Etoh, T., Matsuda, J., Ohashi, Y. Clean unit system platform (CUSP) based upon 100% feed-back closed-system. In Proceedings of the 35th Annual Technical Meeting on Air Cleaning and Contamination Control,

Tokyo, Japan, 24–25 April 2018; pp. 38–41.
[16] Ishibashi, A., Eto, T., Noguchi, N., Matsuda, J. Building, and Method for Controlling Gas Molecule Concentration in Living and/or Activity Space in Building. U.S. Patent 11364465, 21 June 2022.
[17] Respiratory droplets: https://www.ncbi.nlm.nih.gov/books/NBK143281/ (accessed December 15, 2023)
[18] Oxygen Diffusion Constant: https://compost.css.cornell.edu/oxygen/oxygen.diff.air.html (accessed December 16, 2023
[19] T. Hsieh, Y. Liu, S. Liang, M. Yasutake and A. Ishibashi: *Proc. 3rd Int.l Conf. on Comp. Biology and Bioinformatics*, Association for Computing Machinery, New York, NY, United States 47-51 (2019)
[20] S. Liang, Y. Shih, Y. Hu, and C. Kuo, “A Method for Napping Time Recommendation Using Electrical Brain Activity”, *IEEE Trans. on Cognitive and Developmental Systems*, **12** 645-657 (2020)
[21] Lee, S. Y., & Park, S. J. A review on solid adsorbents for carbon dioxide capture. *Journal of Industrial and Engineering Chemistry*, *23*, 1-11. (2015)
[22] Filtering mechanism: http://motosyuuriyadesu.blog.fc2.com/blog-entry-18.html (accessed December 16, 2023), [in Japanese].
[23] Ferreira, A., & Barros, N. COVID-19 and lockdown: the potential impact of residential indoor air quality on the health of teleworkers. *International Journal of Environmental Research and Public Health*, 19(10), 6079. (2022).
[24] https://www.co2meter.com/en-jp/blogs/news/ashrae-co2-standards-classrooms, ASHRAE CO_2 Standards for Classrooms, August 21, 2023
[25] https://www.epa.gov/coronavirus/ventilation-and-coronavirus-covid-19, Ventilation and Coronavirus (COVID-19), LAST UPDATED ON JUNE 7, 2023
[26] https://msf.org.au/sites/default/files/attachments/msf_bubble_operating_theatre.pdf, The bubble operating theatre
[27] Yan X., Guannan L., Haibo H., Shougui L. (2014). *Airgel nano tube and preparation method of molecular sieve* (CN104326484B))
[28] "A Common Definition for Zero Energy Buildings" . *US Department of Energy*. September (2015)
[29] Ishibashi, A., Okura, Y., & Sawamura, N. Lifting Off Spatial Degeneracy of Functions, Where Does It Lead Us for Photovoltaic Device Systems?. *Energies*, 13(19), 5234. (2020)

List of presentations at national and international conferences

[Paper]

1. Zhou, Z., Kato, N., Hsieh, T. H., Liang, S. F., Yasutake, M., & Ishibashi, A. (2023). Closed airflow system, CUSP, for preventing SARS-CoV-2 infection, promoting health care, and achieving Sustainable Development Goals. *Japanese Journal of Applied Physics*, 63(1), 017003.
2. Ishibashi, A., Liang, S. F., Kato, N., Zhou, Z., Hsieh, T. H., Matsuda, J., & Sawamura, N. (2023). Designing Coupling of 2-Dimensional PhotoRecepto-Conversion Scheme (2DPRCS) with Clean Unit System Platform (CUSP). *Energies*, 16(4), 1838.

[Academic conference]

1. Z. Zhou, H. Wu, T. Hsieh, S. Liang, H. Yamaguchi, and A. Ishibashi: "Sleep Assessment Trial in a High Air-Quality Nap-Box based on Clean Unit System Platform (CUSP)", IEEE GCCE 2023, Japan (2023-10)

2. Z. Zhou, S. Liang, N. Kato, T. Hsieh, J. Matsuda, N. Sawamura and A. Ishibashi: "Application of Two-Dimensional PhotoRecepto-Conversion Scheme (2DPRCS) to compact Clean Unit System Platform (CUSP)", The 5th Optical Wireless and Fiber Power Transmission Conference (OWPT 2023), PACIFICO Yokohama, Japan (2023-04)

3. Z. Zhou *, Liang Sheng-Fu, X. Wang, D. Wu, H. Wu, A. Ishibashi: "Study on metabolism of Bunashimeji and Enokitake mushrooms in a clean environment using a closed airflow system", MSJ Meeting 66 Online, Japan (2022-08)

4. Z. Zhou *, X. Wang, X. Hong, N. Kato, Y. Wang, Chiu Ching-Yu, Hsieh Tsung-Hao, Liang Sheng-Fu, M. Yasutake, A. Ishibashi: "Application of closed airflow system in the treatment of SARS-COV-2 and promoting health care", JSAP 2022 Spring, Japan (2022-03)

5. X. Wang *, Z. Zhou, J. Yu, M. Yasutake, A. Ishibashi: "Clean Unit System Platform (CUSP) and Connected CUSP Booth (CCB)", JSAP 2021 Spring Online, Japan (2021-03)

6. X. Wang*, Z. Zhou, C. Chiu, T. Hsieh, S. Liang and A. Ishibashi: "Clean Unit System Platforms and Developing Connected CUSP Booths", The 6th Hokkaido University Cross-departmental Symposium, Hokkaido University, Japan (2020-10)

7. Z. Zhou *, Chiu Ching-Yu, Liang Sheng-Fu, A. Ishibashi: "Comparison of the dust particles number and mass using new sensor module in Clean Unit System Platform (CUSP)", JSAP 2020 Spring, Tokyo, Japan (2020-03)

8. C. Chiu*, Z. Zhou, T. Hsieh, S. Liang and A. Ishibashi: “A versatile isolated closed-system, Clean Unit System Platform (CUSP), and its application for sleep enhancement-system design and performance verification”, The 5th Hokkaido University Cross-departmental Symposium, Hokkaido University, Japan (2019-11)
9. A. Ishibashi *, Z. Zhou, Hsieh Tsung-Hao, Liang Sheng-Fu, M. Yasutake: “Isolated and closed clean environment (CUSP) and its application to sleep analysis”, JSAP 2019 Autumn, Hokkaido Univ., Japan (2019-09)

[Symposium]

1. H. Wu*, S. Liang, D. Wu, Z. Zhou and A. Ishibashi: “Flow-rate dependence of cleanliness in a new clean unit system platform (CUSP), CAQLEA”, The 23rd RIES-Hokudai International Symposium, Sapporo, Japan (2022-12)
2. Z. Zhou*, S. Liang, X. Wang, D. Wu, H. Wu and A. Ishibashi: “Metabolism study of bunashimeji using clean unit system platform (CUSP)”, The 23rd RIES-Hokudai International Symposium, Sapporo, Japan (2022-12)
3. Z. Zhou*, Y. Ishigaki, D. Wu, H. Wu, T. Mori and A. Ishibashi: “Development of a high-purity, energy-saving closed airflow system”, The 8th Hokkaido University Cross-departmental Symposium, Hokkaido University, Japan (2022-10)
4. Z. Zhou*, X. Wang, X. Hong, N. Kato, Y. Wang, C. Chiu, T. Hsieh, S. Liang, M. Yasutake and A. Ishibashi: “Tent-type clean unit system platform (T-CUSP) for the fight with SARS-CoV-2 and other diseases and health care”, The 22nd RIES-Hokudai International Symposium, Sapporo, Japan (2021-12)
5. Z. Zhou*, X. Wang, X. Hong, N. Kato, Y. Wang and A. Ishibashi: “The Application of Clean Unit System Platform (CUSP) and its derivatives”, The 7th Hokkaido University Cross-departmental Symposium, Hokkaido University, Japan (2021-10)
6. X. Wang*, Z. Zhou, M. Yasutake and A. Ishibashi: “Clean Unit System Platform (CUSP) and developing connected CUSP Booths (CCB)”, The 21st RIES-Hokudai International Symposium, Sapporo, Japan (2020-12)
7. Z. Zhou*, C. Chiu, S. Liang and A. Ishibashi: “Comparison of the relation between dusts particles and mass in Clean Unit System Platform (CUSP) by different devices”, The 20th RIES-Hokudai International Symposium, Sapporo, Japan (2019-12)
8. Z. Zhou, H. Wu, T. Hsieh, S. Liang, H. Yamaguchi, and A. Ishibashi: “Research for sleep in a high air quality nap box based on Clean Unit System Platform (CUSP)” The 24th RIES-Hokudai International Symposium, Sapporo, Japan (2023-12)

[Colloquium, seminars, etc.]

1. H. Wu*, S. Liang, D. Wu, Z. Zhou and A. Ishibashi: "Handy jump-up Clean unit system platform (CUSP)", The 17th Renewable Energy 2023, TOKYO BIG SIGHT, Japan (2023-02)
2. Z. Zhou*, X. Wang, X. Hong, N. Kato, Y. Wang, C. Chiu, T. Hsieh, S. Liang, M. Yasutake and A. Ishibashi: "Application of closed airflow system in the treatment of SARS-COV-2 and promoting health care" The 16th Renewable Energy 2022), TOKYO BIG SIGHT, Japan (2022-01)
3. Y. Ohkura*, J. Yu, Z. Zhou, X. Wang, M. Yasutake, A. Ishibashi: "Isolated closed clean environment Clean Unit System Platform (CUSP) as a new type of solar cell process and a platform for responding to coronavirus", The 15th Renewable Energy 2020), Tokyo, Japan (2020-12)
4. Z. Zhou, et al. "Reaching high-cleanliness by using closed air-flow system (CUSP) and the expanding applications on life" DX (2023-09)