WHITEPAPER

WHITEPAPER INDOOR CLIMATE RESILIENCE IN BUILDINGS

Lessons learned from Covid-19 on how to ensure a good indoor climate in times of a pandemic

Swegon

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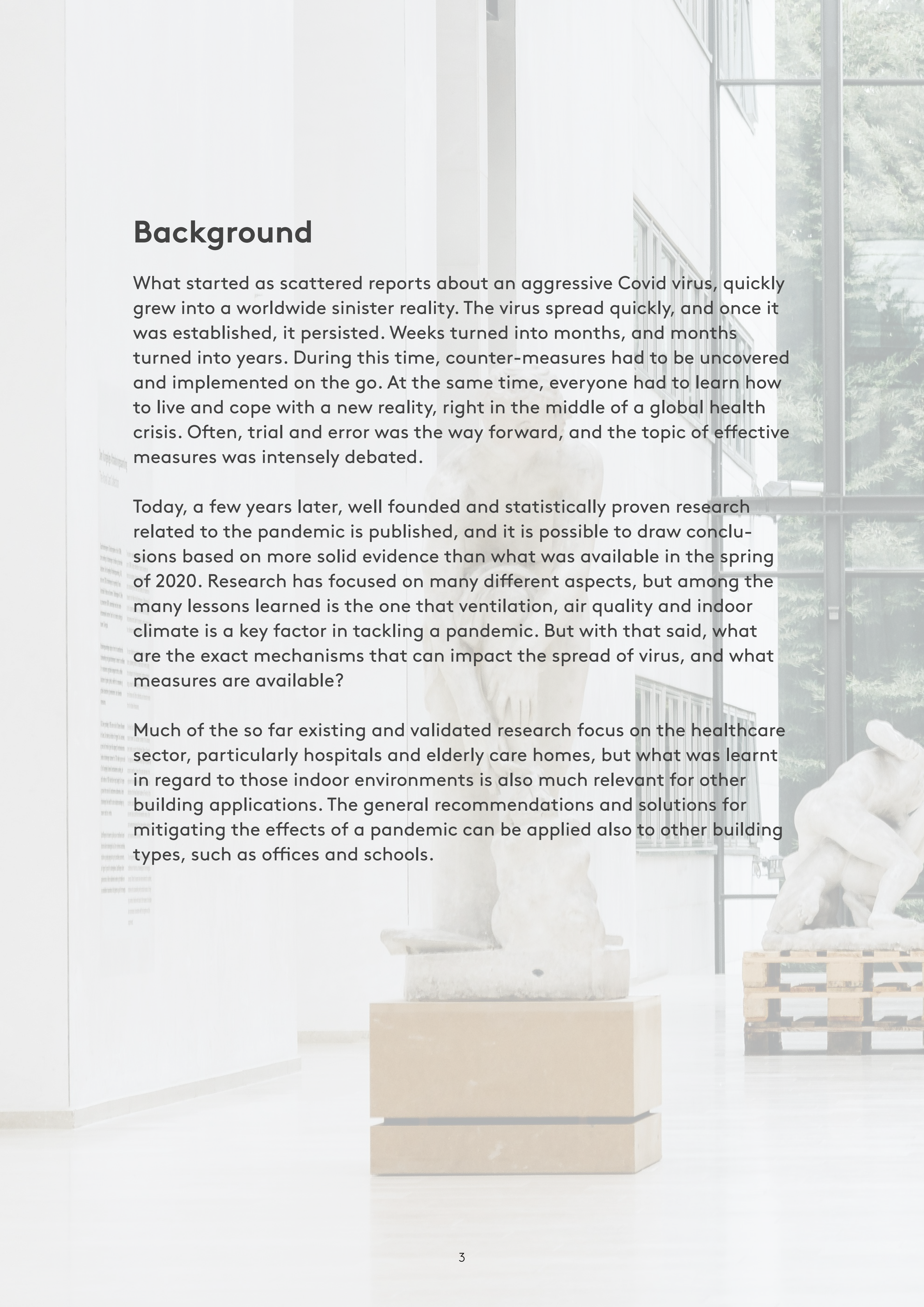


Background

What started as scattered reports about an aggressive Covid virus, quickly grew into a worldwide sinister reality. The virus spread quickly, and once it was established, it persisted. Weeks turned into months, and months turned into years. During this time, counter-measures had to be uncovered and implemented on the go. At the same time, everyone had to learn how to live and cope with a new reality, right in the middle of a global health crisis. Often, trial and error was the way forward, and the topic of effective measures was intensely debated.

Today, a few years later, well founded and statistically proven research related to the pandemic is published, and it is possible to draw conclusions based on more solid evidence than what was available in the spring of 2020. Research has focused on many different aspects, but among the many lessons learned is the one that ventilation, air quality and indoor climate is a key factor in tackling a pandemic. But with that said, what are the exact mechanisms that can impact the spread of virus, and what measures are available?

Much of the so far existing and validated research focus on the healthcare sector, particularly hospitals and elderly care homes, but what was learnt in regard to those indoor environments is also much relevant for other building applications. The general recommendations and solutions for mitigating the effects of a pandemic can be applied also to other building types, such as offices and schools.

The white paper in more detail

It will become evident that this paper highlights the importance of preparation in order to cope with future pandemics. Guidelines in the midst of the pandemic had to be issued while fighting a round-the-clock battle against the virus, they sometimes turned out to be adverse, overly simplistic or costly for little effect. It is today, in a situation less pressed for time, possible to make sure measures are well-balanced and sustainable from a people, planet and economics perspective.

Building design plays a significant role in current research, likely because the many temporary solutions for social distancing were unsuitable or insufficient for permanent use. This is why the building industry in many parts of the world has moved past the traditional "building for durability, utility and beauty", and is now focusing also on sustainability and liveability.

This white paper will briefly present how architecture and interior design can change to better cope with future pandemics and provide building design that put health in focus, and it concludes that ventilation cannot be done in just any way – opening windows can create uncomfortable and unproductive indoor environments due to noise, draughts and vast temperature changes and it is a fact that many buildings pose limitations to provide sufficient air supply in all meteorological conditions. Furthermore, insufficient ventilation methods have led to substantial energy waste which is why many recommendations for the future are letting mechanical ventilation take centre stage.

Since mechanical ventilation is either implicitly or explicitly recommended in a majority of the published research available today, it is also crucial to consider details of these systems, such as air filtering and filters, monitoring, demand controlled airflow etc. in order to make this a comprehensive material - a factual guide for understanding how to create indoor climate resilient buildings.

Questions to answer

While this introduction outlines the path to create future resilient buildings, how will this be achieved? What options are available today, what could new technology such as digital monitoring offer? And, are there measures for resilient buildings which can be introduced proactively, that also bring benefits when we are not in pandemic-mode?

Delimitations

This white paper does not attempt to present a complete summary of the chosen topic. There are innumerable pandemic related research studies ongoing as this paper is being written. Vast amounts of further research are expected to be published in the coming years. However, the body of available academic research today allows for sound conclusions and recommendations to be drawn. Matter-specific advice can also be provided by knowledge-based and well established organisations within their industry of expertise. Swegon, in this case, will conclude this white paper and offer guidance in regard to heating, ventilation and air conditioning (HVAC) solutions.

Perceptions of virus prior to Covid-19

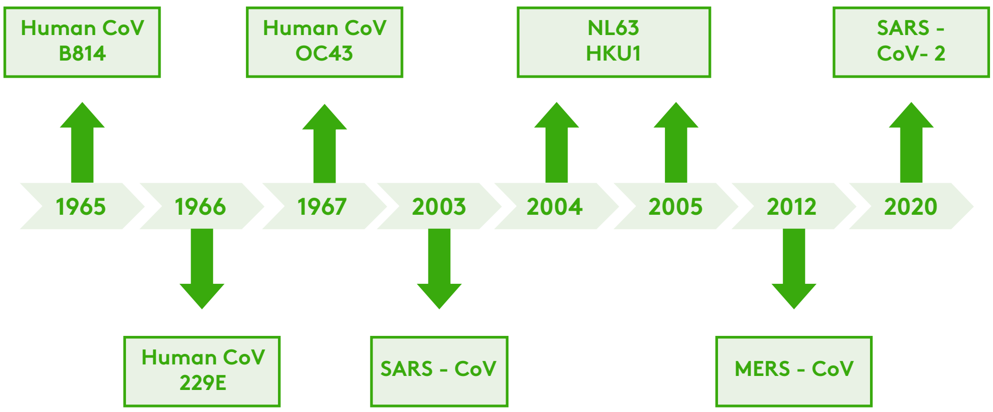
As the Covid-19 pandemic swept across the globe in early 2020, most people were fairly indifferent to virus and virus transmission, despite the fact that it was only a few generations since the Spanish flu caused millions of casualties. For most people, that event and consecutive, less serious waves of viruses, was a distant phenomenon. At the same time, the "seasonal flu" and common colds were seen as expected occurrences in life. A runny nose or mild cough was not a hinderance to go to work, school or even social gatherings. In fact, there could be a sense of pride in pushing through mild illnesses and cope with a full day at work despite the inconvenience.

It was merely expected for workers to come into the office despite a cold, and sick leave policies were written to encourage people to continue their daily work despite symptoms of a cold. "Build immunity" was close to a mantra for school-aged children, hand washing practise was not universally adopted, and hand sanitisers was most commonly found in hospitals and medical environments. As long as a person was not elderly or fought other underlying illnesses, the perception of virus was that of a nuisance, but it cannot cause much harm.

The casual attitude towards virus spreading led to crowded public transports, packed public venues, busy restaurants and fully occupied offices, where very few people reflected upon virus transmission. The lack of real concern was probably shaped by cultural norms as well as a somewhat limited understanding of how virus spread among people. Covid-19 completely reframed the view of virus. Both the virus' severity and efficient way of spreading made the situation alarming.

The Covid virus changed everything

The first human Covid virus was identified in the mid-1960s and since then, a total of seven such viruses, known to infect humans, have been identified. The more known are the severe acute respiratory syndrome virus (SARS-CoV), Middle East respiratory syndrome virus (MERS-CoV) and SARS-CoV-2. These mentioned are known to be virulent and capable of widespread infections with clinical symptoms of varying severity.



Timeline of detection of coronavirus. Note for image: CoV: coronavirus; SARS: severe acute respiratory syndrome, MERS: Middle East respiratory syndrome

SARS-CoV-2, known as the Covid or Corona virus, is an RNA virus with a diameter ranging from 60-140 nm and featuring distinctive spikes giving the appearance of a solar corona. The virus predominantly affects the respiratory and vascular systems. However, SARS-CoV-2 has been associated with widespread disease involving all organ systems, but the most devastating effects are seen in the lungs. As a range of vital organs are affected, a variety of symptoms are associated with the Covid-19 virus.

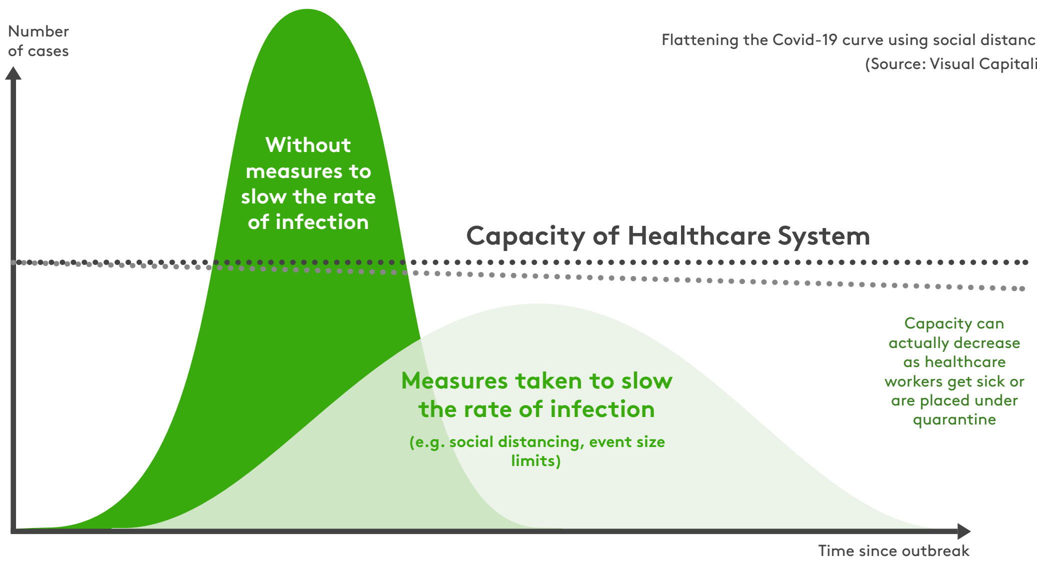
SARS-CoV-2 is transmitted in the form of respiratory droplets approximately 0.3-0.5 mm in size and which contains respiratory secretions, including water, protein and salt. The aetiology of SARS-CoV-2, Covid-19, is almost the perfect storm as a transmissible pathogen because it can be shed before any symptom onset and it can survive on a wide range of touch points/surfaces.

In sum, Covid-19 completely changed the view of virus due to the severity and efficient spreading across countries, regions and continents. All of a sudden people were forced to understand and confront airborne transmission, asymptomatic virus dispersal and virus spreading from all sorts of surfaces, touch points and near human interaction. And the indoor climate took centre stage in all discussions regarding spreading and tackling of the virus.

Strategies for tackling virus transmission

Aiming for herd immunity, i.e. letting a substantial part of the population catch the virus to create resistance among the population as a whole, is one way to tackle a pandemic. The problematic side is that a rapidly spreading and serious illness may cause vital societal functions to break down, and the health care system may become over-loaded, which can cause an increased mortality rate, before the wanted level of immunity is reached.

Another alternative then, is to limit the virus transmission by applying measures such as remote work, school closures and restrictive use of public spaces – frankly, minimising human interaction. However, this strategy also has many side effects, such as a negative impact on the global economy to destructively affecting people's mental health.



In terms of Covid-19, the perfect storm, the virus effects were so problematic that a laissez-faire strategy to achieve herd immunity was expected to completely devastate existing healthcare systems and the number of deaths were expected to rise unbearable levels, far beyond just an increase. Measures were needed to at least 'flatten the curve', i.e. slowing the spread of the disease enough for the healthcare system to cope with the number of cases.

How Covid-19 was tackled

During Covid-19, politicians, virology experts and numerous advisory boards worldwide were pressed to set guidelines and make firm decisions on various policies to address the rapid spread of the infection and hinder a catastrophic mortality rate. At the time, research was not always sufficient, and the pandemic progression involved continuous surprises. As a result, some decisions turned out to be utterly inadequate, counterproductive and short term - not fully considering neither people nor planet.

To realise building adaptations to fit the pandemic reality, was more challenging than setting the policies. This because buildings are complex and adjustments take time and can bring a significant cost. Actions taken, sometimes turned out to lack long term founding and conversely, a number of sound measures were not fully implemented during the time of the pandemic for lack of resources.

It all boils down to a need to prepare for the next pandemic well in advance, as preparation is key to ensure that it will be less complicated to go from a normal state to pandemic state. For the building industry, it is vital to apply measures today to make sure that the indoor climate is up to the task, not taking centre stage in virus transmission again.

Resilient buildings - preparing for the next pandemic

To understand resilient building design, buildings have to be looked at from a few different perspectives – the actual design and architecture, the layout of indoor spaces and the design of HVAC solutions for a good indoor climate – and then consider the key factors contributing to the indoor air quality (IAQ) of the building.

Design and construction

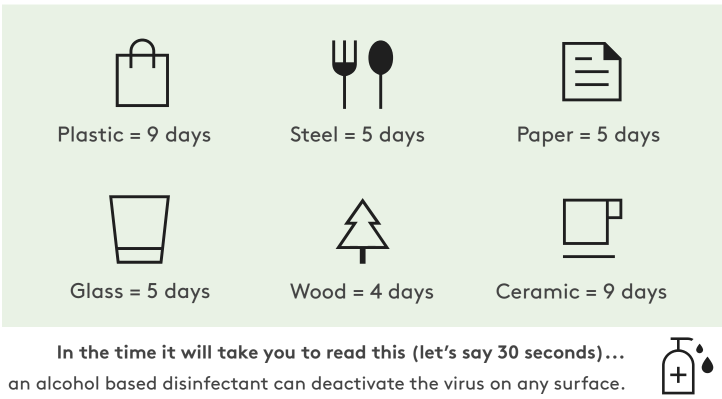
Resilient building construction, in terms of indoor climate, has flexibility as a key aim. Engineers and architects put emphasis on designing properties with adaptability in mind. They put attention on floor layouts that can be divided into zones, and large spaces that can be easily converted into smaller, single offices. This way of thinking is applicable to many building types, including hospitals where expandable walls are introduced to be able to divide spaces. Hospitals are also more often designed with multiple separate entrances and exits, and care-specific solutions for minimised virus transmission includes sluices, isolation rooms with access from the outside, smaller waiting rooms etc.

Also from an architectural standpoint, the development of modular prefabricated building systems plays a vital role in preparing for similar disruptive events as the last pandemic, and courtyard building developments are attractive solutions to healthy living concepts which can minimise virus transmission.

Layout and the use of the indoor space

The pandemic brought a massive shift from the traditional work and business practices towards a much more digital approach, i.e. meeting digitally instead of physically, chat groups for social interactions instead of the traditional coffee breaks etc.

It also affected the layout of indoor spaces. While IT and computer infrastructure itself may not make that much of an impact on interior design, layouts with open areas, for instance office landscapes, auditoriums and large wardrooms, require a new approach to avoid spreading of virus. This can be achieved in different ways, for example by utilising interior partitions between opposing desks, by creating more space between seats and by introducing more technology to avoid human interaction. By changing the floor layout and creating smaller hubs where people are facing away from each other or sitting a bit apart, it is possible to limit the virus spread. Digital technology can also be used for keeping occupants informed about the current state of the indoor environmental quality which allows them to decide on their own, if the indoor environment is resilient or not.



How long the Covid virus can survive on different surfaces (Graphic Credit: @monachalabi via Instagram)

The Covid pandemic taught the world a number of lessons in terms of social distancing, sanitation and hygiene. In the future, resilient buildings in terms of indoor climate, are expected to offer contact-free components and touch-less technologies, intelligent systems and automated functionalities. Engineers and architects are also believed to be more observant in terms of materials, it is known that some surfaces are more hospitable to microorganisms than others and research shows that SARS-CoV-2 survives for a shorter time on permeable materials such as textiles and paper towels, compared to impermeable surfaces.

Much of the research focuses on hospitals and care facilities, it is also relevant for offices or hotels to consider resilient measures to maintain high occupancy and productivity despite a pandemic situation.

HVAC solutions post-pandemic

While the mentioned measures can assist in limiting virus transmission, there is much research to suggest that in many cases the critical design factor is the HVAC solution – heating, ventilation and air conditioning. At the time of writing, there is a unison recommendation for ensuring adequate ventilation. However, researchers also emphasise that virus transmission cannot be considered in isolation – comfort aspects for the people in the building and economics aspects needs be taken into account as well.

All buildings answer to their unique needs, set by a multitude of prerequisites, from the activities conducted inside the building to the geographical location. Any HVAC solution needs to be adapted to these needs – and it is therefore difficult to make precise design recommendations that fits all scenarios. Nevertheless, there are a number of key lessons from Covid-19 that should be considered in the design phase today.

Starting in a pre-pandemic state, HVAC systems in buildings were designed to provide comfort indoors and acceptable indoor air quality (IAQ) and doing so in an energy efficient manner. During the pandemic, many buildings were advised to increase the ventilation rate, but only some had the HVAC capacity to do so. Even in the cases with adequate capacity, the forced air flow sometimes increased the risk of virus transmission due to an unwanted overpressure caused by an imbalance in the system. This was especially critical for hospitals.

Experts now advocate HVAC solutions to be designed to cope with greatly increased air exchange levels - when needed - but to also be able to operate efficiently under normal conditions.

Meaning, HVAC designers must adopt a similar approach as the engineers or architects and opt for solutions that can be adjusted over time, hence handling forced operation (pandemic) as well as a normal use scenario. Additionally, a "holistic IAQ management plan" should be a priority alongside a human-centred building design. A holistic plan gives bearing to both passive and active measures to create resilient buildings.

Indoor air quality and strategies to limit virus dissemination

The concept of indoor air quality is central to understanding the dynamics behind virus spread in indoor environments, and it is a good starting point for setting strategies to prevent virus spread.

IAQ - temperature, relative humidity, airflow and ventilation rates

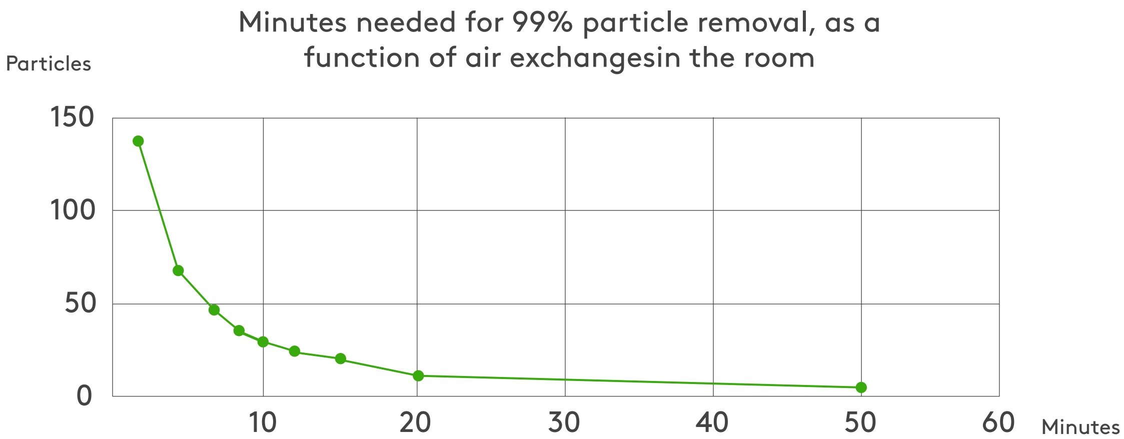
Research indicates that it is reasonable to aim for a temperature somewhere between 17 to 28 degrees Celsius when creating indoor climate resilience in buildings. Bear in mind that, included in this range, is both summer and winter design conditions and various applications from offices to auditoriums and warehouses.

Most countries have their local legislation to follow, for which i.e. office recommendations is around 21 degrees. However, taking into consideration the energy aspect etc., it could be good to know that from a virus transmission point of view there is a temperature span where, if in a pandemic situation, air flow needs to be increased significantly.

Relative humidity (RH) levels are also advised to be varying within a certain range, between 30 and 60% at 21-23 degrees Celsius. It is pointed out that paying careful attention to the relative humidity is critical because humidity is a major contributor for promoting contagious diseases, it affects both growth and transmission of airborne virus. On the other hand, the lack of humidity in the air negatively affects the immune system and impacts its ability to cope with microorganisms. Hence, from a building and human perspective, both too high and too low humidity levels are causing discomfort and negative impacts. A resilient indoor climate therefore requires sufficient RH levels.

In regards to ventilation rates, the number of air exchanges obviously make a difference in terms of particle removal from the indoor space. However, it is important to realise that 100% particle removal, is not realistic.

As indicated in the graph below, the time needed to reach a 99% removal rate is quickly reduced as the ventilation rate is increased. Translated into terms of virus transmission, if starting at low ventilation rates, even modest increases in ventilation rate will have a significant effect.



Air changes/hour (ACH) and time required for 99% airborne-contaminant removal

Because research is still ongoing at a very high pace, there is a wide variety of recommendations regarding post-pandemic HVAC solutions, but they boil down into three main paths: increased ventilation, adoption of mixed-mode ventilation and strategies for natural ventilation, meaning - the recommendations range from increasing air exchange rates and running HVAC solutions 24/7, to ventilating naturally and opening windows.

All the strategies have the same basic goal – to increase air exchange in the room – but the means to achieve these differs, and all methods have their pro's and con's. What is needed, is to find the right solution for each building and to make sure the solution can guarantee the needed ventilation rates, and can do so with the least amount of energy consumption, while also safeguarding a productive indoor climate with regards to temperature, draught, sound and humidity. And the solution needs to be easy to operate for the people in the building, preferably being entirely automated.

The summary below gives an overview of some of the strategies highlighted in academia today and in what way these can contribute to minimised virus spreading and improved indoor environmental quality:

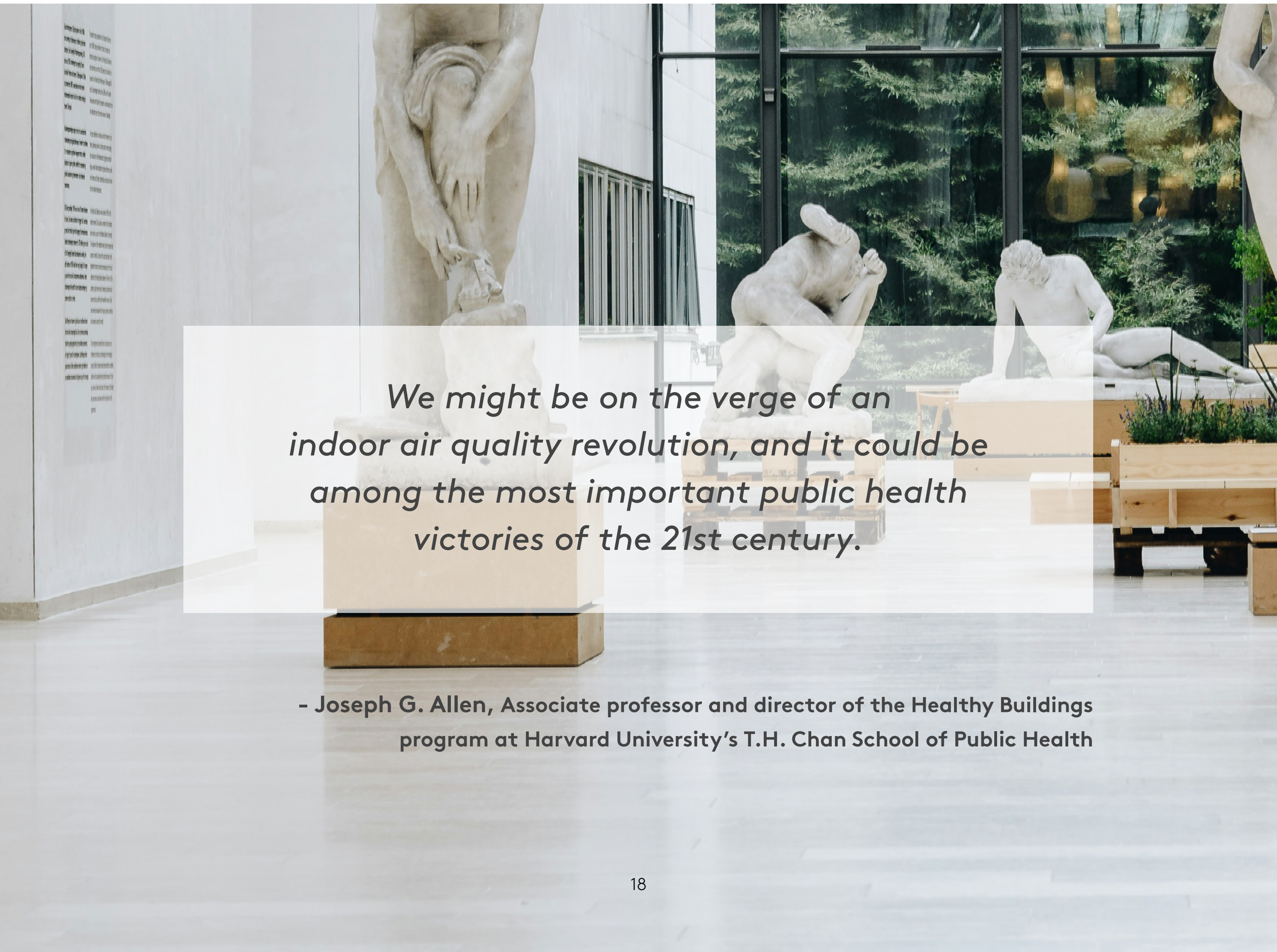
Reduce concentration of contaminants	**Hinder dissemination of contaminants**	**Monitor air quality**
• Determine ventilation rates	• Social distancing	• Determine acceptable indoor air quality conditions
• Specify air changes per hour	• Contain contaminant sources	• Diagnose the indoor air quality situation
• Secure correct filter functionality	• Control room air distribution	• Control the HVAC system
• Consider alternative air cleaning technologies	• Control pressure differences between spaces	

S. Li, "Review of Engineering Controls for Indoor Air Quality: A Systems Design Perspective," September 2023. [Online]. Available: https://www.mdpi.com/2071-1050/15/19/1423

Monitoring and engineering controls

It has been concluded that Covid-19 underscored how important indoor air quality (IAQ) is to public health, and research promptly established that ventilation, relative humidity and air circulation are key factors in terms of virus transmission indoors. Furthermore, a significant amount of research has focused on what else can ensure a good indoor climate, while being aware that not even the best designed buildings can rely on its initial setup alone.

In this context, continuous monitoring and proactive maintenance are believed to be essential. These measures can allow facility managers to regularly assess and adjust the indoor climate conditions in order to minimise virus transmission, reduce the potential for pandemic outbreaks and provide indoor spaces that are safer and healthier for the people inside.



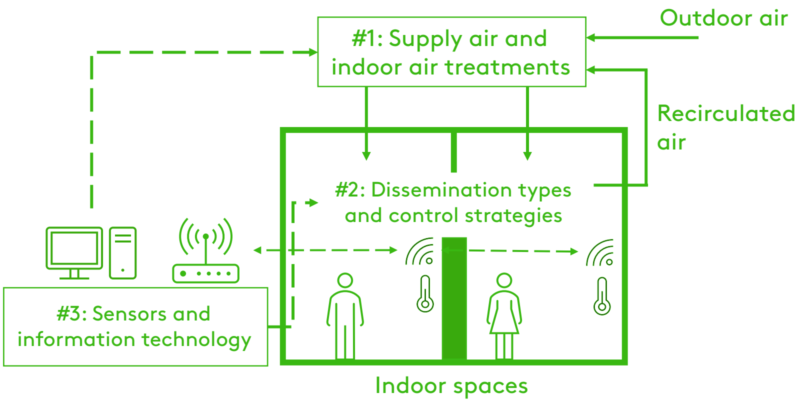
We might be on the verge of an indoor air quality revolution, and it could be among the most important public health victories of the 21st century.

- Joseph G. Allen, Associate professor and director of the Healthy Buildings program at Harvard University's T.H. Chan School of Public Health

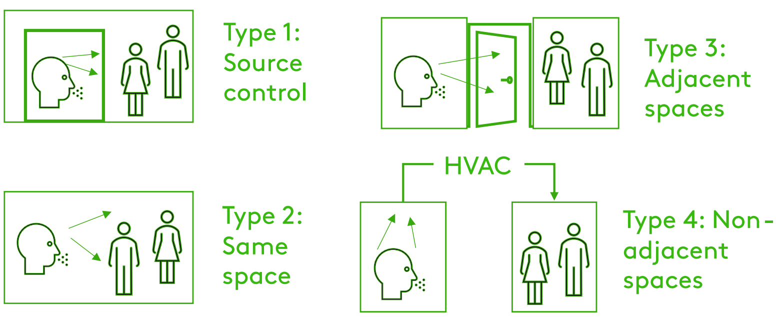
Engineering controls for indoor air quality - a system design perspective

When taking a system design perspective, research has indicated that it is important to plan with health and safety in mind, thereby limiting exposure to hazards such as viruses. The design strategies aimed at ensuring safe indoor air quality (IAQ), can be divided into three categories:

- Indoor air treatment
- Dissemination types and control strategies
- Information technology

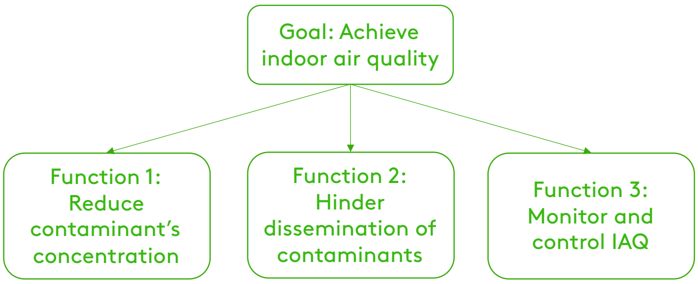


An integrative framework for the review



Four types of dissemination of contaminants

One key finding in the system design approach is that it may be beneficial to separate the functions of indoor air treatment from the strategies used to control how air is disseminated or spread within an indoor space. This can make it easier to come to terms with air quality issues, such as concerns about pollution and virus transmission in the room, and easier identify the most appropriate solutions to resolve other potential problems. IAQ sensors and IoT technology can support the development of smart systems that support the IAQ goals and includes functional design for adaptability and resilience.



Top-level functions for IAQ

Research on indoor air quality (IAQ) has explored at least two different approaches to future solution design in regards to monitoring and control.

- **Integrating IAQ controls with technology:** Traditional air quality controls, such as ventilation and air pressure zones, may be even more useful when combined with smart technology. While smart ventilation is already available and in use, additional tech-driven solutions may enhance functionality and allow for further smart features, for instance dissemination control.
- **Flexible HVAC solutions:** Buildings need adaptable air quality solutions to respond to changing conditions and occupant demands. Creative approaches may allow for better use of existing solutions, such as hybrid ventilation, which combines natural and mechanical airflow to improve IAQ. Demand controlled ventilation is another example, which allows for adjustments of the airflow based on occupancy, this in turn, ease the balance between air quality and energy efficiency.

It is suggested that monitoring and control of indoor air quality (IAQ) should be designed to support facility managers in overseeing the building and its HVAC solution in an efficient manner. The tools should therefore be able to help them detect concentration of air pollutants and execute control actions. Ideally, a monitoring system should diagnose the state of IAQ and notify if conditions deviate from set IAQ targets, and learn over time how the system and people in the building interact. These learnings should enable extensive data collection and statistics which, in turn, can be used to optimise energy use, indicate investment needs etc.

Monitoring and control systems should contribute to shape a sustainable facility management strategy. Important, this is beneficial not only for the building, economics and sustainability but also for ensuring resilient spaces, in regard of indoor climate, that are safe for people to spend time in.

Buildings with prevention capacity – possible thanks to new technologies

Prevention capacity refers to the level of preparation in response to public health emergencies. Here are examples of prevention measures that can be applied in terms of monitoring, maintenance and controlling pressure differences in HVAC solutions:

1. CO2 sensors can be installed to monitor the indoor air quality. Since CO2 can serve as an indicator of exhaled pollutants from occupants, the monitoring of CO2 concentrations can help control HVAC operations to ensure good air quality with sufficient fresh air supply, particularly important during a pandemic.
2. To improve the ability to prevent airborne transmission, key sanitary components of the HVAC solution, such as filters, air supply outlets, surface coolers and ducts, should be cleaned and maintained regularly. For systems with recirculated air, these main components should be disinfected regularly, especially during epidemics.
3. In hospitals, areas with infected patients need proper pressure differences between the isolation ward and the neighbouring space. When there is a need to convert general wards to isolation wards, an adaptive pressure control and monitoring system is essential.

Modern monitoring tools enables facility management teams to optimise energy use, reduce operational costs and extend the longevity of HVAC equipment by improving operational efficiency. In addition, this enhance overall indoor environmental quality, increase comfort and allow for a sustainable and healthy indoor space for the people inside.

Switching and recovery capability

Switching and recovery capability refers to an HVAC solution's ability to rapidly convert into an epidemic prevention and control mode at the time of a virus outbreak, and then return to normal once the hazard is over. This flexible design primarily depend on three aspects: spatial planning flexibility, functional layout flexibility and energy-saving flexibility.

Furthermore, variable frequency technology, variable fresh air systems and demand control technology may be integrated into HVAC solutions to improve energy efficiency across many different operational scenarios.

The future of indoor climate control

There is a growing demand for digital control, and the number of parameters being managed continues to increase. While digital advancements offer an unprecedented level of automation, human oversight remains essential to ensure that technology meets real-world demands.

Air filtration

Filtration is an important tool for improving the indoor quality, but it is vital to also understand its limitation, this in order to not introduce ineffectional measures against flu virus. Worst case, the measures could even be counterproductive, as they may create a false sense of security.

Increased ventilation and filtration, as recommended by the Centers for Disease Control (CDC) and World Health Organization (WHO), help reduce airborne virus transmission. Mechanical filters are widely used in the HVAC industry to improve air quality. They capture particles through interception, impaction and diffusion — larger particles are removed by the means of impaction and smaller ones through diffusion.

Research shows that increasing filter efficiency, especially above certain filter standards such as ePM1 50% (MERV 13), reduces virus transmission but with diminishing returns. Due to the small size of the corona molecule, the virus can pass through most filters. However, HEPA filters will be able to catch larger particulates that contain or carry the virus. Finally, it is also to be understood that filtration alone is not considered to be sufficient — proper installation and design in combination with other mitigation strategies, such as vaccination and distancing, are mentioned as crucial measures.

Filters from different manufacturers with the same ePM (MERV) rating can also show variable perfomance which complicates the choice of filter solutions. It is vital to choose filters that have verified functionality throughout their entire lifespan. While increasing filtration efficiency helps reduce transmission, higher filtration ratings are often less cost-effective compared to other ventilation alternatives. However, improving air quality infrastructure is generally profitable, and upgrading to an ePM1 50% (MERV 13) filter is effective in capturing particles and will have some effect in reducing infections.

Alternatively, there are other solutions for cleaning the air. Ionization, for instance, offers high particle removal (79%-100%) but may instead produce ozone, harmful to respiratory health causing both long- and short-term damage. Further, there is the development of ultraviolet germicidal radiation (UVGI) technology which reduces the virus concentration in the indoor environment.

Changes in legislation and guidelines

Covid-19 led to significant changes in legislation and guidelines governing indoor climate as well as heating, ventilation and air conditioning (HVAC) solutions. The changes aim to reduce the transmission of airborne viruses, particularly in enclosed spaces where people gather. Below is an overview of key shifts in standards and practices related to indoor climate and HVAC systems post-pandemic.

Enhanced ventilation requirements

Ventilation standards have been updated globally to focus on increased amounts of fresh air brought into buildings and reduced air recirculation. Regulatory bodies, such as the American society of heating, refrigerating and air-conditioning engineers (ASHRAE) and European Standard EN 16798-1, now prioritise the following:

Increased air changes per hour (ACH): Minimum ventilation rates have been raised in many settings in order to dilute airborne contaminants, including viral particles. As an example, public buildings, offices, schools and healthcare facilities now have stricter ACH requirements.

Natural ventilation encouragement: Natural ventilation is emphasised to bring in fresh air and reduce reliance on mechanical solutions, but only where possible. Opening windows and utilising hybrid systems are recommended or required in certain building codes.

Reduced air recirculation: Guidelines now advocate for limiting or eliminating air recirculation in buildings, particularly so in high-risk applications, in order to minimise the risk for spreading viruses in the air.

Stricter air filtration standards

The pandemic has prompted increased attention to the types and effectiveness of air filters used in HVAC solutions. New legislation and guidance require more efficient filtration to capture smaller particles.

Ratings: HVAC solutions are now commonly required to use filters rated ePM1 50% (MERV 13) or higher, as these filters are more effective for trapping smaller airborne particles, including viral aerosols.

HEPA filters: High-efficiency particulate air filters (HEPA) are increasingly mandated in healthcare settings and recommended for buildings for high-risk populations. HEPA filters capture 99.97% of particles as small as 0.3 microns, including viruses.

UV-C light and air cleaning technologies: In some applications, guidelines now suggest the use of ultraviolet germicidal irradiation systems (UVGI) or other air cleaning technologies, such as ionisation, this to inactivate airborne pathogens in HVAC ducts or occupied spaces.

Focus on indoor air quality (IAQ) monitoring

Post-pandemic regulations emphasise the importance of real-time indoor air quality (IAQ) monitoring to ensure optimal ventilation and air filtration.

CO2 monitoring: Many buildings are now required to install CO2 sensors to track ventilation efficiency. Elevated CO2 levels are often used as a proxy for poor ventilation, and real-time monitoring helps maintain safe indoor environments.

Humidity control: Guidelines also focus on maintaining optimal indoor humidity levels (typically between 30-60%) to limit viral transmission and maintain occupant safety and comfort.

Data transparency: In some regions, regulations mandate that IAQ data be shared with building occupants or made accessible to the public to promote trust and adherence to new air quality standards.

Sector-specific HVAC standards

Buildings with certain purposes have adopted more stringent HVAC requirements due to their particular vulnerabilities or high occupancy levels:

Healthcare facilities: Hospitals and clinics have been at the forefront of HVAC upgrades, with an emphasis on negative pressure rooms, increased ventilation rates and the use of advanced air filtration technologies to prevent the spread of infectious diseases.

Educational institutions: Schools have seen significant updates to their ventilation requirements, with many educational authorities mandating improved airflow and air filtration in classrooms. Some have invested in portable air purifiers to complement existing systems.

Office buildings and commercial spaces: Workplace environments now feature enhanced HVAC protocols, particularly in open-plan offices and shared workspaces. Many office buildings have adopted demand-controlled ventilation systems that adjust air exchange rates based on occupancy levels.

Energy efficiency and HVAC operations

Balancing energy efficiency with enhanced ventilation and air quality measures has become a key focus in post-pandemic HVAC guidelines.

Energy recovery ventilation (ERV): Systems that recover energy from exhaust air to condition incoming fresh air are being promoted as a way to reduce the energy use of increased ventilation.

Demand-controlled ventilation (DCV): Sensors that monitor occupancy and IAQ parameters, such as CO2 and VOC levels, allow HVAC systems to adjust airflow and filtration dynamically, optimising energy use while maintaining air quality.

Smart building systems: Advanced HVAC systems are being integrated with building automation technologies to enable real-time adjustments based on IAQ data, occupancy levels and external conditions, ensuring both health and energy efficiency.

Global coordination and regional differences

While international organisations such as the World Health Organization (WHO), REHVA and ASHRAE have provided broad guidance, while specific regulations vary by region. For instance:

In the United States, ASHRAE has led efforts to update guidelines on ventilation, filtration and air cleaning technologies, with federal and state governments adapting these recommendations into building codes.

In the European Union, updates to the EN 16798-1 standard reflect a push for higher ventilation rates and better air filtration across the continent.

In Asia, countries such as Singapore and South Korea have adopted strict HVAC requirements for high-occupancy public spaces like malls, airports and hotels, ensuring better air circulation and virus mitigation.

Conclusion

As mentioned in the introduction of this paper, we now have the advantage of a vastly increased body of research to draw conclusions from, even though we are well aware that research is ongoing and a lot more will be published in coming years. But, we can today understand what measures are effective to minimise virus transmission. The challenge is to transfer the available knowledge to practical recommendations and make sure that they are proactively implemented.

What we learned was that the costs of a pandemic has many components, from the emotional and physical suffering from losing loved ones, to the aspects of shutdown of operations, a worldwide economic downturn with losses of income and companies going out of business, to the environmental costs of increased energy consumption.

The costs have naturally triggered actions and a determination to be better prepared for future pandemics. This has led to a fundamental rethinking of indoor climate and HVAC solutions with ventilation, air filtration and IAQ monitoring in the absolute spotlight. These changes are becoming permanent features of building codes and industry standards, not only because of the changes in regulations and legislations, but because technologies such as smart building systems and advanced energy recovery ensure that indoor environments are healthier and safer for occupants, while also balancing sustainability concerns.

In sum, air quality and indoor climate is discussed with a new sense of importance and urgency, and the direction is clear – we simply cannot afford being as ill-prepared as we were in 2020.

Indoor climate in general, and mechanical ventilation in particular, is at the very intersection of where these factors overlap making it a key component in creating resilient buildings. Mechanical ventilation uses energy for the operation of fans, but compared to the alternatives such as opening windows, mechanical ventilation with heating and cooling recuperation saves significant amounts of energy. At the same time is draught, noise and pollution minimised, factors that otherwise may cause an uncomfortable and unhealthy indoor environment. Mechanical ventilation is also vital for buildings as such, healthy buildings can stand for many decades.

In short, the indoor climate is linked to many aspects of sustainability – from what affects us as humans, to the buildings we live and work in, as well as the society around us. So, when preparing for future pandemics, the indoor climate has to be key when creating resilience on all levels of the built environment.

Recommendations going forward

So, what is possible to do to start the process of creating better resiliency already today?

The challenge is considerable, but the good news in terms of heating, ventilation and air conditioning is that the technical solutions are already available and ready to be implemented. These are our most relevant HVAC recommendations in regard to creating indoor climate reciliency in buildings:

- The air handling unit (AHU) is a key component to ensure adequate air quality in an energy efficient manner. Air handling units with heat recovery have been on the market for many years and there are today units which can recuperate a minimum of 80% of the heating or cooling energy in the indoor air.
    - One of the most apparent differences between various AHUs are controls and functionality. Make sure to choose air handling units that can allow for high energy efficiency and a high level of flexibility, easily switching from everyday operation to "pandemic boost mode".

- To meet comfort requirements, and also minimise energy consumption, it is most relevant to ventilate, heat and cool according to the actual need. Systems for demand controlled ventilation (DCV) use advanced sensor technology distributed across the building to identify the exact demand in all spaces, at all times, and adapt heating, ventilation and cooling to ensure an optimal indoor climate.
    - A notable advantage of DCV is that operational costs and the environmental footprint are kept at a minimum as the indoor climate corresponds to the occupancy and activity inside, rather than to a time scheme or assumed use.

- Referring back to the research, being able to provide a sufficiently high air flow in an efficient way to minimise the risk of virus transmission.
    - Make sure to select flexible and adjustable air diffusers and hydronic products that can be adapted to ensure a safe and healthy indoor environment, while also supporting energy efficiency and peoples' productivity and strategic thinking, rest and recouperation.
    - There are different ventilation principles – and while mixing ventilation is the most common, the displacement principle is a good alternative, as it will supply air with low velocity at a low level into the room, the air will be heated by natural heat sources and rise to the ceiling level, minimising the movement of potentially contaminated air in the occupied zone of the room.

- The last few years have seen rapid developments of HVAC controls and digital tools for creating a good indoor climate. Today it is possible to manage both single air handling units and entire building installations remotely, and thanks to advanced data collection as well as artificial intelligence, it is possible to predict service and maintenance needs. Various tools have been developed for all relevant stakeholders – from facility management technicians to tenants – to visualise the otherwise invisible indoor climate, providing a better understanding of the indoor climate in the building, and its relation to energy consumption.
    - By combining high performing HVAC equipment and then adding an extra layer of digital tools to monitor the entire system over time, people inside the building can be well catered for, today and tomorrow.

Today, all of the mentioned categories of products and services are well-known, and have proven that they can provide a healthy and productive indoor climate, while also addressing the increasingly important aspect of energy efficiency. When applying these technical solutions with the right design knowledge and skilled technicians, it results in seamlessly operating systems, without unmanageable complexity or expensive maintenance needs. Investing in modern HVAC solutions simply makes good sense, and there is constant progress with more modern systems installed every day.

What has slowed down a wider implementation of indoor climate solutions is mainly a lack of knowledge, and to some extent an absence of long-term thinking within the building industry. The benefits of a good indoor climate, energy efficient operations and low maintenance costs are strong arguments for investing in modern HVAC solutions today, and even prior to the Covid-19 pandemic.

With the need for creating resilient buildings to better cope with future pandemics, or to simply tackle next year's "seasonal flu", the arguments for modern indoor climate solutions are stronger than ever.

Hopefully the research and knowledge compiled in this whitepaper shows that there are many lessons learned from Covid-19, and that there are ways to minimise the impact of a future pandemic. At the same time this paper aims to call for action – preparation really is key, and what is done today, will allow us to 'feel good inside', tomorrow and for many years to come.

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