White Paper

Clean air for pandemic-proof buildings

Saubere Luft für pandemiegerechte Gebäude

De l'air propre pour des bâtiments adaptés à la pandémie

A strategy presented by the expert group on "Pandemic-proof buildings". June 2022.

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Summary

Over 150 years ago, the risks of waterborne diseases such as Cholera were tamed by the public provision of clean water. We argue that similar efforts are warranted to provide clean indoor air for all by removing the threats posed by airborne diseases such as COVID-19, influenza and tuberculosis.

The coronavirus SARS-CoV-2, which causes coronavirus disease 2019 (COVID-19), is a pathogen transmitted primarily via respiratory aerosols in the indoor air. These small particles, consisting of fluid released from the upper and lower respiratory tract, become airborne when people breathe, talk and sing. In this way, the pathogen becomes airborne. After exhalation, fine respiratory aerosol particles can remain in the air for a long time, distribute themselves in the room and continue to accumulate as long as the sick person remain there. Thus, infections can occur even if there is a large distance between individuals. A room's design and type of use can have a major influence on the aerosols and pathogens they contain, as can the operation and maintenance of the building's technical systems.

There are proven and commercially available methods for providing clean air. Clean air can be achieved by preventing the release of respiratory aerosols, diluting air contaminated with pathogens, or removing the pathogen via filtration or disinfection. Research suggests that very strong pathogen reductions, often the equivalent of 5 to 6 air changes per hour or more, should be reached to have a substantial effect. This is much more than what is the current standard.

Our panel of scientific experts strongly recommends that the clean air needs of offices, schools, theaters, public buildings, and mass transportation systems be assessed and that measures be taken to ensure clean air in all indoor environments.

In the past, buildings ventilation systems were developed to optimize energy consumption and occupant comfort. They were designed so as not to pose a risk to hygiene during normal times. However, preventing the transmission of the pathogens in respiratory aerosols during waves of disease like COVID-19 was never a design goal in a normal building.

Since the beginning of the pandemic, many ideas to reduce the transmission of SARS-CoV-2 have been formulated. However, the approaches implemented mainly involved wearing masks and more frequent, consistent ventilation. Neither option has proved acceptable in the long term. Many people perceive wearing a mask as uncomfortable, and vigorous ventilation is too energy-intensive and unpleasant in winter. Future solutions will have to be pandemic-proof, energy-efficient, and comfortable enough for the users to accept and go along with the solutions.

Building and operating buildings that are at once pandemic-proof, energy-efficient, and fit for our future climate will be a major challenge. Initial small-scale projects are already underway, but a massive research push will be needed to develop new methods for the buildings of the future. Which ideas and concepts can be implemented efficiently and quickly? Are they sustainable? What are the unanswered questions and the gaps in knowledge requiring more in-depth research? How to balance economic, energy and ecological aspects, and what about user acceptance and comfort? What might be different solutions for existing and new buildings look like? Which framework conditions, improvements and, if necessary, restrictions will be required to safely operate the buildings of the future, even in times of pandemics?

The solutions resulting from short- to long-term research activities must subsequently be implemented in practice. This means that the research findings must be integrated into the body of standards and regulations. In addition, funding and incentive models combined with information campaigns will be required to realize the vision of pandemic-proof buildings.

For all these reasons, we propose a three-phase approach:

Phase 1: Introduce temporary measures for clean air, as well as:
a) Evaluation of existing but not yet analyzed data, and
b) Accompanying interventions in selected buildings such as schools, offices or theaters.

Phase 2: Establish a National Research Programme on *"Clean air for pandemic-proof buildings"*.

Phase 3: Reinforce knowledge transfer as well as funding and incentive models for the implementation of results.

Phase 1: Introduce and accompany temporary measures for clean air

Clean air is urgently needed in offices, schools, theaters, public buildings, and mass transportation systems to prevent another winter wave of the coronavirus pandemic. While many scientific questions remain unanswered, there are none speaking against immediately implementing at least temporary solutions to improve indoor air and lower the risk of aerosol transmission.

We recommend installing better mechanical ventilation systems, equipping rooms with CO_2-sensors that enable users to act when their air quality is poor and installing in-room filtration or UV air disinfection systems.

At the international level, there are already initial results of theoretical and practice-oriented studies. Also a few Swiss studies have already started and are collecting data and a rapid yet detailed evaluation of this existing data is urgently needed. In addition, a selection of the above interventions should be accompanied by scientific projects so that we can learn from them for the future. Interventions can be tested individually or in combination with each other. Schools and offices where studies are already underway would be ideally suited, as would buildings where owners and occupants have expressed an interest in taking action. Interventions to assess include "CO_2-controlled ventilation", "Forced displacement ventilation", "Recirculating air filtration" and "Overhead UV-light disinfection". Planning for such projects is best done using a coordinated approach involving control and intervention objects. At a minimum, temperature, humidity, CO_2, and microbiological parameters shall be determined in each case, and these should be accompanied by studies on the quality of user acceptability of the measured implemented. Pre-existing data should also be evaluated in a coordinated manner, where possible, in combination with data on the health, mental performance and energy usage of buildings. Rapid, straightforward funding must be found for these pilot projects.

Phase 2: A National Research Programme on *"Clean air for pandemic-proof buildings"*

In a second phase, we need a National Research Programme on *"Clean air for pandemic-proof buildings"* with the long-term perspective of a healthy, low-energy building stock adapted to our future climate. This program should further test existing concepts and develop new approaches. In particular, office, commercial and public buildings, particularly schools, should still be able to operate with low risks during pandemics. A National Research Programme on *"Clean air for pandemic-proof buildings"* should promote both basic research and the development of application-oriented solutions. It would be aimed at both academic institutions and innovative companies. Innovative actors should propose, lead and be compensated for their projects, analogous to the rules of the EU Horizon Program. Phase 2 should be developed in parallel with the start of the pilot phase so that a first call for projects could be issued as early as 2023. In this way, the pilot phase could be followed up without gaps.

Phase 3: Programs to implement results

The third phase should begin as early as possible and continue after the first two phases have been completed. The new or improved solutions and products developed for pandemic-proof buildings as part of the National Research Programme on *"Clean air for pandemic-proof buildings"* must subsequently be applied in practice. The program's findings will have to be efficiently implemented in new buildings and renovations, training programs, building codes and standards as well as funding and incentive programs.

An indoor air competence center could be created to take over these tasks. This could work with stakeholders, even during the National Research Programme, to create a catalog of ideas documenting how buildings can be used and operated in normal times and during pandemics. Thereafter, the competence center would be available to advise on implementation so that the health, economic and societal impacts of future epidemics and pandemics can be mitigated while still achieving national energy transition goals.

Zusammenfassung

Vor über 150 Jahren wurden durch Wasser übertragene Krankheiten wie die Cholera durch die Bereitstellung von sauberem Wasser eingedämmt. Wir sind überzeugt, dass ähnliche Anstrengungen gerechtfertigt sind, um saubere Innenraumluft für alle bereitzustellen, um die Bedrohung durch luftübertragene Krankheiten wie COVID-19, Influenza und Tuberkulose zu beseitigen.

Das Coronavirus SARS-CoV-2, das die Coronavirus-Krankheit-2019 (COVID-19) verursacht, ist ein Krankheitserreger, der in erster Linie über die Innenraumluft durch Atemaerosole übertragen wird. Dies sind kleine Partikel bestehend aus Flüssigkeit der oberen und unteren Atemwege, die beim Atmen, Sprechen und Singen in die Luft gelangen. Auf diese Weise gelangt auch der Erreger in die Luft. Nach dem Ausatmen bleiben die feinen Atemaerosole lange in der Luft, verteilen sich im Raum und reichern sich weiter an, solange sich die erkrankte Person dort aufhält. So kann es zu Infektionen kommen, auch wenn ein grosser Abstand zwischen den Personen besteht. Die Gestaltung und Nutzungsart der Räume sowie der Betrieb und die Wartung der gebäudetechnischen Anlagen haben einen grossen Einfluss auf die Aerosole und die darin enthaltenen Krankheitserreger.

Es gibt erprobte und auf dem Markt erhältliche Methoden, mit denen für saubere Luft gesorgt werden kann. Dazu gehört das Verhindern der Freisetzung von Atemwegsaerosolen, die Verdünnung der mit Krankheitserregern belasteten Luft und die Entfernung der Krankheitserreger durch Filtration oder Desinfektion. Neuere Forschung zeigt, dass starke Pathogen-Reduktion, oft um das Äquivalente von 5 bis 6 Luftwechseln pro Stunde oder mehr, erreicht werden sollte, um eine wesentliche Wirkung zu erzielen. Das ist wesentlich mehr als der derzeitige Standard.

Unsere Expertengruppe empfiehlt eindringlich, dass der Bedarf an sauberer Luft für Büros, Schulen, Theater, öffentliche Gebäude und Massenverkehrsmittel geprüft und Massnahmen ergriffen werden, um saubere Luft in allen Innenräumen sicherzustellen.

In der Vergangenheit wurde das Design der Belüftung von Gebäuden im Hinblick auf Energie und Komfort der Bewohner optimiert. Das Lüftungssystem wurde so konzipiert, dass es zu normalen Zeiten kein Hygienerisiko darstellt. Die Verhinderung der Übertragung von Krankheitserregern durch Atemwegsaerosole während Krankheitswellen wie der derzeitigen COVID-19 Pandemie gehörte jedoch nicht zu den Zielen für normale Gebäude.

Seit Beginn der Pandemie wurden schon viele Ideen zur Reduktion der Übertragung von SARS-CoV-2 formuliert. Umgesetzt wurde aber vor allem das Tragen von Masken und häufigeres und konsequenteres Lüften. Beides ist langfristig nicht akzeptabel. Viele empfinden das Maskentragen als unangenehm und intensives Lüften ist im Winter zu energieintensiv und unbehaglich. Zukünftige Lösungen müssen Pandemie-sicher, energieeffizient und komfortabel genug sein, damit die Lösungen von den Nutzenden akzeptiert und mitgetragen werden.

Der Bau und Betrieb von pandemiegerechten und zugleich energieeffizienten und dem zukünftigen Klima gerecht werdenden Gebäude stellt eine grosse Herausforderung dar. Erste kleinere Projekte haben bereits begonnen. Es bedarf aber eines massiven Forschungsschubs, um neue Methoden für die Gebäude der Zukunft zu entwickeln. Welche der Ideen und Konzepte lassen sich effizient und rasch

umsetzen? Sind sie nachhaltig? Wo gibt es offene Fragen und Wissenslücken, die vertiefter Forschung bedürfen? Wie lassen sich ökonomische, energetische und ökologische Aspekte in Einklang bringen, und wie steht es um die Nutzerakzeptanz und den Komfort? Wie können Lösungen für bestehende, wie solche für neue Gebäude aussehen? Welche Rahmenbedingungen, Verbesserungen und allenfalls Einschränkungen sind nötig, um in Zukunft Gebäude auch in Pandemiezeiten sicher zu betreiben?

Die aus kurz- bis langfristigen Forschungs-Aktivitäten hervorgehenden Lösungen müssen auch in die Praxis umgesetzt werden. Dazu braucht es in die Integration der wissenschaftlichen Erkenntnisse ins Normen- und Regelwerk. Darüber hinaus braucht es Finanzierungs- und Anreizmodelle in Verbindung mit Informationskampagnen, um die Vision von *pandemiegerechten Gebäuden* zu verwirklichen.

Wir schlagen aus all diesen Gründen ein dreiphasiges Vorgehen vor:

Phase 1: Einführung von temporärer Massnahmen für saubere Innenluft, sowie:
a) Auswertung bereits vorhandener aber noch nicht analysierter Daten sowie
b) Begleitforschung in ausgewählten Schulen, Büros und Sälen

Phase 2: Etablierung eines Nationalen Forschungsprogrammes *"Saubere Luft für pandemiegerechte Gebäude"*

Phase 3: Wissenstransfer sowie Förder- und Anreizmodelle zur Umsetzung der Ergebnisse

Phase 1: Einführung und Begleitung temporärer Massnahmen für saubere Luft

Saubere Luft ist in Büros, Schulen, Theatern, öffentlichen Gebäuden und Massenverkehrsmitteln dringend erforderlich, um eine weitere Winterwelle der Corona-Pandemie zu verhindern. Es gibt zwar viele offene wissenschaftliche Fragen, aber keine von ihnen spricht gegen die sofortige Umsetzung zumindest vorübergehender Lösungen zur Verbesserung der Innenraumluft und zur Verringerung des Risikos einer Aerosolübertragung.

Wir empfehlen die Installation besserer mechanischer Belüftungssysteme, die Ausstattung der Räume mit CO_2-Sensoren, damit die Nutzer bei schlechter Luftqualität Massnahmen ergreifen können, und die Installation von Filtersystemen oder UV-Luftdesinfektionssystemen in den Räumen.

Auf internationaler Ebene gibt es bereits erste Resultate theoretischer und praxisorientierter Studien. Einige wenige Schweizer Studien haben auch bereits begonnen und sammeln Daten. Eine rasche und dennoch detaillierte Auswertung dieser vorhandenen Daten ist dringend nötig. Darüber hinaus sollte eine Auswahl der oben genannten Interventionen durch wissenschaftliche Projekte begleitet werden, damit wir daraus für die Zukunft lernen können. Die Interventionen können einzeln oder in Kombination miteinander getestet werden. Besonders geeignet wären Schulen und Büros, in denen bereits Studien durchgeführt werden oder in denen Eigentümer und Nutzer ihr Interesse an Massnahmen bekundet haben. Zu den zu prüfenden Massnahmen gehören die "CO_2-kontrollierte Lüftung", die "forcierte Verdrängungslüftung", die "Umluftfiltration" und die "Überkopf UV-Licht Desinfektion". Die Planung der Projekte erfolgt am besten in einem koordinierten Ansatz mit Kontroll- und Interventionsobjekten. Im Minimum werden jeweils Temperatur, Luftfeuchtigkeit, CO_2-Gehalt und mikrobiologische Parameter ermittelt und Studien zur Nutzungsqualität und Akzeptanz durchgeführt. Auch bereits erhobene Daten sollen koordiniert ausgewertet und nach Möglichkeit mit vorhandenen Daten zu Gesundheit, psychischer Leistungsfähigkeit und Energie kombiniert werden. Für diese Pilotprojekte muss eine schnelle und unkomplizierte Finanzierung gefunden werden.

Phase 2: Nationales Forschungsprogramm *"Saubere Luft für pandemiegerechte Gebäude"*

In einer zweiten Phase brauchen wir ein Nationales Forschungsprogramm *"Saubere Luft für pandemiegerechte Gebäude"* mit einer langfristigen Perspektive hin zu einem gesunden, energieeffizientem und dem zukünftigen Klima angepassten Gebäudepark. Im Rahmen dieses Programmes sollen bestehende Konzepte weiter getestet und neue Ansätze entwickelt werden.

Insbesondere Büro-, Gewerbe- und öffentliche Bauten, namentlich Schulen, sollten während Pandemien mit einem geringen Risiko weiter genutzt und betrieben werden können. Das Nationale Forschungsprogramm "*Saubere Luft für pandemiegerechte Gebäude*" soll gleichermassen Grundlagenforschung als auch die Erarbeitung anwendungsorientierter Lösungen fördern. Es richtet sich sowohl an akademische Institutionen als auch an innovative Unternehmen. Innovative Akteure sollen Projekte vorschlagen, leiten und dafür entschädigt werden, analog den Regeln des EU Horizont Programmes. Phase 2 sollte parallel zum Start der Pilotphase erarbeitet werden, damit ein erster Aufruf für Projekte bereits 2023 erlassen werden kann. So kann lückenlos an die Pilotphase angeschlossen werden.

Phase 3: Programme zur Umsetzung der Ergebnisse

Die dritte Phase sollte so früh wie möglich beginnen und muss nach Abschluss der ersten beiden Phasen fortgesetzt werden. Die im Rahmen des Nationalen Forschungsprogramms "*Saubere Luft für pandemiegerechte Gebäude*" entwickelten neuen oder verbesserten Lösungen und Produkte für pandemiegerechte Gebäude müssen anschliessend in der Praxis angewendet werden. Um das neu erworbene Wissen bei Neubauten und Sanierungen effizient umzusetzen, braucht es Schulungen, Regelwerke und Normen sowie Förder- und Anreizprogramme.

Ein zu schaffendes Kompetenzzentrum könnte diese Aufgaben übernehmen. Bereits während des Nationalen Forschungsprogramms könnte es gemeinsam mit den Akteuren einen Ideenkatalog erstellen, der dokumentiert, wie Gebäude in normalen Zeiten und bei Pandemien genutzt und betrieben werden können. Danach würde das Kompetenzzentrum bei der Umsetzung beratend zur Seite stehen, damit die gesundheitlichen, wirtschaftlichen und gesellschaftlichen Auswirkungen künftiger Epidemien und Pandemien gemildert und gleichzeitig die Ziele der Energiewende erreicht werden können.

Résumé

Il y a plus de 150 ans, les risques de maladies d'origine hydrique, telles que le choléra, ont été maîtrisées grâce à une distribution publique d'eau potable de qualité. Nous soutenons que des efforts similaires soient justifiés pour fournir un air intérieur propre pour tous afin d'éliminer les menaces posées par les maladies transmises par l'air telles que le COVID-19, la grippe et la tuberculose.

Le virus SRAS-CoV-2 qui provoque la maladie à coronavirus 2019 (COVID-19), est l'un des agents pathogènes qui se transmet principalement par les aérosols respiratoires présents dans l'air. Ces petites particules libérées par les voies respiratoires supérieures et inférieures, se retrouvent en suspension lorsque nous respirons, parlons, et chantons. De cette manière, l'agent pathogène se retrouve également dans l'air. Après l'expiration, les fines particules d'aérosols respiratoires peuvent rester longtemps en suspension dans l'air, se disséminer dans la pièce et s'accumuler tant que la personne malade y reste. Les infections peuvent donc survenir même si la distance entre personnes est importante. La conception et le type d'utilisation d'une pièce peuvent avoir une influence majeure sur les aérosols et les agents pathogènes qu'elle contient tout comme le fonctionnement et l'entretien des systèmes techniques du bâtiment.

Des méthodes éprouvées pour fournir de l'air propre dans les locaux sont disponibles dans le commerce. Un air propre peut être obtenu en empêchant la libération d'aérosols respiratoires, en diluant l'air contaminé par des agents pathogènes et en éliminant ces derniers par filtration ou désinfection. Les recherches suggèrent qu'il faut l'équivalent d'au moins 5 à 6 renouvellements d'air par heure pour produire un effet substantiel. Ce chiffre est beaucoup plus élevé que les normes actuelles.

Notre groupe d'experts scientifiques recommande vivement d'évaluer les besoins en air propre des bureaux, des écoles, des théâtres, des bâtiments publics et des systèmes de transport en commun pour garantir un air propre dans tous les environnements intérieurs.

Par le passé, les systèmes de ventilation des bâtiments étaient développés pour optimiser la consommation d'énergie et le confort des habitants. Ils étaient conçus pour ne pas présenter de risque pour l'hygiène en temps normal. Cependant, la prévention de la transmission des agents pathogènes présents dans les aérosols respiratoires lors des vagues d'une maladie telle que le COVID-19 n'a jamais été un objectif de conception dans un bâtiment normal.

Depuis le début de la pandémie, de nombreuses idées visant à réduire la transmission du SRAS-CoV-2 ont été formulées. Cependant, les approches mis en œuvre ont principalement consisté à porter des masques et à ventiler plus fréquemment et de manière plus conséquente. Aucune de ces deux options ne s'est avérée acceptable à long terme. De nombreuses personnes perçoivent le port du masque comme inconfortable, et une ventilation vigoureuse est trop gourmande en énergie et incommodant en hiver. Les solutions futures devront être résistantes aux pandémies, efficaces sur le plan énergétique et offrir suffisamment de confort aux utilisateurs des locaux pour qu'ils acceptent la solutions et s'y conforment.

La construction et l'exploitation de bâtiments à la fois résistants aux pandémies, économes en énergie et adaptés à notre climat futur constitueront un défi majeur. Des projets prospectifs à petite échelle ont déjà commencés, mais un effort de recherche massif sera nécessaire pour développer de nouvelles méthodes pour les bâtiments du futur. Quelles idées et quels concepts peuvent être mis en œuvre efficacement et rapidement ? Sont-ils durables ? Quelles sont les questions sans réponses et les lacunes dans nos connaissances qui nécessitent des recherches plus approfondies ? Quels sont les aspects économiques, énergétiques et écologiques pertinents à prendre en compte, et qu'en est-il de l'acceptation et du confort des utilisateurs ? A quoi pourraient ressembler les différentes solutions pour les bâtiments existants et neufs ? Quelles conditions-cadres, améliorations et, le cas échéant, restrictions seront nécessaires pour exploiter les bâtiments du futur en toute sécurité, même en période de pandémie ?

Les solutions résultant des activités de recherche à court et à long terme doivent ensuite être mises en œuvre dans la pratique. Les résultats de la recherche doivent être intégrés dans l'ensemble des normes et réglementations relatives au bâtiment. En outre, des modèles de financement et d'incitation, associés à des campagnes d'information, seront nécessaires pour concrétiser la vision de bâtiments à l'épreuve des pandémies.

Pour toutes ces raisons, nous proposons une approche en trois phases :

Phase 1 : L'introduction de mesures temporaires pour un air propre, ainsi que :
a) Une évaluation des données existantes mais non encore analysées, et
b) Des interventions pilotes accompagnées dans des bâtiments sélectionnés tels que des écoles, des bureaux ou des théâtres.

Phase 2 : Établir un Programme national de recherche pour "*De l'air propre pour des bâtiments adaptés aux pandémies*".

Phase 3 : Renforcer les activités de transfert de connaissances ainsi que les modèles de financement et d'incitation pour la mise en œuvre des résultats du programme de recherche.

Phase 1 : Introduire et accompagner des mesures temporaires pour un air propre

Il est urgent d'assainir l'air dans les bureaux, les écoles, les théâtres, les bâtiments publics et les systèmes de transport publics pour éviter une nouvelle vague hivernale de la pandémie de coronavirus. Si de nombreuses questions scientifiques restent sans réponses, aucune donnée ne s'oppose à la mise en œuvre immédiate de solutions, au moins temporaires, pour améliorer l'air intérieur et réduire le risque de transmission par aérosol.

Nous recommandons d'installer de meilleurs systèmes de ventilation mécanique, d'équiper les locaux de capteurs de CO_2 permettant aux utilisateurs d'agir lorsque la qualité de l'air est mauvaise et d'installer des systèmes de filtration ou de désinfection de l'air par UV.

Au niveau international, les premiers résultats d'études théoriques et pratiques sont déjà disponibles. Quelques études suisse ont également déjà commencé et collectent des données, et il est urgent de procéder à une évaluation rapide mais détaillée de ces données existantes. En outre, une sélection des interventions susmentionnées devrait être accompagnée de projets scientifiques afin que nous puissions en tirer des enseignements pour l'avenir. Les interventions peuvent être testées individuellement ou en combinaison les unes avec les autres. Les écoles et les bureaux où des études sont déjà en cours conviendraient parfaitement, de même que les bâtiments où les propriétaires et les occupants ont exprimé leur intérêt d'agir. Les interventions à évaluer comprennent "La ventilation contrôlée par le niveau de CO_2", "La ventilation par déplacement forcée", "La filtration de l'air recyclé" et "La désinfection par rayonnement UV". Il est préférable de planifier de tels projets en utilisant une approche coordonnée impliquant des bâtiments de contrôle et d'intervention. Au minimum, les paramètres de température, d'humidité, de CO_2 et de microbiologie devraient être déterminés dans chaque cas, et ils devraient être accompagnés d'études sur la qualité et l'acceptabilité des mesures mises en œuvre. Les données préexistantes doivent également être évaluées de manière coordonnée, dans la mesure du possible, en combinaison avec les données sur la santé, les performances mentales et le niveau d'énergie des occupants des bâtiments. Un financement rapide et direct doit être trouvé pour ces projets pilotes.

Phase 2 : Un Programme national de recherche sur *“De l'air propre pour des bâtiments adaptés aux pandémies“*

Dans une deuxième phase, nous avons besoin d'un Programme national de recherche sur le thème *“De l'air propre pour des bâtiments adaptés aux pandémies“* avec la perspective à long terme d'un parc immobilier sain, à faible consommation d'énergie et adapté à notre futur climat. Ce programme devrait permettre de tester les concepts existants et de développer de nouvelles approches. En particulier, les immeubles de bureaux, commerciaux et publics, notamment les écoles, devraient pouvoir continuer à fonctionner, avec de faibles risques, pendant les pandémies. Le Programme national de recherche *“De l'air propre pour des bâtiments adaptés aux pandémies“* devrait promouvoir à la fois la recherche fondamentale et le développement de solutions axées sur des applications. Il s'adresserait à la fois aux institutions académiques et aux entreprises innovantes. Les acteurs innovants devraient proposer, diriger et être indemnisés pour les projets, par analogie avec les règles du programme Horizon de l'UE. La phase 2 devrait être développée en parallèle avec le début de la phase pilote, de sorte qu'un premier appel à projets puisse être lancé dès 2023. De cette manière, la phase pilote pourrait être suivie sans discontinuité.

Phase 3 : Programmes de mise en œuvre des résultats

La troisième phase doit commencer le plus tôt possible et se poursuivre après l'achèvement des deux premières phases. Les solutions et produits nouveaux ou améliorés mis au point pour des bâtiments adaptés aux pandémies dans le cadre du Programme national de recherche *“De l'air propre pour des bâtiments adaptés aux pandémies“*, doivent ensuite être appliqués dans la pratique. Les résultats du programme devront être mis en œuvre efficacement dans les nouveaux bâtiments et les rénovations, les programmes de formation, les codes et les normes du secteur du bâtiment, ainsi que les programmes de financement et d'incitations. Un centre de compétences sur l'air intérieur pourrait être créé pour prendre en charge ces tâches. Il pourrait travailler avec les parties prenantes, même pendant le Programme national de recherche, pour constituer un catalogue d'idées documentant la manière dont les bâtiments peuvent être utilisés et exploités en temps normal et pendant les pandémies. Par la suite, le centre de compétences serait disponible pour prodiguer des conseils sur la mise en œuvre, afin que les impacts sanitaires, économiques et sociétaux des futures épidémies (par exemple la grippe saisonnière) et pandémies puissent être atténués tout en atteignant les objectifs de la transition énergétique.

Introduction

A key insight in the mid of the 19th century was that infectious diseases are caused when germs such a bacteria or viruses transmit from one human to another, typically mediated by the environment. Cholera is an example of a microorganism that is transmitted by contaminated water. A key concept of hygiene is to define strategies that prevent the transfer of harmful substances or germs. In the case of Cholera, the game changer was not to teach people about washing hands, it was the provision of every household with clean drinking water and the installation of sewer systems. Today, thanks to communities providing drinking and waste water systems, cholera and other waterborne disease are rare in developed countries.

For a long time, it was believed that respiratory infectious pathogens such as influenza, the common cold viruses and tuberculosis are transmitted mostly by large cough and sneezing droplets. This is a possible transfer mechanism in the near-field of an infected person. However, over the past two decades, increasing evidence emerged that pointed to the importance of respiratory aerosols. These respiratory aerosols are small particles consisting of fluid of the upper and lower respiratory tract that become airborne when we breathe, talk and sing. These microparticles will carry along whatever is originally dispersed in the liquid, thus also the pathogen in the case of an infectious individual. Two major size modes of respiratory aerosols can be distinguished: a fine mode that is at exhalation around 0.5 to 20 µm and a larger mode between 20 to 200 µm. After exhalation, these aerosols will quickly shrink to about half of their initial diameter due to evaporation of water. Biomolecules present in the liquid will slow further shrinkage. In turbulent air, the resulting, partly shrunk aerosols can stay suspended in the air for a prolonged time, the larger ones for a few minutes, the finer ones for many hours.

The coronavirus SARS-CoV-2 is a pathogen that is predominantly transmitted by such respiratory aerosols. The virus-laden fine respiratory aerosols distribute in a room and accumulate if an infectious person is present. Infections can occur over a large distance between infectious and susceptible individuals. During the current pandemic, indoor environments such as buildings or public transport vehicles were recognized as highly important transmission sites. The design and use of the rooms as well as the operation and maintenance of the ventilation systems has a major influence on the airborne pathogens.

Recommendation for immediate action

A large number of studies showed that the risk of infection by respiratory agents such as SARS-CoV-2, influenza and tuberculosis, to name just a few, can be noticeably reduced with measures that reduce the number of pathogen-carrying aerosols in the indoor air. Clean water was key for getting cholera under control. Clean indoor air is necessary against airborne pathogens and similar efforts are justified and urgently needed.

Clean air can be achieved by preventing the release of respiratory aerosols, by diluting the pathogen-loaded air, and by removing the pathogen by filtration or disinfection. Research suggests that very strong pathogen reductions, often the equivalent of 5 to 6 air changes per hour or more, should be reached to have a substantial effect[1]. This is much more than what is currently the recommended standard. Several strategies to reduce the load of pathogens exist and devices and methods applying them are already available and on the market:

- *Preventing the release into the room*. In places where people are very close together over prolonged periods of time and in places with vulnerable people, preventing the release by wearing masks is a very effective measure, but this puts the burden on the individual. In hospitals, another approach is to capture the air exhaled by a patient with movable extraction hoods over the bed or the headspace.
- *Dilution and removal* of contaminated air by ventilation systems. Ventilation systems range from opening windows to mechanical ventilation and self-venting buildings. Most ventilation

[1] Observations and simulations for class rooms and mid-sized offices. More is needed in smaller rooms, less in large halls.

approaches mix the incoming fresh, clean air with the used one. Displacement ventilation aims to create a directional flow. Push-pull systems are similar but create a stronger flow, usually from the bottom to the top of a room. Yet other systems target clean incoming air to individual work places.

- *Filtration* works by removing aerosols, including those carrying the pathogen, with high efficiency filtration systems. In this type of air purification method, gaseous indoor toxics stay in the room. Therefore, such methods supplement but do not replace ventilation. To have a relevant impact on the amount of pathogens in the air, it is important that the clean air delivery rate (CADR) is sufficiently high.
- *Disinfection* is another air purification method. It works by destroying pathogens by ultraviolet (UV) light. There are boxed and over-head systems[2]. Boxed systems have efficiencies similar to filtering air purifiers. Over-head systems reach up to 20 air change equivalents per hour in rooms with good convective air flow. Skin and eyes need to be protected from direct irradiation with UV-light. UV-C systems also require optical filters to block wavelengths that lead to the formation of radicals such as ozone. The photochemical formation of undesirable secondary pollutants by this new method needs to be carefully evaluated.

The above methods can be combined with each other to increase the efficiency. A smart strategy would be to first ensure that the ventilation meets current standards so that gaseous air toxics are sufficiently well removed. This is then complemented by increasing the ventilation flow, installing air purifiers and overhead UV-systems, masking mandates or several methods combined. The exact configuration will depend on the specific location and room specifications. For example, permanently installed filtering air purifiers may be a smart choice in polluted cities, while communities with clean air may prefer temporary (movable) air purifiers or UV-disinfection.

These methods are tested and on the market. They are efficient at reducing the spread of airborne diseases. The panel of scientist strongly recommends that offices, schools, theaters, public buildings, and mass transportation assess their need and install at least temporary measures before the fall of 2022 to dampen the expected next wave of the COVID-19 pandemic.

Recommendation for research

There is no doubt that these methods work, and they should be introduced rapidly to protect the population. However, there are more, not yet tested ideas and also the existing ideas may profit from further improvements, for example regarding their energy usage, their user-friendliness and to optimize other health benefits from improving ventilation and providing clean air in indoor environments.

→ To achieve the goals of the Energy Strategy 2050, it is important to study these and also novel approaches and to find ways to operate and design them so that they have minimal energy consumption. An optimum between sufficient indoor ventilation and energy-efficient air treatment (filtering, physical or chemical inactivation, heating, cooling, possibly humidification) must be found so that buildings can be operated safely and sustainably in the future.

→ Some of the measures such as disinfection, strongly elevated ventilation or recirculating air filtration may only be needed ("switched on") when the disease risk is high. How shall one decide when it is necessary to change to such a "pandemic-proof" mode? How to make it most user-friendly in the sense of technically easy but also by allowing most normal activities to continue during times of heightened protection needs? Finding the answers will require research by interdisciplinary teams and likely also regulatory guidance.

→ Good ventilation is not only important to keep pathogens under control. Low levels of CO_2 and indoor toxics are also important for the well-being and performance of people spending an extensive proportion of their time indoors. Efforts in this area will thus need to assess how to

[2] A new development is far-UVC with wavelengths between 207 and 222 nm, which was documented to be safe for humans. While current exposure limits do not yet account for this and thus prevent direct exposure of humans, these direct radiating systems have a promised efficiency of well over 50 air change equivalents per hour.

create additional health, economic and educational or other mental performance benefits beyond mere infectious disease prevention.

Worldwide, countries started programs to increase research in the area of clean air for the indoor environments. Switzerland has already many companies providing services and products in the domains of building technology, hygiene, and clean air provision. By teaming up these practitioners with experts from the higher and applied universities, Switzerland can make a substantial contribution in this field - provided the research is adequately supported and funded.

Open Questions

There are many research questions that need to be answered as part of a large-scale, inter-disciplinary research program that includes practitioners and that keeps an eye on the users and planned uses of indoor environments. Burning questions that should be addressed include:

- What happens to respiratory aerosols and the pathogens they contain after they were emitted?
- What methods can be used to detect airborne pathogens more quickly and easily?
- How do factors such as age, gender, health status, activities and infection type influence human aerosol emissions and the release of pathogens with these aerosols?
- Which factors of the physical environment influence indoor infection risk and to what extent (CO_2 content, humidity, chemistry, ventilation efficiency, light, etc.)?
- What influence do social, economic, and learning interactions have on infection risk?
- What surrogate agents and organisms can be developed to study the behavior of hazardous organisms outside of safety laboratories?
- How efficiently are different pathogens (enveloped/unenveloped viruses, spores, exosomes, bacteria) reduced by different measures?
- What measures effectively reduce indoor disease transmission and what does this mean for the design and use of indoor environments?
- How much do new and alternative methods affect air quality (e.g. by producing potentially harmful by-products) and how can this be prevented or mitigated, if needed?
- How can existing and new buildings best be evaluated regarding the disease transmission risk?
- How do different measures influence user acceptance and quality of use in buildings?
- How can concepts of usability and ergonomics help to make the best use of new concepts?
- How can measures and systems be designed to be energy-efficient, climate friendly and sustainable?

Ideally, this is accompanied by a review of ethical, societal and regulatory aspects related to the provisioning of clean air. Examples of questions include:

- Who is carrying the burden, who gains from these measures?
- Could there be situations that would make it acceptable to use chemical or direct irradiating disinfection methods in rooms that are occupied?
- How can we ensure that clean air is not only available to the wealthy ones?
- How can the goal of clean air be best translated into regulations and standards?
- Could regulations for clean indoor air be inspired by existing rules for water and food?
- What are the obligations and rights of planners, builders, owners, maintainers and users of indoor environments?

Phase 1: Introduce and accompany temporary measures for clean air

Clean air is urgently needed in offices, schools, theaters, public buildings, and mass transportation to prevent more winter waves of the COVID-19 pandemic.

In the coming months, it is important to implement at least temporary solutions to improve the indoor air and to lower the risk of aerosol transmission, namely by installing better mechanical ventilation systems, by equipping rooms with CO_2-sensors to allow users take actions when the air quality is poor, and by installing in-room filtration or UV air disinfection systems.

In addition to temporarily or permanently installing such systems, it seems advisable to review the planning of upcoming renovations and new buildings to ensure that the planning still meets the newly elevated requirements for clean air provision during periods with elevated health risk by airborne pathogens. Ideally, a governmental incentive and promotion program accompanies these efforts to encourage wide-spread adoption of clean air measures.

From a scientific and long-term economic perspective, it is important to use this first phase of clean indoor air provision for the collection of data that helps answer some of the questions listed earlier.

For this purpose, a selection of these interventions should be accompanied and ongoing projects continued. Furthermore, already existing data from projects that started before or during the pandemic should be evaluated with high priority.

Evaluation of already existing data

Since the beginning of the pandemic, millions of data points on temperature, humidity, CO_2 and other parameters have been collected as part of various projects and also during routine measurements in numerous offices and schools in Switzerland. Measures such as mandatory masks are also documented or can be reconstructed. For many of these objects it should be possible to obtain data on health such as infection and absence rates, and on the performance of the people using the rooms, e.g. standardized school tests. Quite obviously, rules and guidelines for data protection and ethics need to be followed.

These data should be compiled, cleaned and evaluated according to the rules of epidemiology. Answers to the following questions should be summarized:

- How strong is the association between good indoor air quality and lower infection rates and absenteeism?
- How strong is the impact of indoor air quality on cognitive performance (e.g. school exams or standardized tests)?
- What types of indoor air quality monitoring and feedback have been most effective?
- How do the different measures compare regarding cost, energy use and sustainability?
- What can we learn from targeted measurement campaigns that used more advanced tools such as tracer gases and aerosols, optical laser sheets etc.?

Here, indoor air quality factors include CO_2, temperature, and humidity. Other measures such as masks, distance rules, etc. and also confounders such as age, education, etc. should be included in the evaluation.

Parameters to evaluate new and ongoing interventions

For a comprehensive assessment of the new and ongoing interventions, it is important to assess a range of indoor air and building parameters. The following parameters seem to be useful as they can be determined relatively easily and often continuously with sensors.

- Building parameters (size, ventilation strategy, occupancy rates, energy performance)
- Ventilation parameters (air exchange rate, ventilation efficiency, turbulence)
- Thermal parameters (insulation, sun exposure, heating system etc.)

- Intervention parameters (energy consumption, installation costs, maintenance intervals & cost)
- Time-course of temperature and humidity
- Time-course of gases (CO_2, total VOC, other source-specific gases)
- Time-course of aerosols (number and mass concentrations, e.g. PM1, PM2.5, PM4 and PM10)
- Microbiology (viruses and bacteria) at multiple time points
- Chemical parameters such as acidity of gases and aerosols in selected studies

It will be important to compare the methods used to collect these parameters. This will allow to identify and control for systematic differences, address non-systematic differences and improve methods. Minimally, temperature, humidity, CO_2 content, and microbiological sum parameters are determined in each case and the flow pattern in the room documented with test fog.

Parameters of health, user acceptance and quality

Whether a measure is successful with respect to the goal of "pandemic safety" depends largely on the health consequences. In addition, other factors can be used to check how the intervention affects the performance, comfort and acceptance of the people using the rooms. The following factors can be collected for this purpose.

- Case numbers and rates of respiratory and other diseases
- Figures on occupational and school absences
- School progress tests, if already existing
- (Standardized) questions on acceptance of the intervention and quality of indoor conditions.

It will be important to analyze the evolution of these parameters over time. Thus, each room with its users serves as its own control, which requires a much smaller number of study subjects to make statements about the impact of interventions on these parameters.

Types of interventions to be studied

We propose a coordinated approach with control and intervention objects. One or more of the following interventions shall be tested by the participating project teams. The interventions can be combined, especially if this serves to comply with the CO_2 guideline values. Especially in case of ventilation-intensive interventions, humidity may also have to be taken into account, especially in winter.

Control objects are rooms in which data are collected but no targeted interventions take place.

Intervention objects are rooms in which one or more of the following measures are tested. As part of the coordination of the pilot phase, groups of similar rooms (type of use, type of ventilation, size, ...) are first formed in which investigations are already taking place or which are willing to participate in the trials. Within the groups of similar rooms, interventions are then randomly assigned as far as possible.

CO_2-controlled ventilation: when humans are the main source of air pollution, CO_2 represents a good measure of gaseous air pollution emitted by humans. In addition, CO_2 correlates with respiratory aerosols in the absence of other measures. However, CO_2 also has direct effects on cognitive function, alertness and fatigue. Therefore, it makes sense to keep CO_2 low. In addition to controlled mechanical ventilation, methods such as automated window ventilation or user-operated windows with indications from sensors (traffic lights, value display) can also be investigated. Potential problems due to secondary pollutant formation should also be considered.

Forced displacement ventilation: In ventilation systems with air stratification, clean air is introduced at the foot of a room and exhausted in the ceiling area. Thermals created by people in the room support this flow. Displacement ventilation reduces the mixing of stale air with fresh air and counteracts cross-flow between occupants, which reduces the transmission of germs. However, too few inlets and outlets will result in diagonal rather than bottom-up flow patterns. Furthermore, many people in the room, furniture, thermal loads (computers, sunshine, cold exterior walls, ...) and other factors may interfere with "ideal" operations. Displacement ventilation projects should aim to better understand such factors. Improved approaches such as numerous inlets and exhausts distributed throughout the space, closer to the user, should also be investigated.

Recirculating air filtration: in recirculating air filtration, airborne pathogens are removed with a filter or by other types of treatment and the air is recirculated back into the room. There are various systems, from simple filter boxes to complex recirculation systems with forced displacement ventilation and CO2-controlled supply of outside air. For these projects, in addition to filtration performance (filter efficiency and airflow), noise levels and the impact of the air diffuser on flows in the space should be documented.

Overhead UV-Light disinfection: An overhead UV light system (also called upper-room ultraviolet germicidal air disinfection) disinfects the air reaching the upper part of a room by irradiating that space with UV-lamps. Professional systems use UVC. In addition to professionally installed UVC-overhead systems, we recommend to evaluate also the "poor-man" solution of blacklight lamps directed against the ceiling, i.e. lamps that emit mostly UVA and some UVB. More research is also warranted on far-UVC, which is UV-light with wavelengths between 207 nm and 222 nm. Far-UVC was reported to be safe for human skin and eyes at disinfecting intensities, even though current regulations prevent directly shining far-UVC against humans. Besides testing the effectiveness at reducing pathogens, it is also important to assess how much scattered light reaches the humans below and the potential contribution of the different systems to secondary pollutant formation.

All interventions and also controls: In all of these interventions, it will be important to look at the spatial and temporal distribution of aerosols and to document the air currents (direction, velocity over the course of the day and the seasons to better understand potential daytime and seasonal variations in the effectiveness of the systems.

It is strongly recommended that the different studies assess the interventions in coordination with other groups. They need to harmonize assessment protocols, compare measurement and assessment methods and aim from the start for pooled analyses to compare different intervention strategies. Funding bodies should demand and financially support such coordination and harmonization activities.

Phase 2: National Research Programme *"Clean air for pandemic-proof buildings"*

Solutions for the built environment must be planned for the long term and be sustainable. To find such solutions, we need a national research program *"Clean air for pandemic-proof buildings"*. Within the framework of such a program, new approaches should be developed in addition to the types of existing interventions done in offices, schools, theaters, public buildings, and mass transportation to prevent another winter wave of the COVID-19 pandemic. The goal of this national research programme should be to greatly mitigate in the long term the health, economic, and societal impacts of future epidemics (e.g. seasonal flu) and pandemics through knowledge, innovation, and awareness-raising, while still achieving the energy goals of the energy transition.

The concept and call for Phase 2 is to be developed in parallel with the launch of the pilot projects. This National Research Programme *"Clean air for pandemic-proof buildings"* intends to support both, fundamental research and investigations of application-oriented solutions. It is aimed at academic institutions as well as innovative companies of all sizes. All innovative actors should be allowed to propose, lead and be compensated for projects, analogous to the rules of the EU Horizon Program. The aim is for a first call for projects to take place as early as 2023, so that the projects can follow on seamlessly from the pilot projects. Because of the relatively long time it often takes in the construction sector from the idea to implementation, approaches for long-term accompanying financing of projects should also be examined (ideally several decades), including a different funding and supervision model that includes for example the federal government, cantons, SNF and Innosuisse in consultation with national and international experts.

Objectives of the National Research Programme

The objectives and questions to be addressed by the National Research Programme *"Clean air for pandemic-proof buildings"* should be elaborated by a group of experts consisting of engineers, natural and social scientists, and be accompanied by representatives of authorities, industry and social partners such as trade unions and environmental associations. In this way, the interests of society as a whole can be included at an early stage.

Burning questions the research program should include those listed before, namely:

- What happens to respiratory aerosols and the pathogens they contain after they were emitted?
- What methods can be used to detect airborne pathogens more quickly and easily?
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- Which factors of the physical environment influence indoor infection risk and to what extent (CO_2 content, humidity, chemistry, ventilation efficiency, light, etc.)?
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- Could regulations for clean indoor air be inspired by existing rules for water and food?
- What are the obligations of planners, builders, owners, maintainers and users of indoor environments?

Keywords

- Aerosol research
- Ventilation and building technology
- Measurement technology, sensors and smart buildings
- Sustainable buildings for future climate
- Work organization and usage concepts of buildings
- Usability, human-machine interaction
- Health effects of bioaerosols

Phase 3: Programs to implement the research results

In the coming months companies and public authorities will hopefully start implementing solutions. Professional associations started putting together guidelines and also governmental agencies support workshop and create documentation to increase the awareness of planners, builders, owners, building users and other decision makers about the concepts useful to provide buildings with cleaner air. The proposed National Research Programme *"Clean air for pandemic-proof buildings"* will also develop new and improved solutions and products for healthier and pandemic resistant buildings.

In the first, immediate phase, it will be important to translate already existing knowledge into appropriate actions. In a later step, once the scientific output from the National Research Programme has become available, it will be important to ensure that this newly acquired knowledge and the corresponding solutions will be implemented in the planning and design of renovations and new buildings. Considerable efforts are needed to enhance awareness, provide education and training and translate the findings into new or updated construction rules and building standards.

It seems worthwhile to consider this need already at this early stage. Given that long-term thinking is needed, it may seem appropriate to establish a permanent competence center that collects and makes available the state of the art in science and technology, advises standardization bodies during the updating of norms, and supports governmental offices in staying up to date. It is anticipated that with such measures the health, economic and societal impacts of future epidemics and pandemics can be greatly mitigated while still achieving the goals of the energy transition.

Who is the expert group "Pandemic-proof buildings"?

We are a loose working group of people working in science, government and policy making with the goal of using knowledge, innovation, and awareness to greatly mitigate the health, economic, and societal impacts of future epidemics and pandemics and to achieve the goals of the energy transition.

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