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Infection Resilient Environments: Buildings that keep us healthy and safe | Initial Report

Summary

The Royal Academy of Engineering and its partners in the National Engineering Policy Centre have been asked by the Government Chief Scientific Adviser to undertake a rapid review of actions to make infrastructure more resilient to infection.

This short-turnaround response provides an initial overview of the strategic challenges we as a society face, along with advice on immediate measures that can make a significant difference ahead of winter 2021/2.

We have found that the COVID-19 crisis has revealed flaws in the way in which we design, manage and operate buildings that, if left unchecked, will disrupt management of this and other pandemics, impose high financial and health[1] costs on society, and constrain our ability to address other challenges such as climate change.

By delivering infection resilient environments we mean to ensure that public and commercial buildings (places of work and leisure, specialist settings such as hospitals and care homes, and potentially transport hubs and carriages) minimise the risk of disease transmission, to support public health during and beyond the current COVID-19 pandemic.

There is a moment of opportunity to make a transformational change to how we design and manage our buildings to create good, healthy and sustainable environments for those who use them. Many of these changes have relevance well beyond COVID-19. This is explored in **Part A** of this report. Our initial recommendations are:

1 Government should provide support to map the knowledge and skills requirements across the building industry, general businesses, and the engineering professions to manage buildings in a way which minimises infection risks. It should then work with professional bodies, sector skills organisations and training boards to put in place plans to address the skills gaps identified.

2 Working with the National Core Studies Programme, UKRI and the National Academies, government should put in place an action plan to address key research gaps on an accelerated basis.

3 Government should undertake a rapid review of the capacity and capability requirements among regulators (including local authorities) to support and enforce standards in maintaining buildings for public health.

4 Demonstration projects should be commissioned to fill specific knowledge gaps to underwrite regulation and enforcement such as the acceptable minimum standards for ventilation to manage infection risk.

5 Government policy on net zero must be developed in a way that is consistent with priorities around indoor air quality and making buildings resilient to infection.

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While many of these recommendations will require sustained action, this should start now.

The removal of restrictions on 19 July 2021 can only increase the importance of buildings and transport management as a means of infection control that does not generally constrain individuals' behaviour or liberty. We start from a low base, and the majority of owners and operators have modest levels of relevant knowledge, skills, budgets and organisational maturity on crucial issues such as ventilation. To enable impact ahead of winter, government should concentrate its immediate efforts here.

Part B of this report discusses shorter term options and identifies some relatively simple measures that could make a significant difference this winter. We recommend that:

6 Government and its agencies should collaborate to rapidly develop and deliver clear communications aimed at building owners and operators with the lowest capability, emphasising the importance of improving ventilation whilst maintaining wider good practice on infection control.

7 Communications should be accompanied by guidance, available via trusted and widely accessible sources, to support owners and operators to establish an appropriate balance of measures to manage infection risks, alongside thermal comfort, air quality and energy efficiency.

8 Government and professional engineering bodies should provide rapid and specific technical guidance to enable owners and operators to select and effectively implement appropriate technology (e.g. conventional ventilation systems, CO_2 monitoring).

9 Government should provide incentives to encourage private and public sector organisations to improve the poorest performing spaces in buildings.

The commission

The Academy has been asked by Sir Patrick Vallance FRS FMedSci to explore:

a. how we can redesign and retrofit buildings and transport to make them more infection resilient in the future[2] (the strategic challenge).

b. what should be done ahead of winter 2021/2 to operate buildings and transport in a way that reduces the risk of COVID-19 transmission, and makes them acceptably safe, while enabling a degree of normality (the immediate focus).

We designed the project as an initial short-term sprint, focused on the most time-sensitive issues ahead of winter (b above), to be followed by a more detailed review of the strategic issues (a above). These issues are linked, however, and our early work uncovered systemic weaknesses that will form the subject of the second phase of this work, and which we describe and outline in this report. Together they form an agenda for change, and we will work alongside policy makers to develop detailed solutions to them.

We have conducted the first stage of the project with the help of a series of evidentiary hearings. The hearings were designed to ensure that the project was informed by evidence from people who are currently facing the challenges in operating buildings. We held 14 sessions covering a range of sectors including hospitals, care homes, local government, higher education, hospitality, offices and transport. We heard from people with a range of job roles, backgrounds and expertise, including both experienced facilities management professionals for who this was their primary role, and others for whom responsibility for the building was not their primary role but an additional responsibility. These have given us an insight into the presenting issues on the ground.

We have interpreted what we have heard, and developed our responses to it, with help from our working and reference groups which draw from a wide range of engineering and other expertise. These include both researchers and practising engineers with insight into the cultures, practices and commercial realities across our built environment.

We made an early decision to focus on horizontal issues that apply to multiple types of settings, rather than focusing solely on specialist settings. We expect that some of the messages in this report will translate to other settings such as domestic buildings and transport, although we have not been able to evidence the degree to which they do so.

The National Engineering Policy Centre

The project has been taken forward by the Academy through the National Engineering Policy Centre (NEPC). The NEPC is a partnership, led by the Royal Academy of Engineering, between 43 different UK engineering organisations, between them representing 450,000 engineers. It connects policy makers with critical engineering expertise to inform and respond to policy issues of national importance, giving policymakers a route to advice from across the whole profession. We are very grateful to the Chartered Institution of Building Services Engineers (CIBSE) for acting as our primary partner on this project. We also acknowledge the helpful contributions of Fellows of the Institution of Mechanical Engineers (IMechE), the Institution of Civil Engineers (ICE), the Institution of Chemical Engineers (IChemE) and the Institute of Healthcare Engineering and Estate Management (IHEEM) on the working and reference groups.

We have also drawn upon advice from expertise outside of engineering, including architecture and social sciences.

Part A: The strategic change required

There is evidence that the way in which buildings and transport perform makes a great difference to how easily infections can be transferred within them, including across all three main routes of transmission for COVID-19: airborne, droplet and contact.[3]

The role of buildings within public health has received a relatively low profile in recent years. The focus on infrastructure has been dominated by its role in energy and climate emissions, although high profile reports[4] and new National Institute for Health and Care Excellence (NICE) guidelines around indoor air quality were raising awareness prior to COVID-19,[5] as well as CIBSE guidance on health and wellbeing in building services.[6] **Infection control is part of creating a good indoor environment and can, and should, be designed into buildings and transport**, including how spaces are ventilated and how people move within and through spaces.

The quality of the indoor environment is in part a matter of design and build. This includes:

a. design, installation and commissioning of ventilation systems
b. how layout influences the way people use buildings, and how building design manages the potential for crowding and bottlenecks
c. the provision of sufficient facilities for hygiene and sanitation, and
d. managing interactions such as touching handles and lift buttons.

The ability for even well-designed buildings to provide a good indoor environment and effective infection control is impacted by quality assurance issues: it is not uncommon, for instance, for ventilation and air conditioning in a building to be poor even at handover.[7,8] This reflects both the difficulty of getting ventilation right, but also the modest importance that designers and builders, regulators and ultimately clients can place upon creating healthy indoor environments. Many of the endemic quality issues in the built environment revealed by Dame Judith Hackitt FREng in *Building a Safer Future*[9] are just as relevant to the provision of good ventilation and safe indoor air quality as to the more acute and immediate issues of fire safety.

The management of buildings (and to some degree transport facilities) during operation is at least as important as design and build, and relevant again to all three COVID-19 transmission pathways. This includes how buildings are cleaned, how well their ventilation is maintained and operated, their levels of occupation, and how people are situated and signposted around the building or facility. The ways in which those buildings are subsequently modified, adapted or retrofitted to a purpose, and the intended and unintended impacts of those changes, are also important.

The impact of building management and maintenance, and the impact that has on public health, has arguably had a lower profile in recent years than issues of design and build quality. Building management is often incidental to the business purposes of many owners and operators, and may not receive appropriate prioritisation, investment and support. In addition to this, there is a wide variation in resource and expertise between sectors and scale of organisation; for many buildings there is no operator as such and the responsibility for how a building performs is handled on a casual basis, with intervention only when something breaks or causes a perceptible problem.

> “The UK building industry and maintenance industry has for many, many years not achieved what it needed to do with indoor air quality”
>
> Evidentiary hearings

Infection Control and Net Zero

It is feasible to achieve an indoor environment that can mitigate transmission of infection within a thermally comfortable and energy efficient building. With appropriate technology and effective management, the need for appropriate ventilation and indoor air quality in a building is compatible with strategies to reduce carbon emissions and attain net zero.

There are synergies here that should be exploited: raising skills and awareness can enable better management of both air quality and energy efficiency. New solutions may not always force us to make binary choices, and where trade-offs between ventilation and energy conservation exist they should be controlled and well managed.

Proactive action is required however, and it is essential that we integrate thinking on infection control and indoor air quality into the UK’s approach to net zero, to prevent inadvertently hard-wiring a susceptibility to infection and other health risks into the UK’s building stock and management practices.

Even where facilities management is professionalised and resourced, it is often highly complaints-driven in ways that are very germane to issues around COVID-19. If the occupant doesn’t feel uncomfortable, they won’t complain; if they don’t complain there will be no change. Given the shortcomings in design and performance identified above, well-managed buildings that are ventilated to the standards appropriate in a major health crisis, while also able to keep occupants comfortable, are somewhat unusual.

These issues can be complicated by contractual issues where services are outsourced or where the interests of owners, occupiers or service providers diverge.

This combination of issues has left us with a legacy of modest knowledge, skills and capacity in how buildings are maintained, compounding patchy design and build quality. This forms a difficult background against which to ask all those with some responsibility for managing a building to rapidly improve how they manage the buildings they own or occupy to control a pandemic.

Addressing this challenge will require action across the following issues.

A. Skills, capacity and capability

Skills barriers include the need to ensure that those responsible for buildings know what good ventilation and wider infection control looks like, have a considered approach to managing it, including understanding what to do about poorly ventilated spaces (and have motivation and agency to act accordingly), and knowing when to call on additional technical support and where to find it.

Even in sectors such as healthcare, which have a clear regulatory framework and an explicit remit for managing the health and safety of vulnerable populations, levels of skill and competence vary. This comes with differing levels of organisational maturity across operators and sectors, and the ability and motivation of owners to understand, manage and govern issues of infection control. The Academy of Medical Sciences’ report looking ahead to winter 2021/2 explores the role of environmental and behavioural interventions, such as ventilation and infection prevention and control in healthcare settings in reducing the spread of SARS-CoV-2.[10]

Urgent attention is needed to understand and document these skills gaps, and to put in place the training, re-skilling and recruitment needed to fill it. This should involve professional bodies and trade associations, and will require government support.

Recommendation one
Government should provide support to map the knowledge and skills requirements across the building industry, general businesses, and the engineering professions to manage buildings in a way which minimises infection risks. It should then work with professional bodies, sector skills organisations and training boards to put in place plans to address the skills gaps identified.

> “The key barriers? At the outset, and this still applies a little, it was very much about the building’s maintenance and facilities side, and it was skills. I actually have a different team in place now, but the lack of skills and understanding… on what their plant and equipment actually does and how it runs – I found that shocking. Truly shocking. I think that is just generally the industry… with the lack of understanding and interest in what we run. It blows me away”
>
> Evidentiary hearings

B. Research and development

COVID-19 has raised several urgent research questions, both specific to this outbreak and of wider scope. Research is underway under the leadership of the National Core Studies Programme[11] and other bodies such as the Wales COVID-19 Technical Advisory Group, with further work funded by UKRI.

While a number of these research needs are medical in nature[12], others concern issues of engineering and technology, and of the built environment and its management. Much of this work is building on a small research community, in areas perceived to be highly specialised before the pandemic, and critical issues remain unresolved: we cannot yet say with confidence, for instance, whether there is significant aerosol transmission risk in buildings that operate at current building regulations.[13]

> "I don't know what good ventilation is. I've had litres a second per person, I've had air changes per hour, I've had litres/second/square metre as benchmarks that we could use"
>
> Evidentiary hearings

Alongside specific knowledge gaps, the crisis has also stretched the limits of the UK's research capacity: current research programmes have already engaged much of the UK academic expertise in the relevant disciplines, and it is likely that longer-term investment and retraining will be needed to increase the national capability and capacity in the area.

Support will also be needed for late-stage R&D. This includes studies to evaluate the success of new approaches in practice with evidence on user satisfaction and behaviour alongside technical assessment, and support to enable manufacturers and others to rapidly develop and deploy innovative responses to the challenges that upgrading our management of infection is uncovering.[14]

Recommendation two
Working with the National Core Studies Programme, UKRI and the National Academies, government should put in place an action plan to address key research gaps on an accelerated basis.

Many of the key research questions have already been highlighted in UKRI's broad-ranging *Research Questions for COVID-19: Priority Areas* report issued in October 2020.[15] Areas that we have identified as particular priorities for further research include:

- understanding of the scale of respiratory disease transmission in UK indoor environments and its economic impacts, including both seasonal infections and COVID-19
- understanding the aerosol transmission risk for COVID-19 and other respiratory infections for buildings of different types that are operated at current building regulations
- understanding the matters of fact around minimum standards for ventilation to manage infection risk to underwrite regulation and enforcement
- evidence of effective ventilation design, maintenance and owner/user knowledge across different sectors. While there is some data for schools, homes, offices and hospitals there is a huge lack of data for social care, hospitality, retail and transport
- evidence of effectiveness of potential technology solutions, including air cleaning devices, to mitigate transmission of infections in a range of different building types and their impacts on other issues such as building energy use, indoor air quality and accessibility. (Annex A highlights key research, innovation and user needs issues for a variety of more common technologies)
- understanding of interactions between user behaviour and infrastructure to understand real-world effectiveness of solutions and barriers and opportunities for innovations in digital interfaces and controls
- understanding potential airborne infection risks around plumbing, drainage and hand drying
- developing frameworks for standard comparisons of different technologies, understanding their impact on respiratory infection risks within representative settings, in the context of the requirements for deployment and use of technologies captured below
- exploration of potential for novel sensing technologies and other interventions currently at proof of concept or earlier stage, such as sampling airborne DNA, to manage risk of respiratory infections in the long-term.

With a view to this winter, rapid independent study should be prioritised to understand the role of hand driers in controlling or worsening infection risks. Clear analysis, including collating real-world data, is also needed to inform the circumstances in which air cleaning devices can be effective, and how and where they can be used.

Given the evolving risk, studies need to be designed to adapt as rapidly as possible to new understanding of COVID-19, particularly more infectious variants, and emerging respiratory pathogens. Research will need to consider how buildings work as 'systems', where there is a strong interaction between people, processes, technologies and pathogens, necessitating an appropriately multidisciplinary research approach.

C. Regulation and support

There is more to do to ensure that the impact of buildings on public health is fully supported by the regulatory structures that normally underwrite minimum standards, across the whole life cycle of our built assets, to include design, build, modification and maintenance, management and use in operation.

Thinking on the impact of a building's design, build, and modification on occupant health will need to go beyond the scope and effectiveness of building regulations, to include issues post-building handover, and after the point at which building regulations apply. There is an urgent need for greater regulatory focus on buildings in operation, not just to improve resilience to infection and indoor air quality but also to address the pressing need to deliver significant carbon emission savings from our buildings. These two ambitions need to be driven forward in tandem and efforts across government need to be fully coordinated.

COVID-19 has changed the risk profile facing regulators of the businesses operating buildings, including local authorities. In many respects, we are starting from a low base: regulation is risk based, and pre-pandemic little emphasis was placed on ventilation for infection control by regulators and inspectors. There is no background of enforcement orders regarding general ventilation prior to or since COVID-19, and capacity and capability within some regulators should be reviewed.

Health and Safety Executive (HSE) spot checks found most businesses were taking action on COVID-19, but it is challenging to measure the quality of this action in practice. As discussed in *Skills, capacity and capability* on page 5, there is an urgent need to clarify issues of fact such as the acceptable minimum standards for ventilation. There is an accompanying need to develop the detailed guides and best practice guidance which help build the shared understanding of standards on that good regulation depends. This consensus about what is reasonable normally evolves over time, with help and support from regulators, industry associations, professional bodies and others, and this needs to happen at an accelerated pace.

Recommendation three
Government should undertake a rapid review of the capacity and capability requirements among regulators (including local authorities) to support and enforce standards in maintaining buildings for public health.

Recommendation four
Demonstration projects should be commissioned to fill specific knowledge gaps to underwrite regulation and enforcement such as the acceptable minimum standards for ventilation to manage infection risk.

D. The Role of Technology

The COVID-19 pandemic has inspired much innovation, accelerating the development and deployment of new technologies and repurposing others to help manage risk. Both new technologies, and good use of existing technologies, can play an important role as part of an effective risk management strategy, across the following areas.

Ventilation. Buildings may have passive or natural ventilation, mechanical ventilation (potentially with heat recovery) or, in specialised circumstances, personalised ventilation systems. Some buildings have a mix of two or more systems. This acts to reduce risk by diluting and removing airborne pathogens. Where buildings have existing mechanical ventilation systems, simple actions like ensuring filters are clean and dampers are set correctly can ensure ventilation is effective. The settings on demand control and recirculating systems can be adjusted to optimise outdoor air flow. This must be done with consideration of thermal comfort.

Air cleaning. Air cleaning devices come in many forms. Some are marketed aggressively and should only be used where they have been tested and there is clear evidence they are effective and safe.[16] Air cleaning is never a substitute for ventilation, but may be effective at reducing infection risks in locations where good ventilation is difficult to achieve. Some of these technologies have low energy use, however some are relatively energy intensive, and efforts should be made to minimise that impact.

The main types of air cleaning that are likely to be effective at reducing infection risks include high-efficiency particulate air (HEPA) filters and ultraviolet light (UVC). Other air cleaning devices based on technologies such as ionisers, plasma, chemical oxidation, photocatalytic oxidation and electrostatic precipitation have uncertain effectiveness against SARS-CoV-2, and some have been associated with secondary pollutants that may cause respiratory and skin irritation. Further research and development is required before these devices should be recommended.

Environmental monitoring. Simple, cost-effective environmental monitoring can be a useful tool to understand how the environment changes with different mitigations and levels of occupancy to inform decision-making. The use of air quality monitoring, such as carbon dioxide (CO_2) meters, can be used by facilities management teams to assess ventilation and occupancy. When used actively by occupants alongside measurements of temperature and humidity it can also allow ventilation in an environment to be appropriately balanced with thermal comfort and energy use.

Surfaces. While technical solutions are not an alternative to cleaning and hygiene, there are approaches that can assist in reducing microbial contamination on surfaces[17], including no-touch technologies to remove touchpoints entirely, or material choice (for instance silver and copper and antimicrobial solutions), or antimicrobial-impregnated coatings[18] where touchpoints are needed.

Distancing. Effective risk management must consider all the transmission mechanisms, how the space is used, and the interactions that are occurring. Social distancing has been shown to be effective, and even when it is not required by law, there are likely to be advantages in continuing to manage occupancy and interactions to reduce crowding and the need for long duration close contact. A range of tools can help manage these processes including tools for occupancy management, reducing contact and crowd control, and proximity monitoring.

Plumbing and drainage. While there is limited evidence of the faecal-oral transmission route for SARS-CoV-2, plumbing and drainage may play a role in minimising infection transmission. SARs was shown to be transmitted through dried out drain traps, and there have been some suggestions that this mechanism is also possible for COVID-19.[19] Measures range from good maintenance and good plumbing design to specialist positive air pressure attenuator (PAPA) drainage systems. There is a need for the safe management of waste particularly in bathrooms; it is possible that hand driers pose a risk through dispersing microorganisms into the air. However, there is a need for further research in this area to better understand the risk.

These technologies are addressed in greater detail with discussion of further research, innovation and user needs in **Annex A**.

However, technological solutions are not a 'silver bullet', and uninformed reliance on technology can have negative consequences. Deployment and use of the above technologies rests on the following requirements:

a. The efficacy of such technologies both in laboratory and 'real life' circumstances must be thoroughly and impartially established. Laboratory capacity to test and certify these devices against COVID-19 has been a challenge.
b. Effectiveness must be continually assessed and reviewed, especially as further evidence emerges.[20]
c. Issues of integration must be anticipated and addressed if technologies are to be effective in practice: how a technology will integrate with other systems, whether it is appropriate for the climate, location and activities of the occupants, who will use it and how, and who will be responsible for management and maintenance. Late-stage R&D will be needed to address these issues, and to enable a move to real-world application.
d. Organisations installing any technology to reduce transmission need to be clear on its limitations and any wider impacts, including broader health benefits or harms and how it may affect different groups of people within an organisation.
e. Organisations should assess the capital and operational cost and impacts of installation to the business, alongside wider impacts such as influence on individual behaviour because of heightened awareness of risk or a perceived sense of greater safety.
f. New technologies place demands on industry including manufacturing capability, supply chain scalability and the skills to effectively assess and install devices according to the specific demands of the spaces. Where a technology can be demonstrated to be effective, demand spikes are possible, which could present challenges to global supply chains. These issues need to be anticipated and addressed ahead of rapid widespread adoption.

There is no 'one-size-fits-all' approach to technologies, and the solution that is appropriate for one building and group of occupants may not work for another. Some technologies may be effective against several transmission routes, while others may only target one transmission route and other mitigations may be needed to manage other risks.

Addressing the strategic issues above should be seen as the start of an exercise in joining systems up to deliver multiple benefits. As above, this includes designing policies on net zero and infection control together.

Recommendation five
Government policy on net zero must be developed in a way that is consistent with priorities around indoor air quality and making buildings resilient to infection.

Designing and maintaining buildings for infection control should also run alongside, and be integrated into, other initiatives including those to deliver better air quality, fire safety, and increased accessibility, and delivered with a clear view to ensuring that the costs do not fall disproportionately on those least able to bear them.

There should also be a strong read across to initiatives to improve wider air quality outside as well as inside buildings. In some locations, outdoor pollution means that ventilation through unfiltered systems, including natural ventilation, cannot guarantee indoor air quality, while improving outdoor air quality could open the way for increased use of outdoor environments, for example for eating and drinking.

Addressing all these strategic issues constitutes an essential investment for the country, which will yield health and infection benefits well beyond COVID-19. With targeted action, improved indoor air quality will have a positive impact well beyond that of infection control, with significant benefits for our health, safety and productivity. There is significant evidence of the financial and health costs associated with poor air. For example, according to the Office for National Statistics, "in 2019 5.3 million days lost were due to respiratory infections"[21], causing an economic impact for employers and the country. The impact of poor indoor air quality on health is also highlighted in a recent report by the Royal College of Pediatrics and Child Health.[22]

There is potential for litigation on a significant scale if we ignore what we now know, and there is a need to explore what insurance issues might be posed by the health impacts of poor environments. We were struck that a number of owners and operators were concerned that they might be open to litigation, perhaps being held to standards that they did not currently understand, or that could not be satisfactorily defined, or that they were not able to attain.

This amounts to a major turning point for how we design and operate our buildings, and the forthcoming, second phase of this project will explore what that change looks like in more detail.

The role of engineers

Engineers have multiple roles in the built environment and in wider public health. They design and build many of the major systems our society relies upon, conduct research and develop new knowledge, and also run or contribute to the businesses and enterprises that take new knowledge through to commercially viable products and services. As a profession they are also responsible for engineering education, and the professional standards of 450,000 professional engineers.

Within the built environment, engineers work alongside a wide range of different professions, including designers, architects, planners, surveyors, builders, facilities managers, and others, to create and maintain the spaces where people live and work.

As above, we have taken this project forward as part of the NEPC, which connects government and engineers on policy issues of national concern. In phase two of this project we will bring together the relevant parts of the engineering community to work through the implications of this report for the engineering profession, and to support them to develop new skills and integrate infection resilience into their thinking and processes.

Part B: Immediate actions ahead of winter 2021/2

"The other knowledge gap is really the weighting that we apply to the different transmission methods – fomite, droplet and aerosol. That is a huge mystery"

Evidentiary hearings

We are entering a new phase of the disease. Good management of the spaces where people meet is an essential tool to manage the next phase of the COVID-19 virus as the 'stay at home' message is rescinded. Although the vaccine success has substantially reduced the likelihood of serious disease, it is already evident that we will have large numbers of cases that will cause significant disruption in schools and workplaces.

Over the colder months it is more challenging to balance good ventilation with thermal comfort, people are more likely to spend time interacting indoors, and respiratory infections are usually more prevalent.[23] There may also be direct impacts of the environmental conditions such as increased survival of respiratory viruses at the lower temperatures and different humidity experienced during the winter months.[24]

At the same time, the consequence of the strategic issues discussed in Part A is that, while there are operators and owners who have a very sophisticated grasp of buildings management, a majority have modest levels of relevant knowledge, skills, budgets, and organisational maturity in this area.

We recommend that the most simple and inexpensive measures that government could make ahead of winter are **to provide clear, consistent communications and guidance** to those with the lowest capacity and capability.

To manage a disease requires some understanding of the routes through which it spreads, and knowledge of how different interventions can disrupt those routes, which is currently highly variable.

We have seen great variation in understanding and in practice, from those who have come to believe that ventilation is the overriding priority and have almost completely abandoned attention to cleaning surfaces, to those who remain focused on surfaces and/or distancing and are taking little or no action on ventilation. Many operators are adopting a 'pick-and-mix' approach somewhere between these poles.

Whilst this uncertainty may in part reflect current scientific uncertainty and knowledge gaps of the sort identified in Part A above, it also reflects the fact that the scientific evidence that is available, and that points to some transmission link across all three pathways, has not been communicated to or understood by many owners and operators.

Ensuring good ventilation is often particularly neglected, fed both by uncertainty on transmission routes within buildings and additional drivers: while ensuring the cleanliness of the premises and regularly cleaning and inspecting surfaces is habitual and familiar to many businesses, managing and improving ventilation is considered difficult, especially if additional investment is required. Good ventilation is not widely considered in normal times, and we have heard generally excellent operators admit to finding this technical subject confusing.

What is ventilation?

Ventilation means the *supply of air* to a space. Ventilation can be 'natural' (for example, opening windows) or mechanical (using systems of ducts and fans to provide air to the building) or a combination of the two (for example an extract fan such as in a bathroom to remove 'waste' air with fresh air coming from openings in the building). In the context of COVID-19 it is most important to try to ensure an adequate rate of supply of fresh (outdoor) air to a space. This acts to dilute any virus particles in the space and remove them from the building and hence reduces risk of exposure to the airborne virus.

Guidance for owners and operators on infection control should explain how ventilation works in terms that are easy to understand.

In addition, the quality of ventilation is invisible and hard for the occupant to assess, which is in turn reflected in the business benefit of attending to it: we have heard suggestions that customers receive less reassurance from being told that an unseen ventilation system is working well than they are by seeing that surfaces are being cleaned, for instance.

All of this militates against ventilation receiving attention, and yet this is in fact a part of the picture that the owner/operator of buildings can do something about, without being too beholden to – or impinging upon – the behaviour and compliance of individuals. Precisely because ventilation can be invisible to individuals, it is very much in owners/operators' hands, and there is a strong need for owners and occupiers to attend to it. We give particular emphasis to ventilation in this document for this reason.

There is a need to clarify and communicate as far as possible what the available scientific evidence does and does not indicate with regards to priorities for infection control. This does not mean an as-yet unattainable level of certainty as to the transmission routes for COVID-19. Rather it requires clarity on a reasonable balance of priorities for an owner/operator given the level of understanding that currently does exist. These messages come against the background that businesses may feel that the imperative and incentive to improve their environments will drop as legal controls for COVID-19 end and greater emphasis is placed on personal responsibility.

These communications should:

- raise the profile of buildings management as an important front in ongoing actions to control COVID-19 and other respiratory infections
- raise the importance of improving inadequately ventilated spaces in particular
- remind owners of the continuing need to keep surfaces clean and manage occupancy and crowded areas
- advise on approaches for managing the environment for infection control alongside other priorities such as energy efficiency
- emphasise the importance of preparing before winter 2021–22.

The variable understanding of the priorities for action comes with uncertainty on how to then respond.

There has been an explosion in the production and circulation of guidance targeted at building owners and operators outlining steps that can be taken to reduce the transmission of SARS-CoV-2.

Who provides the guidance?

In the UK, guidance has been provided by Public Health England and by relevant government departments. Main non-government authors of guidance are the Health and Safety Executive (HSE), and the Chartered Institution of Building Services Engineers (CIBSE). However, guidance is also commonly accessed from The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the World Health Organization (WHO), the Safety Assessment Federation (SAFED) and the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA).

Specific guidance aimed at particular sub-sectors is issued by a wide range of providers.

"We will still treat the surfaces, primarily because it is visually reassuring for our colleagues, which is a huge aspect of this: if a cleaner is being seen to clean high touchpoints on a regular basis, that is way more reassuring than us telling people that we have increased our air supply rate to 16 litres per second, because that means nothing to the average office occupant"

Evidentiary hearings

This guidance addresses a need, and much of it is good and well received. However, we have heard that many on the receiving end of guidance continue to face obstacles to fully absorbing, understanding and implementing it. This includes:

Issues of understanding: Ensuring guidance is well written, easy for the recipient to understand, with easy to find information at the right level of detail, and clarity as to when to apply it, and what good looks like. Guidance is written by people who understand the issue for those who don't, and there is much guidance on COVID-19 that, even when based upon sound evidence, would fail the criteria of well-written guidance, and is therefore less likely to have the intended effect.

Issues of duplication, divergence and conflict: Due to the rapid onset of the SARS-CoV-2 pandemic, guidance has been developed quickly, by different organisations with little coordination. Some organisations are struggling to navigate multiple sources of guidance, or to reconcile guidance relating to multiple elements of their business (estates, catering, sporting activities, and so on.)

Issues of emphasis: At the time of writing much of the guidance available, still lacks emphasis and useful information on ventilation.

Appropriateness to audience: There will be different information needs for those with responsibility but no technical background, such as a headteacher or office manager, and an engineer or facilities manager who does have a technical background but who lacks specific expertise in ventilation.

"There is complexity involved in setting guidance… Unless they are written particularly well, the interpretation of those documents could be misconstrued numerous times by different individuals"

Evidentiary hearings

Issues of contextualisation: Many operators find it a challenge to apply guidance written for a range of contexts to the specific building they are responsible for.

Issues of proportion and balance. In the guidance that they have received, many operators we spoke to cannot find sufficient clarity to establish what constitutes acceptable minimum performance to reduce the transmission of COVID-19 within the environment they are responsible for. This leads to some 'overshooting' and many to substantially 'undershoot'. (This is related to the regulation issues discussed on pages 5 and 6).

What is 'good enough'?

A particular aspect of the issues around knowledge and guidance is that many building owners and operators are not clear what constitutes 'good enough' performance.

A shared sense of what constitutes best practice, and what constitutes an enforceable legal minimum, normally develops over time, and many operators lack the necessary skills, governance, capacity and maturity of understanding and process to determine what is 'good enough' in their business. This is particularly the case for ventilation, and especially in the context of a public health emergency where the scientific evidence is suggesting ventilation rates may need to be higher than would normally be considered acceptable in many buildings.

Some well-resourced businesses were going far beyond what would reasonably be expected, with some measures adopted more for reassurance rather than infection control. Over-mitigating to this extent comes at an economic cost and can also come at the expense of other concerns such as fire safety and climate change. We spoke to one building operator who was leaving the fire door open to increase ventilation, aware that this compromised security of the premises.

We spoke to others who were doing relatively little to address infection control, despite being conscientious in dealing with other more traditional health and safety issues such as food safety and hygiene.

"It is easy for these really good, solid pieces of guidance to be lost, and, again, I feel as though I personally, but also our organisation, because of what we do, the services we provide, we are at an advantage here that we are able to sift through the rubbish"

Evidentiary hearings

There is a continuing need for easily accessible guidance that is clear enough for operators with low capacity and experience to understand what it means for them. As a test, it should be possible for a member of the public to read and understand the guidance, and also to understand what they should expect when visiting a premises.

Such guidance needs to meet user needs in the context of the current state of the building stock and facilities management capacity. Even simpler measures such as opening windows will require some consideration and contextualisation to implement: discomfort generates complaints, and operators/owners will need to address what sort of mitigation of, and accountability for, any health or productivity impacts from cold and noise is reasonable. Some settings may need to consider how to arrange and use their floor area where the area immediately next to open windows cannot be used.

Guidance should explain how to assess levels of ventilation and establish an appropriate balance of measures to manage infection risks. It should also consider issues of culture and communications within organisations to encourage everyone in a building (including guests) to help create a resilient environment, for instance by reporting failed windows.

Much of this information exists in different places and CIBSE and others would be able to assist in bringing it together in an accessible form.

Other priorities include:

- government and professional bodies taking more ownership of issues of duplication and divergence from each other
- providing additional materials such as 'how to' videos and user guides
- ensuring guidance adequately covers and emphasises ventilation, including government guidance on gov.uk
- stress-testing guidance documents against the body of knowledge that is available on what makes good guidance and testing with end users.

This approach does not remove the need to continue to target specialist guidance to settings, particularly institutional settings such as hospitals, care homes, schools and prisons, which have different challenges, such as vulnerable occupants susceptible to cold and hypothermia or enhanced security and safeguarding requirements. Operators of these settings have different information needs and different agency.

International case studies

The UK is not unique in its need to improve the way in which we design, operate and manage buildings, and to grapple with the near-term requirement to improve the understanding and implementation of good ventilation.

The Government of Singapore have released a simple and easily digestible guidance document aimed at Facilities Managers with a significant focus on air conditioning and ventilation. It also sets out both general and sector specific guidelines.[25]

Infrastructure Canada has designated $150 million for better ventilation in public buildings to help reduce the risk of COVID-19 transmission. The initiative funds projects to improve and monitor indoor air quality and ventilation, including upgrades to heating, ventilation and air conditioning systems.[26]

The above are examples of some immediate initiatives that can be drawn upon, and phase 2 of this project will seek to explore the more structural initiatives across the international community further.

Recommendation six
Government and its agencies should collaborate to rapidly develop and deliver clear communications aimed at building owners and operators with the lowest capability, emphasising the importance of improving ventilation whilst maintaining wider good practice on infection control.

Recommendation seven
Communications should be accompanied by guidance, available via trusted and widely accessible sources, to support owners and operators to establish an appropriate balance of measures to manage infection risks, alongside thermal comfort, air quality and energy efficiency.

Recommendation eight
Government and professional engineering bodies should provide rapid and specific technical guidance to enable owners and operators to select and effectively implement appropriate technology (for example, conventional ventilation systems, CO_2 monitoring).

Recommendation nine
Government should provide incentives to encourage private and public sector organisations to improve the poorest performing spaces in buildings.

These actions are recommended as an immediate response to the need to manage winter 2021/2 differently to the winter before. However, they are only a start. In taking forward this work it has become very evident that this is an area where significant action is needed from government and wider civil society to close knowledge gaps and ensure that appropriate risk mitigation is in place, to shorten this pandemic and respond to others, and also to secure health and infection benefits beyond COVID-19.

Annex A: The role of technology

This annex sets out some further detail on the most common technologies, their scope, limits and outstanding research questions.

Ventilation

- **Passive systems (louvres/air bricks/trickle vents)** – these can be relatively simple vents that bring fresh air into the building. Ensuring these are used regularly can improve airflow.
- **Natural ventilation (opening windows)** – good maintenance can ensure that all windows can be opened safely. Use of different openings with weather and season can maximise flows. For example using high level windows in cold weather can minimize cold drafts, while using high and low level openings and keeping internal doors open can create through drafts in hot weather. Intermittent opening may also be effective at providing ventilation without compromising comfort or energy use.
- **Mechanical ventilation system, potentially with heat recovery** – likely to be a higher cost and longer-term solution to install a mechanical system, but can provide very good energy efficiency and control. These systems will change the flows and pressures in a building so the implications for room layouts need to be considered.
- **Personalised ventilation systems** – these systems provide clean airflows directly to individuals, reducing the exposure to aerosols in the wider environment and reducing the energy costs associated with large space ventilation. However, there is not good understanding of their effectiveness in real-world settings and they are only suited to certain applications.

Air cleaning

- **High-efficiency particulate air (HEPA) filters** – stand-alone HEPA filter units can remove microorganisms and other particulate pollutants locally from room air. There is some evidence that they may be effective at reducing the risk from SARS-CoV-2. However, they may be noisy and their effectiveness depends on their ability to circulate the air in a room.[27] HEPA filters can also be added to some heating, ventilation and air conditioning systems to remove viruses from the recirculating air but these are not widely applicable and may negatively impact on energy use.
- **Ultraviolet light (UV)** – the short wavelength of germicidal UV (UVC) can deactivate the infectious abilities of cells. For air cleaning this requires sufficient exposure of the microorganisms to the UVC light, which can be achieved with slow moving air or with sufficient intensity lamps. There is some confidence that UVC air cleaning devices may be a useful strategy to reduce airborne transmission, these are most useful in poorly ventilated spaces.[28] This technology is well established in hospital infection control but can be hazardous to health if applied or operated incorrectly.

Caution As mentioned above, further research and development is required before other novel technologies can be recommended.

Further research, innovation and user needs

- Good guidance and new regulation are needed to help users select appropriate technology and to ensure that manufacturer claims are balanced and properly supported by evidence.
- Evidence of effectiveness – need for real world trials and data to show how effective these technologies are for reducing transmission in different settings and configurations.
- Further research into far-UV technology is promising as a control but is far too early in development to be applied in real-world settings without significant further research.
- Exploration of improvements in performance, cost, safety and energy efficiency of these technologies is needed to reduce the complexity of the trade-off decisions.

Environmental monitoring

- **Carbon dioxide (CO_2) monitors** – in relatively small, multi-occupant spaces monitoring CO_2 gives an indication of the level of fresh air in the building and the occupancy that relates to the ventilation quality and is linked to the risk of airborne transmission. This can enable better awareness and support informed public and organisational decision-making.[29] CO_2 monitoring can be used by facilities management to evaluate ventilation and occupancy, and by occupants to directly manage ventilation, particularly in naturally ventilated buildings. In large spaces CO_2 levels are a less effective indicator of ventilation or occupancy.[30]

- Monitoring for other pollutants such as particles and volatile organic compounds provides a marker for exposure to indoor air pollutants, and that if these pollutants are kept to a low level it is likely to be an indicator that the environment is well ventilated.
- Waste-water monitoring is possible at large building scale. It provides an indicator that people in the building may be infected and hence can help to spot outbreaks.

Further research, innovation and user needs

- Clear guidance is required to inform installation and use of these devices in different settings and articulate how decisions can be made based on CO_2 data.
- There is a need for research to understand whether use of CO_2 monitors can support long-term behaviour change to manage ventilation.
- Further evidence is needed to determine appropriate values for many indoor air pollutants and whether they are associated with health impacts.

Surfaces

Transmission via shared surfaces can largely be controlled by regular cleaning and good hand hygiene. Regular shared surfaces are likely to provide the greatest risk of transmission and environmental conditions such as temperature and humidity will alter the risk.[31] Additional approaches include:

- **Materials** – material choice can improve ease of cleaning or actively destroying the infection. Silver and copper have proven effective at inactivating respiratory viruses such as severe acute respiratory syndrome (SARS)[32]. There may be a role for antimicrobial solutions for common touch points.
- **Coatings** – there are a range of antimicrobial-impregnated products available such as paints, curtains and powder coatings that can be used for touch points like door plates and toilet handles.[33]
- **No touch technologies** – for common touch points such as doors and lift buttons, contactless sensors and digital apps can provide alternatives. These may also provide additional benefits for accessibility of people within a building. Good positioning of hand sanitation stations can also manage touch points.

Further research, innovation and user needs

- Need for further validation of coating effectiveness and longevity for inactivation of SARS-CoV-2 and other microorganisms in real-world settings.
- Need to consider wider impacts of anti-microbial products including whether they pose risks for anti-microbial resistance for some microorganisms.

Distancing

- **Digital tools** – digital tools can serve multiple purposes from reducing contact, to crowd control or co-ordination of cleaning operations to ensure timely and appropriate levels of cleaning and disinfection.
- **Occupancy management** – reducing the number of people sharing an environment will reduce the risk by enabling greater distancing, reducing the likelihood that an infectious person is present and reducing the number of people who can be exposed.
- **Proximity monitoring** – devices that alert you if someone else is in a certain radius can be used for more conscious social distancing.

Plumbing and drainage

- **Good maintenance** – simple actions such as regularly running taps and refilling floor drains can ensure that drain traps do not dry out. This will also mitigate other risks such as legionella, which may be a particular concern in buildings which have had low occupancy and have had sinks/urinals taken out of use to manage social distancing.
- **Positive Air Pressure Attenuator (PAPA) drainage systems** – effective drainage systems should be designed to ensure the venting to atmosphere has been considered. Pressure fluctuation in pipes can cause water traps to be 'pulled' leading to open air paths between drainage pipework and habitable spaces creating a transmission route for airborne viruses.
- **Looped or daisy chain pipework** – plumbing design can encourage full circulation of water through the system and pipe insulation, system wide temperature monitoring or a circulating return domestic wholesome water system can maintain appropriate temperatures. Copper pipework should be used between the wholesome water pipework and the sanitary fittings to further reduce infection.

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