National
Engineering
Policy Centre

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Infection resilient environments: time for a major upgrade

Royal Academy
of Engineering

CIBSE

Foreword

Engineering and urban design play central roles in reducing the spread of infectious diseases from one person to another. Over the past 200 years, some of the most significant improvements in health have resulted from engineering, and many still do. Engineering is often as important as biomedical science in reducing major infections.

The design and installation of clean water and sewerage systems improved sanitation, reduced transmission of major infections such as cholera and typhoid, and significantly improved the health of urban populations. Urban planning and building design reduced overcrowding in housing and helped to reduce the spread of respiratory infections, including tuberculosis.

The routes by which infectious diseases transmit between people pose different engineering challenges. The main routes of infectious transmission are through the air, for respiratory infections, through food or water, from the touch of people and surfaces, via sexual routes, or through vectors such as insects, depending on the infectious agent. In the UK, engineering in the built environment has a major influence over the airborne, oral ingestion of food and water and touch routes. For many diseases, it can reduce risk to minimal levels.

The COVID-19 pandemic has shown again how people's risk of being infected by respiratory infections is heavily influenced by their environment. Engineering interventions, such as effective ventilation indoors, can help to reduce transmission of many infections in places of work, study, at home, and on public transport. Infections can also be transmitted through food and water. Engineering systems for clean water, effective sewerage to keep human faeces away from human ingestion, and cooking and freezing technology to make food safe are all needed to reduce this.

The spread of some infectious diseases can be through direct person-to-person touching but also contact with surfaces where an infectious agent is present. Engineering solutions can include infection-resistant surfaces and design to encourage effective handwashing behaviour.

Some engineering solutions to reduce infections also have health co-benefits; for example, effective ventilation potentially reduces indoor air pollution.

The National Engineering Policy Centre's work exploring how the design, construction, and use of built environments and transport systems can remove or reduce the transmission of infections from one person to another is therefore both timely and important. Engineering and technological solutions, along with medical and behavioural interventions, are central for society to create environments that are resilient to both known and future infectious diseases.

Professor Chris Whitty KCB FMedSci
Chief Medical Officer for England

Government Chief Scientific Adviser Sir Patrick Vallance FRS FMedS, said:

"The COVID-19 pandemic has made clear how important infrastructure and the built environment are for our health. I would like to thank the Royal Academy of Engineering and the National Engineering Policy Centre for this independent report which provides government with important evidence and insight to consider as we learn lessons from COVID-19 and ensure we are prepared for the future.

"We spend most of our time in indoor environments and making these healthier and more sustainable spaces will have wide benefits to our public health, wellbeing, and the economy. This will require action."

Professor Peter Guthrie OBE FREng, Chair of the Infection resilient environments Working Group, said:

"COVID-19 has demonstrated that adequate ventilation is important for infection control, but it is only well managed in a minority of buildings. It is vital that we address the long tail of buildings that are poorly or unmanaged, through recommendation to embed infection resilience in this report. It is timely to act now as changes are afoot, which creates an opportunity to join up these initiatives to create safe, healthy, and sustainable indoor environments."

Professor Devi Sridhar FRSE Professor of Global Public Health, University of Edinburgh, said:

"This report is a pragmatic and necessary step forward to advancing healthier indoor built environments. COVID-19 has prompted reflection on clean air and hygiene measures to keep us all healthy. Governments should reflect on the report's recommendations and how best to operationalise them."

Professor Chris Jones Deputy Chief Medical Officer for Wales, said:

"The pandemic has highlighted the link between public health and our built environments. There are lessons we can learn from the transmission of coronavirus as we adapt and design the environment around us to promote good infection control and help reduce future transmission risks. There are good opportunities for us to combine this work with climate mitigation and adaptation action to help achieve greater resilience and improved environment and health outcomes for the future."

Executive summary

The commission and background to this report

In the midst of the COVID-19 pandemic, the Government Chief Scientific Adviser Sir Patrick Vallance invited the Royal Academy of Engineering, together with the Chartered Institution of Building Services Engineers (CIBSE) and other partners to the National Engineering Policy Centre (NEPC), to identify the interventions needed to reduce infection transmission in the UK's built environment. This took the form of a two-phase programme of work, exploring the actions necessary to create more infection resilient environments.

Phase 1 of this programme was initiated in March 2021. This set out to increase our understanding of the barriers to increasing infection resilience, and how they might be overcome. It found flaws in the way in which buildings are designed, operated, and managed for infection control that were impeding the response to the pandemic. Our short-turnaround response *Infection Resilient Environments: Buildings that Keep Us Healthy and Safe*[1] provided an overview of the strategic challenges these weaknesses presented for the UK, and presented advice on immediate measures to manage the situation ahead of winter 2021/2022, including much better communications and guidance to those managing buildings.

Phase 2: A systems approach and the case for change

This second phase of the project asks why these vulnerabilities existed at all, and what needs to change in order for the UK to be better placed ahead of future pandemics, and to provide greater protection against seasonal disease outbreaks.

COVID-19 provided a stark illustration of the direct health costs of poor infection resilience in terms of severe illness or death and longer-term health problems, along with significant economic and social costs from the consequent disruption of business, education, and the wide variety of activities that we depend on every day. In monetary terms, a commissioned economic analysis[2] found that, in the event of another severe pandemic in the next 60-year period, the estimated total societal cost (health, social, and economic) of infection caused by influenza-type pandemics and seasonal influenza in the UK could equate to £23 billion a year. Even outside of the extreme circumstances of a pandemic, the lives lost and sick days caused by seasonal influenza equate to an estimated annual cost of £8 billion. These costs are not evenly distributed across the population, or the building and transport stock. The public have a right to expect that buildings and transport provide infection resilience. Therefore, action is required to reduce the risk of transmission as well as the associated costs.

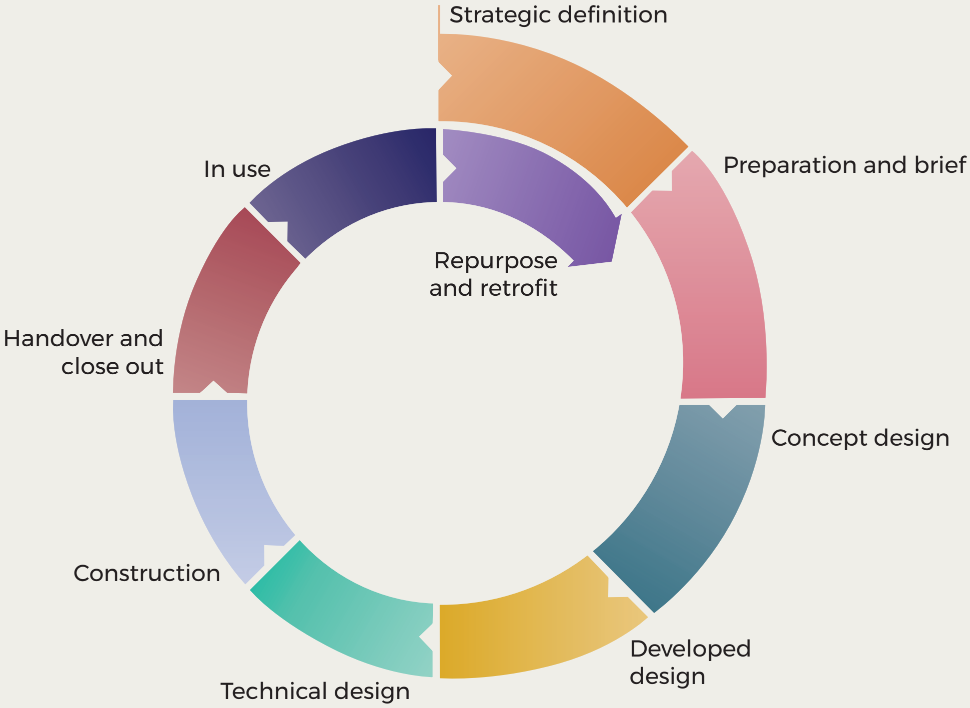


Figure I.1. Stages of a building lifecycle (Credit: adapted from *RIBA Plan of Work*[3])

The way in which our built environment and public transport operate is the result of a range of factors right across the lifecycle: from the strategic definition of what it is intended to do, to how it is designed, constructed, and handed over – and, perhaps, adapted, refurbished, or retrofitted – and how it is then managed and operated over its lifetime. Achieving the profound change we need required us to look across all the stages of that lifecycle (Figure I.1). We explored the implications of any changes through health, economic, social, environmental, and governance lenses. This ensured that changes could be implemented together to deliver indoor environments that have much greater infection resilience while also delivering the many other things we expect and need from our buildings – that they are safe, they provide clean water, they are comfortable to be in, and they support good physical and mental health. It involves taking a people-centred approach that considers all of the stakeholders across the diversity of indoor environments.

In developing this systems view, we drew upon expert workshops involving policy-makers and regulators, alongside experts from the architecture, engineering, and construction professions, institutional bodies, and industry representatives, including those responsible for managing buildings, building controls, and transport systems. We also surveyed the broader landscape of legislation, standards, and regulation – including, for instance, the Climate Change Act 2008 and the Clean Air Act 1993 – to understand how the wider policy environment drives the way in which we design and manage buildings, and how this might be aligned with health objectives. This perspective revealed, for example, a significant opportunity to align infection resilience with the current drive to retrofit buildings and public transport to meet net zero targets.

What change is the right change?

All of this points to the need for buildings to be safe, healthy, and sustainable. Our eight recommendations (Table I.1) cover the lifecycle of buildings and design and in-use considerations for public transport. Together, they comprise the coordinated action needed to embed infection resilience, alongside the other core needs of safety and energy efficiency.

Table I.1. Recommendations

To reduce the life-changing impacts of future pandemics and seasonal diseases, the public have a right to expect that buildings and transport provide infection resilience. Eight key recommendations have been identified to improve the health of our indoor environments. All of these recommendations apply to the built environment and some to transport, as signified by the icons, which are explained in the key below. These recommendations should be **accompanied by further multidisciplinary research collaboration in the areas**, as outlined in Section 6 of this report.	
Strategy and design	1. To develop a clear baseline of what best practice in infection resilience looks like, the **BSI should convene the relevant expertise and develop meaningful standards that are embedded into existing design and operational practices**. This should draw on existing standards committees from built environment, transport, healthcare, and other relevant sectors. The existing standards landscape for indoor environments should be reviewed to ensure that they address infection resilience.
Construction and handover	2. To create a culture shift toward embedding considerations of health and wellbeing in the built environment, the Department for Levelling Up, Housing and Communities (DLUHC) should **increase the prominence of health and wellbeing across parts of the Building Regulations**. A new part of the Building Regulations for health and wellbeing should be established, with an explicit functional requirement that the building should provide an adequate indoor environment that protects the health and wellbeing of persons using the building from adverse effects. This needs to be accompanied with guidance and training to build the competence of the sector.
	3. To ensure that buildings operate as designed in terms of infection resilience, **industry bodies and public procurement must drive improvements to the commissioning and testing of the building systems**. This should be supported by better enforcement of the existing building regulations both at handover and through the lifetime of a building.
In-use and retrofit	4. To maintain standards of safe and healthy building performance over a building's lifetime, **in-use regulations need to be established with local authorities**. This needs to be accompanied by the capacity, skills, and capability for enforcement, as well as clear mechanisms to measure and publicly communicate compliance. Lessons should be learned from the Building Safety Regulator model in England, to explore potential wider applicability for regulating the operation of healthy and sustainable buildings.

	5. To enable innovation, assure the efficacy of technical products and systems, and provide guidance for those adopting them, **BSI should develop a standard(s) that manufacturers can use and that can be independently certified** by UKAS-accredited certification bodies. Regulators (including Advertising Standards Authority, Health and Safety Executive, Office for Product Safety and Standards, and Trading Standards) should support the development – and use – of standards by businesses to improve infection resilience.
	6. To seize the opportunity created by the net zero strategy to make UK infrastructure safe, healthy, and sustainable, the **Department for Business, Energy and Industrial Strategy, Department for Transport, and DLUHC must ensure major retrofit programmes also address infection resilience**. This needs to be accompanied by professional upskilling through professional bodies and trade associations to ensure that, where changes are in tension, informed trade-off decisions can be made.
	7. To create greater awareness about the role of the built environment and transport systems in public health, the **UK Health Security Agency (UKHSA), in collaboration with others, should undertake a communications campaign for building and transport owners and management, as well as the wider public**, that heightens awareness of infection resilience, indoor air quality, and wider health considerations for indoor environments.
Leadership	8. To create the joined-up policy-making that will align infection resilient environments with net zero, safety, equality, and accessibility goals, **government should identify a lead department**. This department should act as a strategic coordinator, with a mandate to bring together policy-makers across devolved administrations, government departments, arm's-length bodies, and the professions. This should be supported by a scientific advisory committee that provides independent advice. As owner of the majority of the policy levers, DLUHC is well placed to take this leadership role.

Key

Public transport | New builds | Existing infrastructure | Retrofit

Acknowledging there may be a need to prioritise action, four considerations for prioritisation have been included, as follows:

Prioritisation

It is critical to improve the infection resilience of the UK's built environment and transportation systems to reduce transmission of upcoming waves of COVID-19, seasonal diseases, and future pandemics. Implementing the recommendations provided requires significant change. While it is important to improve the quality of the majority of our indoor environments, some prioritisation may be required. This could be based on the following four considerations:

- the spaces that are of greatest risk because of high densities of people, or the presence of vulnerable people
- the spaces that do not have the equivalent of a duty-holder with the awareness and competence to manage for infection resilience
- the spaces that enable maximum benefit to be achieved for the resources available
- where action can be aligned with other planned activities, such as safety improvements in high-rise residential buildings or home retrofit programmes for net zero.

Professor Catharine Noakes © thisisjude.uk

Contents

Civil engineer discusses flood risk management with colleague

1. Introduction

What is infection resilience?

In this context, infection resilience concerns the use of engineering controls in the built environment and public transport to minimise the risk of the transmission of infections to individuals. Understanding infection resilient environments lies at the intersection of research into communicable diseases and into the built environment. Delving into this area of infection resilience provides an opportunity to better manage the role of the built environment in health protection, creating the option to improve public health – both during and beyond the COVID-19 pandemic.

Improving infection resilience requires a broad range of interventions to existing infrastructure. These range across occupancy standards, contactless technologies, plumbing and drainage systems, and ventilation systems. They are intended to respond to what is known about the transmission of existing diseases within the built environment, and to protect against future pandemics as well as more common seasonal diseases. They must reflect the ways that people interact with the built environment, which vary in sometimes unpredictable ways throughout their day or week as they move from home, to transport, to workplaces or leisure activities. This means that interventions for achieving infection resilience cannot be considered in isolation if they are to provide effective protection of public health, requiring a systems approach to infection resilience.

Pandemics and the built environment

Throughout history, pandemics and epidemics have played a significant role in how cities have been designed, and in how people manage risk of disease within them. In the Roman Empire, disease outbreaks in military camps led to the installation of aqueducts, public baths, and the division of water and sanitations systems. After the peak of the bubonic plague in 1350, English cities began to plan for more organised public spaces to reduce the number of dirty and cramped quarters. Later, cholera epidemics in the early 19th century led to the development of elaborate sewage systems across European cities. In the late 19th and early 20th centuries, when tuberculosis was rife across Europe and the US, buildings were redesigned to allow for more sunlight and air.[4]

During the Spanish flu in 1918 and 1919, along with quarantine and social distancing, the wearing of gauze masks was another measure used to control the pandemic in US cities.[4] Following the 2003 outbreak of the SARS epidemic in Hong Kong, the city's Building Department issued a new W-trap design for drainage, along with ventilation in new infrastructure, to minimise disease transmission.[5] Similarly, major outbreaks of Legionella and E. coli in the UK have resulted in regulatory reform to bring in monitoring and control measures to significantly reduce the risk.[6]

COVID-19

The COVID-19 pandemic underlined the role buildings and transport play in the transmission of disease.[7] It has especially brought risks of airborne diseases and the importance of indoor air quality to the fore. While an understanding of how COVID-19 is transmitted from person to person and across different settings and environments is still an area of ongoing research,[8] transmission has been observed in poorly ventilated or crowded indoor settings as aerosols can remain suspended in air or travel further than conversational distances.[9] It is increasingly being recognised that adequate supply of outdoor air to indoor spaces is crucial to limiting disease transmission.[10]

The pandemic has brought about a notable increase in research into infection resilient environments, albeit from a low baseline: while earlier publication peaks are aligned with previous epidemics, the scale of COVID-19 saw a fivefold increase in the number of publications on the topic of infection resilient environments (Figure 1).[11] The COVID-19 pandemic is another historic moment where the impact of the built environment on disease transmission is brought to the fore, and requires us to rethink how we commission, design, manage and operate buildings.

Beyond COVID-19

While COVID-19 continues to have a significant impact, it is critical that we look ahead to longer-term improvements that will create indoor environments that support our health and wellbeing, and that minimise the risk of transmission and super-spreader events in future epidemics, pandemics, or for seasonal flu. Future pandemics may be driven by different transmission mechanisms to those of COVID-19 – for example, through waterborne or surface (fomite) transmission – but existing design evolutions should reduce these risks. Given that mitigating airborne transmission specifically is a known limitation for much of the UK's

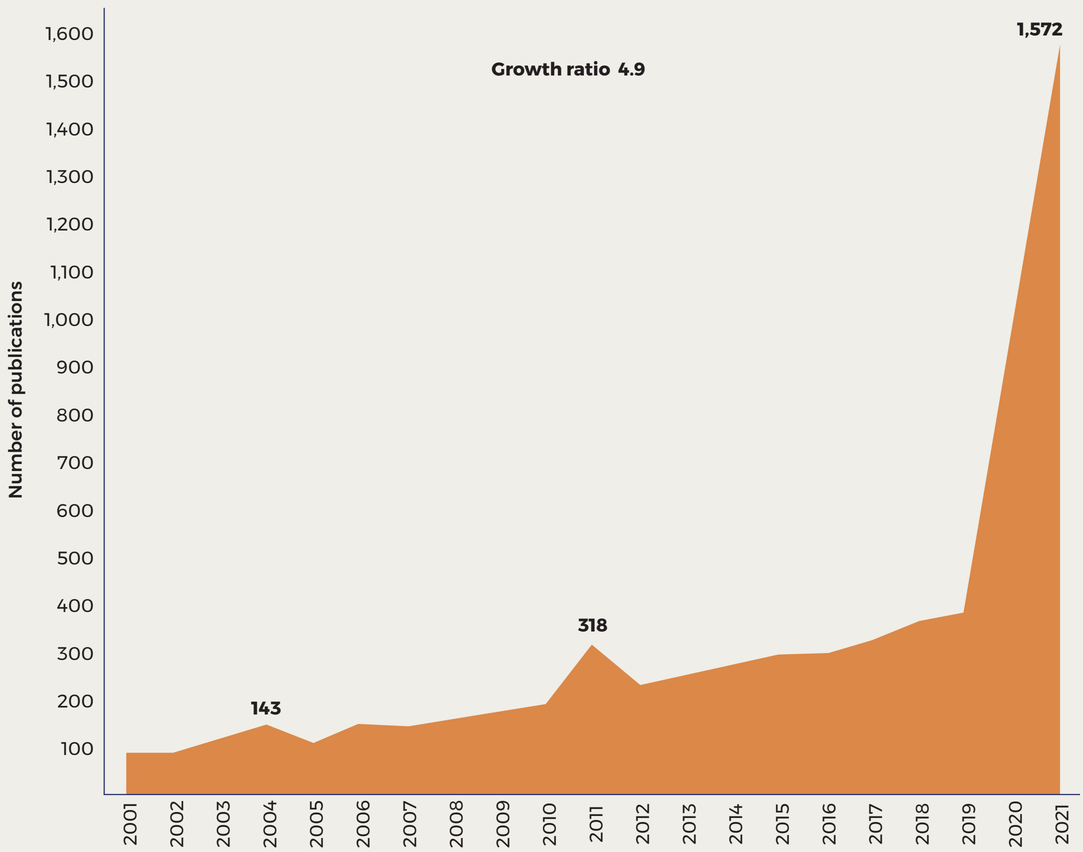


Figure 1. Chart of research published pertaining to infection resilient environments over the past 20 years[11]

infrastructure, it is the predominant focus of the present report.

It has long been acknowledged that the places and spaces we use affect public health.[12,13] The built environment and transport systems influence our everyday behaviours, impacting on our health in a wide range of ways. Building design, as well as broader factors in urban planning and public transport provision, can influence levels of pollutants, encourage active travel, and affect mental health and wellbeing.[14,15,16,17,18]

Beyond public health, a wider context must be considered. Infection resilience needs to be aligned with consideration of climate change mitigation and progress to net zero,[19] access to green spaces,[20] safety and security, accessibility, and air pollution.[21] Modern buildings have to fulfil multiple criteria on energy efficiency, acoustics, lighting, thermal comfort, and indoor air quality. A well-designed and effectively operated building could be adapted to meet all of these needs, once the criteria exist for how to do so in practice. Embedding infection resilience into the design and use of buildings and transport systems is a multifaceted challenge with many competing and complementary needs, sectors, stakeholders, and potential co-benefits.

This project takes a systems-based approach to the challenge, in order to acknowledge different drivers, reconcile them wherever possible, and ensure that interdependencies and trade-offs between all of these factors are identified and managed. By taking a systems approach to the built environment, we can create buildings that are safe, healthy, and sustainable.

Engineer overlooks site © Arup

Engineering controls

Health and safety and infection prevention and control principles use a hierarchy of controls to eliminate or reduce exposure to risk and prioritise interventions.[22] The prioritised levels, as illustrated in Figure 1.2, are:

- elimination – remove the hazard (eg through mechanisms such as vaccination)
- substitution – replace the hazard (eg working from home, rather than in the office, or with reduced occupancy levels)
- engineering controls (eg ventilation, coatings, or screens)
- administrative controls (eg installing one-way systems, providing safe spaces for staff breaks)
- personal protective equipment (PPE) (eg facemasks).

Figure 1.2. Infection prevention and control: Hierarchy of controls to be applied in order of priority[22]

Where elimination or substitution is not possible, **engineering controls** can play a critical role in reducing risk of disease transmission. Through design, retrofit, and management and operation practices, engineering controls can be embedded in our buildings and transport systems to help reduce the risk. This needs to be accompanied by the right administrative controls and PPE to manage risk effectively.

2. Methodology

The commission

In March 2021, the Royal Academy of Engineering and its partners in the NEPC were commissioned by the Government Chief Scientific Adviser Sir Patrick Vallance to identify the interventions needed to reduce infection transmission in the UK's built environment and public transport systems. This two-phase programme of work has been led by the Academy and CIBSE, working with the Institution of Mechanical Engineers and the Institute of Healthcare Engineering and Estate Management. The programme explores how to increase understanding of the barriers to achieving infection resilience and how they might be overcome.

This second report of the programme focuses on the **transformational change required in the way we design, operate, and manage buildings to create healthier, more sustainable, and infection resilient environments** for those who use them.

Phase 1

The first phase of the programme focused on delivering a rapid review of the value and importance of developing infection resilience in the short term, outlined in *Infection Resilient Environments: Buildings that Keep Us Healthy and Safe*.[1] As a time-sensitive response to the challenges of winter 2021/2022, this rapid review provided a series of high-level recommendations to support the move toward creating healthier buildings.

The research found that infection control was neglected across many classes of buildings, with ventilation understood to be particularly limited at that stage of the COVID-19 pandemic. This issue was shown to be a symptom of a general lack of priority given to building management that resulted in a reduced capacity and capability to respond rapidly to the public health crisis. This weakness was exacerbated by multiple sources of guidance, not all of it clear or consistent, and a research and regulatory landscape playing catch-up.

As a short-term response, the NEPC recommended that government and its agencies should collaborate to deliver clear communications on improving ventilation and infection control, accompanied by trusted and accessible guidance, and incentives to encourage private and public sector organisations to improve performance.

In response to the systemic challenges, the report proposed strategic changes needed for buildings to be healthier, better-managed spaces in the long term. Specifically, government should:

- provide support to map the knowledge and skills requirements necessary to increase infection resilience

- work with research councils to create an action plan to address research gaps
- undertake a rapid review of the capacity and capability requirements among regulators
- commission demonstration projects to fill knowledge gaps
- ensure alignment between net zero policy, indoor air quality, and infection resilience.

Impact

The Phase 1 report was discussed with stakeholders from government, industry, and at parliamentary committee inquiries. The Cabinet Office took steps to implement the recommendations, improving the ventilation guidance and public information campaigns, and establishing a Ventilation Technical Advisory Group with strong engineering representation. Additionally, the Engineering and Physical Sciences Research Council explored how to address the research gaps in order to build on the UK's impactful research base.[11]

Phase 2

Where Phase 1 identified an opportunity for transformational change in the built environment, this second phase – referenced in the government's *Living with COVID-19* plan,[23] – provides an in-depth exploration of how to embed infection resilience in the UK's built environment and public transport to create safer, healthier, and more sustainable environments.

> **Definitions**
>
> **safe**: protected from harm
>
> **healthy**: supporting people's physical, psychological, and social health and wellbeing
>
> **sustainable**: efficient with resources, affordable to operate, and considerate of whole-life performance

Taking a systems approach

The recommendations from Phase 1 were used to guide the direction of research for the present report, alongside a series of discussions with expert stakeholders and a short literature review to determine the current understanding of infection resilience within the UK. This reinforced the complexity of the challenge and the requirement for a **systems-based approach**.

To explore this, we adopted a framework published in *BMJ Global Health* in a paper titled 'Building a Multisystemic Understanding of Societal Resilience to the COVID-19 Pandemic'.[24] Authored in the wake of COVID-19, it considered ways to improve resilience related to health crises, and identified five critical areas of resilience:

Health resilience – 'capacities to promote, restore, and maintain health when confronted with a shock … broadly referred to the capacity to prevent or reduce both transmission and mortality [resulting from pathogens such as] COVID-19.'

Governance systems resilience – 'maintain the essential functions of the state including stability and security and the continuity of executive, judicial legislative, and administrative processes in full respect of human rights and the rule of law.'

Economic resilience – 'limiting the magnitude of economic losses, recovering quickly and forging new developmental paths for prosperity.'

Environmental resilience – 'adapt or transform in the face of unexpected change in socio-ecological systems, in ways that continue to support human wellbeing.'

Social resilience – 'address vulnerabilities and distributive social effects at different scales of social organisation including individual, family, and community.'

This systems framework was used to design a research approach that took a broad perspective regarding infection resilience, incorporating health, sustainability, and wider societal implications.

In addition, the validation criteria for the research scope were identified as follows:

- high potential impact on infection resilience, reflective of the Phase 1 findings
- actionable results, directly usable by an explicit policy customer
- clear benefits aligned to other key policy objectives
- determinable within the research timescale and/or in line with other relevant policy levers
- meets the strategic goals of the Academy and the NEPC.

Within this framework, the approach aimed to be **people centred, exploring the issues through the lenses of different building and transport classes in order to recognise the diversity of purpose and stakeholder incentives**.[i] As relationships with, and experiences and uses of, buildings and transport systems differ between groups and across demographics, the research involved a breadth of stakeholders. These included designers, owners, operators, managers, and users.

To identify areas for change, a map of the governance system was developed using a combination of the Royal Institute of British Architects' *Plan of Work 2020*[3] and Network Rail's governance for railway investment projects (GRIP) process.[25] To bring a focus on in use and retrofit issues, the International Organization for Standardization's ISO 55001[26] and BSI's PAS 55 asset management standards[27] were incorporated.

Together, these resources refined the overarching stages of 'strategy', 'design', 'construction', 'handover', and 'use'. The five building and transport classes ('industrial', 'residential', 'commercial', 'local community', 'transport') were examined over these stages, starting with 'use' and working backwards to identify leverage points for change. These leverage points were then analysed through the lenses of the 'health', 'governance', 'economic', 'environmental', and 'social' areas of resilience to identify co-benefits and tensions. The research design strategy is summarised in Figure 2.1.

To achieve the aims of the research design, the Academy undertook a series of 'evidence workshops' and commissioned a social cost benefit analysis (SCBA), a research capability review, and a summary of international good practice. Further details are provided in Annex A.

Scope and limitations

The scope of the second phase of this project was limited in a number of ways:

- It was framed by the findings in Phase 1, with a focus on indoor environments as an opportunity for transformational change.
- Research and interest in infection resilience has been prioritised, because of the COVID-19 pandemic, and recent experiences influenced the discussions. This report has a strong focus on reducing the airborne transmission as this was identified as a significant gap.
- While transport systems were included in the research objectives, the final recommendations apply more specifically in the building sector. Building regulations were identified as offering the greatest impact toward improving infection resilience. However, this would include buildings within transport systems (eg airports) that are covered by the same regulations.

i The building and transport classes were identified from planning use classes as follows: class B – general industrial and storage or distribution ('industrial'); class C – hotels, residential institutions, secure residential institutions, dwelling houses, and houses, multiple occupation ('residential'); class E – commercial, business, and service ('commercial'); class F – learning and non-residential institutions and local community ('local community'); plus, transport and its associated infrastructure and buildings ('transport').

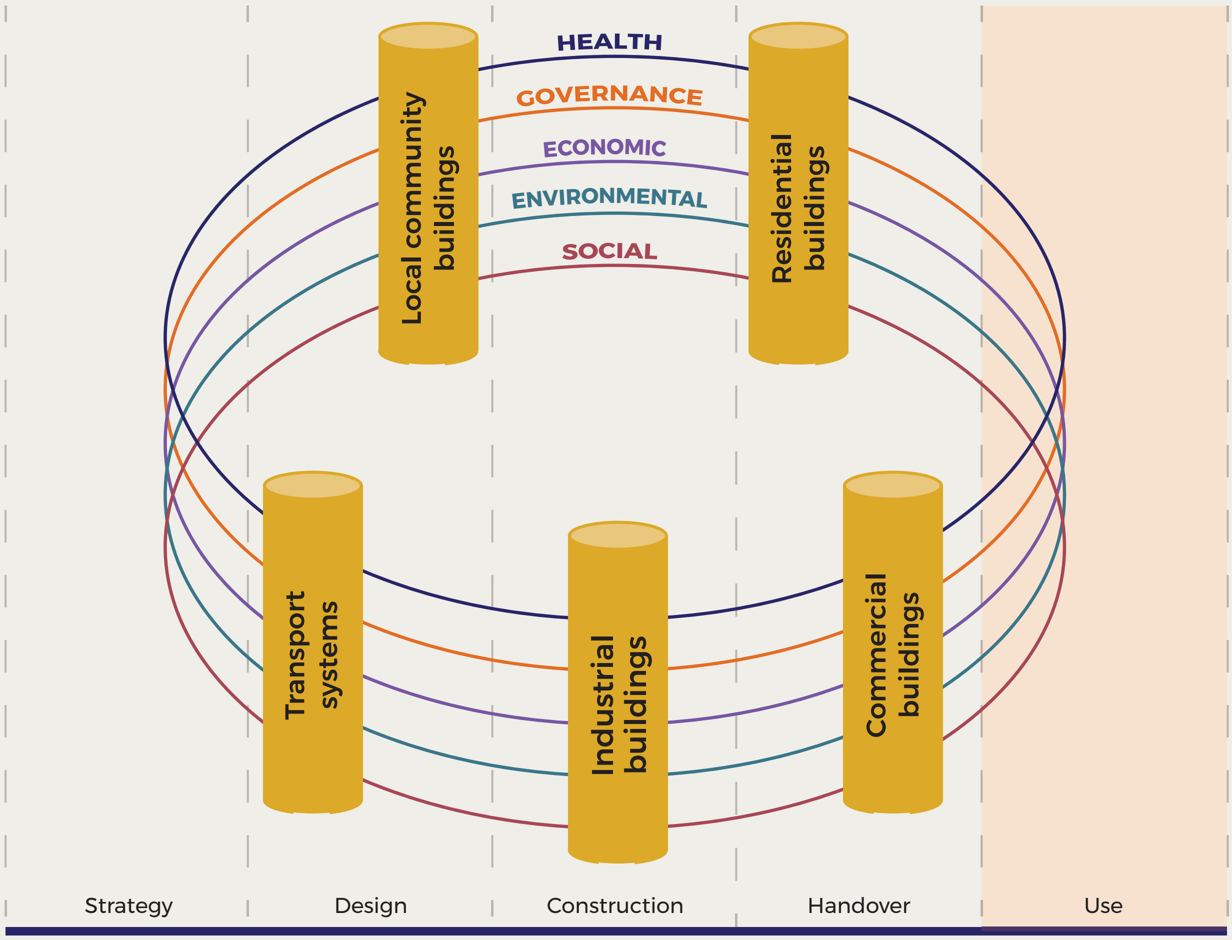


Figure 2.1. Research framework taking into account the different governance stages, components of resilience, and building and transport classes

Recommendations about standards, technology certification, management and operation, the retrofit opportunity, and public awareness are also applicable to public transport.

- The nuance of the context for change and recommendations for the devolved administrations has been explored, but is not documented in detail in this report. The final recommendations are intended to be applicable across the devolved administrations, but will need to be considered within the specific local legislative frameworks, and there is scope for further refinement based on the needs of each administration.
- This research considers broad building types and groups together buildings that may have different individual needs and operating models; for example, grouping schools, hospitals, and museums together under 'local community' buildings. However, the range of buildings and public transport within each of the five broad groups have similar incentives and comparable policy levers.

3. Case for change

We spend up to 90% of our time in indoor environments, while mixing in the built environment and on public transport creates a risk for viral transmission. Densely populated shared spaces can increase rates of infections and disease, especially when virus prevalence in a population is high. There are a range of social and economic motivations that lead people to want to travel and gather indoors, and the design and operation of these environments can affect how airborne, waterborne, fomite (surface), and vector-borne infections are transmitted within them. Most of us have a reasonable expectation that the water in buildings that we use is potable and that the electrical systems within them are safe. There is a strong case for extending those expectations to good air quality and wider infection resilience.

Lessons from COVID-19: Impacts on people and society

Early in the pandemic, the Scientific Advisory Group for Emergencies' (SAGE's) Environmental Modelling Group specified that ventilation is a mitigation against the risk of aerosol transmission indoors and should be considered as part of a hierarchy of risk controls approach.[28] Yet, assessment of the capacity of building stock and public transport to put this mitigation in place found that there was limited operational information available for these environments. In the areas where this was investigated, it was common to find suboptimal performance, suggesting that much of the UK's building stock is not being operated at the standard necessary to ensure healthy indoor environments. The assessment highlighted a significant proportion of inexpertly managed or entirely unmanaged environments. If the UK's built environment and public transport systems are not equipped to limit the spread of infections, there will be impacts on individuals, society, and the economy as illness and poor mental health affect people's wellbeing and disrupt education and business.

This transmission risk in different environments correlates to both direct and indirect impacts. As part of the evidence-gathering workshops (Annex A), we collected feedback from a broad range of stakeholders on the impacts of a lack of infection resilience in the built environment (summarised in Figure 3.1 and further discussed in Annex B). This highlighted that, in poor-quality environments where people mix for prolonged periods – such as some schools, or hospitality venues – there can be viral outbreaks with subsequent health, social, and economic consequences for those who use these spaces. These include effects on physical and mental health, strain on health and social care services, reduced productivity, and loss of customers. These impacts have not been distributed equally: individuals from poorer socioeconomic backgrounds and underrepresented ethnic groups[29] have experienced disproportionate impacts, often as a result of poor-quality housing,

Figure 3.1. Workshop word cloud highlighting the implications of a lack of infection resilience

the professions they work in, and other existing health inequalities.[30]

As illustrated in Figure 3.1, failure to address health risks associated with indoor environments is likely to lead to loss of public confidence in systems and heightened levels of fear. This might, in turn, prevent people from using buildings and services. Building owners would incur the costs of managing low-occupancy buildings, risk exposing staff to sickness, and face high rates of absenteeism – all leading to loss of revenue. Furthermore, a lack of confidence in public transport and subsequent increase in private car use risks increasing carbon emissions from transport.

The economic argument for action

Given these direct and devastating impacts on health, and the associated loss of confidence regarding the safety of indoor spaces, it is clear that a lack of infection resilience has economic and social costs. To quantify this cost, we commissioned a social cost benefit analysis (SCBA) (summarised in Annex C; more information can be found in the NERA report and economic model).[2]

In the event of another severe pandemic during the next 60-year period, the estimated total societal (health, social, and economic) cost of infection caused by influenza-type pandemics and seasonal influenza in the UK could equate to £23 billion a year. Even outside of the extreme circumstances of a pandemic, the lives lost and sick days caused by seasonal influenza amount to an estimated annual cost of £8 billion (Figure 3.2).

The SCBA highlighted that costs and benefits associated with developing infection resilience

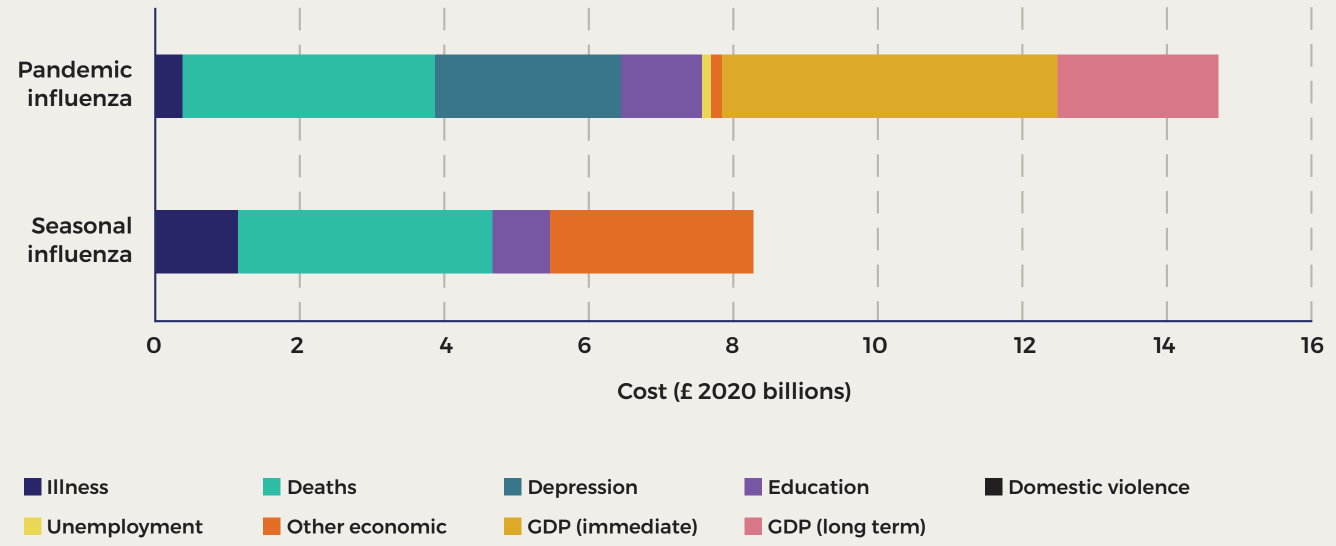


Figure 3.2. UK annual discounted expected costs of illness (£ 2020 billions). These costs consider the impacts of illnesses, healthcare costs, deaths, depression, domestic violence, lost education, unemployment, and immediate and long term impacts on gross domestic product (GDP)

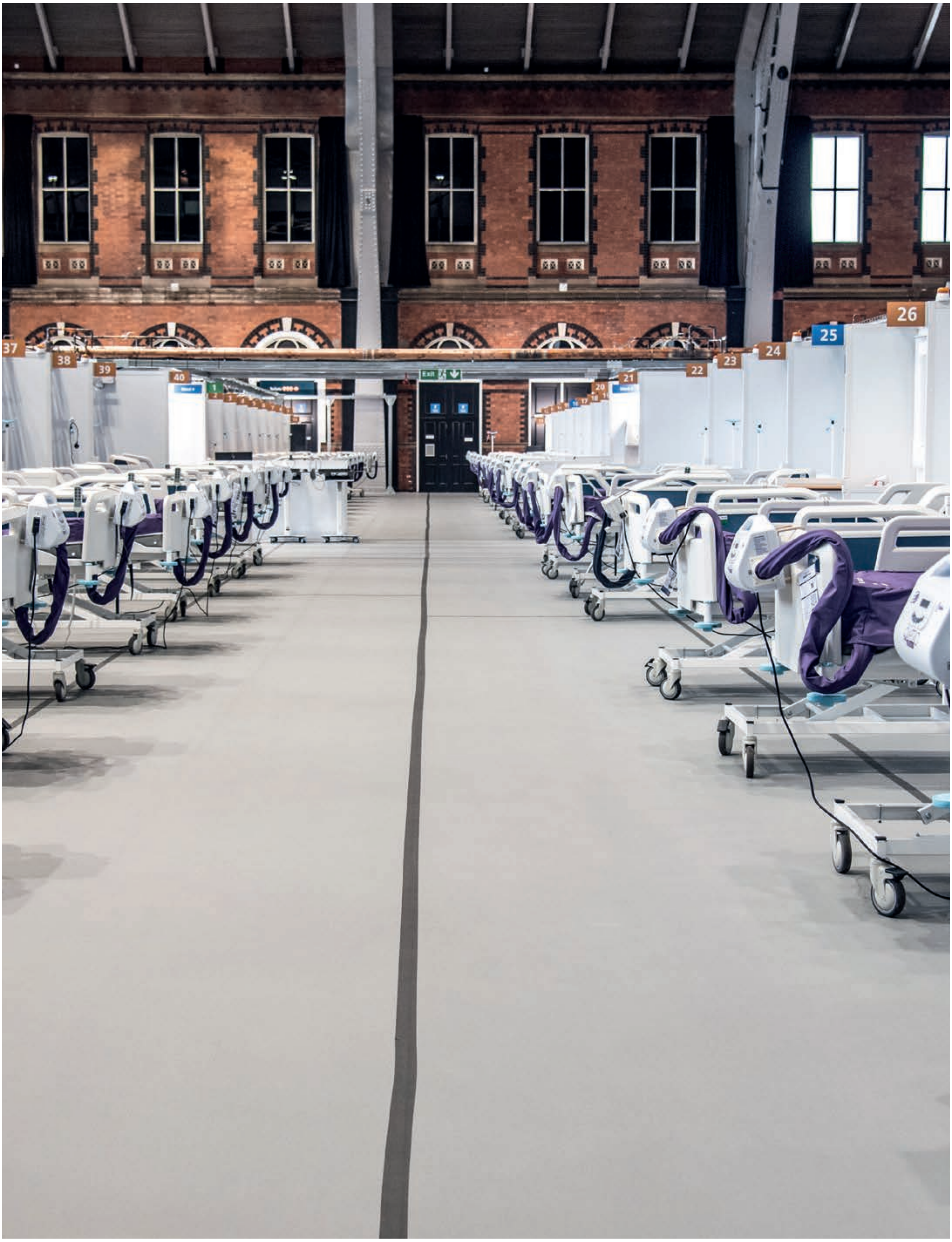
are not evenly distributed across the population, or the building and transport stock. In most environments, major interventions will be costly and not justified by the economic and health benefits alone. It is therefore important to seek opportunities where co-benefits with other policies arise or simple, low-cost interventions to improve the quality of the indoor environment can be implemented. This requires an improved understanding, clear standards, and ongoing enforcement of engineering controls to reduce infection transmission.

Wider opportunity

As well as reducing the impacts of future pandemics and seasonal flu and the associated economic and social costs, there are additional benefits from improving the infection resilience of indoor environments. A key example is ventilation, which has been proven to reduce rates of asthma and general exposure to air pollutants that can contribute to 'sick building syndrome'[31] and to boost productivity in students[32] and employees.[33] While there are clear social benefits for addressing additional health risks – for example, by reducing levels of seasonal sickness that take people out of work or education – there will also be an economic benefit that can help organisations to develop a financial case for implementing new interventions.[2] Some analysis on productivity is included in the SCBA[2] and discussed in Annex C.

As another example, no-touch technologies reduce fomite transmission routes, as people will not be touching shared surfaces. Additionally, these types of technologies can improve accessibility; for example, sensor-operated doors can help wheelchair users access and move through a building.

As set out throughout this report, changes required for infection resilience need to be considered in the context of other essential retrofitting needs, such as ensuring energy efficiency in order to reduce energy costs and reach net zero. There is an opportunity now to address these needs in a coordinated way.



Nightingale Hospital in the Manchester Central Convention Complex © thisisjude.uk

4. Policy context

The previous section provided a rationale for why infection resilience should be considered in the context of the UK's built environment and transport systems. There is now a clear 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, with those changes having relevance well beyond COVID-19.[1]

However, these changes must be informed by the current state of the sector, the changes it is already undergoing, and the existing complexity and challenges. There are multiple areas of policy, serving multiple legitimate objectives, which will have an impact on how buildings are commissioned, designed, built, used, and managed, and these may either stand in tension with, or work along the grain of, good infection control. A systems approach should address these together, and be explicit about any tensions or trade-offs that remain.

There are reasons to expect that, in many cases, progress on infection control will go hand in hand with progress in other areas; indeed, many of the problems that create a barrier to infection resilience (identified in Phase 1 of this project) are common to other issues. For instance, in *Building a Safer Future* – an independent review of building regulations and fire safety – it was recognised that the key issues underpinning system failure in the safety of buildings include 'ignorance', 'indifference', 'lack of clarity on roles and responsibilities', and 'inadequate regulatory oversight and enforcement tools'.[34] It was also recognised that this was 'most definitely not just a question of the specification of cladding systems, but of an industry that has not reflected and learned for itself, nor looked to other sectors.' Following the recognition of the role of buildings and transport in the transmission of infection resulting from COVID-19, the flaws apparent in the system should be considered as part of the context for interventions relating to health and wellbeing as well as fire and structural safety.

This wider policy context needs to be taken into consideration when deciding what will be the right change for infection resilience. Understanding how the wider system operates will help to identify the right 'leverage points'[ii] to effect lasting change.

Current legislative context

Current legislation and regulations already have a significant impact on infection resilience in buildings and transport. Requirements for design

ii 'Leverage points' draw attention to areas in the system where interventions would strongly influence different aspects of the system. These are starting points for exploring where interventions might have greatest impact and where unintended benefits and consequences could result.

Structural engineers assess evacuation and disaster relief map © This is Engineering

and general safety set out across this framework are set by different bodies and can apply to different building types and lifecycle stages. 'Legislation' sets out the statutory laws from government outlining the principles for underlying regulations, and, where necessary, the punitive measures for non-compliance. 'Regulations' are secondary legislation that provide instruments and rules for implementation and enforcement. 'Standards' then provide technical specifications, which are typically voluntary unless compliance is stipulated by the legislation.

The primary legislation set out in the UK includes the acts listed in Table 4.1. This legislation provides the framework under which regulations or other statutory instruments may be used. The most relevant selection of secondary legislation for the purposes of the present report has been detailed in Table 4.2. Note that there is some variation in the legislative contexts across the devolved administrations, which is not discussed in this section.

Table 4.1. UK primary legislation

Public Health (Control of Disease) Act 1984 (updated 2021)	Health and Safety at Work etc Act 1974	Housing Act 2004	Landlord and Tenant Act 1985	Town and Country Planning Act 1990
Health and Social Care Act 2012	The Occupiers' Liability Act 1957	Building Act 1984	Sustainable and Secure Building Act 2004	Building Safety Act 2022

Table 4.2. UK secondary legislation (regulations and statutory instruments)

Legislation	Relevance
Workplace Health, Safety and Welfare Regulations (updated 1992)	The Workplace (Health, Safety and Welfare) Regulations 1992 set out the duties and requirements under the Health and Safety at Work etc Act 1974 for workplaces to provide a safe environment. This requires: • adequate training of staff to ensure health and safety procedures are understood and adhered to • adequate welfare provisions for staff at work • a safe working environment that is properly maintained and where operations within it are conducted safely • suitable provision of relevant information, instruction, and supervision • for workplaces with more than five employees, a written record of their health and safety policy and consultation with employees on relevant policies and associated health and safety arrangements.
Control of Substances Hazardous to Health Regulations 2002 (updated 2020) (COSHH)	COSHH provides a framework for employers to control the risks associated with exposure to substances hazardous to health during work activities. This includes biological agents, and so the risk of infection. This framework requires employers to assess the risk and put suitable protection(s) in place for all their workers who come into contact with an infectious agents, either directly, by their work activity (eg a laboratory worker handling infectious agents), or because of a work activity (eg a healthcare worker caring for infectious patients). Assessment includes the review of control strategies such as ventilation, but also information, instruction, and training for employees. This framework includes design requirements to prevent or minimise release of biological agents into a place of work and collective protection measures and hygiene measures. COSHH does not cover situations where: • one employee catches a respiratory infection from another • a member of the public has infected an employee through general transmission in the workplace/community.
Housing Health and Safety Rating System (updated 2006) (HHSRS)	This system is concerned with minimising potential hazards related to dwellings. It covers crowding, noise and lighting. Appendix III: Part C outlines 'protection against infection' and covers: • domestic hygiene, pests, and refuse • food safety

Legislation	Relevance
	• personal hygiene, sanitation, and drainage • water supply. Enforcement is by the local authority through environmental health officers and depends on the HHSRS hazard rating, the duty of power under the Housing Act 2004 to take action depending on seriousness of the hazard, and the best way of dealing with the hazard according to enforcement guidance.
Construction (Design and Management) Regulations 2015	These regulations apply primarily to the construction phase. However, the appointment of a principal designer and requirement to compile a health and safety file could have potential impact on infection resilience. Client responsibilities also mean that the client is required to pass on relevant information reasonably available to them about health and safety matters relating to the project to those planning it. Designer responsibilities mean that the designer should ensure that they assess the foreseeable health and safety risks in construction, as well as the eventual maintenance and cleaning of the structure in balance with the other design considerations such as aesthetics and cost.
Building Regulations 2010 (amended a number of times; most recently, 2021)	The Building Regulations apply to most new dwellings and non-residential buildings, but various parts also apply to extensions and refurbishment. Enforcement is currently via an approved building inspector or local authority to sign off the building regulations before completion of construction. However, the system will change with the introduction of the Building Safety Act 2022. Infection resilience has crossover with a substantial number of the Building Regulations, as discussed in Annex D. These include Part C (contaminants and moisture), Part D (toxic substances), Part E (sound), Part F (ventilation), Part G (hygiene), Part H (drainage), Part L (fuel and power), and Part O (overheating).
The Health Protection (Coronavirus) Regulations 2020	During the 'emergency period' (pandemic), these regulations imposed restrictions designed to curtail the spread of infection. The regulations laid out detail on business closures, restrictions on movement, restrictions on gatherings, offences and enforcement, and the expiry or termination in the event that they were no longer necessary (requiring review every 21 days).

Standards landscape

It is vital that change is also encouraged in the existing building stock. There is a range of voluntary independent certification standards that could have infection resilience more directly incorporated, as follows:

- The Building Research Establishment's Environmental Assessment Method (BREEAM) is a rating scheme on the sustainability of the built environment.[35]
- The WELL Building Standard from the International WELL Building Institute is a performance-based system for assessing features of the built environment that impact human health and wellbeing.[36]
- The Leadership in Energy and Environmental Design (LEED) rating system by the U.S Green Building Council certifies healthy, efficient, carbon, and cost-saving green buildings.[37]
- There is a range of detailed professional guidance on health and wellbeing in buildings, including CIBSE's *TM40*[38] and CIBSE's *TM61-64*.[39] There is also guidance that aims to specific elements of healthy indoor environments, such as the Institute of Air Quality Management's *Indoor Air Quality Guidance: Assessment, Monitoring, Modelling and Mitigation*[40] and CIBSE's *Guide B*.[41]
- Some building-specific guidance exists; for example, BB101 for schools[42] or HTM 03–01 healthcare settings.[43]
- COVID-19 resulted in a range of additional technical guidance on improving the performance of systems such as ventilation, air-cleaning technologies, and CO_2 monitoring.

Environmental policies

The need to address climate change requires significant intervention in the built environment. The Climate Change Act 2008 commits the UK government by law to reducing greenhouse gas emissions by at least 100% of 1990 levels (net zero) by 2050. The UK government has set out a net zero strategy that identifies 10 key areas to address and setting out proposals and policy priorities for decarbonising each sector, which includes greener buildings and transport.[44]

The Climate Change Act reflects the following points relevant to the context of the present report:

- To address overheating in homes and other buildings (focusing on schools, hospitals, care homes, and prisons), goals have been set for improving insulation and preventing overheating buildings in summer months, which will likely require changes in construction practices, in occupier behaviour, and in greater use of green spaces.
- The 25-year Environment Plan includes a goal to 'create more, better quality, and well-maintained green infrastructure and embed an environmental net gain principle for development, including housing and infrastructure'.[45]
- Direct greenhouse gas emissions from building operations make up around 17% of the UK total, split between homes (77%), commercial buildings (14%), and public buildings (9%). There are specific policy recommendations for buildings that include producing a heat and buildings strategy, building standards for energy efficiency in new and existing buildings, and green recovery, which looks at installation of heat pumps.[46]
- The Future Homes Standard and Future Buildings Standard are proposals for more stringent energy conservation measures under the Building Regulations, and are intended to reduce emissions from all buildings built or refurbished from 2025. These standards also specifically address reducing the risk of transmission of infection via aerosols in non-domestic buildings.[47]

In addition, the UK's 2019 Clean Air Strategy recognised the need to address indoor air pollutants through a number of measures, including improving awareness of the importance of effective ventilation to reduce exposure to air pollutants at home.

Leverage points in the governance map

This policy, legislative, regulatory, and standards environment has shaped the governance system that surrounds new buildings, major projects, and transport systems. A map of the governance system was assembled from the stages set out in the *RIBA Plan of Work 2020*,[3] the GRIP framework,[25] and asset management standards ISO 55001 and PAS 55.[26,27] This is illustrated in Figure 4.1 *(pages 22–23)*.

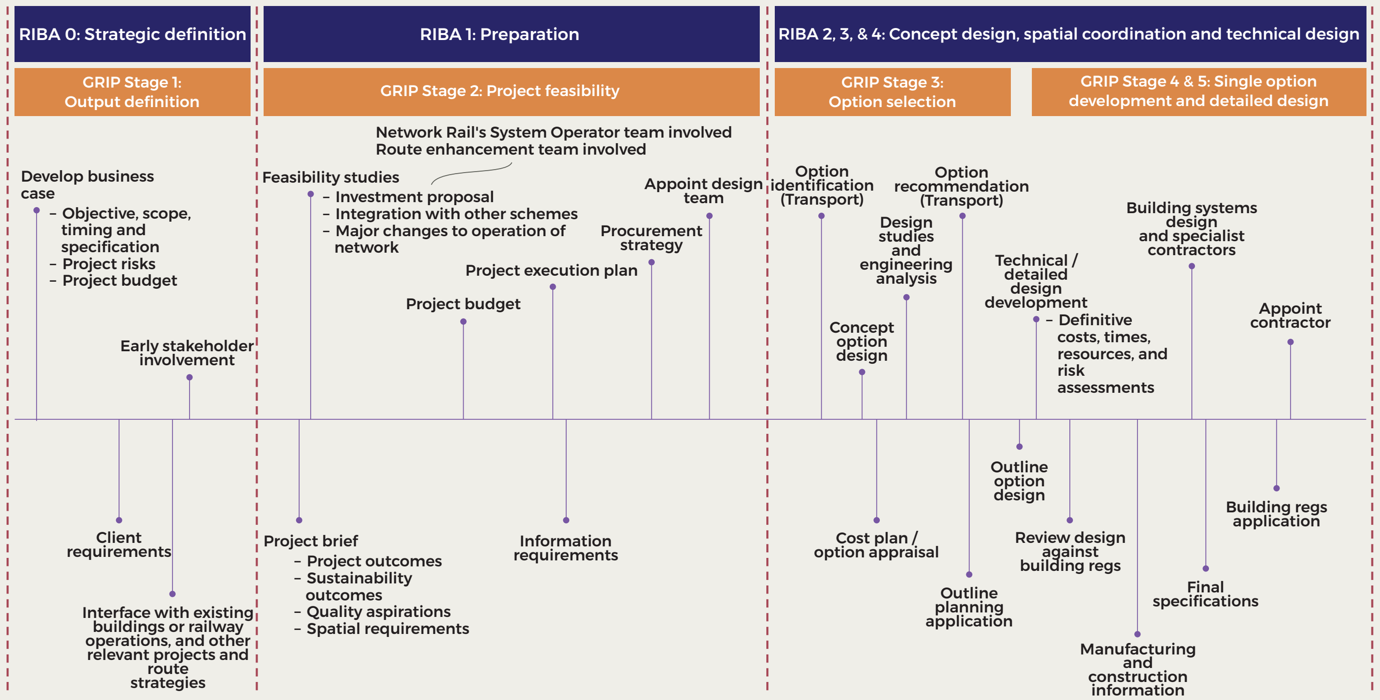
The evidence workshops (Annex B) identified a range of leverage points across the lifecycle of our buildings and transport systems. There are a number of possible intervention points from 'strategy and design', 'construction and handover', and 'in-use and retrofit' with the potential to embed infection resilience, as outlined in Table 4.3.

Table 4.3. Leverage points identified at the workshop

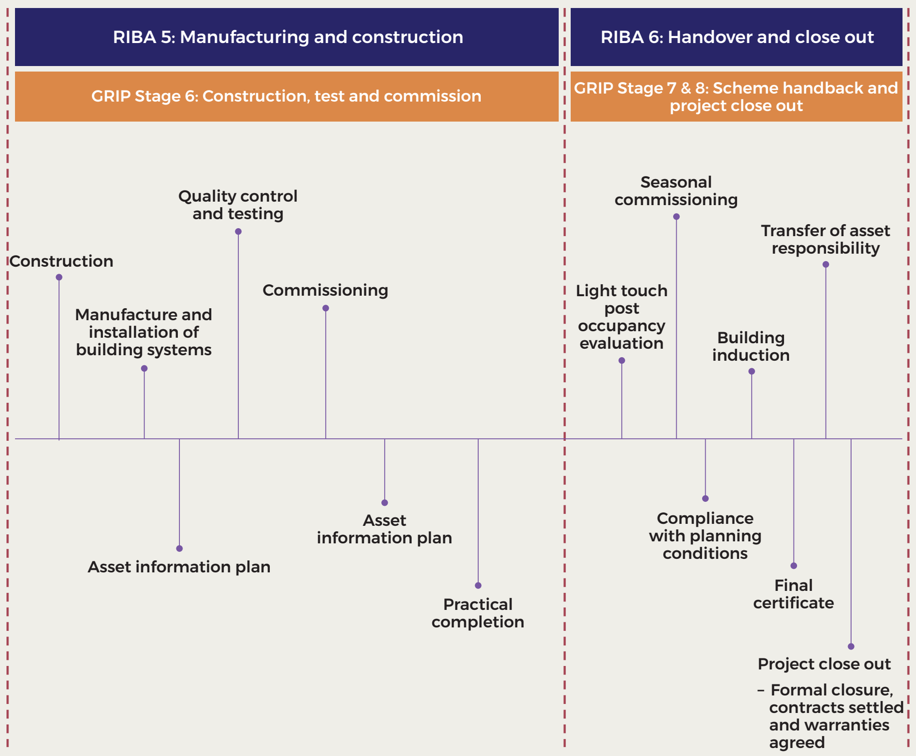
Strategy and design	Construction and handover	In-use and retrofit	
Meaningful standards for infection resilient environments embedded in design	Clear and simple building regulations for infection resilient environments	Better engagement with and education for users	Create regulations for in-use buildings
People-centric strategy for change of use	Effective codes of practice with guidance	Professional assessment system of buildings	Risk management plans for infection control
Health assessment at the planning stage	Improving commissioning and testing of buildings	Monitoring of performance against standards	Promote changing role of facilities management
Evaluating competing pressures trade-off	Ensuring 'golden thread of information'	Create a single point of responsibility	Promoting best practice and what 'good' looks like
Financial incentives	Methods to enforce compliance at handover	Financial incentives for in-use improvements	Strategies for ensuring compliance of standards in-use

Figure 4.1. Governance map

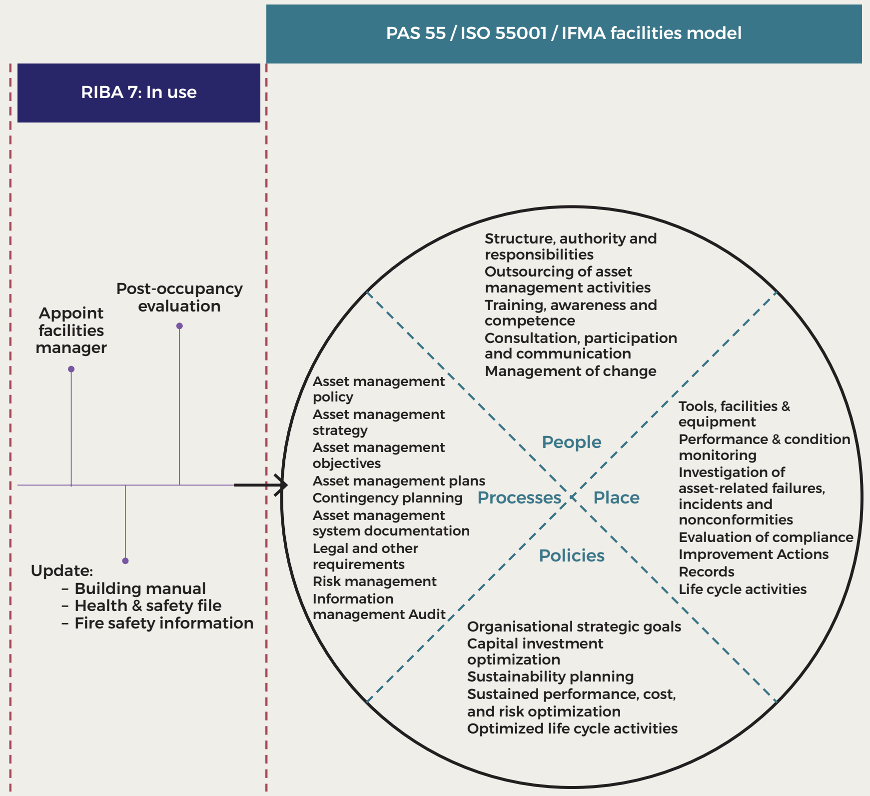
Strategy and design



Construction and handover



In-use and retrofit



District line S7 S Stock trains on the platform of Earl's Court underground station in London © Shutterstock

5. What change is the right change?

Range of interventions

There is a significant and growing body of research investigating a variety of interventions with which to reduce indoor transmission. These can be categorised as short, medium, and long-term strategies, as well as by type of intervention. Types of intervention include technological and physical change, behavioural change, risk management, research and innovation, development of skills and capacities, and governance and responsibility. The focus during the COVID-19 pandemic has been on short and medium-term interventions.

For a more detailed discussion on intervention types, the commissioned report on international practice produced by Arup[48] highlights some of these potential interventions, with particular focus on the short and medium-term options. Meanwhile, the present Phase 2 report focuses on longer-term change in the UK. The interventions discussed in this report are intended to embed infection resilience through policy changes. Where possible, overlap and the potential for integration with existing guidelines have been identified.

Recommendations for action

Strategy and design

In assessing strategy and design, it is first necessary to consider what makes a successful building or transport system, and who experiences the benefits. Limiting negative impacts on health that occur because of building or transport design should be part of the definition of success. This means that the people who use the building, whether regularly or transiently, should not suffer adverse effects to their health because of design aspects such as provision of ventilation, light, or layout.

To deliver on this design case, clearer specifications are required. These need to be driven both from the client side, to understand the use cases for buildings or transport, and from the wider sector, to influence the way the building operates in practice and its consequent impact on health. This could be accompanied by design tools that provide accurate predictions of performance, incorporating energy, ventilation, and thermal comfort. New design tools need to be accepted by building control to enable adoption.

To achieve infection resilience – and healthier, more sustainable buildings – the initial stages of strategy and design for new buildings and transport systems must be driven by a people-centric approach that understands the needs of the end user, and, accordingly, designs for improved health and wellbeing. With collaborative design for infection resilience, there are opportunities to encourage wider benefits for health. For example, making stairways more prominent encourages physical activity and reduces the number of people in lifts. This will require involvement with different stakeholders throughout the design process.

The design of the building fabric should be flexible in order to achieve longevity. This will allow for change of use and adaptations in the longer term, so that, as user needs change, the design does not adversely impact health and carbon can be saved.

> **Example**: Design for flexibility can have more significance in certain types of buildings. Part of the consideration for the custodial estate, such as prisons, is the relationship of the building with occupant behaviours. The building's primary design driver is public protection, security, and rehabilitation, but this can make it difficult to redesign to use in a different way, with far less flexibility to control the environment than in commercial buildings, for instance. Early incorporation of design flexibility allows for later shifts in use, particularly when considering pandemic response mechanisms. Additionally, placing occupant health as a core consideration can improve outcomes. Without due consideration of health, a consequence may be sedentary lifestyles, which can have knock-on health effects. Due consideration is needed to deliver a coordinated pandemic response alongside improving health in the wider framing of building design for different purposes.

This challenge, however, is not simple to overcome. Because of the split incentives that currently exist within the construction sector, the benefits are not accrued by the actor bearing the cost, meaning that change is unlikely to emerge from small shifts in the sector. Instead, more substantial directives, such as changes to regulations and standards, are likely to be required for the scale of change required. For example, a client often has different incentives than those of the end user, and these can also differ from those of the owner, operator, or designer. The incentive for health provisions incorporated into design is likely to be highest from the end user who is most at risk from using the building. However, design is often most influenced by those funding the project, where the key success metric may be the profitability of the development rather than the creation of healthy spaces. There is an ethical responsibility to ensure health measures are, where possible, designed into buildings. Change must come from a shift in responsibility of those actors, rather than relying on incentives, and, as such, more regulatory requirements are necessary to drive change at this design and strategy stage.

The Building Safety Act 2022 has been introduced in order to drive the focus on safe buildings, particularly in the higher-risk residential sector. The objective is that those who own and operate buildings have a statutory duty to deliver, demonstrate, and then maintain the safety of the assets for which they are responsible. There may be a role for the future Building Safety Regulator, and equivalents in the devolved administrations, to address health outcomes as well as structural and fire safety, and there may need to be a wider obligation than just higher-risk residential buildings. The Public Accounts Committee reported, in April 2022, that 13% of privately rented homes have a category 1 health and safety hazard and are costing millions to the NHS, highlighting the need to address health and safety beyond just the structural issues.[49] At present, there are few punitive measures for non-compliance with standards, both for new buildings and for the retrofitting of existing building stock.

In existing building stock, building owners and operators may also have different incentives to those of the building users. Building operators, where they exist, must weigh up the operational expenditure of an existing maintenance backlog against the capital cost of retrofitting a building. This is also difficult to act upon without clearer specifications of achieving good design. It is important that the regulations and standards extend to include the repurposing and retrofitting of buildings. Design standards need to be updated to reflect the changing understanding of risks and effectiveness of interventions for improved health in design or retrofits. The retrofit opportunities are significant as the sector continues to align with net zero goals and meet carbon targets.

> **Example**: During the pandemic, there were struggles to make changes within some existing buildings. Short-term thinking exacerbated the lack of investment in retrofitting, with the assumption that the pandemic would be over in a few months. This also highlighted the lack of longer-term thinking for general health protection in buildings, and a stronger reliance on dictating behavioural measures or visible infection-control measures that would continue to encourage footfall and revenue, with lower capital expenditure. Greater understanding and awareness of the best measures to improve health in existing buildings is required, and could be developed through a set of implementable standards that allow building owners to improve their indoor environments.

Understanding the overlaps in design and strategy for improving infection resilience and achieving net zero is required for decision-making that meets multiple objectives and delivers multiple outcomes. With increasing subcontracting of specialisms, there can be a reduced understanding of the system as a whole. In any updated standards, there should be clarity for designers through to managers and users on how their decisions affect both infection resilience and net zero. Primarily, achieving healthy, comfortable, and sustainable buildings or transport is a balancing act that requires taking a systems approach to design. This extends throughout the building fabric, from material use through to ventilation strategies, plumbing, windows, and layout. However, to provide clear guidance will require more research on how to balance these objectives and develop the skills and tools needed by designers.

Ultimately, to achieve greater prominence of health measures in building standards, designers and building users need to be able to match SMART outcomes for the building or transport system at the design and strategy stages. Standards should also consider factors across health, governance, environmental, social, and economic resilience. It is necessary for standards to be understood, respected, and incorporated by actors across the industry and to be used in existing design practice. Thus, integration with existing design codes, stages, or frameworks and professional codes of practice is necessary for effective incorporation and uptake.

Recommendation 1: Clear standards
To develop a clear baseline of what best practice in infection resilience looks like, the **BSI should convene the relevant expertise and develop meaningful standards that are embedded into existing design and operational practices**, using existing standards committees from built environment, transport, healthcare, and other relevant sectors as a starting point. The existing landscape of standards for indoor environments should be reviewed to ensure that they address infection resilience.

The standards for infection resilience in built environments and transport systems need to be developed by a cross-disciplinary group. They should be people centric, so that interventions are understood by and work well for building users, and encourage flexibility to be able to respond to future demands. It is important that they reflect the different types of buildings and transport, alongside different use cases. Building an understanding of the existing standards landscape (including relevant industry guidance), with alignment to established management system standards such as occupational health and safety (BS ISO 45001[73]) and asset management (BS ISO 55001[26]) will provide a basis for understanding knowledge gaps and convening the creation of new standards.

These standards should be split into minimum and aspirational requirements for both new buildings and public transport and retrofit. Performance against these standards could be ranked against different thresholds. Regular review will be important to ensure the standards remain up to date with emerging knowledge and innovation.

Existing design standards should be reviewed for alignment with infection resilient environments and wider health considerations. Where possible, the standards should be incorporated into existing design codes, guides, and classifications, such as the WELL Building Standard, *RIBA Plan of Work* stages, BREEAM, LEED, or the Soft Landings framework.[50] Consideration should be given to how these could be incorporated into GRIP and other transport governance processes. Likewise, thought should be given to how these could be incorporated in public transport systems. The standards should be embedded into professional codes of practice to ensure widespread understanding and competency across the sectors.

Construction and handover

Within the construction and handover phase of building projects, two key leverage points were identified: development of improved building regulations and improved commissioning and handover.

Current building regulations are complex. Elements that are relevant to minimising infection spread or ensuring healthy environments are considered across multiple parts. For instance, Part F discusses ventilation and air quality, thermal health is addressed in Part L and Part O, Part C considers moisture, Part L includes lighting, Part E describes noise, while Parts G and H cover water quality. In addition to building regulations, other legislative documents reference infection spread but are not comprehensive; for example, the Housing Health and Safety Rating System, which discusses infection but does not include aspects such as ventilation. Further voluntary certification systems, such as BREEAM, include guidance on health and wellbeing, but do not reference infection spread.[51] This has resulted in a complex legislative and regulatory environment that does not make occupant health a clear priority. This makes it difficult to understand 'what "good" looks like' and where improvements can be made, essentially preventing the full benefits of improving the health of occupants from being achieved. This has resulted in the lack of a clear, coherent 'baseline' for minimum requirements of health and wellbeing in buildings, let alone guides for how to achieve good or excellent design and construction of buildings.

The distribution of health considerations in the Building Regulations has contributed to a culture in which adverse health impacts driven by building design are not considered or not understood. For some unseen risks, such as air quality, there is a need to 'make the invisible visible' to all stakeholders in the system, including designers, owners, operators, and users of buildings. Consequently, monitoring, education, and awareness are also key elements of achieving improved health in buildings and a clear and simple set of building regulations can help to achieve this.

There is a clear opportunity for health and wellbeing to have greater prominence within UK building regulations. With a focus on intended outcomes rather than just design aspects, a new part to the Building Regulations would help to create a culture shift toward valuing health and wellbeing alongside critical areas such as fire safety and structural safety. It would create a functional requirement to provide an adequate internal environment to protect the health and wellbeing of those using the building. While many elements of health and wellbeing are already discussed across the regulations, their distributed nature results in a lack of context and purpose, reducing their force. A new part could have a positive influence in setting out a clear responsibility for occupant health, increasing awareness, improving education, and catalysing a culture shift that sees health as a meaningful consideration in building design and retrofit. A similar approach was adopted with Approved Document M: Access To and Use of Buildings,[74] which has resulted in significant improvements to both existing and new builds. As part of the Building Regulations, this will then also require sign-off at handover of the building by an approved building inspector or local authority, increasing enforceability. Developing such guidance would also help to address the call in the *Building a Safer Future* review[34] for less siloed thinking and a greater emphasis on systems thinking.

Recommendation 2: Specific building regulations
To create a culture shift toward embedding considerations of health and wellbeing in the built environment, DLUHC should **increase the prominence of health and wellbeing across parts of the Building Regulations**. A new Part of the Building Regulations for health and wellbeing should be established with an explicit functional requirement that the building should provide an adequate indoor environment that protects the health and wellbeing of persons using the building from adverse effects. This needs to be accompanied with guidance and training to ensure industry competence.

This Part to the Building Regulations and the Approved Document guidance should be clear and simple to follow, establishing a baseline requirement and highlighting the importance of health in the built environment to encourage change. It should extend beyond infection spread and include building health considerations, such as those determined by the Harvard School of Public Health's 'healthy building' research: ventilation, air quality, thermal health, moisture, dust and pests, lighting and views, noise, water quality, safety and security.[16]

The new Part should apply to both new buildings and refurbishment of existing buildings and draw on existing work carried out under CIBSE: TM40.[38] A draft proposed outline of the new Part is presented in Annex D. Consideration needs to be given to how this could be incorporated in the equivalent building regulations in Wales, Scotland, and Northern Ireland.

Increasing the prominence of health and wellbeing in the regulations requires an understanding of how infection resilience can be embedded in building control and commissioning processes, and throughout the building lifecycle.

Commissioning is a process that follows installation to ensure that systems in the built environment achieve the performance they were designed for. This typically involves testing of building services – for example, ventilation, water and sanitation, or security systems –under standard methods and providing accurate documentation. Good practice suggests it should be carried out seasonally, in the first year, to ensure systems operate effectively under a range of conditions. Commissioning is a longstanding issue in the construction industry, with the project workshops suggesting the current system is not fit for purpose. In the commissioning process, individual elements are signed off separately. This lack of consideration of the interactions between parts of a building, combined with the highly distributed nature of the construction sector, means that the ability to track quality and responsibility can be compromised. This is less of an issue within the transport sector, where sign-off for installation is traceable to a specific contractor, and, as such, accountability of action is much higher.

With no end-to-end technical oversight of buildings, there can be poor management of the one-year commissioning and handover period, with a lack of oversight, responsibility, and liability. Commissioning is a regulatory requirement under Regulation 44 of the Building Regulations, although it is currently very poorly enforced.

Alongside this, the 'golden thread of information' that provides the building information management system, enabling someone to understand how it operates, must be maintained. This should demonstrate how a building was designed and built, including changes to design along the way; however, it is often not kept intact or handed over to building users in a comprehensive and accurate form. Collectively,

Infant school teacher in a classroom with her pupils © iStock

this means that contractors and designers are not held responsible for the way buildings operate in practice.

Commissioning, as one of the last stages before handover, can also be rushed to meet deadlines. Or, where budgets are tight and funding has overrun, sufficient funds may not be allocated to the handover and commissioning process. Changing this requires a shift in quality assurance, with a drive from leadership to consider quality on an equal footing to time and cost, and much more active enforcement of the regulatory requirement. This should extend beyond the handover period into the life of a building, ensuring the 'golden thread of information' and long-term commissioning. There is currently no requirement for commissioning or testing of buildings throughout their life, and, consequently, existing buildings can fall below required standards without the knowledge of building users.

Commissioning is also a greater issue within local community buildings, where a local authority or trust is responsible for ownership. Contractual agreements in commercial buildings between tenants and landlords can help ensure buildings are performing to a certain standard. However, within public sectors, where these agreements do not exist, commissioning is dependent on the time and skills available within the local authority to ensure it is happening in an effective manner. When considering this alongside the SCBA, which highlighted the high possible cost of a lack of infection resilience in local community buildings, improving commissioning should be considered as a key recommendation for this building class. However, to ensure commissioning over the life of local community buildings, such as schools or hospitals, funding needs to be specifically ring-fenced to do so. This would result in a continued ability to undertake commissioning over the lifecycle of a building, even under times of pressurised budgets. This continued commissioning could have substantial economic benefits in the long run, through improved learning outcomes and higher productivity, and provide co-benefits to achieving better performance of buildings in line with net zero goals.

Recommendation 3: Improve commissioning
To ensure that buildings operate as designed in terms of infection resilience, **industry bodies and public procurement must drive improvements to the commissioning and testing of the building systems**, both at handover and, subsequently, over the life of a building. This should be supported by better enforcement of the existing Building Regulations both at handover and through the lifetime of the building.

For buildings, commissioning in its current form is not achieving the desired outcomes. Commissioning should extend beyond the completion certificate, over the lifetime of a building. The process should explicitly include means of ensuring that the building and its systems are capable of providing a good-quality indoor environment and that environmental parameters such as indoor temperatures, ventilation rates, and indoor air quality are met.

There is most reticence in relation to public buildings, where there is a lack of commercial drivers to prioritise commissioning, meaning that funding needs to be ring-fenced for commissioning in public buildings. For private properties, incentives may be required to encourage contractors to accrue the costs of re-inspection and recommissioning.

Commissioning needs to be supported by a 'golden thread of information' to maintain a record of design decisions and ensure that buildings are understood fully and functioning and performing as designed across multiple seasons in use.

Building control professionals may need additional resources and support to enable them to improve compliance and enforcement.

In-use and retrofit

To achieve an improved level of infection resilience within buildings and transport systems in the UK, it is essential to develop and implement enforceable regulations that can be assessed in the existing building stock, as well as developing a new Part to the Building Regulations. (Where possible, the new Part to the Building Regulations should reference retrofit or refurbishment of existing building stock, as outlined in Annex D.)

During the lifetime of a building or transport system, it is often the case that compliance with standards may not be required, or responsibilities may not be fully understood. Within the Workplace (Health, Safety and Welfare) Regulations 1992 and COSHH Regulations 2002, there are multiple requirements for employers to ensure the health of their employees. Additionally, within the HHSRS, applying to part of the residential sector, there is a requirement to minimise spread of infection by building owners. However, these do not have a clear set of associated standards to which to adhere, they do not apply across all building types, and they are often not specific enough to ensure action. For instance, it may not be immediately recognisable to employers that the COSHH requirement to control the risks from most hazardous substances, including biological agents, extends to the spread of infection. Or, given that the HHSRS does not include ventilation in its list of considerations for mitigating infections spread, this could easily be missed. Meeting ventilation standards to reduce infection spread also lacks the same visibility as compliance with fire regulations, despite both having significant potential impact on the health of occupants in a building.

A set of standards for in-use buildings is required to underpin enforceable regulations, taking lessons from existing accessibility, *Legionella*, or fire regulations. In addition to this, codes of practice are required to translate the requirements into a health standard expected within the culture of the construction industry and its actors. This should extend from designers through to asset managers, to ensure that health becomes embedded into the education and culture of the building industry. There could be a role for membership organisations across the building sector to help raise awareness with owners and other users of the different regulations and standards they should be maintaining to improve infection resilience. A lack of clear responsibility for the health and wellbeing aspects of a building can make it difficult to drive change. Compliance to standards is typically supported by a clear hierarchy of responsibility, or a clear duty-holder (as set out for fire safety) is established to ensure responsibilities and liabilities are coherent, clear, and simple to understand. Education of building users, owners, and management is essential to make sure that regulations and standards are understood and adhered to. This should be accompanied by intuitive controls, clearer labelling, and information so systems can be operated effectively.

Enforcement is likely to remain a challenging aspect of these standards and previous building regulations, and will require a significant increase in the capacity and skills within the regulator, including resources to undertake enforcement actions. This could include training for public health inspectors or occupational hygienists or even developing a new professional expertise in infection resilience.

Enforcement also requires overcoming the challenges of measuring and assessing the performance of buildings and establishing a meaningful baseline. While food standards or water standards are made visible to building occupants through signage and ratings, the same information does not exist for the standard of ventilation or air quality within buildings and on public transport. Mechanisms are required for building occupants and transport users to be able to visualise and better understand the performance of the indoor environment in relation to air quality, whether through live CO_2 or air-quality monitoring, signage and inspections similar to food standards, grading of the building similarly to EPC ratings, or another visual instrument. Some research is already underway, such as the data collected from the use of CO_2 monitors in schools in the UK or hospitality venues in Belgium. Lessons should be learned from the data and behaviours resulting from these pilots. To make informed decisions verifiable and implementable, evidence-based methods of performance assessment should be developed that outline the type of data that needs to be collected, in quantities that are not unmanageable or unusable.

Example: In some commercial and local community buildings, employers have struggled to get employees to return because of health concerns. The visual nature of hand sanitisers and cleaning regimes has led to their increased use and diminution of these concerns, despite the lower impact on COVID-19 disease transmission than improved ventilation systems. This has had some alternative benefits in the reduction of other types of virus transmission, such as a reduction in sporadic norovirus infections, but does not actually address the concern of the building user. Where understanding of ventilation has been greater, the use of CO_2 monitors has acted as a mechanism to demonstrate good ventilation and a reduced risk.

In addition to the ability to measure or quantify the performance of buildings and transport systems in use, there need to be explicit examples made available to designers through to users on what satisfactory performance looks like. Promoting best practice will be an essential part of providing comparisons for the assessment of building and transport performance. A set of minimum standards will only provide the baseline, but will not demonstrate average, good, or excellent performance. Measurements against the baseline could be aligned with existing practice, such as BREEAM, LEED, or WELL, or integrated into frameworks such as post-occupancy evaluation in the Soft Landings framework. The pandemic saw a substantial increase in the adoption of these independent certification standards to demonstrate that the health of the indoor environment was being considered by building owners and managers and to improve occupant confidence. However, these evaluation schemes must be brought up to date with emerging best practice for infection resilience. Accompanying the above mechanisms, there should be a professionalised system for the assessment of buildings by built environment professionals with expertise in health and wellbeing. This should be independent, to allow for objective evaluation of building performance.

Recommendation 4: Visible enforcement
To maintain standards of safe and healthy building performance over a building's lifetime, **in-use regulations need to be established with local authorities**. This needs to be accompanied by the capacity, skills, and capability for enforcement, and clear mechanisms to measure and publicly communicate compliance. Lessons should be learned from the Building Safety Regulator model in England, to explore potential wider applicability for regulating the operation of healthy and sustainable buildings.

Establishing widespread infection resilient environments requires the creation of regulations for buildings that are already in use. This may be limited to buildings where there is a heightened risk based on occupant capacity or building function. This will have liability implications, which requires insurance industry involvement. However, the regulations should identify clear responsibility, whether through a duty-holder or through another mechanism. The regulations should be accompanied by codes of practice such that this extends to all areas of the construction industry and asset management professions. The codes of practice need to be supported by an extensive training and continuous professional development programme.

The level of adherence with these regulations should be measured and assessed independently by built environment professionals with health expertise. Enforcement will require a significant increase in capacity and skills within the regulator.

There should be clear and simple ways to communicate the assessment information to users to allow them to make informed decisions about the level of risk. Alongside this, a programme of engagement and education will be required for building users and managers. It is important that all stakeholders within the system understand the basic issues and their role within the system to deliver infection resilience.

Regulations for buildings in use should be designed to incorporate wider aspects of operational performance, such as energy efficiency, to ensure multiple goals can be met simultaneously.

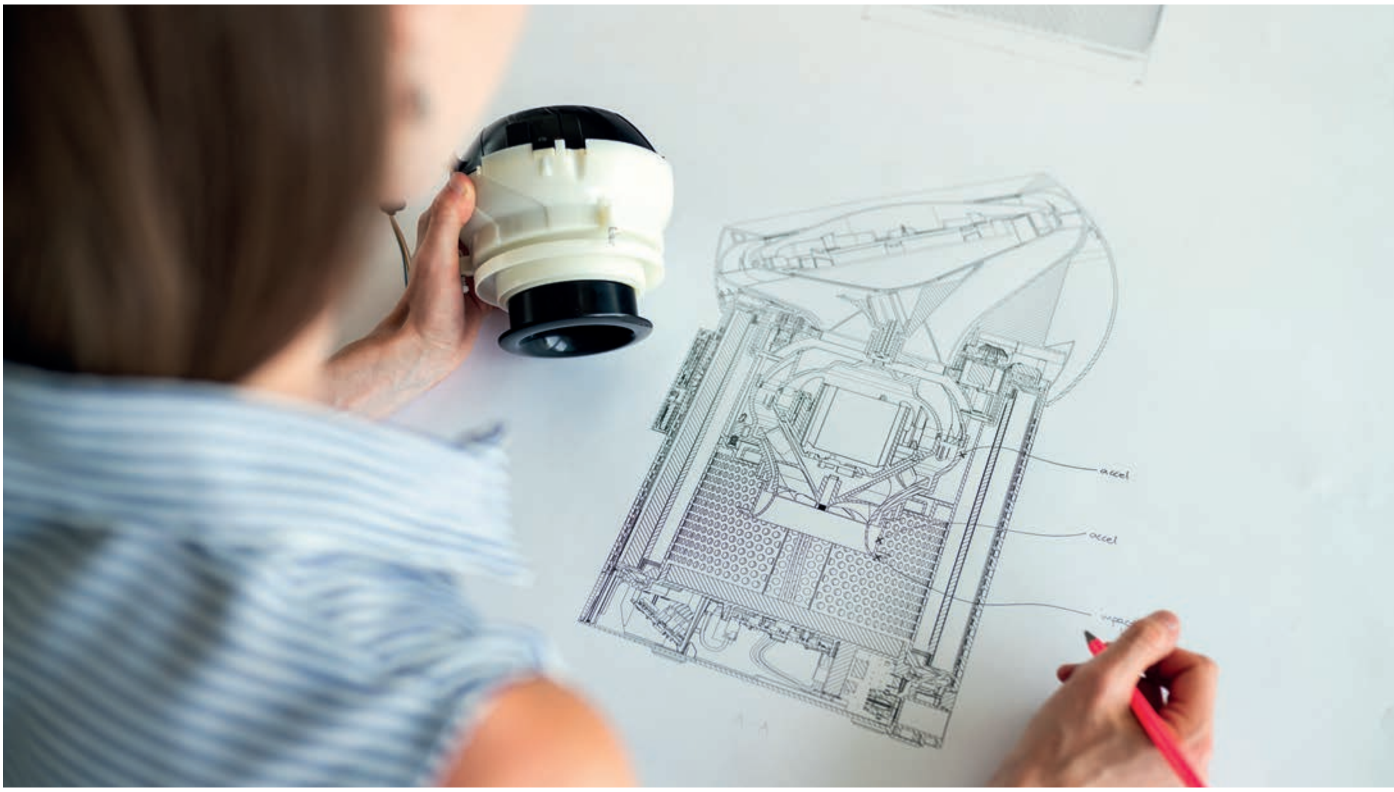
As well as assessing the building itself, an accreditation system is needed for the technological products that aim to improve infection resilience in buildings or on public transport. One such example is air-cleaning devices, which may be useful in buildings with poor ventilation, but there can be uncertainty about their efficacy in situ.[52] These technologies need to be accompanied by clear standards and metrics to assess performance in use. The sector currently has poor mechanisms with which to verify the claims of products, as individuals with commercial interest in products also conduct the testing and evaluation that provides a measure of effectiveness. This creates a conflict of interest in creating commercial advantage. An independent testing organisation with requirements for product standards and marketing would result in greater consumer confidence, and, ultimately, safer indoor environments.

Recommendation 5: Effective technology
To enable innovation, assure the efficacy of technical products and systems, and provide guidance for those adopting them, **BSI should develop a standard(s) that manufacturers can use and that can be independently certified** by UKAS-accredited certification bodies. Regulators (including the Advertising Standards Authority, Health and Safety Executive, Office for Product Safety and Standards, and Trading Standards) should support the development, and usage, of standards by businesses to improve infection resilience.

The certification system for products must be supported by independent testing facilities with the necessary capacity, capabilities, and standard test protocols. Where possible, testing should be carried out in an equivalent to real-world scenarios and take account of how products may be poorly installed or degrade over time. The consumers may benefit from recognisable certification marks to provide confidence in the product.

Infection resilience is not the only challenge facing our built environment and public transport systems: there is also a pressing need for these sectors to make progress toward net zero. The built environment is a major contributor to emissions, with emissions associated with embodied carbon in manufacturing and construction and operational energy used in operation, maintenance, and retrofit. Transformational change is needed, and, in many cases, options for retrofit and reuse will be the preferred option.

There is currently a strong policy focus on retrofitting existing buildings as part of efforts to achieve the UK's net zero goals with programmes to incentivise the improvement of energy efficiency in buildings – including a strong focus on domestic buildings. In considering how the built environment affects health, it is important to focus on existing buildings and what retrofit opportunities could feasibly be applied in the spaces where people are already mixing and spending time. There is a clear opportunity to align retrofit projects for improving both energy efficiency and infection resilience, encouraging



Noise and vibration engineer designs air purification devices © This is Engineering use of design tools to consider co-benefits in the retrofit design stages. Similarly, in public transport, the design of new low-carbon systems or retrofit programmes outlined in the Decarbonising Transport Plan should be considering how infection resilience is incorporated as a co-benefit.

Retrofitting can be a costly and complex task. However, it can provide an important opportunity to address the aspects of the building and indoor environment that are not performing adequately together in order to avoid creating new problems. At a minimum, planned retrofit programmes need to bring buildings into line with existing standards for indoor air quality.

> **Example**: Painting windows closed with the intention to reduce air permeability subsequently removes the option for users to naturally ventilate a space, or decreasing the use of buildings or increasing indoor temperatures can have an impact on water quality as stagnant water left in piping systems can enable microbial growth and in fact introduce new infection risks. Taking a systems approach in decision-making that utilises cross-disciplinary expertise can help to identify opportunities to avoid unintended consequences and realise wider benefits.

A key conflict in managing interventions for infection resilience and reducing carbon emissions is potentially increasing energy demands. In some contexts, health interventions such as mechanical ventilation will affect energy usage, especially when air circulation results in lost heat. This will also have seasonal patterns, with greater demands in colder months when diseases are typically more prevalent. This can be mitigated in several ways. First, it is essential that mechanical systems are properly commissioned and maintained to work effectively and efficiently as designed. Second, incorporation of heat recovery can reduce the heat lost by around 80%, enabling good indoor environments without the huge energy costs from unconstrained winter heat losses. Similarly, in commercial settings, use of heat recovery or air recirculation with air cleaning can reduce the amount of heat lost.

The role of operational performance of a building or transport system while in use will be increasingly important. The owner or management need to be able to make informed decisions on how to manage the balance of energy efficiency alongside managing the internal environment and occupant safety, security, and comfort. This will likely require adaptive strategies based on situational risk.

Delivering effective retrofit and operation will require professional upskilling to fill knowledge gaps; for example, how spatial configuration affects engineering interventions, efficacy of different types of technologies, or guidance provided to users. The development of specific training is needed to equip professionals to make informed trade-off decisions in design. There is also a pressing need to upskill those who undertake retrofit works so that they understand how to deliver low-carbon and infection resilient designs in reality.

Recommendation 6: Retrofit opportunity

To seize the opportunity created by the net zero strategy to make UK infrastructure safe, healthy, and sustainable, the **Department for Business, Energy and Industrial Strategy, Department for Transport, and DLUHC must ensure major retrofit programmes also address infection resilience**. This needs to be accompanied by professional upskilling through professional bodies and trade associations to ensure that, where changes are in tension, informed trade-off decisions can be made.

The effective containment of the cholera pandemic resulted from an understanding of the way in which the virus is transmitted and consequent changes to water infrastructure to stop transmission. This, in turn, led to widespread understanding on the transmission of disease through waterborne routes, and, in the long run, cultural shifts to the expectation of clean water being delivered across the UK (currently at 99.99%). Despite the potential for serious harm, air quality and ventilation has not been included in the education of the general public in the same manner, and, as such, there is little comprehension of the impact of air quality on health or a cultural expectation for clean air in buildings and transport. With improved mechanisms to provide clean air within our buildings and transport systems, education on the importance of this is essential.

The Report of the Committee on Scientific Inquiries in Relation to the Cholera Epidemic of 1854[75] concluded that:

"Either in air or water, it seems probable that the infection can grow. Often, it is not easy to say which of these media may have been the chief scene of poisonous fermentation; for the impurity of one commonly implies the impurity of both; and in considerable parts of the metropolis (where the cholera has severely raged) there is rivalry of foulness between the two."

Education on the impact of indoor environments on health and wellbeing should also be extended. By targeting building and transport owners and management, this could enable more informed decision-making about competing priorities. For example, opening windows and vents to bring in outside air in naturally ventilated spaces can significantly improve the quality of the indoor environment, increasing infection resilience. However, this can create other problems for thermal comfort, noise, safety, security, and, potentially, air quality, if there are high levels of air pollution.

A 2016 public opinion survey on housing showed that few adults considered the built environment to be a concern for health risks. Only 9% of respondents agreed with the statement "I am concerned about the health and wellbeing impacts of the buildings where I spend my time".[53] The COVID-19 pandemic has inevitably increased public awareness of the role of the environment in public health, but, to encourage meaningful conversations, UKHSA should explore mechanisms for the general population to understand more about buildings and their impact on health. This includes the role of systems such as mechanical ventilation or trickle vents. Improved understanding on the interaction between occupant behaviour and the health of the environment is required to translate standards and regulation into meaningful practice. Placing health and the adverse effects on health as a result of building and transport use and design can help to enable a cultural shift in the way that these are used.

Example: Many residential properties are installed with trickle vents. These are often misunderstood and closed shortly after occupation, with the building seemingly operating in a sufficient manner to keep them closed. This, in turn, results in the system not being used in the way that it was designed and a poorer ventilated space than the standard set out. Effective education, guides, and codes of practice for building operators and users are required to ensure consumers are making the right choices, manage behavioural change, and ensure health of building occupants. Until the effect on health is fully understood by building users, risks and trade-offs cannot be sufficiently evaluated in the use of a building.

A lack of education, understanding, and awareness can have further impacts on the risk evaluation processes of users. For instance, in the transport sector, the London Underground was often perceived as very high risk because of the inability to effectively social distance when using it. However, the short nature of travel and high levels of ventilation made the Tube one of the lower-risk activities, compared to long-distance train travel with good social distancing but long journey times and ineffective ventilation. Education should draw upon existing research such as that conducted by the PROTECT study[8] to keep the general public up to date with progress in knowledge. Signage used for public awareness is often left out of date by employers or within buildings, and this can operate as a mass disinformation campaign.

Recommendation 7: Public campaign

To create greater awareness about the role of the built environment and transport systems in public health, **UKHSA, in collaboration with others, should undertake a communications campaign for building and transport owners and management as well as the wider public** that heightens awareness of infection resilience, indoor air quality, and wider health considerations for indoor environments.

To effectively deploy the earlier recommendations, a wider communication and information campaign is required to 'make the invisible visible', raising the importance of ventilation and indoor air quality. Awareness, coupled with visible assurance scheme (Recommendation 4) may empower building users to understand their own level of risk and create mechanisms to hold operators accountable. This should draw on existing research by the PROTECT study[8] and other COVID-19 pilots. This should be accompanied by a longer-term drive to raise awareness of the wider links between indoor environments and health.

Policy leadership

The strategic coordination of interventions in the built environment and transport systems to drive the public health, infection resilience, and air-quality improvements requires long-term oversight and ownership within government. Recommendations included within this report target a variety of departments and arm's-length bodies, and will be supported by a wide range of professional bodies. A system that mandates appropriate collaborations between agencies is needed. As the procurers and operators of significant estates, the recommendations impact a broad government audience, from transport to education, health, and justice. For these recommendations to work effectively and symbiotically with one another, as well as with existing policy priorities such as net zero, safety, accessibility, and levelling up, there will be a need for a single owner to maintain oversight. This will support effective coordination of all the organisations involved and join up policies to ensure a seamless experience for the wide range of end users.

A high-level governance operational group, alongside a scientific advisory group that draws upon independent scientists and engineers, could enable strategic oversight of all of these actions. These bodies could cover the day-to-day operations and standards of health within buildings and transport, adjusting to emerging evidence, as well as future resilience and pandemic planning. This could be coupled with the current responsibility for indoor air quality to ensure a joined-up approach, and this strategic coordination would also allow for alignment with other strategic goals, such as net zero. Given that many of the policy levers are owned by DLUHC, the department is well placed to lead this coordination across other key departments such as the Department for Health and Social Care, Department for Transport, UKHSA, and Department for Education.

Recommendation 8: Strategic coordination

To create the joined-up policy-making that will align infection resilient environments with net zero, safety, equality, and accessibility goals, **government should identify a lead department**. This department should act as a strategic coordinator, with a mandate to bring together policy-makers across devolved administrations, government departments, arm's-length bodies, and the professions. This should be supported by a scientific advisory committee that provides independent advice. As owner of the majority of the policy levers, DLUHC is well placed to take this leadership role.

A team of young businessmen and women working and communicating together © Shutterstock

6. Research opportunities

The changes required need to be informed by additional research that continues to build on the multidisciplinary nature of the infection resilient environments research field and international collaboration to maintain the UK's position as a leader in this area. There is also an opportunity to grow the effective research networks across government and academia that have been developed during the COVID-19 pandemic.

Research capability: Defining the field

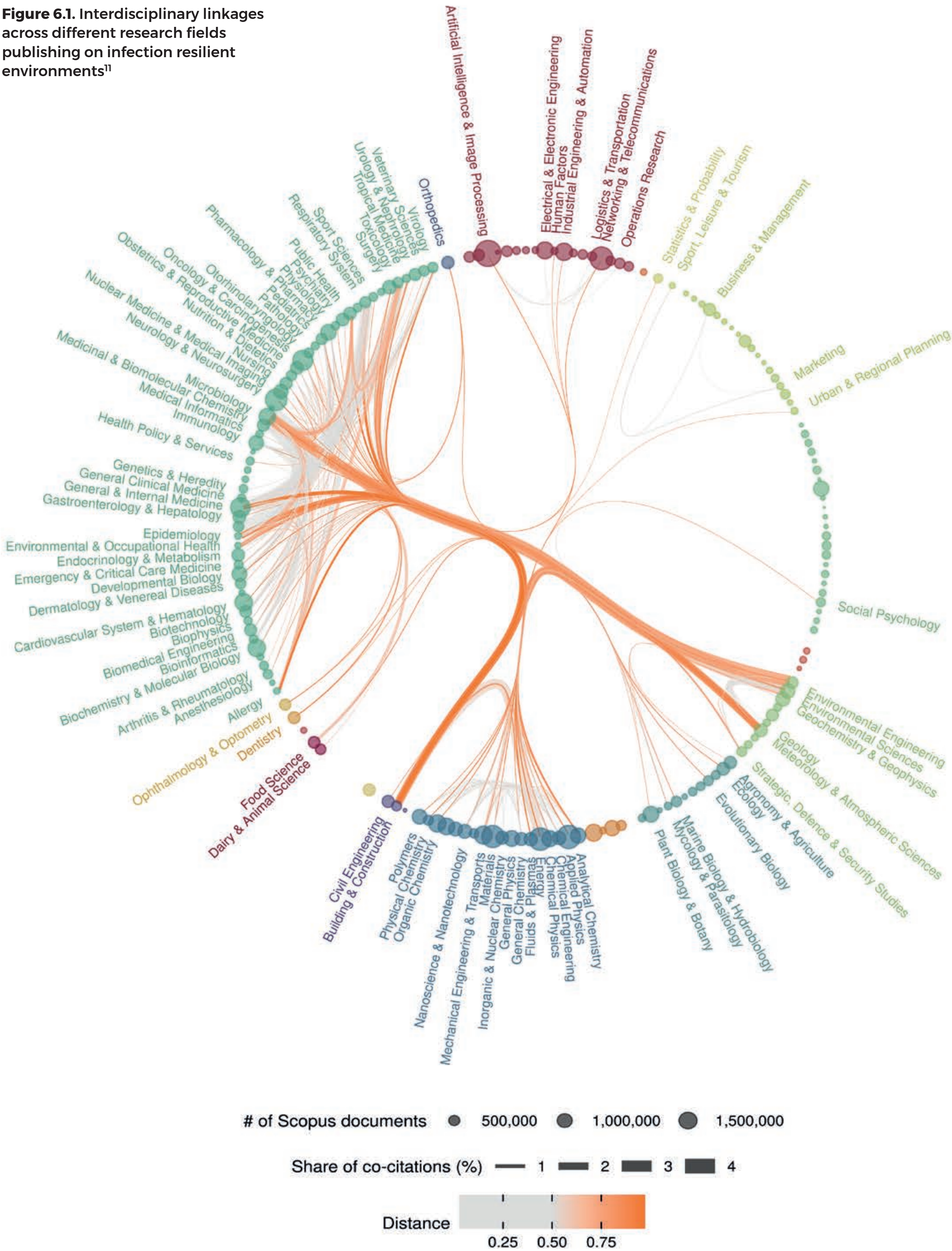
An external commission reviewing the research capability of infection resilient environments undertaken by Elsevier found that the field of infection resilience is small, with just over 9,000 publications identified globally.[11] However, the pandemic resulted in a fivefold growth in the field (between 2020 and 2021) – more than it had in the entire previous decade.

Infection resilient environments is a highly collaborative, interdisciplinary, and multidisciplinary field. Many scientific fields contribute to it, including building and construction, microbiology, energy, social science, meteorology and atmospheric sciences, mechanical engineering and transport, and strategic, defence, and security studies (see Figure 6.1).

The field also has a high degree of international collaboration, with 27% of publications internationally co-written, above the Scopus average of 19%. The UK is among the top 10 collaborative countries for research in this area, with international collaboration rising from 43% in 2011 to 70% in 2021. A key area of focus in the field is applied technologies, with more than half of UK publications focusing on that area and higher than average research citations.

The UK has been contributing to infection resilient environments at a pace faster than the world average, and is among the top three contributors

Figure 6.1. Interdisciplinary linkages across different research fields publishing on infection resilient environments[11]



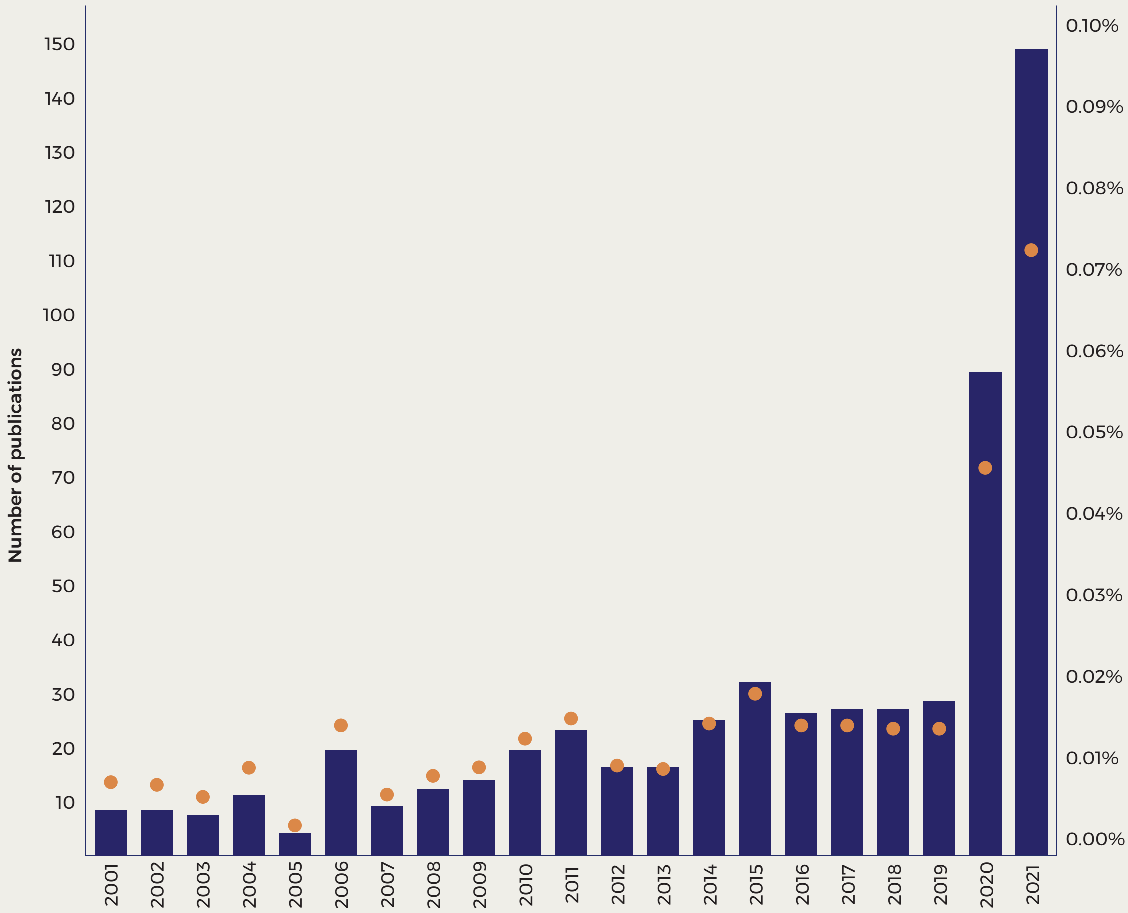


Figure 6.2. **Total annual output (bars) and share of total output (orange dots) of UK publications pertaining to infection resilient environments, 2001–2021[11]**

and leads by the share of total publications. But that output is small; prior to 2020, the UK produced, on average, 30 publications a year. On the other hand, the infection resilient environments field is generally highly cited, suggesting it has a high impact. For the UK, more than a third of the publications are among the top 10% most cited works between 2011 and 2021, while the UK's share of most highly cited publications grew from 29% to 39%. A significant proportion of publications are cited in policy outputs, possibly a result of frequent academic–government collaboration. There have been small increases in publication output that align with instances of infection outbreaks such as SARS or norovirus (see Figure 6.2), suggesting that research in infection resilience will play an important role in protecting public health longer term. This has been demonstrated in the COVID-19 pandemic, with strong academic and government collaboration to provide science advice in emergencies.

Future research

The research undertaken as part of this report identified knowledge gaps that should inform future research. Research capability for infection resilient environments needs to be maintained in order that the UK has the modelling, technology, and behavioural understanding necessary for future pandemics.

Standards for infection resilience

A major area of future research will be to determine how infection resilience can be better measured and assessed across the different building types and transport systems, demonstrating what constitutes sufficient levels of infection resilience. Developing policies about infection resilience will rely on a robust body of evidence to establish minimum and aspirational measures for good infection resilience. Currently, measures such as CO_2 or air-quality monitoring or air exchanges per litre per second exist in some settings. There is scope for further granular scientific research to support the application of standards, especially regarding how they can be applied to the range and scales of building types and transport systems. Another aspect of this research should include studying whether changes in the built environment could create exposure risks, as observed with legionnaire's disease, where the air conditioning, indoor plumbing, and hot water systems risk creating new conditions for its transmission, and how this can be addressed.[4]

Research outputs must also consider how this can be communicated most effectively to different stakeholders. This could inform the Recommendation 1 to provide clear and specific standards, tailored for those who are involved in designing, approving, constructing, managing, using, and inspecting buildings and transport systems.

New technologies

There is also plenty of scope for more research into new technologies. A research capability review[11] found that patent citations are currently rare for infection resilient environments research, though this could be attributed to the relatively recent expansion of research in the field. Research levels show a focus on applied technologies, with more than half of UK publications focusing on this area. Consideration should be given to more sustainable and cost-effective interventions that can be easily installed to reduce the negative health impacts in buildings and transport systems.

Interdisciplinary research

The review also identified that research has largely focused on two topic clusters: buildings, air conditioning, and ventilation, and COVID-19. Other topics are clustered around the health sciences, engineering, and the applied sciences. There are opportunities for renewed interdisciplinary research on the interlinkages, external effects, and co-benefits across different fields on developing infection resilient environments. This includes, but is not limited to, the following areas.

Natural ventilation and externalities

In-depth research is needed on natural ventilation and the externalities involved. There are challenges to the potential benefits when outdoor air quality is poor, especially in urban areas where pollution rates are high and increased ventilation can introduce new pollutants indoors. This is also a challenge in different climates where there are frequent wildfires and dust storms. In different climates, there are also the risks of vector-borne diseases from ventilation, such as malaria and dengue fever. Vector-borne diseases constitute 17% of all infectious diseases in the world.[54] With growing impacts of climate change, there are risks of increases to infectious diseases, such as the tick-borne Lyme disease in the UK, along with further challenges to managing transmissions such as extreme weather events adding pressure to ventilation systems.[55] Basic research is needed on the benefits and costs of ventilation across these various scenarios to inform strategies on optimising ventilation. Research is also needed on new technologies to support both ventilation and quality outdoor air intake and/or to prevent vector-borne diseases. With natural ventilation, there is also scope for further research on 'hybrid ventilation' – that is, the use and mix of natural ventilation with mechanical ventilation.

Mechanical ventilation and energy needs

With mechanical ventilation, the challenge of energy requirements needs to be better understood in order to closely align the goals of infection resilient environments with net zero carbon emissions. In some configurations, mechanical ventilation requires higher energy consumption, especially during summertime.[56] The need for ventilation can also lead to higher energy consumption for maintaining ambient indoor temperatures in colder climates. Hybrid working scenarios, introduced during the COVID-19 pandemic, decreases the efficiency of workspaces while needing similar energy consumption levels to heat and ventilate buildings, despite variances in occupancy, while also increasing energy consumption at home.[57] There are ways to manage this balance, from simple design decisions to engineering interventions. Further research can improve our understanding of energy needs to optimise energy use across various sectors and consider issues such as maintenance and longevity, impacts of noise, and user interfaces.

Public transport

There is an opportunity to conduct further research regarding public transport. Transport was a unique challenge to this report because of the similarities and differences in how it is designed and used compared to buildings. Early in the pandemic, people were more wary of using public transport while private vehicle use increased.[58] The UK Research and Innovation-funded *Transport Risk Assessment for COVID Knowledge* programme concerning infection risk across different transport vehicles will bolster our understanding of the various transmission mechanisms.[59] Further research is needed to establish minimum standards for infection resilience in transport, and to understand and support user behaviour to use public transport.

Spatial configurations

Further research is also needed on how people interact with the spaces within buildings and how spatial configurations and occupant density can affect infection spread. This can be used to inform whether the recommendations are working or need to be updated, as well as to provide support to encourage user behaviour to interact with buildings safely. This also aligns with the need for research on how spatial configurations can actively encourage or discourage social interactions and how to maintain optimum density levels when physical distancing is required. This needs to be supported with additional research on the ways in which diseases spread through social interactions, and how we can continue to safely interact across the built environment.

Social and economic factors

Future research must be conducted across the breadth of social and economic demographics. Public health research has commonly documented how people living in deprived neighbourhoods have suffered from poorer health outcomes.[29] This has been reinforced with the COVID-19 pandemic, whereby those living in low-income neighbourhoods were more likely to have poorer baseline health, live in crowded housing, in areas with higher levels of outdoor air pollution, lack access to green spaces, and have to maintain their regular work patterns during lockdowns – traveling via public transport to their workspaces – leading to higher infection and mortality rates, in comparison to people in higher-income brackets.[60] Future infection resilient environments research must consider how to design safer built environments that are affordable, accessible, and available to all.

7. Considering the way forward

The COVID-19 pandemic is a health crisis of a scale that will have a deep, lasting global impact. It is vital that the UK takes the opportunity to learn lessons and respond to the systemic weaknesses uncovered by an airborne virus. We are now aware that the UK's building stock is not being operated according to the current standards – for various reasons, including that it was built to previous standards, or before standards were introduced; it has been modified over time; or is not operated as intended – and this needs to change.

It is critical that the infection resilience of the UK's built environment and public transport is improved to reduce transmission of future waves of COVID-19, seasonal diseases, and the next pandemics. Making this holistic change requires action across the infrastructure lifecycle, from design and commissioning to operation and use, while ensuring that changes to individual components do not adversely affect the system as a whole.

This report makes eight recommendations, the implementation of which will require significant changes to how we design, upgrade, and regulate our built environment, supported by the skills and capacity to be deliverable. While it is important to improve the quality of the majority of our indoor environments, some prioritisation may be required. This could be based on the following considerations:

- the spaces that are of greatest risk because of high densities of people, or the presence of vulnerable people
- the spaces that do not have the equivalent of a duty-holder with the awareness and competence to manage for infection resilience
- the spaces that enable maximum benefit to be achieved for the resources available
- where action can be aligned with other planned activities, such as safety improvements in high-rise residential buildings or home retrofit programmes for net zero.

Annex A: Methodology

Evidence workshops

A series of evidence workshops was designed to identify how best to embed infection resilience across the infrastructure lifecycle. The outcomes of these discussions informed the present report's recommendations.

Workshop A: 'Understanding interventions'

This workshop brought together policy-makers and regulators alongside experts from the architecture, engineering, and construction professions, institutional bodies, and industry representatives, including those responsible for managing buildings, building controls, and transport systems.
Through ideation sessions, the workshop identified potential interventions with which to make environments more resilient to infection and opportunities for change across the governance system. The outcomes were collated into a long list of possible interventions and leverage points.

Workshop series B: 'Contextual prioritisation'

Following the above-described large collective workshop, a series of smaller workshops was conducted, grouping stakeholders around the five different building and transport classes (ie industrial, residential, commercial, local community, transport). Within these workshops, the changes required were discussed and debated. The interventions identified in Workshop A were ranked by participants across the stages of 'strategy and design', 'construction and handover', and 'in-use and retrofit'. For the top-scoring interventions, systems analysis was applied that considered the health, governance, economic, environmental, and social implications.

This workshop series resulted in a number of emerging recommendations, and informed the applicability of those recommendations to different types of buildings and transport. The emerging recommendations were then tested with policy-makers and experts and further refined.

Workshop C: 'Behavioural considerations'

The final workshop was a behaviour-focused group discussion. Participants included expert academics from the fields of behavioural science, public health, and design who discussed the limitations and opportunities across the emerging recommendations.

External commissions

To complement the UK-focused workshops, we commissioned supporting research which was undertaken by external consultants. These included a social cost benefit analysis (SCBA) by NERA Economic Consulting,[2] a UK research capability review by Elsevier's Analytical Services,[11] and a review of international practice by Arup and the International WELL Building Institute.[48]

Social cost benefit analysis

A SCBA was commissioned to assess the full spectrum of costs and benefits, including economic and social, of improving infection resilience in the UK's built environment and transport systems – and the costs of not doing so. Conducted by NERA Economic Consulting, the objectives of this commission were to develop a clear methodology for undertaking an SCBA, including practical techniques for valuation and sensitivity analysis, and to undertake a SCBA across industrial, commercial, residential, and local community buildings. The analysis included transport hub buildings (eg airports), but did not include the wider transport system, because of the lack of available data and the relatively low risks owing to shorter times spent on public transport.

The analysis involved four phases incorporating preparation and literature review, development of analysis methodology, application of the SCBA, and conducting a sensitivity analysis. This process assigned monetary values to different costs of inaction and the effectiveness of interventions. The benefits considered direct health benefits, indirect benefits on the economy, and other non-market impacts and societal costs. The second phase developed a total appraisal methodology to assess the full economic costs and benefits of implementing interventions, and this methodology was then applied to evaluate net benefits. Finally, a sensitivity analysis was completed to identify how variations in underlying assumptions affect the final SCBA results – particularly because measures to improve infection resilience are inherently uncertain, owing to the difficulty of predicting the frequency and intensity of future infectious diseases. The key conclusions are discussed in Section 6.[2]

Research capability review

A research capability review was commissioned to assess the research landscape for infection resilient environments.[11] The objectives of the commission were to understand the key academic stakeholders in the UK, define the volume of research in the field, the impact it has had, and how this compares internationally, including research trends over time. The review also aimed to identify existing multidisciplinary links as well as understand how the research has been funded in the UK.

The review was undertaken by Elsevier, who reviewed an infection resilient environment publication set built from a Scopus query containing over 300 key phrases in the period between 2001 and 2021. This yielded around 9,099 documents, with a precision rate of 95% on the publication set following expert feedback and a recall rate of 87% of the full data set based on a verified set of articles. Their review did not include grey literature. For the results, see Section 6.

International practice

A review of international practice was commissioned to examine international examples of interventions in the built environment and transport systems to reduce transmission of infection. The objectives of the commission were to understand how the idea of making buildings and transport less susceptible to disease transmission is conceptualised globally and identify what is best practice, outlining emerging challenges and opportunities.

The commission was undertaken by Arup. They developed an overview by conducting a literature review, as well as an extraction of practical experience and foresight techniques. Their literature review included relevant research within Arup and the International WELL Building Institute. The research also involved stakeholder consultations through key informant interviews and participatory workshops across different building typologies, in order to verify the findings from the literature review, fill gaps in the data, and source relevant case studies.[48]

Annex B: Wider lessons from COVID-19

The COVID-19 pandemic has inevitably increased public awareness of the role of the environment in public health. The transmission risk in different environments has a wide range of knock-on effects. As part of the evidence-gathering workshops (see Annex A), we collected feedback from a broad range of stakeholders on the impacts of a lack of infection resilience in the built environment.

The workshops highlighted a broad range of health, social, economic, and governance systems, and environmental risks and opportunities. These varied based on the different types of buildings or business models.

Health

The direct health impacts are a key concern. Shared spaces can increase rates of infections and disease, especially when disease prevalence in a population is high. Without mitigating risks of transmission within buildings, infections will continue to be easily spread between occupants. With COVID-19, rapid transmission led to absences from work, reduced capacity due to long COVID, and, in the worst cases, severe illnesses and death.

As cases rise, access to healthcare can become limited as parts of the NHS become overwhelmed. The need to protect healthcare capacity has been a core part of government messaging during the pandemic, and prompted measures such as lockdowns to limit preventable deaths.[61] Additionally, as more patients with COVID-19 are admitted to healthcare residential settings, the risk of hospital-acquired infection needs to be managed carefully.

The COVID pandemic has brought about wider health implications, such as an increase in sedentary lifestyles, which will have longer-term health consequences.[62] There is an opportunity for greater collaboration in building design for infection resilience that encourages wider benefits for health. For example, making stairways more prominent encourages physical activity and correspondingly reduces the number of people in lifts.

Importantly, the pandemic has highlighted the importance of indoor air quality. The National Institute for Health and Care Excellence's guidelines about indoor air quality[63] and the CIBSE guidance on health and wellbeing in building services[38] both raise awareness of the role indoor environments can have on public health.[13,19]

Social

The COVID-19 pandemic has led to severe mental health consequences for many people. There have been changes to working patterns, with more people working remotely and staying in self-isolation out of concern for travelling or working in shared spaces.

Biomedical engineer with projected cells © This is Engineering

A major impact of the recent phases of the pandemic pertained to lost or a reduced quality of education. School closures during lockdowns moved teaching to remote settings and the lack of face-to-face interaction has left many students without effective support and supervision, access to resources, or even opportunities to socialise with one another. For schoolchildren, materials and teaching time were not offered or received equitably, and the success of remote teaching platforms has been variable, depending on family circumstances (eg if parents were working or not, if they were able to offer extra support, whether the family had access to appropriate devices for accessing online learning), with some students not receiving any schooling during the lockdowns. This will have implications for the quality of education provided, and it is likely that there will be longer-term impacts that are not yet understood, such as educational progressions or a loss in long-term earnings potential.[64]

Health inequalities driven by factors such as deprivation, unequal access to education, low income, and poor housing can result in poorer health, reduced quality of life, and even premature death.[30] COVID-19 exacerbated these inequalities, with disproportionate impacts for lower-income communities and other minority groups.[29]

Economic

COVID-19 has had a significant impact on global economies, with the International Monetary Fund projecting in 2020 – during the height of the pandemic – that global growth would decline 4.9%.[65] High infection rates have had direct costs for healthcare and have led to increased unemployment and income losses and supply chain challenges. Beyond the immediate economic costs, there are concerns that the condition known as 'long COVID' may also correspond to increasing costs with respect to healthcare and productivity.

For customer-based businesses, such as public transport, museums, and retail, recovery from COVID-19 lockdowns has meant a strong reliance on reducing capacity and influencing individual behaviours through one-way systems and hand-sanitiser stations, to ensure the willingness of customers to come inside. Keeping businesses open with significantly reduced capacity reduces revenue and risks leading to closures and job losses. By not addressing health risks, the subsequent decreasing confidence in systems and growing public fear will prevent people from using buildings and services. In worst-case scenarios, building owners are worried about incurring the costs of managing low-occupancy buildings or exposing staff to sickness and facing high rates of absenteeism again, linking back to loss of revenue.

Governance

COVID-19 has highlighted a lack of consideration of health and wellbeing in relation to how buildings and transport are commissioned, designed, managed, and operated. Building policy has largely focused on physical safety, accessibility, and energy efficiency, with comparatively little attention within policy frameworks on the indoor environment and its impact on public health. Legislation relating to health in buildings can be disjointed, with different aspects of health or even different types of infection risks covered by different regulations and little consideration of the interactions between risks to encourage health to be considered as a whole.

A range of voluntary certification standards exists that recognise the health performances of buildings through their guided assessment criteria. The pandemic saw a substantial increase in the adoption of these standards to demonstrate that the health of the indoor environment was being considered by building owners and managers.

Management of the built environment will play a role in public health and protection. A lack of monitoring of indoor environments or clear and accessible standards to monitor against limits the ability to make informed decisions. Building and facilities managers will also need support to design the right intervention strategies for various spaces and how they are used.

Environment

Infection resilience is not only having an impact on the physical health of the population but is also changing travel, energy demands, and the use of spaces, which in turn is going to have an impact on the environment. Lifecycle emissions need to be considered: although overall carbon emissions reduced during the lockdowns, and many buildings also reduced emissions, some emissions were displaced to other sectors – for example, residential buildings saw an increase in emissions in 2020.[66] As lockdowns and restrictions were lifted, emissions quickly 'rebounded' and there are various concerns remaining regarding environmental pressures, such as the lack of confidence in public transport and subsequent increase in personal car use resulting in increasing emissions from transport.

The UK's net zero commitments cannot be met without addressing the performance of buildings. There will be conflicting priorities for associated energy demands of infection prevention measures such as mechanical ventilation; however, these are not always in opposition. Meeting net zero will only be achieved through implementing a large-scale retrofit programme for the housing stock, and it is essential that this addresses not only the need to reduce overall energy usage and switch to low-carbon sources but also to improve health outcomes through the retrofit programme.

Evidence suggests that growing effects of climate change and changing land use have a direct link to the spread of pathogens, and the likelihood of an endemic- or pandemic-prone pathogen is increasing.[67] For example, warming climates could expand the range of disease-carrying species such as mosquitos and increasing farming and habitat loss is increasing exposure to zoonosis whereby pathogens can 'spill over' from animal species to humans. Furthermore, increased global travel and connectivity may facilitate the global spread of new diseases rapidly (as seen with COVID-19).[68]

Annex C: Summary of the SCBA

Defining the base case

A 'base case' was established to understand the social and economic costs of taking no action to improve the infection resilience of our environments. This can also be used to understand the economic argument for potential interventions. For this SCBA, the base case incorporated assumptions about infection transmission routes, infection rates, patterns of behaviours, time to develop vaccines, and the level of government intervention in response to the pandemic (eg lockdowns).

The total economic costs were estimated at £23 billion (discounted 2020) over a 60-year period for an influenza-like infection, with seasonal influenza contributing £8.2 billion and pandemic influenza contributing £14.7 billion. The pandemic costs account for 64% of the total cost. However, the frequency and severity of a potential pandemic are unknown, and so the model took an average of different forecasts to predict the occurrence of such an event every 63 years. Moreover, even outside of pandemics, seasonal respiratory illnesses have a significant cost, with the annual death rate from seasonal influenza and pneumonia estimated at around 1.9 per 10,000-population sample.

These costs consider the impacts of illnesses, healthcare costs, deaths, depression, domestic violence, lost education, unemployment, and immediate and long-term impacts on GDP (see Figure C.1). The majority of the costs are estimated to be economic for a pandemic scenario (48%) and health for seasonal illnesses (51%).

While pandemic illnesses are shown to have a drastic impact with respect to deaths and the associated costs, the responses to pandemics (eg lockdowns) have a direct and detrimental impact on the economy. During the COVID-19 pandemic, the immediate reduction in economic activity due to government lockdowns and restrictions on mobility resulted in a decline in GDP, with an annual average of 6.8% and similar patterns seen in other advanced economies.

Development of the model considered published estimates on the impact of pandemic severity in terms of mortality and income losses: pre-COVID publications suggested mortality and income losses in the order of 0.3%[69] to 20%[70] GDP for an influenza pandemic; however, more recent estimates published since the pandemic, which consider wider societal impacts such as loss of education as well as direct economic impacts of lockdowns, have estimated higher figures – up to 100% of GDP in some economies.[71] The baseline model uses the average GDP decline from COVID-19 figures and includes long-term scarring of 2% per year.

Beyond economic costs, deteriorating health within a population has far-reaching effects detrimental to quality of life. Accordingly, social

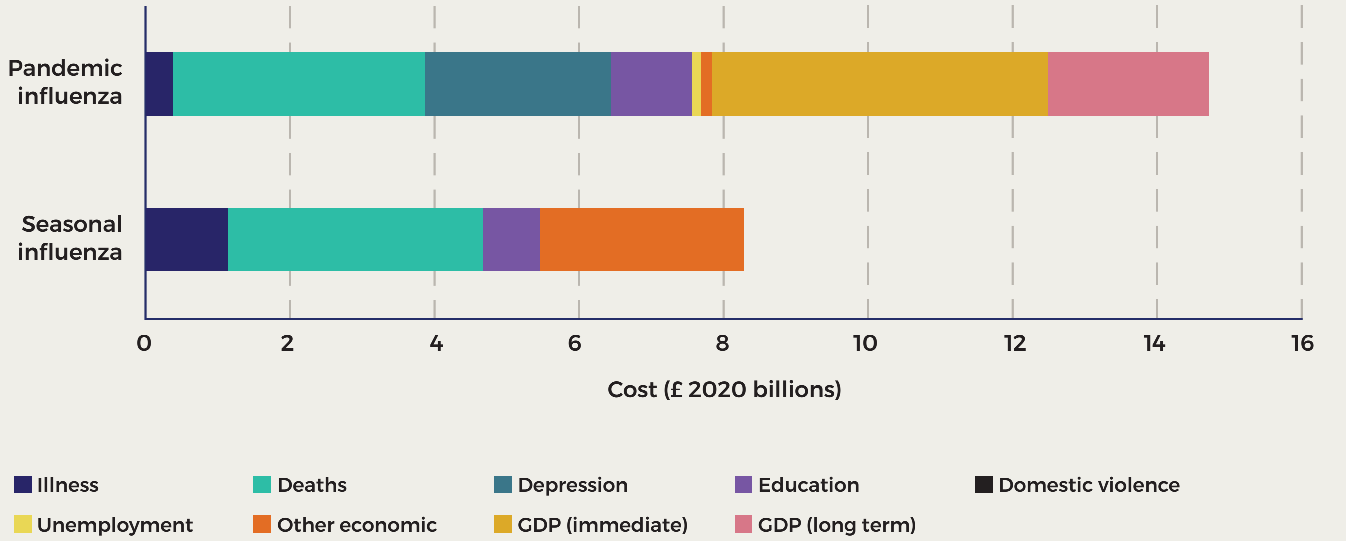


Figure C.1. Annual discounted expected costs of illness (£ 2020 billions)

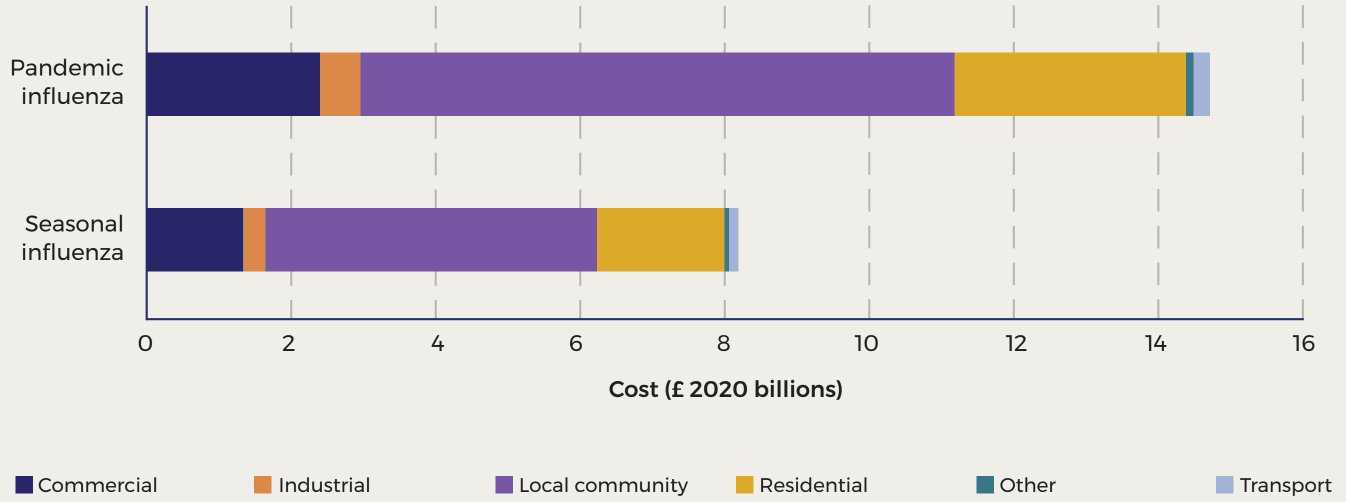


Figure C.2. Annual discounted expected costs distributed over different building types (£ 2020 billions) costs are also considered in the analysis, where a monetary value could be assigned based on accepted health-related quality of life measures and quality-adjusted life years in standard literature. In the SCBA, the measures used included lost education, depression, and domestic violence.

The base case also considered the distribution of costs over the different building and transport classes, based on a transmission model that estimates the frequency, duration, proximity, and exposure in different environments. Over half of the costs are estimated to originate from community buildings, including schools, hospitals, and community services (Figure C.2), despite only making up an estimated 4% of the existing UK floor space. This aligns with recent experiences from COVID-19 wherein high transmission rates were seen in community environments, possibly because of high rates of interactions between different households and the fact that these buildings were more likely to remain open when other parts of the economy were locked down.

These scenarios present the high cost of inaction, especially in our commercial, local community, and residential environments. In the event of a future, severe, influenza-like pandemic in the next 60 years, the total cost of inaction could be up to £1.3 trillion (discounted 2020). Furthermore, this impact is expected to grow over time, as GDP, population, and life expectancy are all projected to increase.

Benefit of intervention

There is an opportunity to make changes that improve our indoor environments now and help reduce the transmission of infections and the associated social and economic impacts.

In the SCBA, benefits were calculated as a reduction in infection costs due to fewer cases. This assumed that the share of social and economic impacts has a linear relationship to the number of cases (eg depression and GDP, which are driven mainly by the likelihood, duration, and nature of lockdown).

This SCBA focused specifically on four defined ventilation strategies across different building types, offering insights into where these changes may have the greatest effect. These insights should aid allocation of resources to where they can have greatest impact. However, the economic benefits for infection resilience should not be the only reason to decide to implement ventilation strategies – instead, the wider health, productivity, and environmental implications should be considered in context. For example, reducing domestic energy demand for net zero may require mechanical ventilation with heat recovery; by considering the agendas together, the long-term benefits have the potential to be significant.

Limitations of the SCBA

There are limitations to the SCBA approach; the analysis takes fundamentally utilitarian assumptions in trade-offs between gains and losses. The approach also relies on assumptions about changes that will happen over time, ways to monetise elements, and how to take trade-offs between the present and future. The results provide generalised insights, and not detailed information taking into account the heterogeneity of buildings.

The calculations for costs incorporate assumptions on healthcare capacity remaining at the same levels, which is strongly related to the likelihood of lockdowns and consequently the social and economic impacts estimated. Improvements to NHS capacity, provision of treatments, or aversion to strict lockdowns might reduce some of the economic costs of future pandemics. The assessment of the interventions also assumes use of current technologies and practices, which offers some room for improvement and cost reduction.

The sole focus on ventilation strategies and on influenza-like pandemics only, as well as the exclusion of transport modes, are known limitations of the scope of the research. The investigation of ventilation strategies and BCR analyses are based on assumptions that each area of floor space gives the same average benefit. However, this is more likely to be heterogeneous

Ventilation example

Long-term changes can be made to reduce viral transmission in indoor environments through the provision of outside air, which dilutes the prevalence of the virus in the air, reducing aerosol and close-contact transmission. Where a pandemic or seasonal flu is airborne, this can reduce incidences of super-spreader events. As a baseline, the SCBA considered that 40% of the transmission of future seasonal and pandemic influenza would be transmitted by aerosols.

The SCBA considered four main ventilation strategies in the different building types: installing mechanical ventilation in all buildings that require improvements, ensuring existing ventilation system are properly operated, installing less expensive mechanical ventilation systems, and combining less expensive ventilation systems and natural ventilation. Two variations of mechanical ventilation were explored to account for a broad range of estimates for installation, operation, and maintenance costs of ventilation systems. The SCBA looked at the cost profile (per m^2) for different building categories to establish which, if any, environments would be cost effective in terms of the implementation of interventions. The SCBA identified the benefits of these different strategies for infection resilience (see Figure C.3). It did not incorporate the implications for wider co-benefits for better-ventilated spaces.

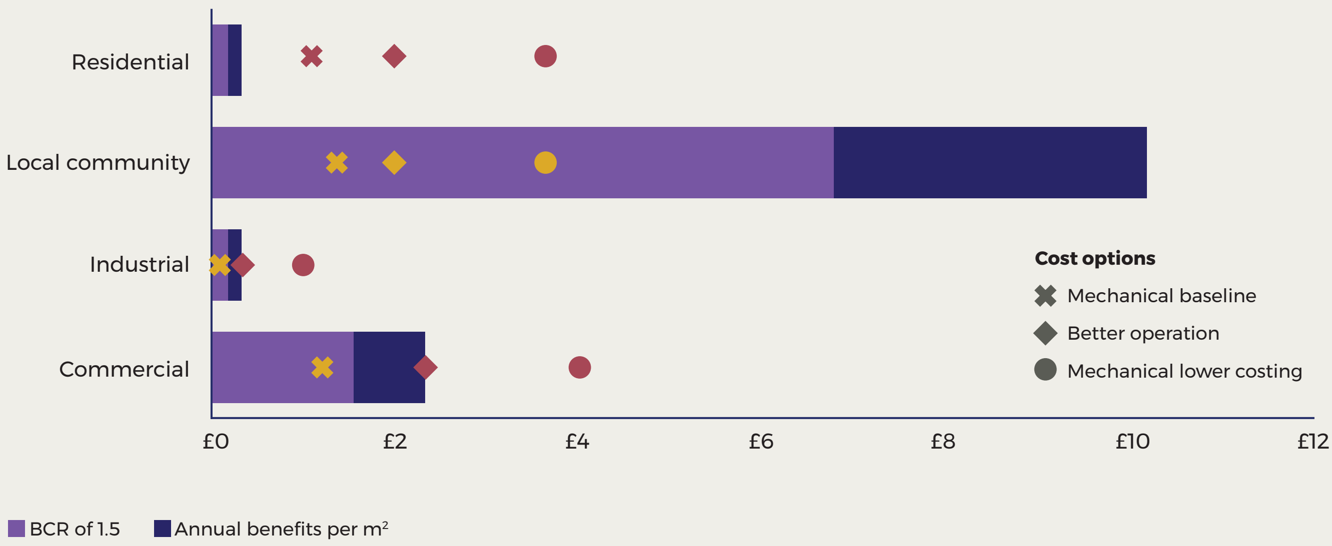


Figure C.3. Potential benefits from using selected ventilation strategies in different building classes

***Notes*: Annual lifetime discounted benefits and costs in £ 2020. Lifetime benefits are the sum of annual infection resilient benefits over 60 years. Benefits do not include wider benefits of ventilation such as though improved productivity. Costs include installation, operation, and maintenance. Yellow indicates a benefit-cost ratio (BCR) of at least 1.5, indicating benefits are at least 1.5 times higher than costs (BCR > 1.5) while red indicates the BCR is below 1.5. Mechanical combined with natural ventilation has similar results as the lower costing scenario. Numbers may not add up due to rounding.**

When considering the benefits for infection resilience, local community buildings were the only building type for which interventions were consistently cost effective in purely economic terms when implementing any of the strategies investigated. In commercial buildings, the benefits for infection resilience outweigh the costs for some interventions (Figure C.3). Mechanical ventilation would not be cost effective in residential buildings solely for the purposes of reducing transmission; consideration is necessary regarding the wider co-benefits, alternative lower-cost strategies, and innovation to substantially reduce costs.

Potential co-benefits

Improving ventilation from substandard levels is projected to reduce aerosol transmission by about 50%, which could have a significant impact on health in public spaces. Beyond transmission risks, there are broader benefits from general improvements to ventilation, such as reducing rates of asthma and increasing productivity in the workplace. Several studies have looked at the impacts of healthy work environments, particularly from ventilation, on employee productivity: although there is an overall lack of data, in terms of range of ventilation rates or how productivity is measured, there is a general trend reported that higher ventilation rates are associated with positive but diminishing marginal improvements in productivity.[33]

The SCBA model included a conservative estimate of the impact of ventilation and the scope of labour productivity. Based on the assumption that meeting a 'good' level of ventilation would be expected to improve productivity by 2.7%, the modelling indicated that the average annual discounted benefits per square metre may in fact significantly increase for commercial and local community buildings, compared to the analysis from the perspective of just reducing cases of infections. Estimates rose from £2.5 to £6.5 for commercial buildings, and from £10.2 to £13.6 (per m^2) for local community buildings. This suggests that the benefits of improving ventilation are greater than for infection resilience alone.

within building type (eg some buildings, such as catering, may be riskier than others, such as retail) and will also depend on the location within the building (eg changing rooms may need ventilation, but not an entire factory floor).

There are further social costs than have been analysed by the commissioned SCBA, but these lack clear evidence regarding their monetary value or direct causal link to infection. Nevertheless, it is worth noting that there will be much broader impacts that should be factored into policy decision-making. Additionally, the SCBA was not able to incorporate disproportionate impacts for low-income households, women, and ethnic minority groups, but it is accepted that the pandemic exacerbated existing financial and health inequalities.[60,72] Minimising the inequitable distribution of costs and benefits is a vital consideration for levelling up.

Further information about the assumptions and sensitivity analysis can be found in the NERA report.[2]

Annex D: Outline of an example building regulation for health

This report recommends consideration of a new building regulation creating a specific duty that requires building work to be carried out with regard to the long-term health of occupants.

This is within the vires of the current powers to make building regulations set out in section 2 of the Building Act 1984 (as subsequently amended by the Sustainable and Secure Buildings Act 2004 and the Building Safety Act 2022). This annex is an initial demonstration of how such a regulation and supporting guidance could be formulated, and demonstrates how much of it brings together a number of existing measures with a focus on achieving enhanced health outcomes from building work.

This proposal could be adopted either through a new part of Schedule 1 of the Building Regulations (2010), as amended a number of times, or through a new regulation similar to Regulation 7 on materials and workmanship. Either a new part or a new regulation would be supported by further guidance in the form of an Approved Document. This example proposes a new regulation and Approved Document to support it.

Health impacts of buildings

7. (1) Building work shall be carried out —

   (a) with adequate and proper materials that are constructed or installed so as to —

      (i) be appropriate for the circumstances in which they are used,

      (ii) provide a healthy indoor environment for all those who occupy the building.

Summary

0.1 This Approved Document would give guidance on how to comply with the new regulation or part of the Building Regulations **for the mitigation of negative health impacts in buildings**.

0.2 We propose that this Approved Document should contain the following primary sections:

Approved Document section	Related Building Regulations requirements
Section 1: Ventilation	Approved Document F
Section 2: Air quality	Approved Document F
Section 3: Thermal health	Approved Documents L and O
Section 4: Moisture	Approved Document C
Section 5: Dust and pests	
Section 6: Lighting and views	Approved Document L
Section 7: Noise	Approved Document E
Section 8: Water quality	Approved Documents G and H
Section 9: Safety and security	Approved Documents B, K, and Q

Application

0.3 The guidance in this new Approved Document should be divided into multiple volumes, whereby they apply to both multiple occupancy dwellings and buildings other than dwellings (non-residential buildings).

0.4 The guidance should apply in the first instance to new buildings.

0.5 Further additional information should be provided on applying the guidance to extensions to and work on relevant existing buildings.

Consideration of listed buildings, buildings in conservation areas, scheduled monuments, and historic and traditional buildings

0.6 Work to the following types of dwellings could be considered for exemption:

- those listed in accordance with section 1 of the Planning (Listed Buildings and Conservation Areas) Act 1990
- those in a conservation area designated in accordance with section 69 of the Planning (Listed Buildings and Conservation Areas) Act 1990
- those included in the schedule of monuments maintained under section 1 of the Ancient Monuments and Archaeological Areas Act 1979.

0.7 In determining whether full health impact improvements should be made, the building control body should consider the advice of the local authority's conservation officer.

0.8 Additional guidance should be made available from Historic England on how to incorporate this new part to the Building Regulations in historic and traditionally constructed buildings.

Interactions with the Workplace Regulations

0.9 Exemptions should be considered relative to risk and ability for organisations to comply with the Health and Safety at Work etc Act 1974 and Housing Act 2004. This includes considerations of the Workplace (Health, Safety and Welfare) Regulations 1992, the Control of Substances Hazardous to Health Regulations 2002, and the Housing Health and Safety Rating System.

Interaction with other parts of the Building Regulations

0.10 Evidence of compliance with specific parts of the Building Regulations covering condensation, damp, water ingress, ventilation, noise, air quality, water quality, and overheating may also provide sufficient evidence of meeting the requirements of Regulation/ Part X in relation to these characteristics. However, in some situations – such as homes being developed close to major roads – noise, ventilation, and air quality issues as well as overheating risk may require additional consideration. In areas of high exposure to driving rain, further consideration may be required to demonstrate that the requirements in relation to moisture ingress and avoidance of damp and mould will be met.

Ventilation

Intention

The Secretary of State should consider here whether the ventilation system is designed sufficiently to protect the health of persons in and about the building from adverse effects. The points could include:

a. The building meets the minimum ventilation requirements required to reduce transmission of infection.

b. The building meets the minimum, sufficient filtration requirements of outdoor and recirculated air for all particle size fractions.

c. The building mitigates the inflow of outdoor air intakes near outdoor sources of pollutants.

d. The building sets out requirements for the commissioning, maintenance, and monitoring of systems to sufficiently prevent and resolve ventilation issues.

e. An analysis is made of the technical, environmental, and economic feasibility of using alternative systems that minimise negative health impacts, such as transmission of infection.

Air quality

Intention

The Secretary of State should consider here whether the building has sufficiently low chemical emissions to secure the health and safety of persons in and about the building. Considerations could include:

a. The building materials fall below the maximum level of chemical emissions to limit sources of volatile and semi-volatile organic compounds that might jeopardise health.

b. In refurbishment or retrofit of existing buildings, the building is inspected for legacy pollutants such as lead, polychlorinated biphenyls, and asbestos, and these are removed where necessary.

c. Reasonable precautions are undertaken to avoid risks to health caused by contaminants or vapour intrusion.

d. Humidity levels fall between the minimum and maximum requirements to mitigate any health and odour issues.

e. Air quality is tested and meets the minimum requirements for health above and as stipulated in Part F.

Thermal health

Intention

In the Secretary of State's view, the requirement relating to thermal comfort would be met by demonstrating compliance with Part O of the Building Regulations and demonstrating achievement of the relevant requirements of the Housing Health and Safety Rating System.

Moisture

Intention

In the Secretary of State's view, the requirement relating to moisture should consider whether the building is constructed to protect the health and safety of persons in and about the building from harmful effects caused by moisture and condensation.

Dust and pests

Intention

In the Secretary of State's view, the requirement relating to dust and pests would be met if the building is able to satisfy the relevant requirements of the Housing Health and Safety Rating System.

Lighting and views

Intention

In the Secretary of State's view, the requirement relating to lighting and views would be met if the requirements relating to lighting in Approved Document L1 or L2 are met, as appropriate.
In dwellings, all habitable rooms other than bathrooms and spaces for sanitary provision should have reasonable access to daylight.

Noise

Intention

In the Secretary of State's view, the requirement relating to noise would be met by achieving the relevant requirements of the Housing Health and Safety Rating System.

Water quality

Intention

In the Secretary of State's view, the requirement relating to water quality would be met by achieving the relevant requirements of the Housing Health and Safety Rating System.

Safety and security

Intention

In the Secretary of State's view, the requirement relating to safety and security would be met by achieving the relevant requirements of the Housing Health and Safety Rating System and of Part Q of the Building Regulations.

Civil engineer designs underground tunnels © This is Engineering

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Building Engineering Services Association

Cabinet Office

Chartered Institution of Building Services Engineers

Department for Business, Energy and Industrial Strategy

Department for Education

Department for Environment, Food and Rural Affairs

Department for Levelling Up, Housing and Communities

Department for Transport

East Suffolk and North Essex NHS Foundation Trust

Elsevier

First Bus

FirstGroup plc

Government Office for Science

Health and Safety Executive

HOK Architects

Hoare Lea

International WELL Building Institute

Institute of Asset Management

Institute of Healthcare Engineering and Estate Management

Institute of Workplace and Facilities Management

Institution of Mechanical Engineers

Lancaster University

London Transport Museum

Ministry of Justice

Mott MacDonald

NERA Economic Consulting

NHS Education for Scotland

Office for Product Safety and Standards

Royal Institution of Chartered Surveyors

Royal Institute of British Architects

Scottish Government

Sodexo

Sweco

Transport for London

UK Health Security Agency

University of Cambridge

University College London

University of Leeds

University of Southampton

Warwick Business School

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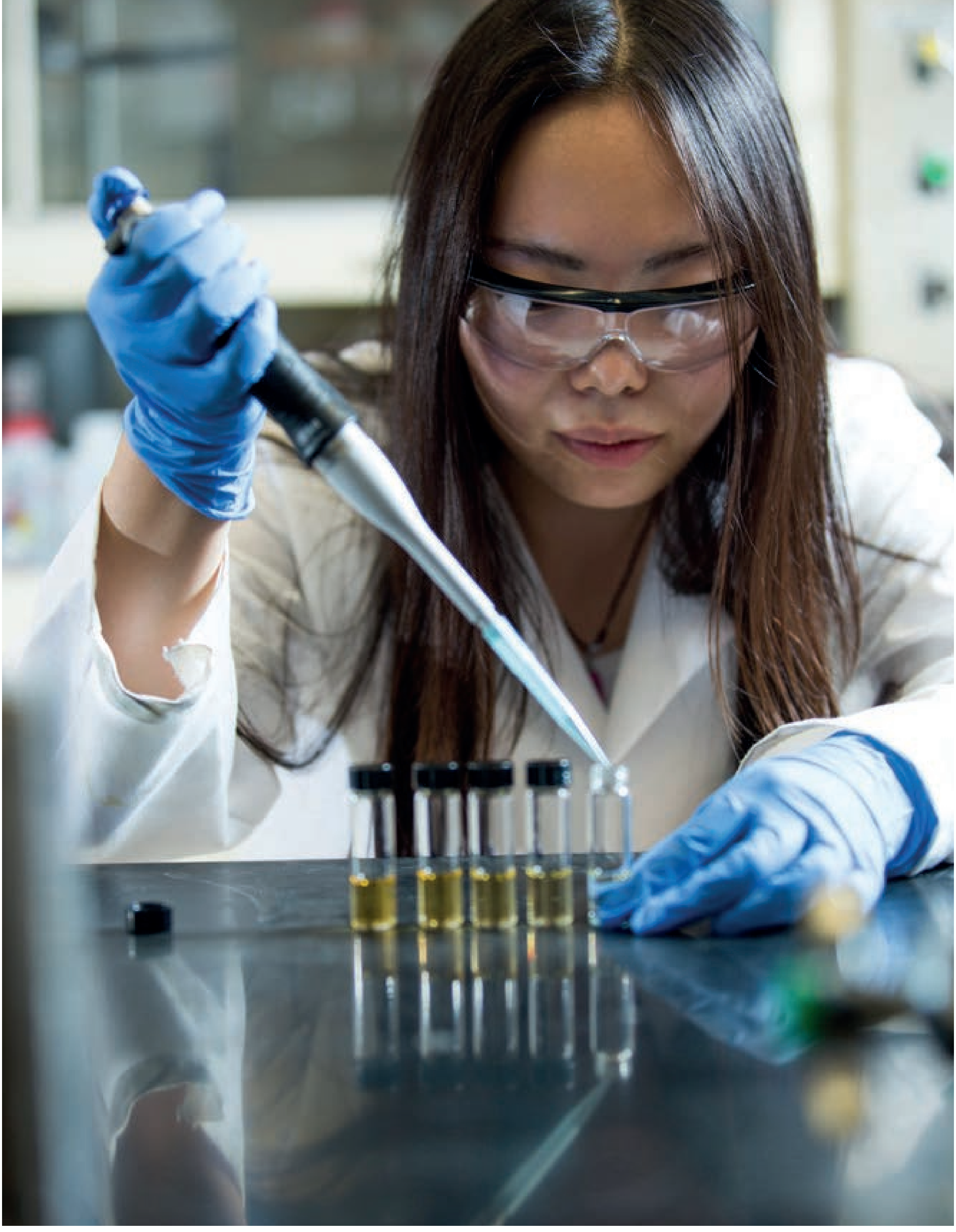

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