
**Buildings and civil engineering
works — Building resilience strategies
related to public health emergencies
— Compilation of relevant
information**

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 59, *Buildings and civil engineering works*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Looking back at the history of building design, improvements have sometimes been driven by epidemics, such as the 19th century cholera outbreak in London, which led to a greater emphasis on ventilation and the use of dense, easy-to-clean materials such as tiles rather than carpets^[1]. After the 1918 flu pandemic, guest bathrooms were added to residences to reduce exposure and infection risk^[2].

Improvements are still required in public health emergencies of the 21st century where buildings based on current design standards show inadequate adaptability. In COVID-19, for example, large numbers of densely populated public buildings such as schools, offices, malls were forced to close due to high risk of infection. Even in homes the risk of infection still existed. Medical facilities could not bear the sudden increase in infectious patients, and some sports stadiums, exhibition halls, etc., were transformed into temporary hospitals. In face of these challenges, a number of improvements have already appeared in some cases, as well as in some guidelines, standards and studies by relevant international, national, and regional organizations and institutions.

This document collects the challenges posed by the epidemic to built environment and the corresponding adaptation solutions during 21st century public health emergencies, particularly COVID-19, to provide a reference for resilience design of built environment to adapt to future changing environment.

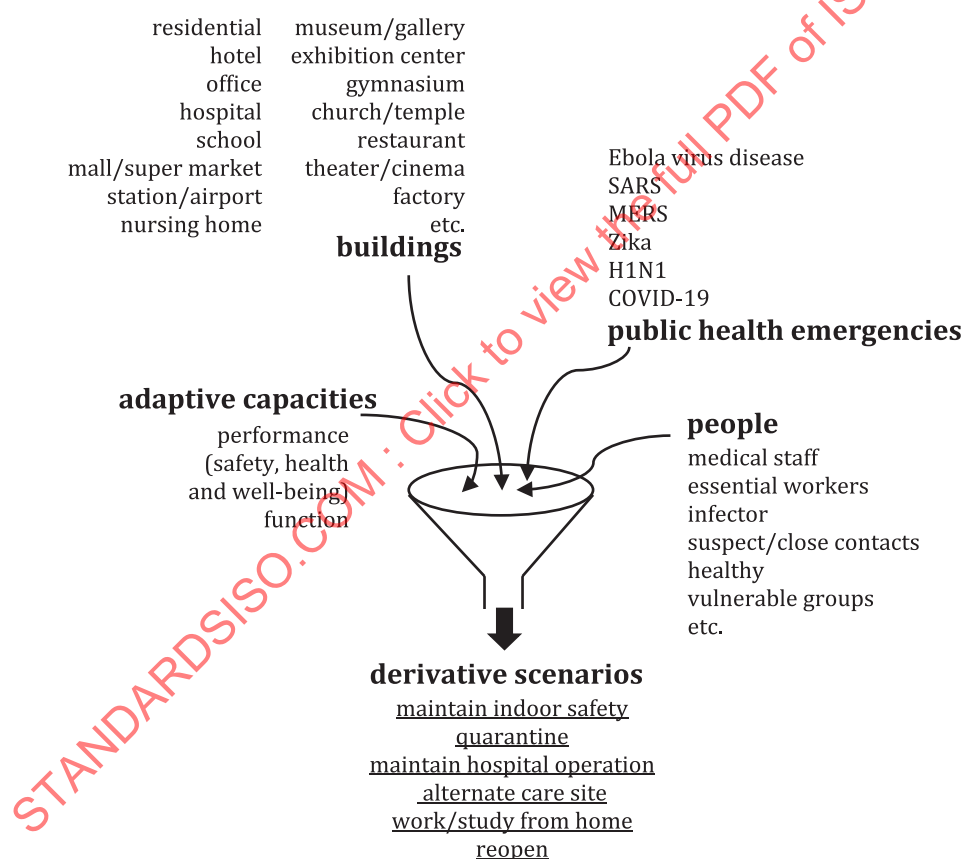


Figure 1 — Generation of derivative scenarios

For better comprehension, this document categorizes the challenges and solutions in terms of six typical derivative built environment scenarios during the pandemic, including maintaining indoor safety, quarantine, maintaining hospital operation, alternate care site, working/studying from home, and reopening. These six scenarios are informed by an information search based on combinations of such key words as different population groups, building types, public health emergencies and adaptive capacities (see [Figure 1](#)).

The document is helpful to stakeholders including end-users, investors, authorities, standards developing organisations, specialists (engineers, architects, etc.), manufacturers and builders, as well as other parties involved in public health emergencies, such as public health administrators, medical staff.

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Buildings and civil engineering works — Building resilience strategies related to public health emergencies — Compilation of relevant information

1 Scope

This document provides a compilation of relevant information on building resilience strategies in response to public health emergencies, including:

- challenges of public health emergencies on built environment;
- resilience strategies to meet the challenges;

excluding:

- emergency operations;
- personnel organization and management.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

resilience

adaptive capacity of an organization in a complex and changing environment

[SOURCE: ISO Guide 73:2009, 3.8.1.7]

4 Concept

4.1 Resilience

Buildings with a service life of decades or even hundreds of years can encounter challenges that were not anticipated when they were designed. Resilience of built assets can reduce losses in the future complex and changing environment.

4.2 Public health emergencies

Expressions of public health emergency vary in different contexts. They are generally described as the events that seriously affect public health. [Table 1](#) lists some typical expressions.

Table 1 — Expressions of public health emergency

Expressions	Description	Source
Public health risk	A likelihood of an event that can affect adversely the health of human populations, with an emphasis on one which can spread internationally or can present a serious and direct danger	International health regulations (2005) [4] WHO
Public health emergency of international concern	An extraordinary event which is determined, as provided in these regulations: — to constitute a public health risk to other states through the international spread of disease and — to potentially require a coordinated international response	
Public health emergency	Outbreaks of major infectious diseases, group diseases of unknown origin, major food and occupational poisoning and other events seriously affecting public health that occur suddenly and cause or are likely to cause serious harm to public health	Regulations on emergency response to public health emergencies [5] China
	An emergency need for health care services to respond to a disaster, significant outbreak of an infectious disease, bioterrorist attack, or other significant or catastrophic event	National disaster medical system memorandum of agreement among the departments of homeland security, health and human services, veterans affairs, and defense [6] United States

5 Derivative scenarios

There are six typical derivative scenarios for built environment during 21st century public health emergencies:

- maintain indoor safety
- quarantine
- maintain hospital operation
- alternate care site
- work/study from home
- reopen

NOTE 1 Quarantine at designated places and home are effective control measures to separate suspected patients from the general population.

NOTE 2 Alternate care sites that are temporarily constructed or converted from exhibition centre, gymnasium, etc., can supplement existing medical facilities to a certain extent.

NOTE 3 In a prolonged public health emergency, people must work or study at home for a long time.

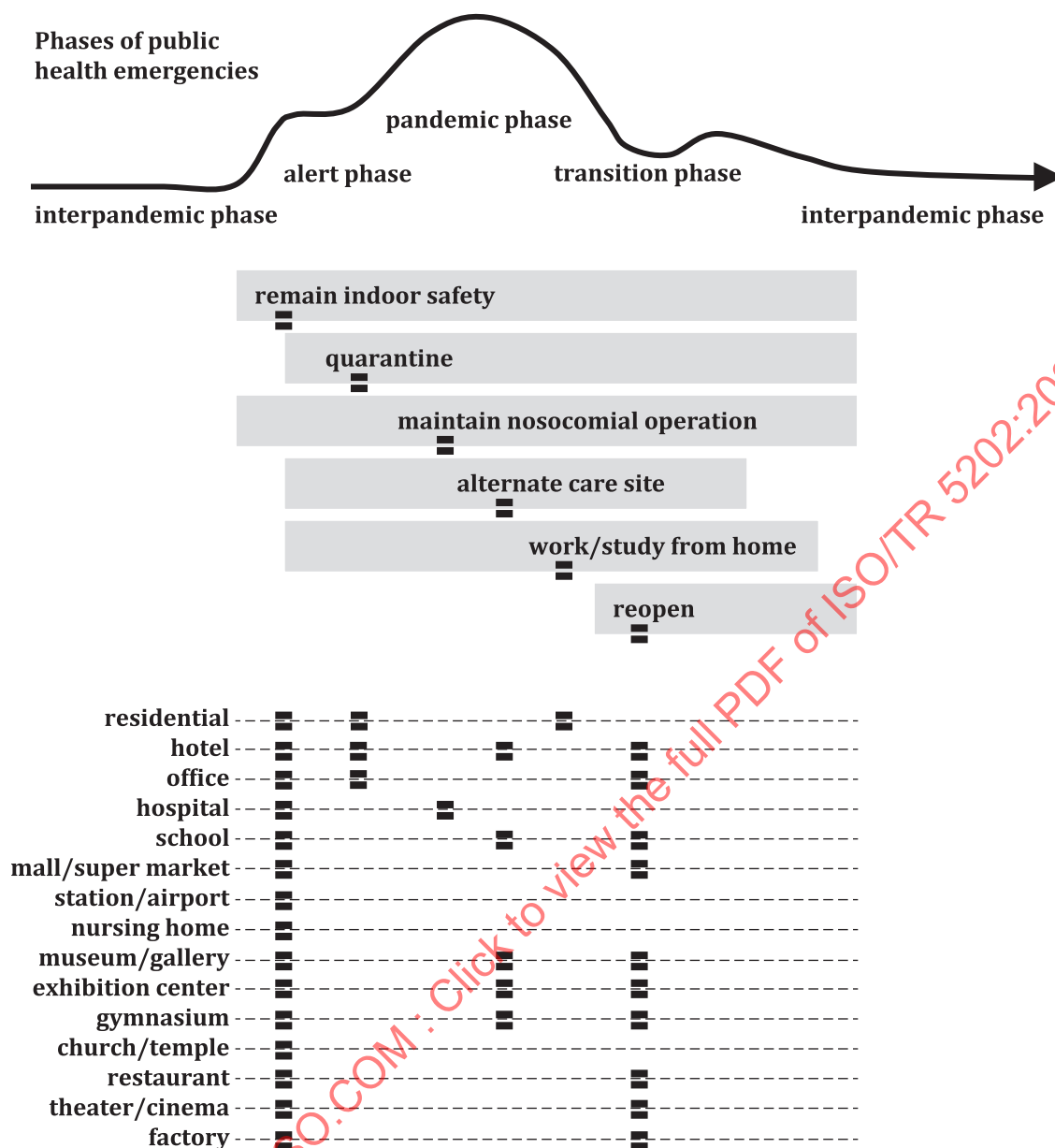
NOTE 4 Buildings that have been closed for a long time must ensure the safety and health of their occupants when reopen.

Table 2 shows the derivative scenarios emerged in typical public health emergencies of 21st century.

Table 2 — Derivative scenarios in typical public health emergencies of 21st century^{[7][8]}

Public health emergencies	Year of breakout	Derivative scenarios					
		Maintain in-door safety	Quarantine	Maintain hospital operation	Alternate care site	Work/study from home	Reopen
Ebola virus disease	2014	√	√	√	√		
Zika	2016	√	√	√	√		
MERS	2012	√	√	√			
SARS	2003	√	√	√	√	√	√
H1N1	2009	√	√	√			
COVID-19	2019	√	√	√	√	√	√

At different phases of public health emergencies, different types of building can experience different derivative scenarios (one type of building can experience one or more scenarios) (See [Figure 2](#)). This document summarizes the challenges in different derivative scenarios (see [Clause 6](#)) and resilience strategies to deal with them (see [Clause 7](#)).



NOTE The phases of public health emergencies are adapted from the “continuum of pandemic phases” of WHO^[9].

Figure 2 — Typical derivative scenarios in different types of buildings in different phases of public health emergencies

6 Challenges

6.1 General

Unlike earthquakes and climate change, in derivative scenarios of public health emergencies, buildings can not be damaged, but their performance and functionality can be inadequate, resulting in impacts on safety, health and well-being of users.

This clause summarizes the challenges in each typical scenario (see [Clause 5](#)) and lists some examples. Infection risks exist in each scenario. Infection risks in work/study from home and reopen scenarios are the same as in maintaining indoor safety (see [6.2](#)) and are therefore not elaborated again. Quarantine, maintaining hospital operation, and alternative care site scenarios have more specific infection

risks due to their treatment functions, which are elaborated in this clause (see [6.3.1](#), [6.4.1](#) and [6.5.1](#) respectively).

NOTE Examples in this document mainly focuses on COVID-19. The examples related to public health emergencies other than COVID-19 are marked (e.g. [Zika]). There are also examples that are generic and labelled [General].

6.2 Maintain indoor safety — Infection risks

All types of buildings must be kept safe indoors, as viruses can transmit through inhalation of aerosols, spray of large droplets, and touching a contaminated surface^[10]. It is possible that the existing built environment is not effective in preventing or reducing these transmissions. The following are some examples.

Virus transmission by droplets or aerosols in crowded and closed indoor spaces such as homes, offices, restaurants, and fitness centres has been mentioned in many literatures. For example, an analysis of 75 465 COVID-19 cases in China shows that 78 % to 85 % of cluster transmission occurred in the home environment^[11].

The transmission is more serious in some places due to their special functions:

- church choirs talking and singing loudly produce more respiratory droplets, including aerosols^[12];
- the small space and poor ventilation in prisons contribute to the high rate of infection among inmates^[13]. The COVID-19 infection rate of inmates in federal and state prisons in the United States is 7 %, four times higher than that of residents^[14].

Several other modes of transmission have been mentioned in some literatures, such as:

- transmission through contact with furniture and interior surfaces contaminated by patients,^[15] even faecal-oral transmission^[16]; [Hepatitis]
- house-to-house transmission can occur in high-rise residential buildings through drainage pipes, ventilation ducts, etc., for example, the SARS spread in Amoy Gardens, Hong Kong SAR, China^[17]; [SARS]
- a nursing home in Ireland has more risk of transmission in COVID-19 due to communal bathrooms and bedrooms^[18];
- mosquitoes carrying the Zika virus can easily enter open doors and windows without screens, thus causing virus transmission^[19]. [Zika]

6.3 Quarantine

6.3.1 Infection risks

Some literatures mention the risk of virus transmission through ventilation ducts, drains, etc., in specialized quarantine stations and buildings temporarily converted into quarantine facilities:

- an institutional quarantine facility in India, where dozens of quarantined people were infected, was found to have spread through stacks connecting the upper and lower bathrooms^[20];
- in a COVID-19 quarantine hotel in New Zealand, two people living on the upper and lower floors were infected, presumably through plumbing system^[21];
- residents living in Room 2502 and Room 2702 of a 30-story residential building in Guangzhou, China, during the COVID-19 home quarantine were infected by residents living in Room 1502 probably due to using the same drainage system^[22].

6.3.2 Decline in activity and mood

Some literatures show that the inadequate built environment negatively affects the physical and mental health of people during quarantine:

- epidemiologic and molecular evidence suggests that substantially decreased physical activity levels during quarantine can increase the risk of cardiovascular disease^[23];
- feelings of loneliness, depression and lack of physical contact due to quarantine can have a negative impact on an individual's mental health^[24];
- residents living in small apartments during lockdown in Milan, Italy, are at increased risk of depressive symptoms due to poor views and scarce indoor quality^[25].

6.4 Maintain hospital operation

6.4.1 Infection risks

Some literatures show that as hospitals shoulder the most important responsibility of treatment in the pandemic, infection risk in hospitals will have a particularly large or even decisive impact on overall infection prevention and control efforts, the risk there is much greater than that in residential and office buildings:

- during the early outbreaks of COVID-19, SARS and MERS, the proportion of nosocomial infection was relatively high, and a considerable part of the nosocomial infected patients were medical staff^[26]; [COVID-19] [MERS] [SARS]
- in Cape Town, South Africa, peripheral clinics that have received confirmed COVID-19 cases were closed for a period of time to decontaminate the facilities, leading to disruptions in patients' regular visits and some people avoiding these clinics for fear of infection^[27];
- the reluctance of individuals to attend hospitals for diagnostic tests or treatment due to heightened public anxiety can have contributed to the decline in acute hospital attendances and excessive mortality toll^[28].

6.4.2 Medical overload

Some literatures show that due to the proliferation of patients caused by COVID-19, medical facilities are overloaded, which can lead to higher mortality rate:

- a study in the US has shown that mortality rates are higher in areas with fewer medical resources per COVID-19 patient; these medical resources include ICU beds, intensivists or critical care physicians, emergency physicians, nurses, and general hospital beds, among which the biggest factor is ICU bed availability^[29];
- during COVID-19, the risk of death of severely sick patients nearly doubles when a hospital's ICU capacity is at its maximum^[30];
- the surge in COVID patients is overloading the healthcare system and disrupting routine care for cancer patients, including the prevention and diagnosis. Study shows that a 4-week delay in treatment can increase the risk of death by 6 % to 13 %, depending on the type of cancer^[31].

6.5 Alternate care site

6.5.1 Infection risks

Some literatures show that alternate care site (ACS) that have been temporarily modified from other types of buildings are at risk of infection due to the limitations of air-conditioning system and temporary partition among others. For example, temporary patient compartments in large spaces have no ceiling

and the curtain is not airtight, so air can flow between the patient compartment and the corridor, thus increases the risk of cross-infection^[32].

6.5.2 Mismatch in function

Some literatures mention the difficulties of ACS renovation due to the mismatch of the existing structure, layout, facilities, etc.:

- the sizes and geometries of some hotels converted to ACS does not match the requirements of hospital. For example, hotel corridors are only 5 ft to 6 ft¹⁾ wide, while hospital corridors are typically 8 ft wide for the gurney to pass through^[33];
- an office building in Suifenhe, China, which has been converted into an ACS, needs to have fire evacuation channels sealed to isolate clean areas from crossing contaminated areas^[34];
- surge field hospitals were found to be inadequate, such as their inability to separate confirmed patients, asymptomatic patients from those who came for testing; inadequate working space and protection for health care workers; facilities without windows or sufficient artificial lighting; inadequate space and facilities in inpatient units, causing many problems such as crowded patients and lack of confidentiality and privacy^[35];
- an alternative care facility converted from a newly built psychiatric centre in New York state, USA, suffers from lack of oxygen supply, small size of the ward, which uses beds smaller than standard hospital beds, and lack of separate sink and bathroom^[36].

6.6 Work/study from home

6.6.1 Infection risks

Residential buildings with people working or studying from home due to the pandemic experience the same infection risks as in [6.2](#).

6.6.2 Low efficiency

Some literatures mention that lack of a specific office space makes people susceptible to being distracted by other family members and noise from household appliances when working from home^{[37][38]}.

6.6.3 Non-ergonomic

When working from home, inappropriate or non-ergonomic furniture can cause musculoskeletal damage in the neck or back^[39].

6.7 Reopen — mold/*Legionella*

Buildings that reopen after prolonged closures due to the pandemic experience the same infection risks as in [6.2](#). Meanwhile, some literatures show that improper maintenance during the closure and ineffective cleaning can pose health hazards including mold, *Legionella*, lead and copper contamination to their occupants:

- when a building is closed for an extended period of time, moisture that leaks in via or condenses on roofs, windows, pipes, etc., can go unnoticed, triggering mold that threatens people with asthma, respiratory problems, mold allergies, and weakened immune systems^[40];
- when buildings are unoccupied due to an outbreak, water stays in pipes and storage tanks for long periods of time, this can lead to water temperatures suitable for the growth of *Legionella* (25 °C to 42 °C). After reopening, people can inhale *Legionella* in areas such as cooling towers, showers, pools, hot tubs and fountains, which can lead to *Legionellosis*^[40].

1) 1 ft = 0,304 8 m.

7 Resilience strategies

7.1 General

In order to make buildings better meet the challenges in public health emergencies, a number of improvements have already appeared in some cases, as well as in some guidelines, standards and studies by relevant international, national, and regional organizations and institutions. This clause summarizes resilience strategies in terms of six typical derivative built environment scenarios during the pandemic (see [Clause 5](#)), and categorizes them by building elements, including indoor and outdoor layout, structure, envelope, interior finish, HVAC, plumbing and waste, electric and smart, etc. (see [Figure 3](#)). Examples of the strategies are given in [Tables 3](#) to [28](#).

NOTE The resilience strategies collected in this clause mainly focus on COVID-19. The strategies related to public health emergencies other than COVID-19 are marked (e.g. [Zika]). There are also examples that are generic and labelled [General].

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derivative scenarios	challenges		resilience strategies						
			layout	structure	envelope	interior finish	HVAC	plumbing and waste	electric and smart
maintain Indoor safety	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
		animal			■				
quarantine	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
	decline in activity and mood		■						
maintain hospital operation	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
	medical overload		■				■	■	■
alternate care site	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
	mismatch in function		■	■			■	■	■
work/study from home	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
	low efficiency non ergonomic		■			■			■
reopen	infection risks	droplets	■			■	■		
		airborne	■				■		
		aerosol	■				■	■	
		contact	■			■		■	
		fecal-oral	■			■		■	
	mold/Legionella						■	■	

Figure 3 — Matrix of derivative scenarios, challenges and resilience strategies

7.2 Maintain indoor safety

7.2.1 Layout

Table 3 — Examples of layout strategies in maintaining indoor safety

Key points	Example
Sequence flow	A route design method that can help keep social distancing indoors was proposed in a Malaysian literature ^[41] . That is, in some public buildings, the space that accommodates a large number of people is arranged near the entrance, while the space for a small number of people is arranged in a deep position, and a one-way route is set.
Safe distance	Some literatures, such as the WHO ^[42] and the US EPA ^[43] , mention ways to maintain a safe distance by reducing the density of people. For example, controlling the maximum number of people per unit area in places such as restaurants, breakfast and dining rooms and bars in hotels, as well as using partitions between staff and clients.

7.2.2 Envelope

Table 4 — Examples of envelope strategies in maintaining indoor safety

Key points	Example
Screens	Literatures from WHO ^[44] and the Borgen Project ^[45] mention the use of screens on windows and doors of buildings to keep mosquitoes out and prevent the spread of Zika virus. [Zika]

7.2.3 Interior finish

Table 5 — Examples of interior finish strategies in maintaining indoor safety

Key points	Example
Easy to clean	The literatures from ASHRAE ^[46] and DHA ^[47] recommend the use of compact non-porous materials that are easy to clean for frequently touched indoor parts such as the surfaces of walls and door, as well as furniture.
Antimicrobial	The WELL ^[48] literature mentions the use of antibacterial active titanium coatings in common areas of buildings, such as elevators and walkways.

7.2.4 HVAC

Table 6 — Examples of HVAC strategies in maintaining indoor safety

Key points	Example
Ventilation	Literature from ECDC ^[12] mentions increasing the rate of air exchange in the room and reducing the risk of virus transmission through natural and mechanical ventilation.
Eliminate air-recirculation	Some literatures mention avoiding air-recirculation in ventilation systems ^[49] .
Air monitoring	Literatures from REHVA ^[50] and Kurabuchi, et al. ^[51] mention installing CO ₂ sensors and visualization devices in indoor spaces, where people spend long periods of time, to warn against insufficient ventilation.

Table 6 (continued)

Key points	Example
Filtration	Literature from the New York State Department of Health recommends that public buildings be equipped with a highly rated filtration at least MERV-13 for central HVAC systems ^[52] .
Air disinfection	The literature from Morawska, et al. ^[49] suggests using indoor air cleaning and disinfection devices such as germicidal ultra-violet in indoor environments with poor ventilation.

7.2.5 Plumbing and waste

Table 7 — Examples of plumbing and waste strategies in maintaining indoor safety

Key points	Example
Water seal	The literatures from ASHRAE ^[53] and Kurabuchi, et al. ^[51] mention that all water seals in drainage piping systems should be ensured to be effective.
Airflow control	The literatures from REHVA ^[50] and Kurabuchi, et al. ^[51] mention flushing toilets with closed lid to control airflow.

7.2.6 Other relevant literatures

- 2019 novel coronavirus (COVID-19) pandemic: Built environment considerations to reduce transmission^[54]
- Future of offices: In a post-pandemic world^[55]
- Ventilation control for COVID-19 and beyond^[56]
- Airborne infectious disease management methods for temporary negative pressure isolation^[57]
- Indoor environmental health^[59]
- Ultraviolet air and surface treatment^[59]
- Protecting workers: Guidance on mitigating and preventing the spread of COVID-19 in the workplace^[60]
- Robotics utilization for healthcare digitization in global COVID-19 management^[61]
- Managing HVAC systems to reduce infectious disease transmission^[62]
- ASHRAE position document on infectious aerosols^[10]

7.3 Quarantine

7.3.1 Layout

Table 8 — Examples of layout strategies in quarantine

Key points	Example
Sequence flow	The literature from MASS Design Group ^[63] suggests separating clean and dirty areas to avoid cross-infection, such as separating entrances for different groups of people including staff, vendors, and residents and create separate area for staff to don and doff PPE.

Table 8 (continued)

Key points	Example
Adequate size	Literature from Dhagat, et al. ^[64] recommends passage of sufficient width such as entrance doors and floor corridors to fit stretchers and medical equipment to pass through in emergency.
Physical distance	Literature from WHO ^[42] recommends setting physical barriers such as glass panels at reception between staff and guests to maintain physical distance.
Adequate facilities	The literature from OCHA ^[65] suggests that quarantine rooms should have separate toilets and adequate ventilation.
Access to nature	Literatures from MASS Design Group ^[63] , NHMRC ^[24] and Australia Department of Health and Aged Care ^[66] propose to provide outdoor activity space and green space that can be safely accessed by isolated personnel. For example, provide balconies for each room, and provide shared balconies for multiple units.

7.3.2 Interior finish

Table 9 — Examples of interior finish strategies in quarantine

Key points	Example
Easy to clean and antimicrobial	The literature from the MHT(India) ^[67] suggests that the surfaces of indoor walls and floors in quarantine facilities should be made of materials that have antibacterial properties and are suitable for cleaning.

7.3.3 HVAC

Table 10 — Examples of HVAC strategies in quarantine

Key points	Example
Natural ventilation	Literature from the WHO ^[42] recommends natural ventilation of isolation rooms whenever possible
Mechanical ventilation	The literature from WHO ^[42] recommends increasing indoor ventilation rates of natural and mechanical ventilation, as well as unidirectional air flow from clean to unclean areas through flow and pressure control.

7.3.4 Plumbing and waste

Table 11 — Plumbing and waste

Key points	Example
Wastewater monitoring	The literature from Nghiem, et al. ^[68] mentions that wastewater monitoring in quarantine facilities can help to monitor and assess the incidence of COVID-19 that will aid public health policy formulation.
Temporary sewage treatment tank	The literature from HTID, et al. (China) ^[69] suggested that temporary sewage treatment facilities should be set up at the quarantine facilities, and the sewage should be disinfected before being discharged.

7.3.5 Other relevant literature

— The future of hotel design^[70]

7.4 Maintain hospital operation

7.4.1 Layout

Table 12 — Examples of layout strategies in maintaining hospital operation

Key points	Example
Partition/ avoid cross infection	Literatures from DHSC, et al. (UK) ^[71] , ASHRAE ^[72] and HHS(US) ^[73] mention that hospitals should avoid infected patients crossing with other patients, visitors and staff by setting designated entrances, reception areas and passageways, etc.
Distance	The literature from WHO ^[74] mentions the safe distance between patients and the rapid triage of patients with acute febrile respiratory diseases through spatial and streamlined planning.

7.4.2 HVAC

Table 13 — Examples of HVAC strategies in maintaining hospital operation

Key points	Example
Natural ventilation	The literature from WHO ^[75] mentions that when natural ventilation is used in new construction and major renovations, the hourly average ventilation rate in the airborne precaution rooms should be 160 l/s per patient (with a minimum of 80 l/s per patient), which is greater than that in general wards.
Mechanical ventilation	The literatures from ASHRAE ^[72] , TAHPI ^[76] , WHO ^[77] and HHS and CDC(US) ^[73] put forward special requirements of mechanical ventilation for AII/PE rooms, isolation rooms, operating room, etc., covering air distribution, pressure gradient, temperature and humidity. It is also required to avoid the use of window air conditioners in new construction.

7.4.3 Plumbing and waste

Table 14 — Examples of plumbing and waste strategies in maintaining hospital operation

Key points	Example
Water quality maintenance	Literatures from HHS and CDC(US) ^[73] and TAHPI(US) ^[78] mention that in order to avoid the breeding of gram-negative waterborne bacteria such as <i>Legionella spp.</i> and NTM in water supply systems, it is recommended to avoid long dead legs in pipes, keep water temperature below 20 °C (cold water systems) or above 60 °C (hot water systems).
Waste disposal	The literatures from WHO ^[77] and HHS and CDC (US) ^[73] mention dedicated storage areas, reasonable sterilization, pulverization and deep burial for medical waste.

7.4.4 Electric and smart

Table 15 — Examples of electric and smart strategies in maintaining hospital operation

Key points	Example
Adequate facilities	The literatures from HKS, et al. ^[79] and Zeidan ^[80] mention redundancy for surge situation, e.g. space, medical gas, telecommunications and critical power, to meet standard care requirements.

7.4.5 Advanced technology

Table 16 — Examples of advanced technology in maintaining hospital operation

Key points	Example
Telemedicine	The literature from NEHI, et al. ^[81] proposes Tele-ICUs to connect medical staff with ICUs in other remote hospitals by audio-visual communication to enable a small number of medical staff to oversee the care of a large number of patients. [General]
Robots	The literature from Khan, et al. ^[61] mentions robots that can take care of patients, clean and prepare food, etc., can help reduce the spread of COVID-19 in hospitals.
Prefabrication	The literatures from WSP ^[82] and Alderton ^[83] mention that lightweight steel prefabrication and modular buildings can be built quickly and facilitate post-pandemic retrofitting, relocation, and components reusing.

7.4.6 Other relevant literatures

- ASHRAE position document on infectious aerosols^[10]
- Planning hospitals of the future^[84]
- Telemedicine: opportunities and developments in Member States: report on the second global survey on eHealth 2009^[85]
- COVID-19: operational advice on the set-up of makeshift isolation and treatment centres^[86]

7.5 Alternate care site

7.5.1 Layout

Table 17 — Examples of layout strategies in alternate care site

Key points	Example
Site selection	Literatures from CECS ^[87] and WHO ^[88] put forward some specific requirements for ACS location, such as proximity to existing medical facilities, proximity to outbreak epicentre, good transportation and municipal conditions, avoidance of flood areas, and distance from densely populated places.

Table 17 (continued)

Key points	Example
Zoning	In order to reduce the risk of transmission and improve the efficiency of treatment, many literatures put forward requirements for separating clean from dirty areas of ACS. For example, the literature from HILLSIDE ^[89] and CDC(US) ^[90] mention “contaminated area” and “uncontaminated area” in ACS of COVID-19. The literature from You, et al. ^[91] mentions three areas of “contaminated”, “potentially contaminated” and “clean” areas in ACS of Ebola virus. The literature from Schroer, et al. ^[92] mentions the partition of entry level of COVID-19 ACS, such as triage of different COVID-19 arrivals, drive-through testing, patient and non-patient partitioning, etc.
Modular unit	The literature from King, et al. ^[93] mentions pop-up multi-purpose modular rooms in ACS for pharmacy, housekeeping, equipment storage, medical gas storage, etc.

7.5.2 Structure

Table 18 — Examples of structural strategies in alternate care site

Key points	Example
Equipment load	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] mentions reviewing the structural load of the location and the moving route of the heavy medical equipment, and taking necessary reinforcement measures.
Partition load	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] mentions checking the structural load of the partition wall temporarily placed on the slab, and necessary reinforcement measures.

7.5.3 Interior finish

Table 19 — Examples of interior finish strategies in alternate care site

Key points	Example
Smooth, seamless, antimicrobial	Literatures from WHO ^[88] , Koffel ^[95] and HILLSIDE ^[89] mention that interior decoration and furniture chosen should have surfaces that are easy to clean, maintain and repair, and resistant to microbial growth.

7.5.4 HVAC

Table 20 — Examples of HVAC strategies in alternate care site

Key points	Example
Direct exhaust	The literature from ASHRAE, et al. ^[96] mentions that in large spaces such as stadiums and conference centre, where there are open cubicle patient spaces, the cubicle air should be exhausted directly to the outdoors, or discharged through HEPA filters back to the space.
Air change rate	The literature from King ^[93] mentions high air exchange rates of different patient areas, such as 1, 5-10, and 12 ventilation times per hour for non-acute, acute, and ventilator-treated patient areas, respectively.

Table 20 (continued)

Key points	Example
Air pressure management	The literatures from CECS ^[87] and ASHRAE, et al. ^[96] mention the design air pressure difference between adjacent functional spaces, such as wards and buffer rooms, buffer rooms and medical corridors. The literature from Gordon ^[32] also mentions modular ventilation system that direct airflow into filters and exhaust to the outdoors.

7.5.5 Plumbing and waste

Table 21 — Examples of plumbing and waste strategies in alternate care site

Key points	Example
Water supply safety	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] suggests that the water supply system of the ACS should be equipped with break tanks and disinfection facilities
Accessible drinking water	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] suggests drinking water points be set up in each ward to ensure adequate drinking water supply of ACS.

7.5.6 Electric and smart

Table 22 — Examples of plumbing and waste strategies in alternate care site

Key points	Example
Equipment location	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] suggests distribution boxes and controllers of the ACS be kept away from the contaminated area, in a separate room for example.
Light environment	The literature from the Department of Housing and Urban-Rural Development of Hubei Province (China) ^[94] mentions avoiding glare influence of luminaires on the top of existing building, by adding luminaires and pole lights with opaque lamp shade or indirect illumination.

7.5.7 Other relevant literatures

- In the future, ports and space will be considered to be able to be reserved for and converted into makeshift hospitals when formulating the building standards of large stadiums and gymnasiums^[97]

7.6 Work/study from home

7.6.1 Layout

Table 23 — Examples of layout strategies in working/studying from home

Key points	Example
Flex and convertible space	The literatures from Katz, et al. ^[98] , Saint ^[99] and Sperance ^[1] mention setting up flexible spaces in residential that can be used for work during pandemic, such as by setting easily closed spaces and adjustable interior partitions, as well as converting attics and walk-out basement to work space.

Table 23 (continued)

Key points	Example
Multifunctional space	The literatures from Morgan ^[2] and ILO ^[100] suggest multi-functional residential spaces, such as dining rooms, kitchens, bedrooms, etc., double as home offices.
Dedicated space	The literatures from Alati ^[101] and Gensler ^[37] mention dedicating space to work in residences that can accommodate quiet and focused work, such as virtual meeting space with good acoustics and sound insulation, well-placed nook in a studio, and flexible lock-off units functioning as home office.
Outdoor space	The literatures from Morgan ^[2] and Pretorius ^[102] suggest creating home environments that are more connected to nature, by adding elements such as roof gardens, micro backyards, porches, balconies, etc., so that residents can relax and access food during the pandemic.

7.6.2 Interior finish

Table 24 — Examples of interior finish strategies in working/studying from home

Key points	Example
Antimicrobial material	The literature from Morgan ^[2] mentions using antibacterial and easy-to-clean materials in home decor, such as copper doorknobs and kitchen cabinet handles.
Ergonomics	Literatures from Birimoglu Okuyan, et al. ^[103] , NYC Health Department(US) ^[104] and HSA(IE) ^[105] mention creating good working conditions at home with, for instance, ergonomic desk, plenty of comfortable natural and artificial light.
Spiritual comfortable decoration	The literature from Morgan ^[2] proposes a home decoration style that can create a serene atmosphere to ease the mental tension caused by the epidemic, by choosing softer fabrics, lighter colours, more natural light, etc.

7.6.3 Electric and smart

Table 25 — Examples of electric and smart strategies in working/studying from home

Key points	Example
Network	The literature from the ILO ^[100] recommends adequate home office facilities, including computers, Internet access, telephones, etc.
Smart appliances	The literature from Morgan ^[2] mentions the adoption of touch-free smart household appliances, such as hands-free sinks, toilets, voice-activated smart devices, etc., to curb the spread of bacteria.

7.7 Reopen

7.7.1 Layout

Table 26 — Examples of layout strategies in reopen

Key points	Example
Safe distances	Literatures from NYSED (US) ^[106] , AEI ^[107] and Crawley ^[108] mention the ways to keep safe distance between users when buildings reopen, such as setting minimum use area per person in different functional spaces in schools and store, and adopting density monitoring to visualize and direct the flow of people.
Flexible space	The literature from Crawley ^[108] suggests flexible and dynamic zoning, and movable lightweight partitions to accommodate changing functionality when office buildings reopen.
Outdoor space	The literature from Crawley ^[108] mentions designing effective outdoor work spaces to maximize work comfort in a suitable climate.

7.7.2 HVAC

Table 27 — Examples of HVAC strategies in reopen

Key points	Example
Increase ventilation rate	The literature from WHO ^[109] mentions that in order to ensure ventilation rate when non-residential buildings reopen, set new openings and cross ventilation rather than single-side ventilation in natural ventilation environment, disable demand-control ventilation controls, and control the number of users according to the ventilation capacity of the system in mechanical ventilation environment.
Use high-efficiency particulate air (HEPA) filters	Literatures from WHO ^[109] and Jones, et al. ^[110] mention the use of HEPA filters when reopening as a last resort to reduce transmission risk, by using for example MERV13 or higher filters in schools.
Use ultraviolet germicidal irradiation	The literature from CDC (US) ^[111] suggests using ultraviolet germicidal irradiation (UVGI) when schools and kindergartens reopen.
Keep suitable relative humidity	The literature from Pyke ^[112] recommends maintaining approximately 40 % to 60 % indoor relative humidity when an office building reopens to reduce disease transmission.
Mold prevention	The literatures from EPA (US) ^[113] and ASHRAE ^[114] mention measures to prevent mold, including maintaining low indoor humidity at ideally 30 - 50 %, and setting dedicated components such as roof overhangs, pan flashing under windows and doors, crawlspaces, etc. [General]

7.7.3 Plumbing and waste

Table 28 — Examples of plumbing and waste strategies in reopen

Key points	Example
Limit <i>Legionella</i> growth	The literatures from ASHRAE ^[115] and AWWA ^[116] mention measures to limit the growth of <i>Legionella</i> , such as controlling the temperature of hot and cold water, minimizing the residence time of water in pipes, maintaining a certain concentration of disinfectant residue, and maintaining flow balance in multi-loop hot water systems.
Remove harmful metals	The literature from AWWA ^[116] mentions installing filters that can remove harmful metals of concern contained in water appliances such as water bottle filling stations and water fountains.

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