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# Buildings and civil engineering works — Principles, framework and guidance for resilience design —

## Part 1:
## Adaptation to climate change

*Bâtiments et ouvrages de génie civil — Principes, cadre et recommandations pour la conception de la résilience —*

*Partie 1: Adaptation au changement climatique*



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# Foreword

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

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# Introduction

Adaptation to climate change has become an urgent need globally. According to the United Nations Environment Programme (UNEP)'s Adaptation Gap Report 2022, "we must also urgently increase efforts to adapt to the impacts of climate change that are already here and to those that are to come".

In the context of global climate change, buildings and civil engineering works with service lives of decades or even centuries will face new climate challenges. These challenges include the increase of frequency and intensity in extreme weather events such as heatwaves, wildfires and floods, as well as chronic changes such as sea level rise. This can result in increase of vulnerability in built assets designed based on the climate of the past decades, risking human health and well-being, and causing economic loss and social impacts. Therefore, adaptation to climate change in buildings and civil engineering works should be considered in a timely manner.

This document provides a design approach called the resilience design adaptive to climate change (RDACC), which offers specific guidance on how to produce buildings and civil engineering works with climate change resilience. It is a method for adaptation to climate change at the engineering level.

The typical actions of RDACC include:

— identifying changes in climatic impact-drivers;

— identifying resilience limits and decision making on strategies;

— monitoring and optimization;

— decommissioning.

This document is useful to stakeholders including asset owners and users, investors, authorities, standards developers, meteorologists, engineers, architects, manufacturers, builders, and other parties involved in the RDACC.

# Buildings and civil engineering works — Principles, framework and guidance for resilience design —

## Part 1:
## Adaptation to climate change

## 1 Scope

The document provides principles, framework, and guidance for resilience design adaptive to climate change (RDACC) in buildings and civil engineering works. RDACC is applicable to both new construction and retrofits.

RDACC does not address:

— adaptation to climate change in the production and procurement of building materials, components and devices;

— adaptation to climate change in construction processes;

— climate change mitigation in buildings and civil engineering works;

— emergency management related to climate change in buildings and civil engineering works.

## 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**
**adaptation to climate change**
climate change adaptation
process of adjustment to actual or expected *climate* (3.3) and its effects

Note 1 to entry: In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

Note 2 to entry: In some natural systems, human intervention can facilitate adjustment to expected climate and its effects.

[SOURCE: ISO 14090:2019, 3.1]

**3.2**
**asset**
whole building or structure or unit of construction works, or a system or a component or part thereof

[SOURCE: ISO 15686-5:2017, 3.4.1]

**3.3**
**climate**
statistical description of the weather in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years

[SOURCE: ISO 14050:2020, 3.8.1]

**3.4**
**climate change**
change in *climate* (3.3) that persists for an extended period, typically decades or longer

[SOURCE: ISO 14050:2020, 3.8.3]

**3.5**
**climate change mitigation**
human intervention to reduce greenhouse gas emissions or enhance greenhouse gas removals

[SOURCE: ISO 14050:2020, 3.8.6]

**3.6**
**climate projection**
simulated response of the *climate* (3.3) system to a scenario of future emissions or concentrations of greenhouse gases (GHGs) and aerosols and changes in land use, generally derived using climate models

[SOURCE: IPCC, 2022]

**3.7**
**climatic impact-driver**
**CID**
physical *climate* (3.3) system condition (e.g. means, events, extremes) that affects an element of society or ecosystems

[SOURCE: IPCC, 2022, modified]

**3.8**
**constraint**
factor that makes it harder to plan and implement adaptation actions

[SOURCE: IPCC, 2014, modified]

**3.9**
**existing resilience**
*resilience* (3.17) that an *asset* (3.2) currently designed can achieve in face of the *CID* (3.7) changing to a certain magnitude

**3.10**
**global climate model**
**GCM**
complex mathematical representation of the major *climate* (3.3) system components (atmosphere, land surface, ocean, and sea ice) and their interactions

[SOURCE: GFDL]

**3.11**
**global warming level**
global climate-change emissions relative to pre-industrial levels, expressed as global surface air temperature

[SOURCE: IPCC, 2022]

**3.12**
**impact**
result of a change or existing condition that may be adverse, neutral or beneficial

[SOURCE: ISO 15392:2019, 3.17]

**3.13**
**maladaptation**
actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased or shifted vulnerability to *climate change* (3.4), more inequitable outcomes, or diminished welfare, now or in the future

[SOURCE: IPCC, 2022]

**3.14**
**projected climatic design parameter**
**PCDP**
meteorological parameter for buildings and civil engineering design base on *climate projections* (3.6)

**3.15**
**Representative Concentration Pathway**
**RCP**
scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover

[SOURCE: IPCC, 2022]

**3.16**
**required resilience**
*resilience* (3.17) that an *asset* (3.2) is desired to have in face of a *CID* (3.7)

**3.17**
**resilience**
adaptive capacity in a complex and changing environment

[SOURCE: ISO 31073:2022, 3.3.39, modified — "of an organization" has been removed.]

**3.18**
**resilience design adaptive to climate change**
**RDACC**
design approach to produce an *asset* (3.2) with *resilience* (3.17) to adapt to changing climatic conditions due to *climate change* (3.4) throughout its *service life* (3.20)

**3.19**
**resilience limit**
maximum magnitude of the *CID* (3.7) that the asset can adapt to, beyond which there is no feasible strategy

**3.20**
**service life**
period of time after installation during which a facility or its component parts meet or exceed the performance requirements

[SOURCE: ISO 15686-1:2011, 3.25]

**3.21**
**Shared Socioeconomic Pathway**
**SSP**
different levels of emissions and *climate change* (3.4) along the dimension of the *RCPs* (3.15) explored against the backdrop of different socio-economic development pathways on the other dimension in a matrix

[SOURCE: IPCC, 2022, modified — "can hence be" has been removed.]

# 4 Principles

## 4.1 Change-oriented perspective

In the context of global climate change, buildings and civil engineering works can face different climatic conditions which are beyond initial anticipations during their service lives. Extreme weather events such as heatwaves and floods are projected to occur more frequently and intensely in some areas, while slow-onset changes such as sea level rise and permafrost thawing will gradually emerge in some areas over time. To address these changes, RDACC should adopt a change-oriented perspective for asset to adapt to future environment.

NOTE See Annex A for Global Building Resilience Guidelines capturing principles for incorporating future focused climate risk into building codes and standards.

## 4.2 Preparing for uncertainty with certainty

Although there are some uncertainties in climate projections, this should not be an excuse for inaction. RDACC should take innovative measures to mitigate the impacts of uncertainties.

## 4.3 Synergy between adaptation to and mitigation of climate change

RDACC should take into account the synergistic effects of adaptation and mitigation of climate change. Actions which can achieve both adaptation and mitigation should be prioritized; and maladaptation should be avoided.

EXAMPLE Better thermal performance of buildings can reduce energy consumption and provide protection from heatwaves in summer.

## 4.4 Synergy with community and urban resilience

RDACC should work within the framework of community and urban resilience, serving as the fundamental resilience element.

NOTE Improving the drainage capacity of individual buildings is part of a comprehensive approach to dealing with urban waterlogging and stormwater discharge. It demands coordination at community and city levels over, for example, rainwater storage of a building which serves as a cushion for community discharge systems.

## 4.5 Equity

RDACC should take into account the needs of assets users of all ages, gender, financial means, ethnicities, education, and physical abilities to ensure equitable reduction of risk and vulnerability[1].

## 4.6 Sustainability

RDACC should be carried out within the framework of sustainable development. Climate, economic, social and environmental factors should be considered when adopting an adaptation strategy.

# 5 Framework

RDACC involves a series of actions integrated into the asset's lifecycle, including design, operation, and decommissioning phases (see Figure 1):

— In design phase, identify how the climatic conditions at the asset's location may change during its service life (see Clause 6). Next, identify the resilience limit and determine appropriate adaptation strategies (see Clause 7).

  These actions can be applied to a specific project with the following guidelines.

  — When no projected climatic design parameter (PCDP) sets are available to quantify magnitude of changes in CIDs at the asset's location, RDACC should start from identifying changes in CIDs (see Clause 6).

  — When the PCDP sets are available, but no resilience limits are specified in current standards, specification, etc., RDACC should start from identifying resilience limits (see 7.1 to 7.4).

  — When both PCDP sets and resilience limits are available, RDACC can directly start from adaptation strategies design (see 7.3) and decision making (see 7.5).

— During operation phase, monitor the changes in CIDs and effectiveness of implemented strategies and embrace the latest climate knowledge and technological advancements to optimize strategies (see Clause 8).

— Decommissioning is required when assets are no longer fit for purpose, and further adaptation is not a viable option (see Clause 9).

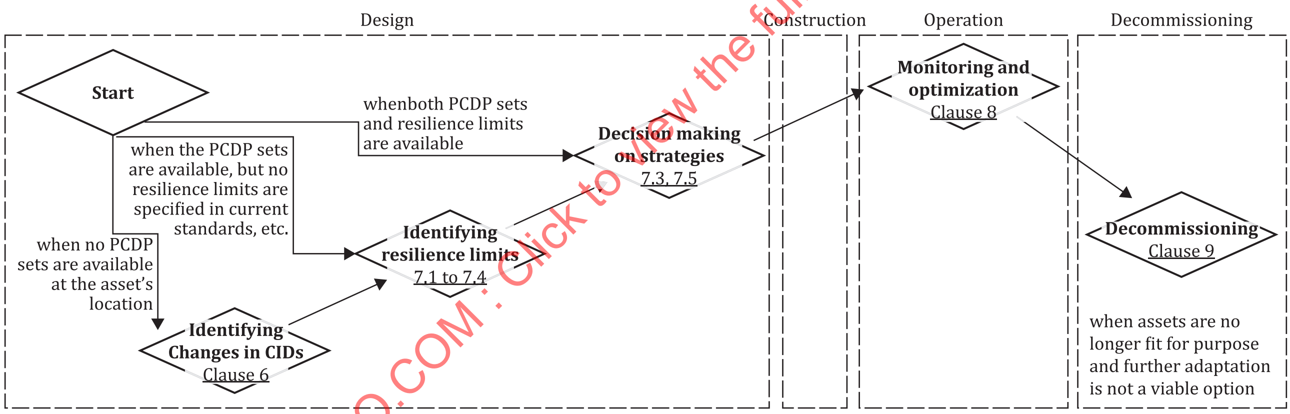



**Figure 1 — Framework of RDACC in an asset's life cycle**

Given the complex and multidisciplinary nature of RDACC, a professional team comprised of architects, engineers, meteorologists, hydrologists, economists, etc. may be required to work with the asset owners.

# 6 Identifying changes in climatic impact-drivers

## 6.1 General

Global climate change results in changes in intensity and frequency of climatic impact-drivers (CIDs) (see 6.2), which can affect the built assets designed based on current climatic design parameters.

The CIDs that are projected to change during assets' service lives and the magnitudes of these changes should be identified. The magnitudes of changes should be quantified as PCDPs (see 6.3) that can be directly applied to buildings and civil engineering design.

NOTE For a given asset, the changes can involve CIDs already considered in current design, as well as CIDs that have not been perceived as risks. For example, a new building over its 60 year design life can face increasing storms, high wind events and heatwaves, as well as sea level rise that previously did not pose a threat.

## 6.2 Climatic impact-driver

Most of the CIDs can have potential impacts on buildings and civil engineering works. Table 1 gives a non-exhaustive list of abrupt and slow-onset CIDs[3].

**Table 1 — CIDs that can have potential impacts on buildings and civil engineering works**

| | abrupt | slow-onset |
|---|---|---|
| heat and cold | extreme heat, cold spell, frost, wildfires | — |
| wet and dry | river flood, heavy precipitation and pluvial flood, groundwater impacts, landslide, drought, fire weather | — |
| wind | severe windstorm, tropical cyclone, sand and dust storm, wildfires | erosion |
| snow and ice | lake, river and sea ice, heavy snowfall and ice storm, hail, snow avalanche | annual snowpack, permafrost level |
| coastal | coastal flood, coastal erosion | relative sea level |
| open ocean | — | ocean acidity, ocean salinity |
| other | air pollution weather | UV emissions |
| NOTE: Most of the names of CIDs are derived from IPCC AR6[10]. | | |

Cascading CIDs should also be taken into account, as CIDs may occur simultaneously or in succession, thus amplifying or altering the impact on assets.

## 6.3 Projected climatic design parameter

The magnitude of changes in CIDs varies under different global warming levels (GWLs). PCDPs for different magnitudes of each CID that assets can experience during their service lives should be obtained.

NOTE 1 GWLs represent the climate change outcomes at different future time points under different input projections of Shared Socioeconomic Pathways (SSPs) (e.g. SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) or Representative Concentration Pathways (RCPs) (e.g. RCP2.6, RCP4.5, RCP6.0, RCP8.5).

NOTE 2 A study shows that historical reference 1 % annual chance flood will occur more frequently in China, thus becoming 71- (interquartile range, IQR: 58–81), 50- (39–60), and 42-year (32–47) events (medians of GCM results) under 1,5 °C, 3,0 °C, and 4,0 °C GWLs respectively[12].

NOTE 3 Table B.1 in Annex B provides the GWLs that assets with different service lives would experience based on the findings of IPCC AR6.

NOTE 4 Table C.1 in Annex C shows examples of PCDPs of some typical CIDs for building design.

NOTE 5 Canada launched a five-year initiative from 2016 to 2021, called Climate-Resilient Buildings and Core Public Infrastructure Initiative, which develops projections of temperature, precipitation, wind, etc. for various locations in Canada under different GWLs such as 1 °C, 2 °C, 3 °C, serving as a basis for updating building and infrastructure codes and standards[13].

PCDPs are calculated using climate projections from global climate models (GCMs). Consult with meteorologists if PCDPs are not available for the asset's location. Utilizing multiple GCMs can also help offset some of the uncertainties in climate projection.

NOTE 6 NYC Climate Resiliency Design Guidelines provides low estimate (10th percentile), middle range (25th to 75th percentile) and high estimate (90th percentile) for temperature and precipitation for 2020s, 2050s, 2080s and 2100 based on 35 GCMs and 2 RCPs[14].

The projected data source and calculation process of PCDPs should be documented to facilitate comparison during monitoring and optimization (see Clause 8) and identifying opportunities to improve data availability and usage.

# 7 Identifying resilience limits and decision making on strategies

## 7.1 General

The steps to identify the resilience limit for a CID are as follows:

— list different magnitudes of PCDPs of the CID that the asset can experience during its service life (see 6.3);

— identify the gaps between existing resilience and required resilience of the asset in face of different magnitudes of the CID (see 7.2);

— design adaptation strategies that can bridge the gaps (see 7.3);

— identify the resilience limit (see 7.4).

When an asset is affected by multiple CIDs, the resilience limits for all CIDs should be coordinated by considering technical conflicts, cost, and other factors among strategies.

The appropriate strategies for each CID should be determined within the feasible strategies that can achieve the resilience limit (see 7.5).

The process of identifying resilience limits and decision making should be documented.

NOTE PIARC International Climate Change Adaptation Framework (2023) – Climate Change and Resilience of Road Networks mentions the Adaptation Framework that can help organizations identify adaptation principles and increase the climate resilience of transportation assets, operations and services[15].

## 7.2 Identifying gap between existing and required resilience

Required resilience should be described quantitively. The quantification for abrupt and slow-onset CID(s) (see 6.2) differs.

— For abrupt CID(s)

The required resilience should be quantified in terms of desired functional recovery level, tolerable recovery time and financial losses caused by direct and indirect impacts, occupant safety and other indicators after the shock of CID(s).

NOTE 1 In face of a flood, an office building is desired to recover its partial functions in one month within acceptable financial losses of 1 million dollars.

NOTE 2 Converting to a backup emergency shelter in face of abrupt CIDs is also a form of functional recovery for assets. For example, according to urban emergency planning, a gymnasium needs to be temporarily converted into emergency shelter, accommodating up to 5 000 people during extreme weather events. Fire evacuation systems, water system, HVAC and other systems are expected to adapt to potential modifications for emergency.

NOTE 3 Direct impacts include physical damage and functional impacts, casualties, contents loss, etc., while indirect impacts include loss in revenue and rent, etc. during recovery period. The impacts caused by urban water and power outages during extreme weather events also must be considered.

— For slow-onset CID(s)

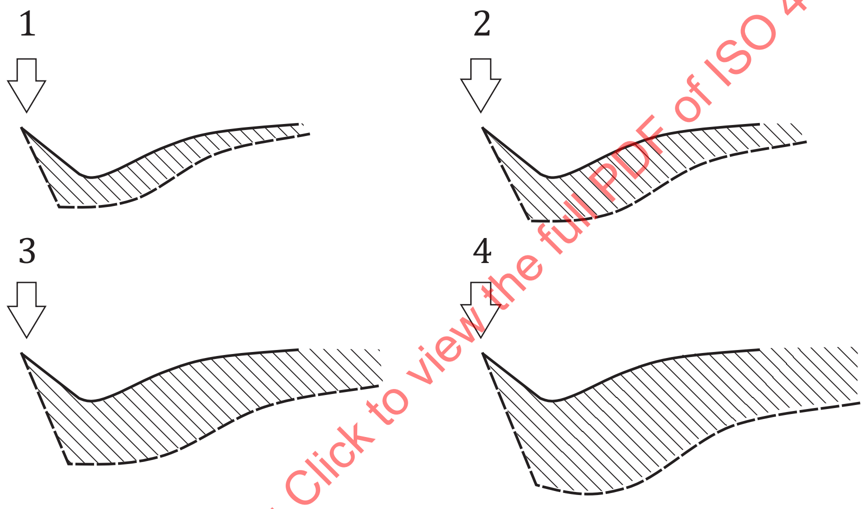
The required resilience should be quantified in terms of desired functional maintenance level, tolerable maintenance cost, occupant safety and other indicators during the stress of CID(s).

Facing the same CID, required resilience may vary for different functional assets and different functional parts of an asset.

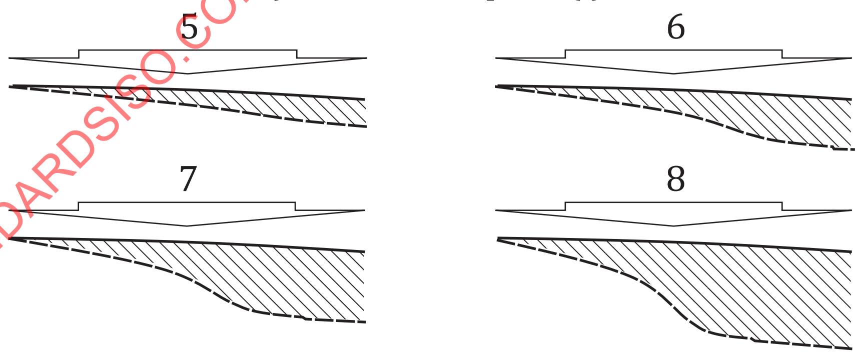
NOTE 4 In case of a flood, functional areas of a hospital such as outpatient, emergency, medical technology, and inpatient department must maintain normal and uninterrupted medical services, while a library can be temporarily closed for a month without significant impact.

NOTE 5 When a wildfire/bushfire approaches a municipal office building, key activities within the building such as the emergency operations centre must remain operational continually, while other governmental functions like motor vehicle registrations can be shifted offline during the event and in the short period of time thereafter.

When the intensity of the CID increases, there can be a gap between the required resilience and existing resilience. The gap should be quantified as the design goal of adaptation strategies (see 7.3). The gaps under different magnitudes of the CID can vary. Figure 2 illustrates these gaps in face of abrupt CID(s) and slow-onset CID(s) respectively.




a) In face of abrupt CID(s)




b) In face of slow-onset CID(s)

**Key**

—— required resilience

– – – – existing resilience

\\\\\\ gap

1 shock from CID at current

5 stress from CID at current

2 shock from CID under a°C GWL
3 shock from CID under b°C GWL
4 shock from CID under c°C GWL
6 stress from CID under a°C GWL
7 stress from CID under b°C GWL
8 stress from CID under c°C GWL

NOTE Using GWLs in this figure is for reference only. They represent different magnitudes of CIDs.

**Figure 2 — Illustration of gaps between existing resilience and required resilience in face of different magnitudes of CIDs**

## 7.3 Designing adaptation strategies

The adaptation strategies should be designed to bridge the gaps between required and existing resilience (see 7.2). They can be either one-stop strategies implemented at the birth of the asset when the part(s) involved are difficult or impossible to be modified or replaced after construction, or phased adaptation strategies implemented at multiple points during the asset's service life when some parts involved can be modified or replaced over time to avoid unnecessary waste or missing opportunities to take advantage of technological advancements. Alternatively, a hybrid approach can be used, applying some strategies initially and other additional strategies when new data, risks, or technologies are identified.

Strategies may include safe-to-fail approaches based on the outcomes of risk assessments and the need to prioritize available resources[16].

Alternative strategies for the failure of adaptation strategies should also be considered.

NOTE 1 To effectively mitigate the impact of summer warming, building shapes that facilitate natural ventilation and reducing indoor temperature are prioritized and considered in one step, because the building shapes are difficult to modify once they are built.

NOTE 2 Annex D describes a case of phased adaptation.

NOTE 3 Annex E lists some typical types of adaptation strategies.

NOTE 4 Annex F features a case study of the Spaulding Rehabilitation Hospital, showcasing a range of adaptation strategies in use.

NOTE 5 Safe-to-fail approach recognizes that there are not enough resources to fix or prevent damage to most infrastructure. Some infrastructure where the consequence of failure is small can be sacrificed based on a risk assessment of the infrastructure system.

## 7.4 Identifying resilience limit

Resilience limit should be identified through feasibility assessment of adaptation strategies, taking into account technical, cost, and other constraints.

— Technical constraint

Technical constraint refers to the limits imposed by the current level of technology.

NOTE 1 As technology advances and new innovations emerge, these constraints can be further expanded, providing opportunities and possibilities for future adaptation.

— Cost constraint

Cost constraints occur when cost-benefit assessment of adaptation strategy(s) yields unacceptable results or/and initial capital investments exceed available funding. "Cost" refers to incremental cost of strategy (s). "Benefit" refers to the prevented losses by closing the gap between existing and required resilience (see 7.2) throughout the asset's service life.

For one-stop strategies, costs include initial and ongoing operation and maintenance cost. For phased adaptation strategies, costs are cumulative with each adaptation.

NOTE 2 The RDACC process can benefit from the conduct of two cost-benefit analysis – one from the perspective of the asset owner capturing costs and benefits that fall directly to the owner (including costs of decommissioning) and a second that also includes costs and benefits to the broader community. The second cost-benefit analysis can help identify or secure additional funding from the community or others who will also derive value from the adaptation investment.

— Other constraint

Cultural, social, environmental, and other factors can also be limiting.

NOTE 3 An electrical substation on a barrier island can be subject to sea level rise. For a moderate level of sea level rise, it can be cost-effective to elevate equipment. However, if sea level rises beyond an identified threshold, either the substation can no longer be accessible by utility equipment because surrounding land is under water or the barrier island's access bridge can be impassable. The barrier island can also see a decrease in residents as the island is inundated, making continued investment in the substation unnecessary.

### 7.5 Decision making on strategies

Asset owners, with feedback from the RDACC team, users and other stakeholders, should determine the appropriate strategy(s) from the feasible strategies that can achieve the resilience limits (see 7.4). Technical reliability, cost-benefit, localized solutions, and environmental friendliness, etc. should be considered. The coordination with other design goals such as seismic resilience is also needed.

NOTE In the design of a new hospital in Gansu, China, it is projected that the rainfall in the second half of this century can increase, exceeding current design standard. This can result in the entrance steps and basement being flooded. To reduce the risk, three alternative strategies were proposed: A. raising the elevation of entrances and roads, B. improving the drainage capacity of the pipe network and C. placing critical equipment rooms and medical facilities on upper floors. In terms of losses, these strategies all have high cost-effectiveness, with incremental costs amounting to 1,2 million RMB, 350 000 RMB, and 660 000 RMB, compared to total losses of 35 000 000 RMB, respectively. After comprehensive consideration, strategy A with highest costs but highest technical reliability was ultimately selected.

## 8 Monitoring and optimization

During the operation phase, long-term monitoring and optimization should be implemented, including but not limited to:

— monitoring the changes in CIDs experienced by assets and the effectiveness of implemented adaptation strategies, summarizing experiences and lessons learned;

— establishing a cadence for reassessing resilience limits based on the latest climate change knowledge from IPCC and regional/local assessments;

— embracing new technologies and innovations and utilizing the knowledge and insights gained from the experience to optimize adaptation.

NOTE Annex G introduces the design of China Qinghai-Tibet Railway embankment adapting to permafrost thawing, including monitoring during its operation phase.

## 9 Decommissioning

When assets are no longer fit for purpose and further adaptation is not a viable option, decommissioning is required. See Annex H.

The appropriate organizational models for decommissioning should be determined, including direct decommissioning (using in-house expertise to plan and manage the entire process), contract decommissioning (hiring experts to do the work), and asset sale (eliminating the need to address decommissioning), etc.

During the execution of decommissioning, asset removal and environmental restoration should be achieved, considering the capital and social costs.

NOTE Decommissioning via in-house experts requires management of the entire life cycle and restoration requirements. Few organizations have such expertise fully in-house, therefore requiring some contract support. Decommissioning via contract support outsources the entire process, but requires the internal teams to understand and orchestrate the program. Selling assets is simplest, but as growing understanding of climate change implications strand assets with rapid devaluations, it can be increasingly difficult to sell assets.

# Annex A
(informative)

# Global Building Resilience Guidelines

## A.1 General

NOTE The content in this annex is an excerpt from the Global Building Resilience Guidelines developed by the Global Resiliency Dialogue, a collaborative of building code development and research organizations from Canada, Australia, New Zealand and the USA, which worked collectively to engage with local interests and participate in coordinated surveys to source a body of information as input to the work.[17]

Buildings being constructed today face in their service life the prospect of experiencing different and potentially more extreme weather than in the past, and possibly in geographic regions where such natural phenomena have not occurred before or with such intensity.

Whilst contemporary building codes typically contain provisions and reference technical standards for design and construction to take account of most weather-related natural hazards, these are primarily based on data and experience from past events, whereas in a non-stationary climate the problem relates to future conditions, which can be characterized based on scientific analysis of current trends and predicted events using sophisticated scenario modelling.

The problem extends further to incorporate going beyond the recognized primary purpose of building codes, being public health and safety, to enabling buildings to continue to perform primary functions of shelter and re-occupation, even if rudimentary.

The Global Building Resilience Guidelines are organized around fifteen principles that provide a basis for advancing building resilience through building codes. They are intended to help inform the development of building codes and standards that incorporate future-focused climate resilience. The Guidelines are relevant for all building code and standards writing bodies, who determine how best to apply them having regard to their own jurisdictional circumstances.

It is important to note that where codes and standards are applied, they cannot guarantee a hazard event will not result in the loss of life or injury, nor that building performance will be maintained through its design life, but rather they can mitigate the overall impact of such event occurrences.

The principles are not weighted, but there is an intentional order as inevitably there are inherent interdependencies.

## A.2 Urgency

"Principle: The need to respond to the associated impacts of climate change and extreme weather events on buildings and building occupants is more urgent than ever."

Communities around the globe are already experiencing the impacts of climate change. As buildings are the foundation of social and economic function throughout society, and as rapid urbanization continues, there is an urgent need to address the vulnerabilities of communities and the risks to the services provided by the built environment from natural hazard events linked to climate change.

## A.3 Clarity of objectives

"Principle: Recognizing that building resilience requires attention to the changing climatic conditions buildings will face over their lifecycle and their expected operation post an event, the importance of building codes focusing on occupant health and safety remains."

Occupant health and safety needs to remain the primary purpose of building code provisions. However, as per the Guidelines' definition for building resilience, enabling a level of building robustness beyond occupant health and safety is considered appropriate within the bounds of the minimum necessary, having regard to the climate-related natural hazard events that may reasonably be expected. This can help communities to quickly resume their daily activities, economies to recover and help make the cost of recovery more manageable.

## A.4 Robust climate science

"Principle: Building code development will benefit from an evidence base that utilizes official climate forecasts in the local jurisdiction or models based on peer-reviewed scientific research and ideally provide a demonstration of various future state possibilities."

For buildings being constructed or substantially renovated from this point in time to provide an appropriate level of building resilience, it is necessary for contemporary building codes and standards to be developed or revised having regard to future climate projections and scenarios from scientific sources. In doing so, there will need to be a transition from historic to predicted climate data to address future risk. This transition must take account of frequency, severity and probable changes to geographic distribution, including routine reviews to maintain fitness for purpose with the latest climate science.

## A.5 Risk clarity

"Principle: Risk informed thinking and decision making is important in providing support for design decisions to balance cost, energy performance, greenhouse gas emissions and resilience, where changing risks can be balanced against certainty of performance for building development and maintenance."

Risk informs the minimum level of performance considered desirable. In turn, this becomes the goal for buildings to achieve, be it through prescribed standards or unique performance solutions that can demonstrate compliance.

## A.6 Forward-looking

"Principle: A baseline assessment of current technical construction standards, where they exist enables a comparison to be made with modelling and scenarios for future climate to help determine if they remain adequate or new ones need to be developed."

On the basis that contemporary codes typically incorporate provisions for construction in areas prone to natural hazards events, including those influenced by climate, as a matter of good regulatory practice, it is important to determine if existing requirements are adequate for future risks. Establishing a baseline assessment of current standards, where they exist, enables a comparison to be made with modelling and scenarios for future climate to help determine if they remain adequate or new ones need to be developed.

## A.7 Durability

"Principle: Understanding building design life is important not only to assist in determining minimum necessary technical construction standards, but to also calibrate the technical design requirements to improve the resilience of buildings with a benchmark of durability that avoids unnecessarily harsh requirements and therefore costs."

There are strong arguments to be made for baseline resiliency consideration to be aligned with the expected life of a building when subjected to reasonable maintenance, particularly the expected life of a building before major repair and/or recapitalization occurs, often described as the design life. This design life, which typically spans well beyond the average period of a building occupant, should also consider the realistic life (service life) of the building and its sub-components, since they are generally used for longer than their anticipated life during design.

## A.8 Holistic approach

"Principle: Building codes can contribute to improving building resilience as part of a broad suite of regulatory and non-regulatory measures, which in some cases will be inter-dependent and take account of multi-hazard weather related events."

Building codes and standards are only part of the answer to achieving improved resilience to extreme weather events in the built environment and it is important they are not thought of as all-encompassing solutions. They are imperfect instruments for such a complex and varied challenge, and it would be folly to rely solely upon them as the means to achieving resilience. Moving beyond building regulation, society needs 'the right buildings in the right places,' since 'how' to build also needs to take into consideration 'where' to build. The two are complementary and address the desire to build higher levels of resilience in the built environment. This is where building codes and the planning system intersect most.

## A.9 Affordability

"Principle: Building codes and standards consider, where possible, a regulatory principle of settings minimum requirements necessary to achieve the level of desired performance cost effectively; whilst achieving the objective of improved building resilience throughout the design life of a building under a range of future scenarios."

Building codes and standards need to maintain the regulatory principle of setting the minimum requirements necessary to achieve the level of desired performance, cost effectively. This process is designed to balance societal needs against societal capacity to pay, which at one level is an economy-wide application, and at another a household.

## A.10 Existing buildings

"Principle: Identify strategies to encourage existing building owners to bring their buildings up to a higher standard of resilience for the types of future weather-related natural hazards they may reasonably be expected to experience based on climate projections, given the geography of their property."

Building codes and standards are typically applied to new buildings and new building work, but they can also be adapted for use in existing buildings, which in the context of future climate, are likely to be more vulnerable, particularly if constructed prior to the adoption of any contemporary natural hazard standards.

## A.11 Building maintenance

"Principle: Promoting to property owners the need for planned periodic and specified maintenance of buildings and the essential building resilience features embedded in them is crucial to their ongoing performance."

As is the case with ensuring compliance with the codes and standards at the time of construction, adhering to periodic and specified maintenance of buildings and the essential systems and products embedded in them is essential to their ongoing performance. As buildings age, the issue becomes more one of maintenance than the initial design life. Routine renewals and maintenance of key elements dictate actual service life, although the frequency is not always clear other than where regulated or required to retain warranty continuity.

## A.12 Compliance

"Principle: Effective regulatory systems will incorporate appropriate resources to properly enforce the building codes and standards, as well as promote an ethic of compliance."

The need to ensure 'good enforcement' of building codes is of great importance. Failure to correctly construct building features designed to minimize the impacts of extreme weather events can significantly compromise the effectiveness of those measures, putting the wellbeing of individuals within buildings and possibly others outside at risk. It also undermines the effectiveness of the additional resilience features the building structure could be expected to benefit from. Ultimately the consumer pays, whether this be directly, through insurance or government.

## A.13 Implementation

"Principle: Complement any regulatory measures to improve compliance and support technical solutions with a wide range of education and practitioner capacity building tools."

Implementation requires significant investment in capacity building to increase understanding of the potential impacts of future climate scenarios and the utility of practical measures to help improve the resilience of buildings. It can be anticipated that some of the potential changes would require re-training and awareness raising amongst practitioners to ensure that installation is conducted correctly and effectively. This information ideally needs to come from a reliable and trusted source, such as professional industry associations, insurance agencies, local government, contractors, and social networks (e.g. neighbours, family).

## A.14 Monitor and evaluate

"Principle: Routinely monitor the need to maintain the currency of building codes and standards in response to updated climate science and projections."

Monitoring is necessary to confirm predicted climate changes and their evolution, and ensure the technical solutions incorporated into codes are effective. This grows the body of knowledge, which should be shared and assessed to determine if further change is appropriate. To do this, it is important to establish key performance indicators across several assessment criteria to help determine the adequacy of the measures and appropriate intervals for their review given the non-stationary nature of the subject.

## A.15 Engagement

"Principle: A clear and uncomplicated communication strategy that embraces and simplifies risk-based information; uses a common, credible and consistent set of evidence; and caters for the many and varied views of those with an interest in this subject."

Engagement with a broad set of interests on a topic that can be divisive, difficult to understand and involves approaches that are not mainstream, requires careful stewardship and patience, even though there is a critical time element to the work. Having a clear communication strategy that both embraces and simplifies risk-based information is essential. Using a common, credible and consistent set of facts from a unified group of climate and building scientists, presented in clear language, proves very useful to policymakers.

## A.16 Emissions reductions

"Principle: Building code development can make an important contribution to mitigating the causes of climate change with subsequent long-term benefits for building resilience."

It is pertinent to note that it is impractical to address all of the effects global warming may have on buildings through relying on resilience alone. Therefore, there will be diminishing returns from investing in resilient buildings if international efforts to mitigate the causes of climate change, for which improving the energy efficiency of buildings is an important and achievable objective, are not acted upon. In other words, if efforts to stabilize global warming are unable to keep global temperature increases to below 2 °C, then the capacity to manage the impacts on buildings through resilience features will be significantly compounded.

# Annex B
(informative)

# GWLs that assets with different service lives may experience

**Table B.1 — GWLs that assets with different service lives may experience**

| period that aligns with end of asset’s service life | Global warming levels (°C) based on different SSPs, in central estimate and the very likely (5 % to 95 %) range | | | | |
|---|---|---|---|---|---|
| | SSP1-1.9 | SSP1-2.6 | SSP2-4.5 | SSP3-7.0 | SSP5-8.5 |
| near term (2021-2040) | 1,5[1,2 to 1,7] | 1,5[1,2 to 1,8] | 1,5[1,2 to 1,8] | 1,5[1,2 to 1,8] | 1,6[1,3 to 1,9] |
| mid-term (2041 - 2060) | 1,6[1,2 to 2,0] | 1,7[1,3 to 2,2] | 2,0[1,6 to 2,5] | 2,1[1,7 to 2,6] | 2,4[1,9 to 3,0] |
| long term (2081 - 2100) | 1,4[1,0 to 1,8] | 1,8[1,3 to 2,4] | 2,7[2,1 to 3,5] | 3,6[2,8 to 4,6] | 4,4[3,3 to 5,7] |
| NOTE: The table is adapted from IPCC AR6 WGI report[11]. | | | | | |

# Annex C
(informative)

# Examples of PCDPs of some typical CIDs for building design

**Table C.1 — Examples of PCDPs of some typical CIDs for building design**

| design | PCDPs | calculation from projection to PCDPS | projection | CIDs |
|---|---|---|---|---|
| elevation | design flood elevation (m) | base flood elevation + sea level rise + freeboard | sea level rise (m) | sea level rise |
| structure | wind pressure (kPa) | wind pressure formula | wind speed (m/s) | wind |
| | thawing depth (m) | permafrost model | temperature (°C) | permafrost |
| HVAC | outdoor design dry-bulb temperature for summer air conditioning(°C)<br>outdoor design wet-bulb temperature for summer air conditioning (°C)<br>outdoor design mean<br>daily temperature for summer air conditioning (°C)<br>outdoor design temperature for summer ventilation (°C) | projected hourly data is processed from daily projection, and the corresponding PCDPs is calculated. | temperature (°C)<br>relative humidity (%) | extreme heat |
| drainage | rainfall intensity (mm/min) | rainstorm intensity formula | recurrence interval<br>duration | rain |

NOTE: The projection and PCDPs are for reference only.

# Annex D
(informative)

# Thames Estuary 2100 Plan

This case study shows how adaptation pathways (APs) were developed by the Environment Agency working with interested parties to produce a long-term strategic plan to manage tidal flood risk in the Thames Estuary for the 21st century[18].

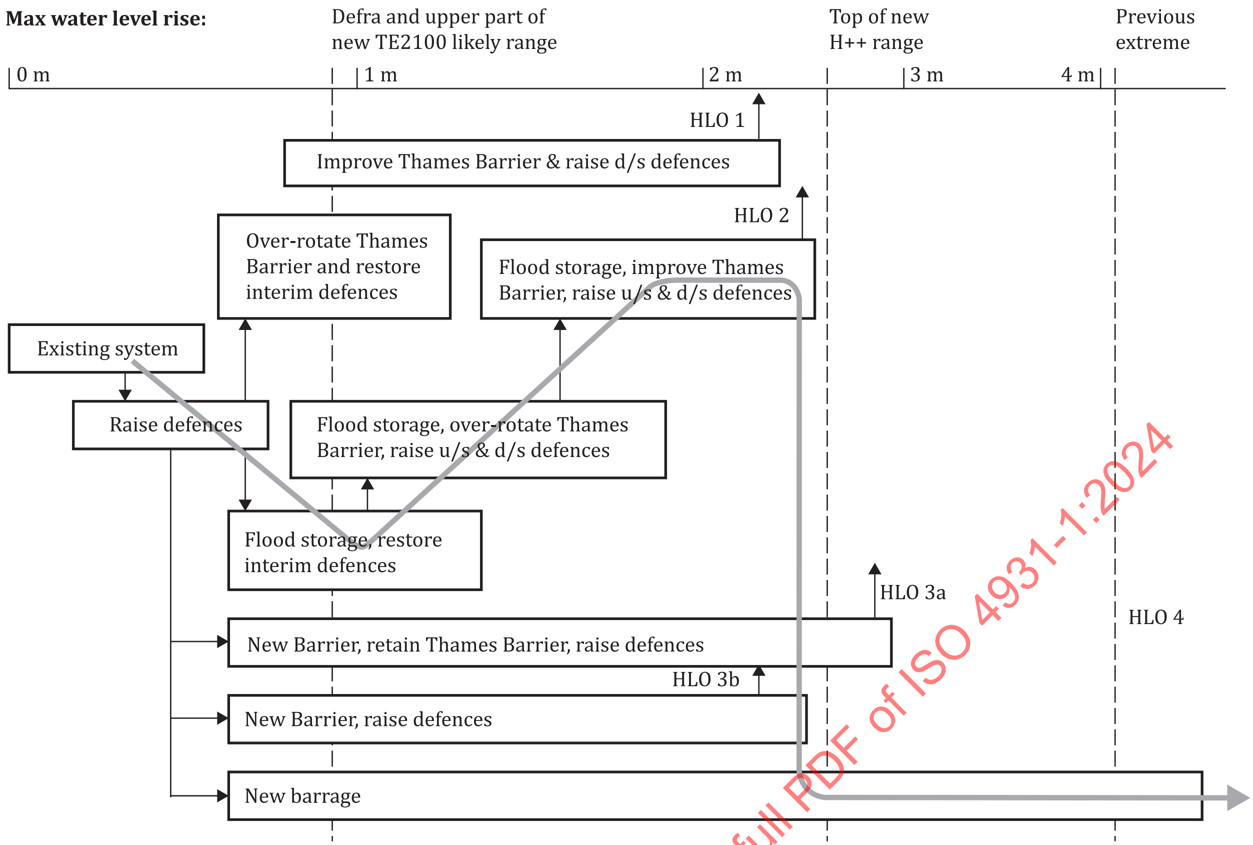
Table D.1 goes through how the nine-step process was used and developed in this case.

**Table D.1 — 9 steps in Thames Estuary 2100 Plan**

| Step | Thames Estuary project and plan |
|---|---|
| 1: Planning | The aim for the project was to produce a cost-effective and sustainable plan for managing tidal risk in the Thames Estuary for the 21st century.<br>The primary drivers were: the need to cope with ageing flood defences, uncertainty around the rate and impacts of climate change and increasing development within the tidal Thames floodplain. |
| 2: Understand the risks and opportunities from current climate | To support this the knowledge of physical, environmental and social issues had to be well understood with well-developed flood modelling to assess levels of flood risk. Studies were put in place to better understand the three main drivers above, in the planning step. |
| 3: Understand risks and opportunities from a range of future climate change scenarios, including the highest climate change scenarios | Sea level rise and maximum water level scenarios were developed, including a High++ scenario. The latter was developed to include, for example, the uncertainties around polar ice cap melt so that planning took place within a large enough envelope of potential change. This was a key step and contributed to the success of the AP approach.<br>Key thresholds were identified and assessed/understood, e.g. the protection provided by the current flood defence system was determined to be approximately 300 mm sea level increase, and the limit for annual barrier closures was set at an average of around 50 closures per year.<br>These thresholds were intensively modelled and assessed. |
| 4: Consider adaptation options for different levels of risks and opportunities, and their thresholds | Developing the adaptation interventions and pathways shown in Figure D.1 started with identifying Early Conceptual Options, e.g. if the over-rotation of the Thames Barrier plus raised defences copes with >1 m extreme water level rise.<br>A new barrier with locks would be needed to cope with >3 m extreme water level rise.<br>These thresholds were thoroughly modelled and assessed. |
| 5: Identify and evaluate the implications of interdependencies with other drivers | Social, environmental and economic issues were assessed in detail.<br>Some key potential trade-offs involved impacts on ecosystems, and their mitigations, and pressures from urban development plans were identified and described. The plan supported sustainable development. |

**Table D.1** *(continued)*

| Step | Thames Estuary project and plan |
|---|---|
| 6: Assemble a route map of adaptation pathways | Four High Level Options (APs) were assembled from measures assessed in step 4, meeting key thresholds. HLO1 focused on improving existing flood defences; HLO2 focused on maximizing flood plain storage; and HLO3 focused on building a new tidal barrier. In HLO4 a new barrage would be built across the estuary to offer protection against extreme estimates of sea-level rise.<br>The HLO development was based on an initial assumption of an increase of extreme water levels in the Thames Estuary driven by a projected sea level rise of 900 mm by 2100. Although the HLO1 adaptation pathway was found to be a sufficient response to these projected conditions, the implications of more pessimistic assumptions of sea level rise were also explored to identify alternative adaptation actions and pathways that might be required in response to unlikely but plausible extreme sea-level rise. The AP that follows the central arrow in Figure D.1 shows how it could be possible during the life of the plan to switch from HLO1 to HLO4 in the event of extreme water levels in the estuary that rise by more than 2,7 m by 2100. The HLOs shown in Figure D.1 provided a high level illustration of sequences of adaptation options that could be easily understood by stakeholders. Diagrams such as Figure D.1 were used to discuss and gain support with interested parties (communities, government, NGOs, etc.). |
| 7: Evaluate and choose adaptation pathways | The options/APs were assessed and appraised against a standard sea level rise scenario of 900 mm by 2100. Formal options appraisal used Multi Criteria Assessment/cost-benefit techniques with sensitivity testing against higher scenarios. |
| 8: Report preferred adaptation pathways | A draft plan was produced in 2009. After final consultation the plan was approved by government in 2012. It essentially recommended option/pathways 1 (improve defences, including existing Thames Barrier) or 3 (new Barrier). These were laid out against time, assuming the most likely scenario (900 mm). The plan was divided into three phases:<br>1. During the first phase, up to about 2030, the current flood defence system is to be maintained with a view to raising defences in the future, e.g. allowing for larger foundations where new defences are built.<br>2. From 2030 to 2050, the existing defences will be raised as and when they reach a replacement age. During all this time initiatives will take place to ensure that the flood plain developments are more resilient by taking on board residual flood risk guidance.<br>3. In the final phase, a decision will be needed on a replacement barrier or upgrade which, given the 900 mm scenario, will need to be in place by 2070. |
| 9: Set out implementation, monitoring and evaluation plans | The TE2100 Plan had an integrated monitoring and review strategy which allows it to be updated to reflect latest projections for climate change and other changes in the estuary. This monitoring involves reviewing 10 key indicators, including sea level rise. The plan is reviewed every five years, with a full review and update every 10 years.<br>A key issue is to ensure that the monitoring of the indicators is linked to the lead times needed to make changes to the plan. The reviews allow a check to ensure that the most appropriate pathway is still being followed. They also enable any deadlines within the pathways to be adjusted, e.g. if sea levels are rising faster than expected, the date for a new or upgraded Thames Barrier to be operational might change.<br>The first review in 2016 found that the indicators were approximately in line with the projected most likely levels in the plan. Therefore no major changes were required. Work is currently underway on the second review. As part of this process, the Thames Estuary 2100 Plan will be updated to reflect latest climate projections.<br>This is expected to be completed in 2022. |




**Key**

– – – – predicted max water level under each scenario

[box] measures for managing flood risk indicating effective range against water level

NOTE In this figure, the x axis is “rise in maximum water levels from 2000”.

**Figure D.1 — Thames Estuary 2100 Plan**