Design Manual
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Climate Action Design Manual for Buildings and Architecture


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Document Verification

Anthony Dewar — Head of Buildings & Architecture
Technical Authority

Frank Anatole — Principal Architect
Buildings & Architecture
Technical Authority

Technical Lead

Ian Grimes — Principal Engineer
Buildings & Architecture
Technical Authority

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Purpose

Network Rail's annual operational and supply chain carbon emissions are equivalent to 1,980,000 average UK homes. This is equivalent to more than the cities of Birmingham, Liverpool, Bristol, Manchester, Sheffield, Leeds, Leicester, and Coventry combined.[1] Emissions from operating and constructing Network Rail's buildings and infrastructure (excluding traction) comprise more than a third of this carbon footprint.

This manual offers clear guidance to project sponsors, asset managers and designers on how to reduce the contribution of Buildings and Architecture (B&A) assets to Network Rail's footprint as low as is reasonably practicable, supporting Network Rail's ambition to be a Net Zero Carbon organisation by 2050.

This document addresses two of the four priorities in Network Rail's Environmental Sustainability Strategy, namely a low-emission railway and a reliable railway service that is resilient to climate change.

By 2050, a changing climate will bring warmer, wetter winters and hotter, drier summers, an increase in the frequency and intensity of extreme weather events, and higher sea levels. B&A renewals and enhancements planned today need to account for these changes to ensure the railway operates safely and reliably in an increasingly unpredictable environment.

This document brings together climate mitigation and climate resilience in one place for the first time for Network Rail, to help ensure measures taken to reduce carbon and to enhance resilience are not in conflict.

Network Rail's Buildings and Architecture assets team have a commitment to design quality. A low-emission design is a quality design, and a well-designed railway is a resilient railway; commitments to climate action and design quality are mutually supportive.

This manual is intended to be read and understood by project sponsors, asset managers and designers at the inception of a project. While designers, contractors and suppliers will be responsible for its delivery, project sponsors are accountable for its implementation. Please read it, understand it, and give it to your teams with the clear understanding they are to deliver against it.

The changes demanded by climate change require innovation and collaboration, both of which thrive on open and honest communication. Please give full and frank feedback to the Technical Authority (TA) on this manual, so that lessons can be learnt and subsequent versions refined.

The manual does not replace sustainability assessment schemes such as BREEAM. In many cases the guidance provided here will mean projects achieve high scores in such schemes; in other cases it will mean projects significantly exceed the requirements of the schemes and set a new benchmark for best practice on the topics covered.

The document has six sections. In each section content is arranged so that strategic, early-stage guidance comes first, followed by more detailed considerations. There are many more cross-linkages between topics than would be practical to reference; readers are therefore encouraged to read sections in full.

A 2018 survey of Network Rail's own staff found that while many wanted to take action on climate change, they did not feel they had clear guidance as to what action they could take. This manual provides that guidance;

- Section 2 introduces guiding principles that can be applied to all projects.
- Section 3 provides one-page summaries of each main topic.
- Sections 4 to 6 provide detailed guidance that can be applied directly to projects.

While the manual should be useful as a general resource, there are also specific moments in projects where it would be especially critical for particular roles to review the document and consider its implications for their works. These have been highlighted in the relevant sections.

1. Arup calculation using data from the Office of National Statistics (https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=2010.) and the Committee on Climate Change (https://www.theccc.org.uk/wp-content/uploads/2016/07/5CB-Infographic-FINAL-.pdf) – both accessed 22/02/21

How to use this document

Section 1
Introduction:

Establishes the context and definitions used in the document.

Section 2
Guiding principles:

Sets out the frameworks and design principles implemented throughout the rest of the document.

Section 3
Climate action area summaries:

Quick reference one-page summaries of each main topic, organised to give readers a clear indication of the order in which suggested interventions should be applied.

Section 4
Operational carbon:

Specific and measurable suggestions regarding building fabric and orientation; heating, ventilation and air-conditioning; water use and heating; lighting and embedded renewables.

Section 5
Capital carbon:

Specific and measurable suggestions regarding flexibility and adaptability; maintenance, deconstruction and reuse; over-provision and over-specification; building form; material selection and specification and waste efficient procurement.

Section 6
Climate resilience:

Specific and measurable suggestions regarding flood risk reduction measures, adapting to extreme heat, extreme cold and snow and resilience to high winds.

This manual is the first step. In response to the new Environmental Sustainability Strategy, all other Network Rail documents – standards, procedures, methods – will be updated to include consideration of climate action. This document will also be revised regularly to incorporate feedback from project teams and include the latest thinking on what will be a fast-moving area. Further guidance and support on this topic will be developed.

Contents

Climate Action Design Manual
for Buildings and Architecture

Introduction

1

1. Introduction

This manual offers guidance on climate action relating to Network Rail's buildings and architecture assets across two areas:

Mitigation	Resilience and adaptation
Reduce emissions sources (decarbonise) and increase emissions sinks to first slow and then reverse the impact of humankind's activities on the planet's climate system. Mitigation is further divided into two areas; operational carbon and capital carbon. Further detail is given in Section 1.1.1.	Assess risks arising from and put in place measures at system and asset level to reduce and manage risks associated with increasingly volatile and intense weather events caused by the impact humankind has already and continues to have on the planet's climate system. Further detail is given in Section 1.2.

Climate action is directly referenced by two of the four core priorities of Network Rail's Environmental Sustainability Strategy[2], and indirectly supports the other two. This manual does not supersede the NR Environmental and Social Minimum Requirements for Projects Standard (NR/L2/ENV/015), instead it goes beyond and aims to increase ambition around net zero carbon and climate resilience objectives.

	Direct	Support
A low-emission railway	●	
A reliable railway service that is resilient to climate change	●	
Improved biodiversity of plants and wildlife		●
Minimal waste and sustainable use of materials		●

Climate action is an area which touches upon all aspects of the railway, its assets and operation. The assets, topics and projects this manual covers are presented in subsequent sections of this Introduction.

2. Accesses here https://www.networkrail.co.uk/wp-content/uploads/2020/09/NR-Environmental-Strategy-FINAL-web.pdf

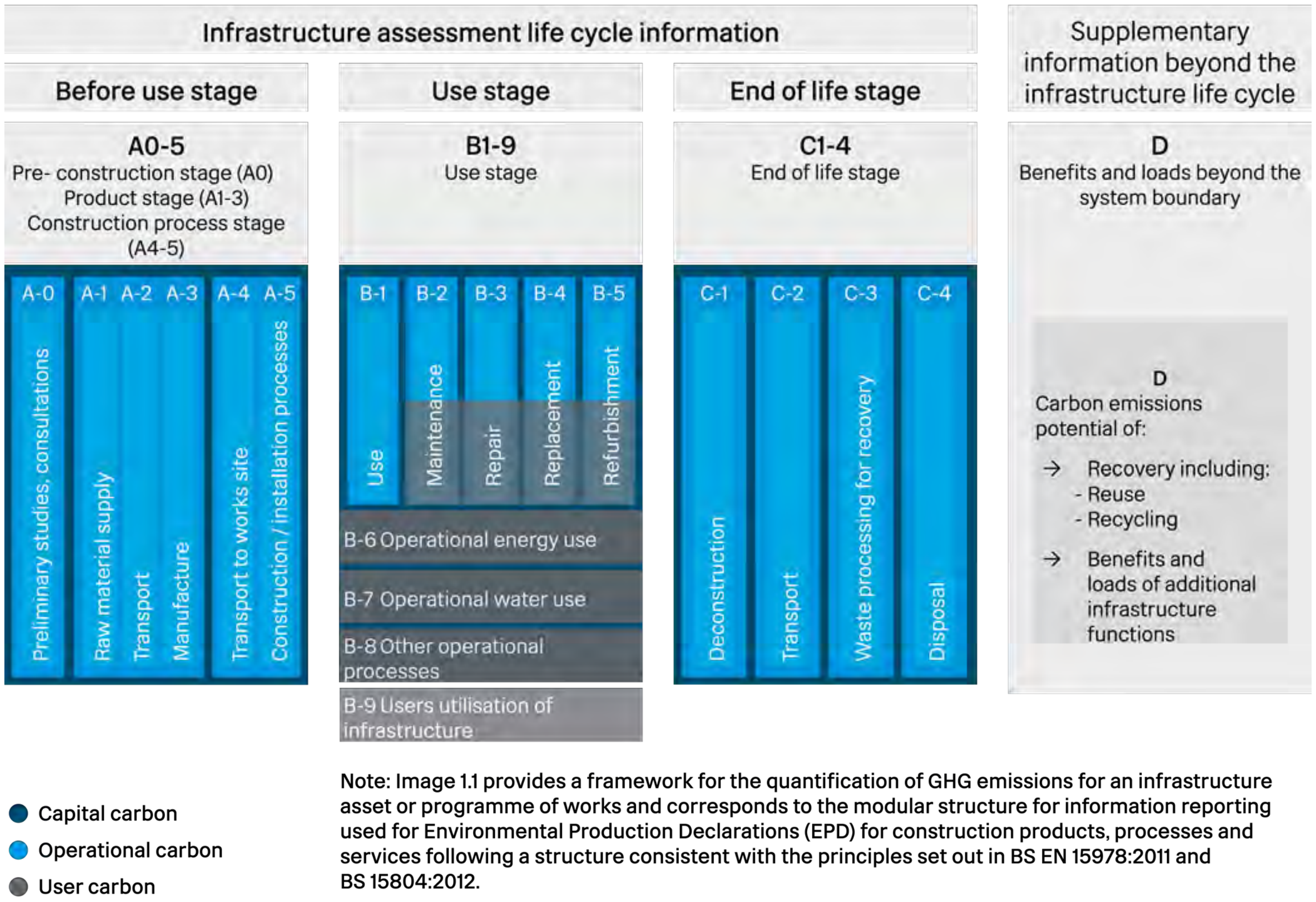
1.1 Whole asset life cycle emissions

1.1 Whole asset life cycle emissions

Network Rail is committed to being a Net Zero Carbon organisation by 2050, with an Environmental Sustainability Strategy that lays out a roadmap of action. Network Rail is also in the process of setting a Science-Based Target (SBT), an emissions reduction target aligned with the Paris Climate Agreement. This means that all projects must take action now. That requires emissions from all activities to be reduced as far as is reasonably practicable, with the residual emissions offset. To ensure projects consider all emissions sources they influence, they should adopt a whole asset life cycle emissions approach.

Whole asset life cycle emissions are taken to be the emissions associated with the design and construction, operation and maintenance, and deconstruction and disposal of an asset, Figure 1.

Figure 1. Asset life cycle stages used for carbon accounting. *Source: PAS2080:2016 Carbon Management in Infrastructure, BSI, 2016*



Note: Image 1.1 provides a framework for the quantification of GHG emissions for an infrastructure asset or programme of works and corresponds to the modular structure for information reporting used for Environmental Production Declarations (EPD) for construction products, processes and services following a structure consistent with the principles set out in BS EN 15978:2011 and BS 15804:2012.

1.1 Whole asset life cycle emissions

Table 1. Emissions sources and influence factors to reduce emissions in the lifecycle stage (1 of 2)

Lifecycle stage	Emissions sources	Influence factors	
A0 Preliminary studies, consultations	Buildings, transport and activities of staff and organisations involved in project planning.	Organisations' (suppliers, consultants, Network Rail) commitments to and actions towards reducing footprints from office and other supporting functions.	
A1-A3 Material extraction, transport and product manufacture	Material extraction, refining, manufacturing, energy supply, waste management, packaging, and supply chain transport. Use of recycled or reused materials and their preparation.	Eliminate over-provision and over-specification. Select and specify materials for low whole life carbon.	Design for waste efficient procurement.
A4 Transport to works site	Aviation, shipping, road and rail freight. Transportation of products/materials and construction equipment to construction site.	Transport mode and distance.	
A5 Construction / installation processes	Construction plant fuel use, construction site electricity and water use, waste generation, workforce commuting.	Procure materials for low whole life carbon. Plant type, fuel types and number, site electricity use and sources, construction methods, workforce size, commuting modes and distances.	Design for waste efficient procurement.
B1 Use	Arising from the fabric of products and materials once installed and in normal use. Refrigerants. Concrete carbonation (emissions credit).	Refrigerant type, system size, maintenance regime. Concrete element aspect ratio and exposure.	
B2 Maintenance	Arising from maintenance activities: capital carbon in materials and products, their transport, the transport of machinery and the transport and processing of wastes	Eliminate over-provision and over-specification. Material selection and specification.	Design for waste efficient procurement.
B3 Repair	Arising from repair activities: capital carbon in materials and products, their transport, the transport of machinery and the transport and processing of wastes.	Design for flexibility and adaptability. Design for maintenance, deconstruction and reuse . Eliminating over-provision and over-specification .	Material selection and specification. Design for waste efficient procurement.
B4 Replacement	Arising from replacement activities: capital carbon in materials and products, their transport, the transport of machinery and the transport and processing of wastes.	Design for flexibility and adaptability. Design for maintenance, deconstruction and reuse. Eliminating over-provision and over-specification.	Material selection and specification. Design for waste efficient procurement.

1.1 Whole asset life cycle emissions

Table 1. Emissions sources and influence factors to reduce emissions in the lifecycle stage (2 of 2)

Lifecycle stage	Emissions sources	Influence factors	
B5 Refurbishment	Arising from refurbishment or renewal activities: capital carbon materials and products, their transport, the transport of machinery and the transport and processing of wastes.	Design for flexibility and adaptability. Design for maintenance, deconstruction and reuse. Eliminating over-provision and over-specification.	Material selection and specification. Design for waste efficient procurement.
B6 Operational energy use	Regulated energy use: lighting, hot and cold-water supply, heating, ventilation and cooling (HVAC), pumps, control and automation, internal transport, communications, safety and security. Unregulated energy use: computers, refrigerators, audio, TV .	User behaviour and expectations, e.g. temperature set-points. Building massing & orientation. Façade performance – U-value, window-to-wall ratio, g-value, air tightness. HVAC: Heat source, cooling strategy, ventilation strategy, system efficiency.	Lighting: daylighting strategy, lighting system efficiency, metering and controls. Water: heat source, length of pipe-runs. Embedded renewables: feasibility, viability, maintainability.
B7 Operational water use	Off-site water treatment (pre- and post-usage) and distribution.	User behaviour. Rain and greywater harvesting.	Low-flow fittings. Storage requirements.
B8 Other operational processes	Sequestration in vegetation and soils (credit). Management and operational waste.	Sustainable land management, landscape design, vegetation management.	
B9 Users' utilisation of infrastructure	Staff travel.	Facilities supporting active travel, integration with other transport modes.	
C1 Deconstruction / demolition	Deconstruction, dismantling and demolition processes including plant fuel use. Demolition water use.	Material selection and specification Design for flexibility and adaptability.	Design for maintenance, deconstruction and reuse.
C2 Transport	Waste volumes. Transport to disposal and/or until the end-of-waste state.	Design for flexibility and adaptability. Design for maintenance, deconstruction and reuse.	
C3 Waste processing	Waste processor energy and water use.	Material selection and specification.	
C4 Disposal	Decomposition processes.	Material selection and specification.	
D Beyond the building lifecycle	Reuse & recycling – avoiding virgin material consumption. Exported energy – avoiding fossil fuel-based energy generation.	Design for maintenance, deconstruction and reuse. Material selection and specification.	Embedded renewables.

1.2 Climate resilience – a reliable railway

Network Rail's Environmental Sustainability Strategy 2020 commits to a greener, cleaner future with a reliable railway service that is resilient to climate change.[3] The ambition is to prepare the railway infrastructure to curb the impacts of climate change by 2050. This means making stations, tracks and trains more resilient to extreme weather. Climate-resilient asset design has a critical role to play in this effort.

Network Rail's Weather Resilience and Climate Change Adaptation (WRCCA) Strategy sets out plans for improved resilience to weather events, based on an assessment of the existing weather impacts on Network Rail's assets and the expected future impacts of climate change[4]. Asset policies and standards, including for buildings and architecture, are in the process of being updated to reflect long-term climate change projections.

The benefits of climate resilient design can stretch well beyond the protection of individual buildings and architecture. There are opportunities for Network Rail to engage and collaborate with third parties such as the Environment Agency to find effective solutions that can inspire, support or catalyse sustainable behaviours by railway users and local communities. Some resilient design options might also deliver carbon, waste reduction, biodiversity and water management benefits for Network Rail or others. If nature-based adaptation options are considered, these can offer more attractive alternatives and greater amenity value than traditional engineering solutions.

1.2.1 Climate risks to Network Rail's buildings and architecture

Network Rail's WRCCA Route Plans identify nine priority weather events that affect the performance of the rail infrastructure. Network Rail has defined 'normal', 'adverse', and 'extreme' weather days, based on the frequency of asset failure under different weather conditions. For example, daily maximum temperatures above 25 °C and below 3 °C result in a significantly higher number of incidents per day, and therefore lie outside the 'normal' weather day range.[4]

Incidents are recorded for the following weather events: flooding, heat, cold, wind, lightning strike, snow, fog[5], adhesion[6], and subsidence[6]. The impacts of these weather events are monitored using Schedule 8 delay costs: the compensation payments to train and freight operators resulting from delay due to network disruption.[4] Weather impacts cost Network Rail £50-£100m per year due to delays and cancellations. If the wider costs to the railway and the economy are included (for example missed targets, repairs and socio-economic impacts) this rises to £200–£300m a year. Whole life value is considered further in Section 2.1.

Network Rail has two climate change guidance documents for projected climate change based on UKCP18 and UKCP09 data and the climate change impact assessment guidance .[4] Table 2 summarises the potential impacts of future weather events based on the UKCP18 climate projections on Network Rail's buildings and architecture.

3. Environmental Sustainability Strategy 2020 – 2050, Network Rail, 2020, available here: https://www.networkrail.co.uk/wp-content/uploads/2020/09/NR-Environmental-Strategy-FINAL-web.pdf
4. Network Rail WRCCA Strategy 2017-2019, available here: https://safety.networkrail.co.uk/
5. Fog was considered to have negligible impact on buildings and architecture assets and so is not considered within this manual. For further information on this weather event, see the WRCCA Route Plans (2019).
6. These incidents are not directly linked to climate change, and so will not be considered within this manual. For further information on these weather events, see the WRCCA Route Plans (2019).

1.2 Climate resilience – a reliable railway

Table 2. Potential impacts of climate change on Network Rail's buildings and architecture

Climate-related hazard	Climate projections	Potential impact on Network Rail's buildings and architecture
Flooding	It is projected that flood risk across the UK will increase, as a result of increased frequency and severity of storms, more intense rainfall, and rising sea levels, and therefore is considered as a high priority risk for Network Rail. [7,8]	Fluvial, pluvial and coastal flooding all have the potential to cause damage to Network Rail's buildings and architecture. Between 2006-2016, flooding was responsible for the highest downtime cost of all the weather events across Network Rail's assets. Flooding can have the consequence of causing water damage, electrical equipment failure, personal injury, and access issues to depots, stations and offices.[9]
Heat	All areas of the UK are expected to become warmer with climate change. By 2070, average temperatures are expected to increase by 0.9°C to 5.4°C in summer, and 0.7°C to 4.2°C in winter, and heat waves are expected to be more common. For example, the summer of 2018 was joint hottest on record in the UK; by 2050 summers as hot as 2018 may occur as frequently as every other year. [7]	High temperatures can cause, *inter alia*, failure of electrical equipment due to overheating, reduced building asset lifetimes, increased passenger and staff discomfort, adverse health and wellbeing impacts to occupants and heat stress to passengers in potentially crowded stations.
Cold	The severity of cold events is likely to stay the same although the frequency is likely to decline as a result of rising temperatures.	Low temperatures can damage equipment directly or through the build-up of ice. Prolonged periods of cold weather can also lead to rock fall. Ice build-up on walkways surrounding depots, stations and offices can also increase the risk of slips, trips and falls to staff and station users.
Wind	It is expected that climate change will increase the frequency and severity of storms and therefore lead to increasing risk of wind damage.	High wind speeds resulted in the second largest weather-related downtime cost between 2006-2016 for Network Rail, largely a result of debris and vegetation blowing onto tracks. Wind can also cause damage to overheard line equipment as well as direct structural damage to buildings, roofs and canopies .
Lightning strike	Climate change projections do not specifically cover the incidence of lightning strikes, however as storms are expected to become more frequent and severe, the frequency of lightning strikes may also increase.	Lightning strikes can cause power system failure and potentially fires if infrastructure is insufficiently protected. They can also result in damage and interruption by causing adjacent trees to fall onto buildings or tracks.
Snow	Climate change projections indicate that snowfall rate is likely to decline across all areas of the UK. Snow days are likely to become less frequent by the end of the century, but natural climate variation means snow events could still occur.	Snow can cause physical obstructions that interrupt service, and increases the risk of slips, trips and falls, which can result in station closure. Snow events could also lead to crowding of stations when trains are not running due to snow on track. The application of road salt can damage structures through corrosion, particularly those made from steel and concrete.

Complete description of the projections of climate change that Network Rail uses in planning can be found in the NR Climate Change projections guidance[10], the Asset Climate Risk Assessment and the route and asset specific WRCCA plans.

7. UK CP 2018, available here: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index
8. UK sea level projections, available here: https://www.metoffice.gov.uk/research/news/2019/uk-sea-level-projections-to-2300
9. Network Rail (2015) Climate Change Adaptation Report.
10 Available here: https://safety.networkrail.co.uk/

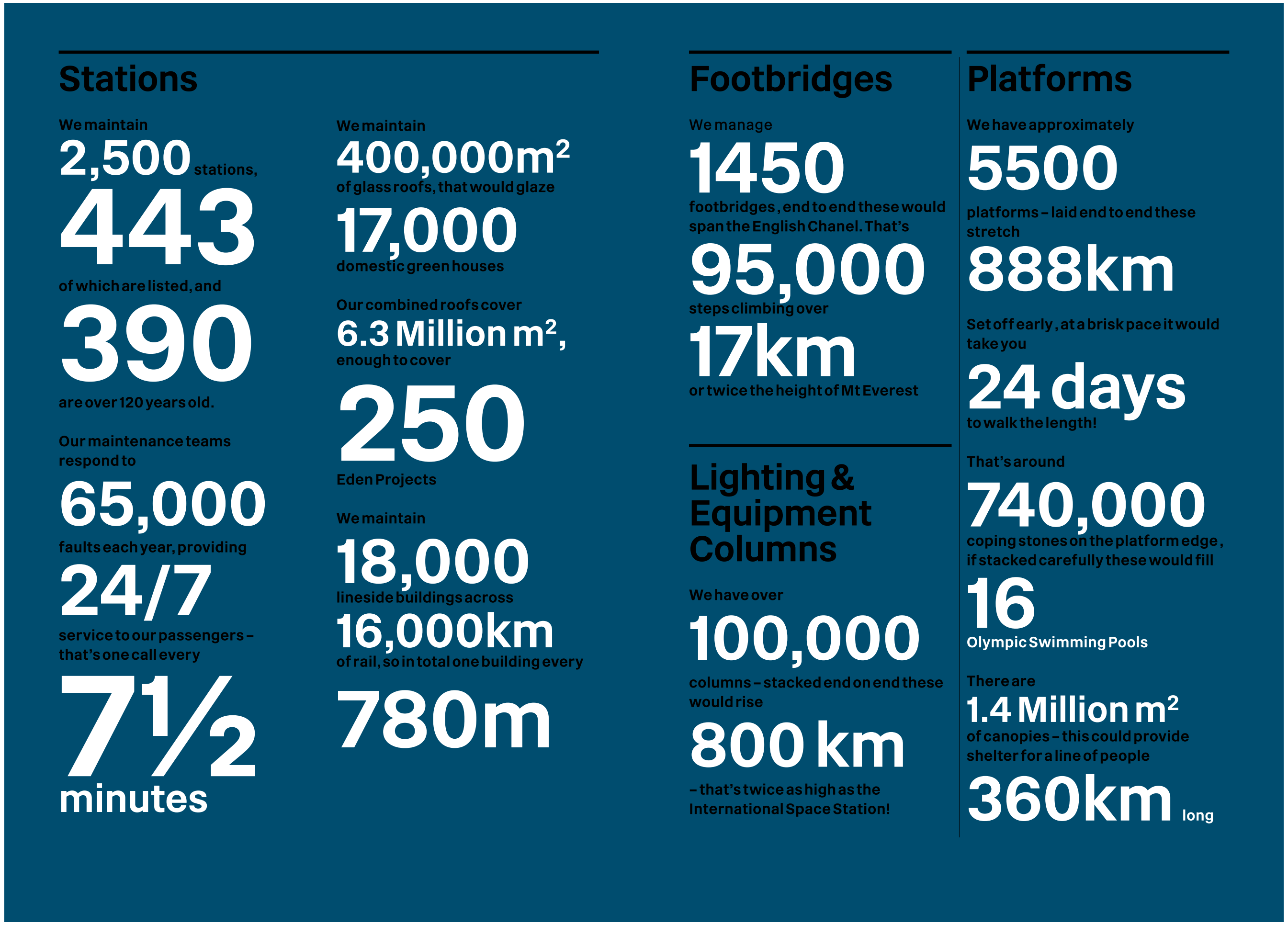
1.3 Asset types

The building and architecture assets considered in this manual are:

- Stations, comprising
  - train-sheds
  - waiting rooms including passenger facilities such as toilets
  - platforms, platform canopies and platform shelters
  - Food & Beverage (F&B) concessions,
  - Operations kiosks
  - F&B kiosks
  - footbridges
- Offices
- Rail Operating Centres, signal boxes and all lineside buildings
- Depots train-care sheds.

Land use is addressed in Section 2.10.

Figure 2. Network's Rail's Buildings and Architecture assets. *Source: Network Rail*



1.4 Projects and activities

This manual addresses both new build and renewals projects for building and architecture assets. It is noted that renewals comprise the bulk of Network Rail's activities. Network Rail has an ambition that like-for-like is replaced with like-for-better in the future so all renewals and enhancements improve resilience. For all projects like-for-better should be tested against the principles and approaches in this document. Options for renewing assets should be exhausted before new build projects are considered. The reduction hierarchies introduced in Section 2.1.5 are equally applicable to new build and renewals. The principles will also help make new assets easier to renew.

This manual is written to be applied to projects. Its principles and primary references can equally be applied to portfolios or programmes of work. For example, the management specification PAS2080:2016 puts requirements on everyone in the construction value chain whether operating on projects or across portfolios.

Figure 3. Redevelopment of King's Cross Station. *Source: © Hufton + Crow*

Gleneagles station

Climate Action Design Manual
for Buildings and Architecture
Guiding Principles

2

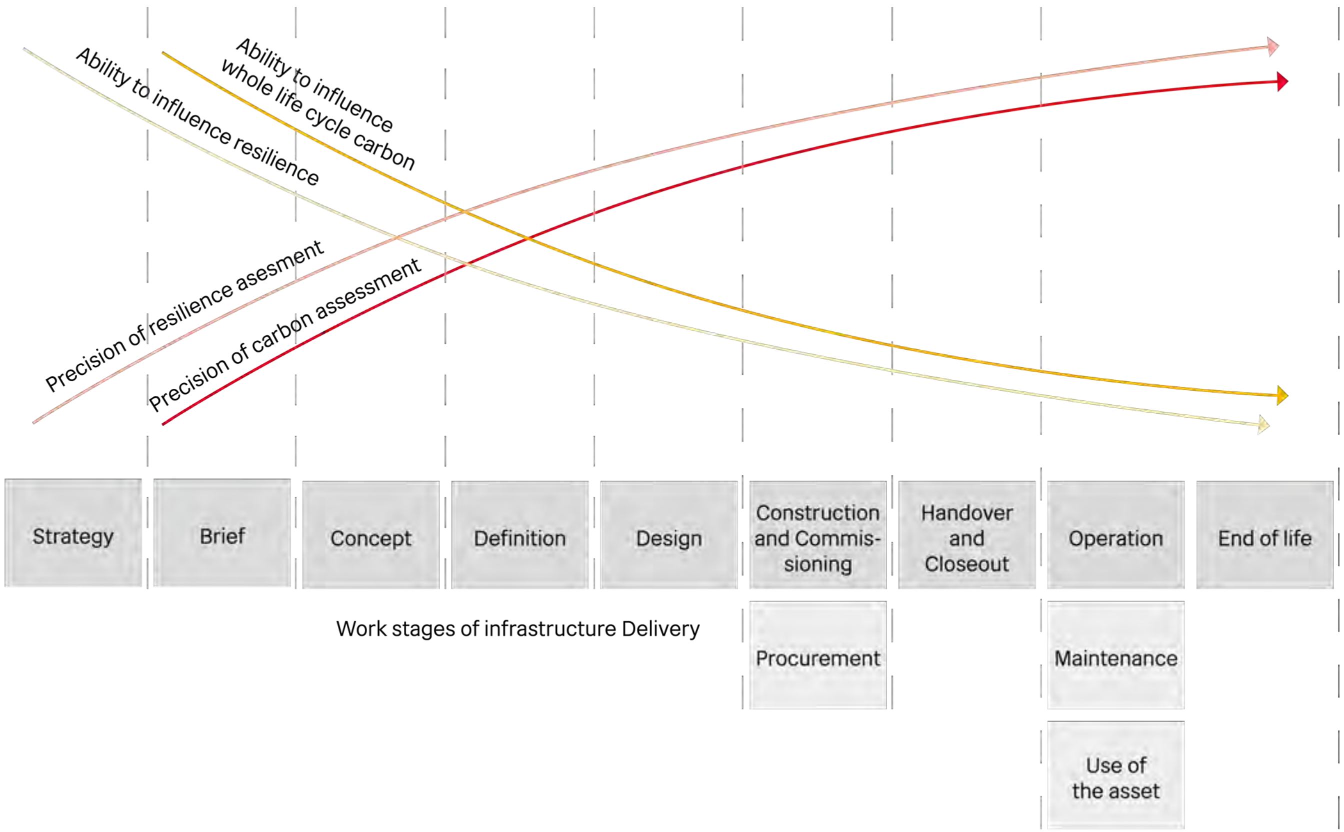
2.1 Whole life value

Whole life value is the total value – social, economic, environmental – delivered by a project over its lifetime. An asset creates value through its role in a wider system; rail improvements can create social value from reduced air pollution and environmental value in reduced emissions if, for example, they are considered as part of a wider mobility system and support a modal shift away from petrol- or diesel-powered private vehicles.[11]

Whole life value considers the lifecycle of an asset, which necessitates considering how value changes over time. Assets maintain their value by:

- meeting the diverse needs of a broad range of stakeholders from inception; and
- adapting to changing needs over time.

Figure 4. Opportunity to influence whole life cycle carbon and resilience, highlighting the importance of project strategy and brief.
Source: Adapted from PAS2080:2016 Carbon Management in Infrastructure, BSI, 2016



[11] An example definition of social value can be found in *Making the Total Value Case for Investment in Infrastructure and the Built Environment*, Arup, available here: https://www.arup.com/perspectives/publications/research/section/making-the-total-value-case-for-investment-in-infrastructure-and-the-built-environment

2.1 Whole life value

Once projects have considered how asset use and performance might change over time, the cost implications can be considered using Whole Life Costing (WLC) methods and the emissions implications can be considered using Life Cycle Assessment (LCA) methods, see Section 2.1.1.
When considering climate resilience, the return on investment typically extends across decades rather than the traditional five-year return period. This should be factored into WLC and LCA methods to ensure that investment in climate resilience now will reduce future impacts and save money across longer time scales. All projects should consider both carbon and climate resilience pay-back periods.

These assessments should be initiated at the strategic planning stages of projects, where opportunities to mitigate emissions and design-in inherent resilience are greatest, Figure 4.

2.1.1 Carbon Management and Life Cycle Assessments

PAS2018:2016 establishes the principles of how whole life carbon should be managed by project team members across the value chain. Network Rail is in the process of adopting its management approach on all its projects.

Life Cycle Assessments (LCAs) assess the environmental impacts associated with a product, process or service over its entire life cycle, across materials extraction, production, construction and transportation, use, and end-of-life treatment.

LCAs on Network Rail projects should consider operational and capital carbon together as a minimum. User carbon should also be considered where relevant.

Industry guidance for calculating carbon is becoming increasingly available for specific disciplines, for example:

- for buildings, Whole life carbon assessment for the built environment, RICS (2017);
- for structural engineers, How to calculate embodied carbon, IStructE, (2020);
- for building services engineers, TM65: Embodied carbon in building services: A calculation methodology (2020);

2. Guiding principles

2.1 Whole life value

Figure 5. Balance between operational and capital carbon in research. *Source: LETI Climate Action Guide, LETI, 2020*

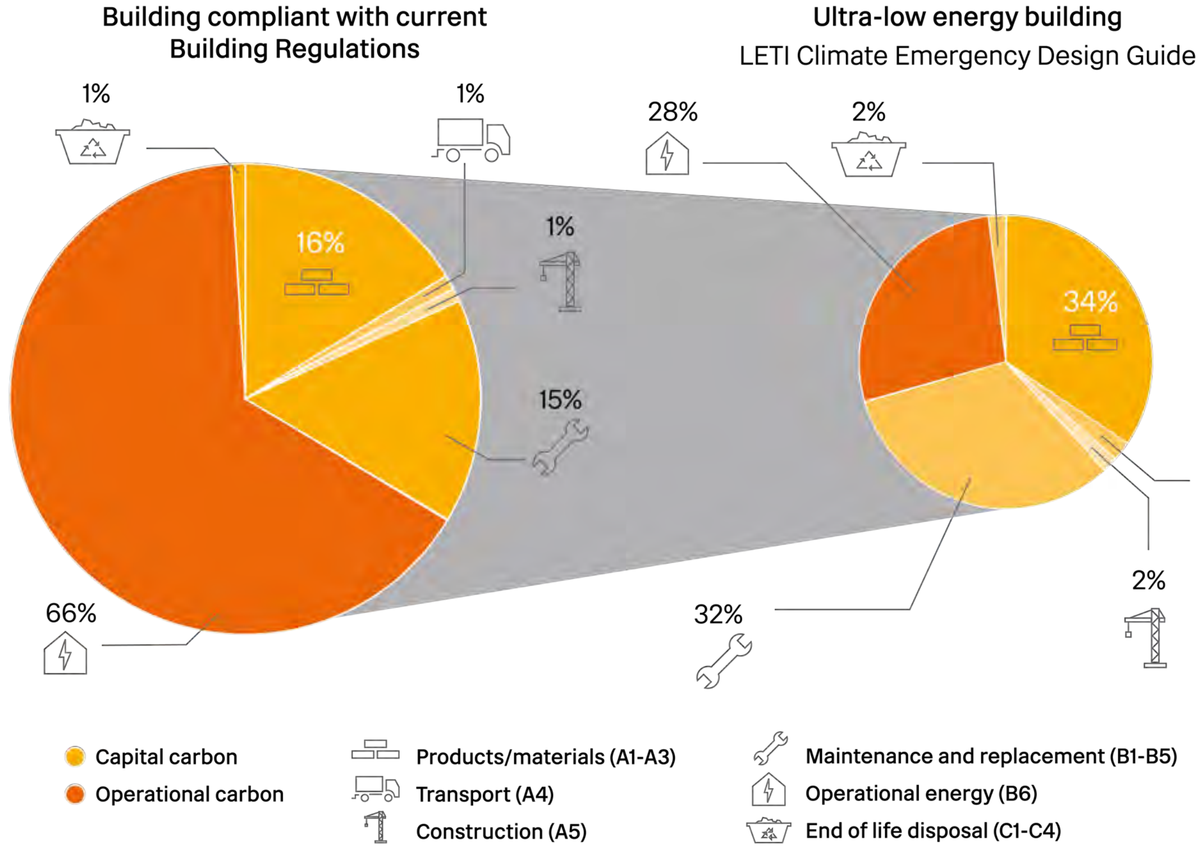


Figure 5 identifies life cycle stages used in LCAs, including capital carbon (A1-5, B1-5, C1-4), operational carbon (B2-B5, B6, B7) and user carbon (B9).

Carbon assessments should be carried out for all Network Rail projects, informed by the guidance above and using the RSSB Rail Carbon Tool (RCT).[12] For more information, see Network Rail's Capital Carbon Guidance Note.[13]

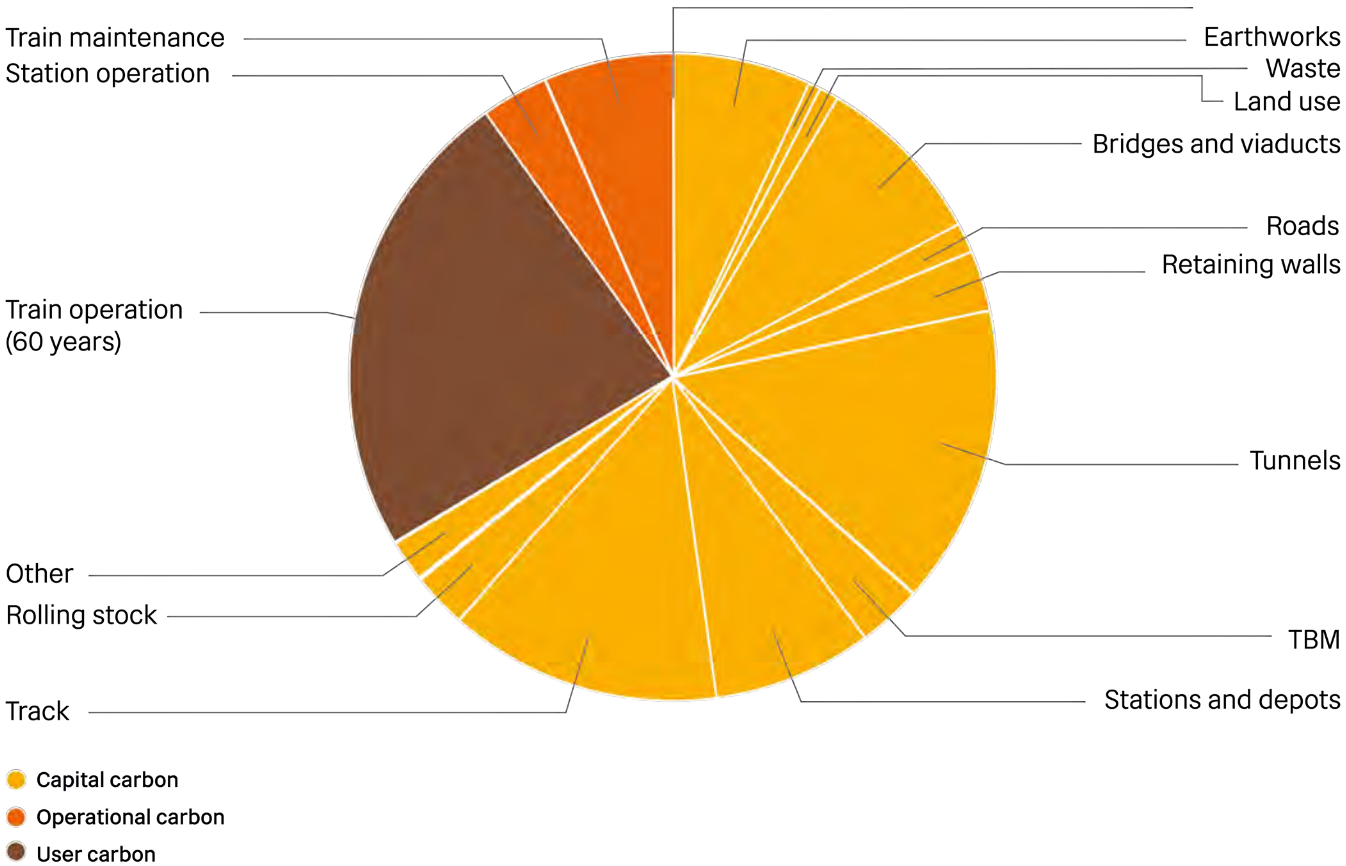
[12] The tool can be accessed at https://www.railindustrycarbon.com/
[13] Network Rail (2018) Capital Carbon Guidance Note. Available at: https://safety.networkrail.co.uk/wp-content/uploads/2019/05/capital-carbon-ESD07-v.11.pdf

2.1.2 Balance between capital carbon, operational carbon and climate resilience

A whole-life carbon methodology allows for the mutual interdependencies between capital and operational carbon to be calculated and evaluated, Figure 5 and Figure 6. These dependencies continue to change over time as, for example, grid decarbonisation reduces the emissions intensity of energy use, while material supply sectors such as cement and steel are yet to make progress on decarbonisation and are considered 'hard-to-abate[14]'.

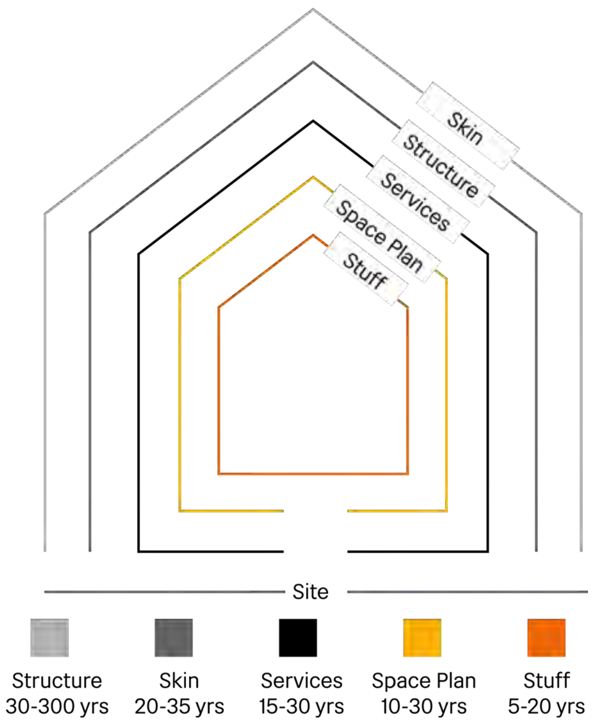
Furthermore, direct trade-offs also exist between capital and operational carbon. For example, it was found using whole life carbon analysis that, at the World Wildlife Fund's Living Planet Centre, triple-glazing created more emissions over the lifetime of the asset than double-glazing, as the capital emissions in the additional framing and glass exceeded the operational emissions savings.[15] In this analysis, the full life cycle analysis revealed that the 'upgrade' to triple glazing was not the lowest carbon solution.

Figure 6. Whole life carbon assessment for high-speed rail. *Source: Adapted from London-West Midlands Environmental Statement, Volume 3 Route-wide effects, HS2, 2013*



[14] Emissions-producing sectors which are likely to be harder to decarbonize include heavy duty transport – trucking, shipping and aviation – and industry – steel, cement and plastics. For more information see https://www.energy-transitions.org/consultation-papers-on-harder-to-abate-sectors/
[15] For more information http://assets.wwf.org.uk/custom/stories/lpc/

Figure 7. Brand's Shearing Layers model. *Source: Adapted from Brand S., How Buildings Learn, Viking Press, 1994*



Site is the fixed location of the building

Structure is the building's skeleton including the foundations and all load bearing elements

Skin is the facade and exterior

Services are the MEP, security and vertical transportation systems

Space Plan is the solid internal fit-out including partitions and floors

Stuff is the rest of the internal fit-out including furniture, lighting, and ICT

Furthermore, adaptation measures intended to build climate resilience can have adverse impacts on climate mitigation efforts. When designing like-for-better assets it is crucial to approach capital carbon, operational carbon and climate resilience holistically by identifying trade-offs, considering return on investment opportunities and then seeking to strike an appropriate balance to maximise benefits for all three.

For example, improving fabric performance (high insulation and air tightness) and passive design (winter solar gains) to reduce heating energy demand in winter can also increase the risk of summer overheating in buildings. Good building design is therefore reflected by balancing these trade-offs and ensuring buildings are energy efficient in winter yet provide thermal comfort in summer.

When balancing high capital carbon emissions with climate resilient material the use of LCA or WLC methods may highlight that weather resilient materials could have higher capital carbon. Effort should be made to identify responsibly made and locally sourced materials to strike a balance between capital carbon and resilience.

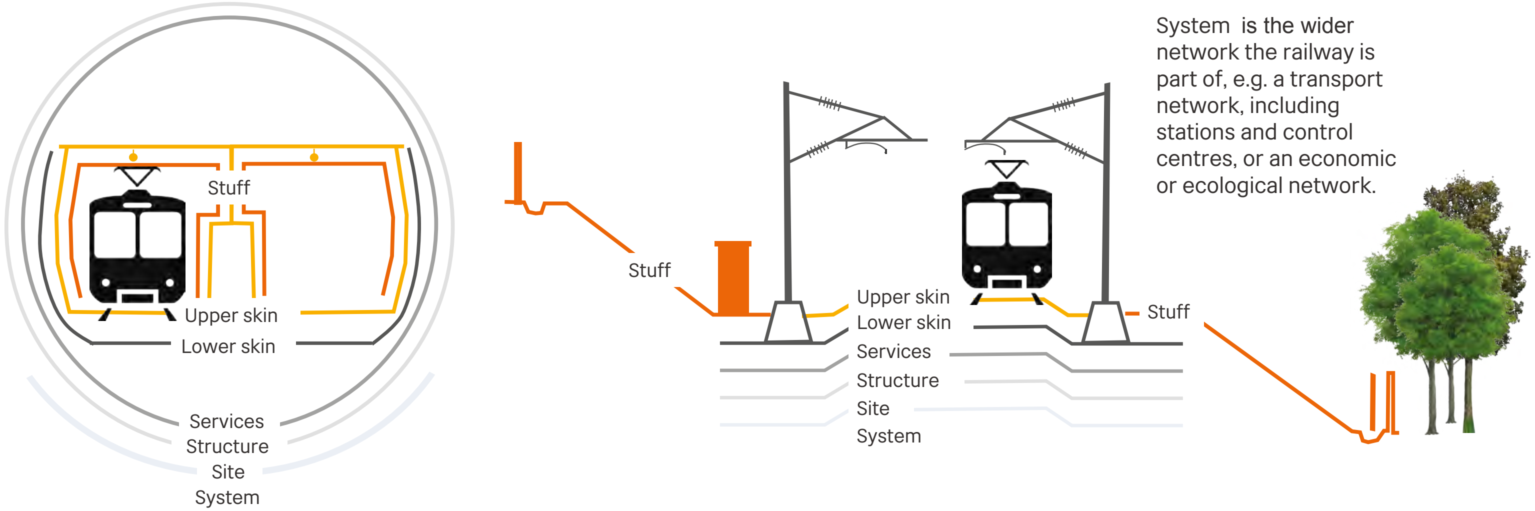
2.1.3 Build in layers

Built assets are not single objects with a single design life; rather they are complicated assemblies of components that deteriorate or become obsolete over different time frames. Stewart Brand, an American architect, proposed the 'shearing layers' model in the early 1990s as one way of understanding how different parts of a building change at different speeds over time, Figure 7.

Arup have adapted this model for rail infrastructure, Figure 8.

Designing in layers – ensuring the layers are independent of each other allowing each to change at their own speed – is a fundamental principle for creating simple, flexible assets that adapt to changing user needs and societal demands, ensuring that assets are low emission and resilient throughout their lives.

Figure 8. Arup has adapted Brand's layers diagram for rail assets. *Source: © Arup*



Stuff and Space Plan is the items on or around the railway, e.g. signage.	Upper skin includes elements such as systems wiring, rails, rail supports and fire protection.	Lower skin includes systems infrastructure, track slab, ballast, and access infrastructure.	Services can include drainage, fire main water supply, lighting, cable troughs, ducts and rail systems.	Structure is the formation of the railway – subgrade, foundations and other earthworks and structures.	Site is the fixed location of the railway and its geographical setting.
10-50 years	5-40 years	15-120 years	25-120 years	50-200 years	Outlasting all

For buildings, UKGBC has expanded Brand's layers to suggest differentiated strategies, based on circular economy principles, aimed at helping project sponsors write better briefs, Figure 9.

Figure 9. Lifetime strategy and tactics sets out examples of the lifetimes of different elements and 'layers' of the building and the different strategies and tactics that can be applied. *Source: UKGBC (2019) Circular economy guidance for construction clients: How to practically apply circular economy principles at the project brief stage*

		Short Life Components		Long Life Components	
	Lifespan	0-5 years	5-10 years	20-30 years	30-300 years
	Example components	Internal finishes, furniture	Internal partitions, ceilings, floors, local services	Building services	Sub-structure, structure, floors, fabric
	Overall Strategy	Match material to lifespan, design for disassembly and return to manufacturer	Design for reconfiguration, use modular systems	Design for maintenance, replaceability, remanufacture	Long life, loose fit Adaptable to different uses Temporary buildings designed to be relocatable
Principles and examples of application	Designing in layers	Ensure finishes allow access to services	Non-structural partitions	Services to be accessible and replaceable	Avoid interdependency of structural frame and facade
	Lean design	Inherent finishes	Exposed soffits Modular tea points	Design out systems	Lightweight structures
	Design out waste and use of reclaimed materials/ components	Remanufactured furniture; Remanufactured paint	Reclaimed glass partitions	Modular systems, offsite manufacture to reduce site waste Challenge supply chain to provide remanufactured equipment	Offsite manufacture Standardised components Select grids that optimise material efficiency
	Partnership models and return to manufacturer	Lease components or arrange for return to manufacturer	Design interiors that can be reconfigured or disassembled	Leasing service arrangements for items such as lifts and lighting	Select elements that can be reused or returned to manufacturer
	Materials selection	Use biological materials that can be composted at end of life or certified products (e.g. Cradle2Cradle/Natureplus)	Use partitions made from bio-composites	Use plant and equipment that can be remanufactured Fabric ductwork	Structural elements with recycled content (or renewable ie engineered timber) Certified facade systems
	Design for disassembly	Use furniture and fittings designed for disassembly	Dry-lay floor tiles Relocatable partitions	Equipment and distribution systems that are modular	Structure and facade that is designed with reversible mechanical fixings

2.2 Decarbonise existing assets

2.2 Decarbonise existing assets

Buildings and assets often consume more energy than predicted during design.

Operational performance of assets can be understood by appropriate metering, data collection and performance monitoring.

Using this data to diagnose commissioning errors and identifying where systems conflict, for example where heating and cooling systems run at the same time, can deliver energy savings of 10% or greater with little or no capital expenditure. The data can also be used to write better briefs for new assets and better specifications when renewing existing equipment.

Figure 10. St Pancras International Station *Source: © Daniel Imade Arup*

2.3 As far as reasonably practicable and sufficiency

Design guidance often suggests ‘minimising’ this impact, or ‘maximising’ that service. Good design is a matter of weighing trade-offs between competing drivers (performance, cost and value, carbon, resilience and programme) to find solutions that give the best outcomes across multiple metrics. In this context the idea of maximising or minimising is unhelpful, as these words say nothing of those constraints.

This manual instead asks project sponsors and designers to work not to minimise or maximise but to reduce or increase, or often in the case of renewals achieve new build design standards as far as reasonably practicable. The manual invites project sponsors and designers to decide what is reasonable as Network Rail works with its designers and suppliers to achieve its ambitious climate goals.

Figure 11. White Collar Factory, London *Source: © Paul Carstairs Arup*

2.4 Feedback

The TA requests that projects report back where they have not been able to meet a suggestion made in this manual, presenting reasons why alongside the chosen design solution selected to progress. This allows the TA to identify which areas require further research and review, and to consider how to provide additional guidance to further support project teams.

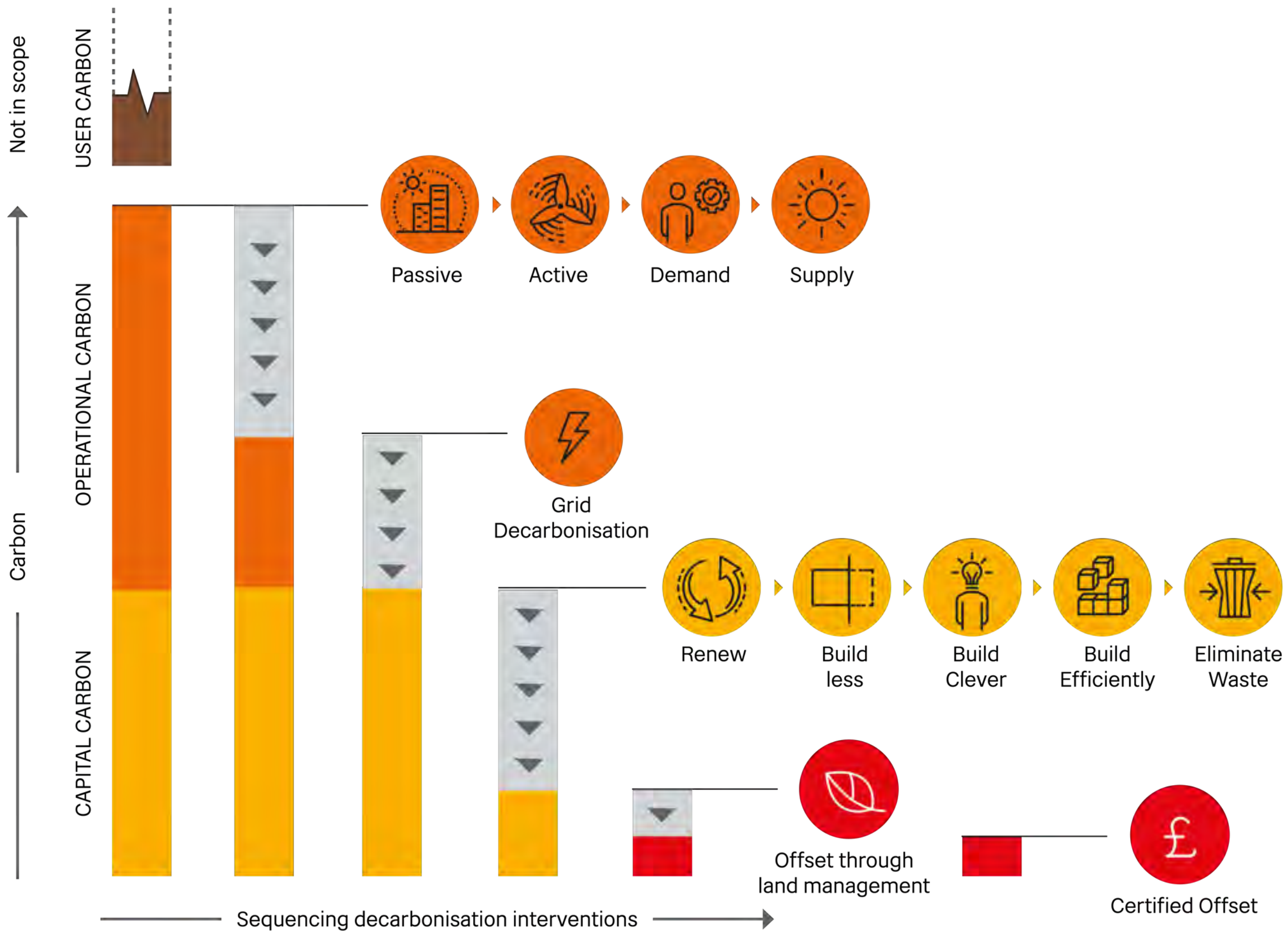
Figure 12. Bristol Temple Meads Station *Source: © Matt Cox Arup*

2.5 Emissions reduction hierarchies sequencing

This manual draws on reduction hierarchies for capital and operational carbon to propose a single framework project sponsors and designers can use to sequence their thinking on climate mitigation, Figure 13.

What this hierarchy means in practice is summarised in Table 3.

Figure 13. Operational and capital carbon reduction strategies in sequence. *Source: © Arup*



2.5 Emissions reduction hierarchies sequencing

Table 3. Emissions reduction hierarchy explained

Principle	Description
Passive	Being lean is the highest priority and most impactful way to reduce emissions. It requires taking action to reduce the energy service demand of buildings and is most effective when considered during the earliest stages of ideation and design.
Active	Meet remaining demand efficiently and cleanly. Electrify
Demand	Manage demand dynamically using on-site storage Contribute to smart grids by installing two-way connections to the grid
Supply	Generate energy on-site Support renewables uptake by grid
Renew, transform & reuse	Evaluate the basic need for the development and exploring whether there are alternative means (reusing existing assets, or nature-based solutions obviating the need for construction, for example) of achieving the same outcomes.
Build less	Consider how the amount of new construction can be reduced, for example by re-using components and materials.
Build clever	Once the overall construction requirements have been reduced as appropriate, the use of low carbon solutions (including technologies, materials and products) should be considered to reduce resource consumption over the asset's life cycle
Build efficiently	Techniques that reduce resource consumption should be utilised during the construction and operation phases of the asset.
Eliminate waste	Choose designs, materials, details and construction processes, for example offsite fabrication, which reduce waste arisings to zero.
Offset through land management	Use sustainable land management across Network Rail's land holdings to sequester carbon in plants and soils
Certified offset	Purchase high-quality, transparent, independently verified and UK-based carbon offsets

2.6 Mitigation Design Topics

This manual identifies five topics project sponsors and designers should consider when reducing operational carbon emissions from buildings and architecture assets.

Table 4. Operational carbon design topics covered in this manual

Topic	Description
Building fabric and orientation	Regulates the indoor environment by controlling the flow of energy between a building's interior or exterior. Reductions in heating and cooling loads can be achieved when the design of a building's fabric and orientation is optimised, i.e. taking a 'fabric first' approach. Good design can increase resilience of the building against future climate change.
Heating, ventilation and air conditioning	Controls the heating and cooling within a building to provide thermal comfort and acceptable air quality. The lifetime of the asset should be accounted for when including climate change resilience measures, and occupant interaction and feedback should be considered.
Water use and heating	The energy source chosen for heating water should consider the lowest carbon option that also reduces water usage. Good design will consider the impacts of future climate change on the efficiency of rainwater systems.
Lighting	Natural daylight should be used where possible. To optimise use of artificial lighting, high efficiency LED lighting should be assumed in all designs. The integration of control systems should be used to provide light only when it is needed.
Renewables	Building integrated renewables offer the opportunity for buildings to meet much of their own energy demands. Considerations such as fire safety, maintenance and return on investment all need to be carefully considered to make sure investment in building integrated renewables delivers on its potential.

2.7 Offset residual emissions

This manual identifies six topics project sponsors and designers should consider when reducing capital carbon emissions from assets, Table 5.

2.7 Offset residual emissions

The need to offset emissions, either internally within Network Rail or through externally purchased offsets, means project sponsors need to provide reliable and accurate assessments of project residual emissions to the Network Rail Decarbonisation taskforce.

Opportunities to offset emissions within project boundaries are explained in Section 2.10 and should be exhausted before the final emissions total is reported by the project.

Table 5. Capital carbon design topics covered in this manual

Topic	Description	
Design for flexibility and adaptability	Flexible spaces change use during the day and week, responding to changing passenger volumes to meet local needs with space required by the railway only during peak times.	Adaptable assets can change their function over years and decades as technology, climate, and society change, creating new demands and expectations. There are strong synergies between design for adaptability and climate resilience.
Design for maintenance, deconstruction and reuse	Designing for maintenance, deconstruction and reuse is fundamental for achieving materials resource efficiency. Minimising the amount of material imported or exported to site is the first step and should be supplemented by maximising the use of material with a high recycled content.	Standardised modular components, often suited to offsite construction, are advantageous for designing for deconstruction and reuse because they present greater opportunities for disassembly and reuse at end-of-life and can be easily replaced.
Eliminating over-provision and over-specification	Over-provision occurs when a design solution conservatively exceeds the design criteria and over-specification occurs when the design criteria is set in excess of what might be considered reasonable and appropriate.	Care should be taken during the early design stages to specify sensible design criteria that optimises low carbon solutions without compromising safety.
Building form	The form of a building is crucial when developing optimised low-emission buildings. Early collaboration and integration	should be sought when considering the building form to reduce material quantities as low as reasonably practicable.
Material selection and specification	The selection of alternative materials such as engineered timber can significantly reduce capital carbon emissions. Material selection should be guided by the following prioritised principles: • Circular economy: prioritise non-toxic, reused and reusable materials, followed by recycled and recyclable materials. WRAP's Designing-out Waste principles should be used. • Low carbon: choose materials produced with low carbon energy and through low-emission processes emissions, or choose sustainably harvested bio-based materials.	Responsibly sourced materials with transparent and ethical supply chains should be selected, including social, economic and environmental dimensions. The following frameworks can be used to guide responsible sourcing: • BS 8902 - Responsible sourcing sector certification schemes for construction products - Specification (from BSI). • BES 6001 - Framework Standard for the Responsible Sourcing of Construction Products (from BRE) All other things considered, materials should be selected on the basis of lowest whole life carbon.
Design for waste efficient procurement	Identifying opportunities to eliminate waste early on in the design process is key to maximising the use of materials during construction. Considering options to standardise design can reduce offcuts, and early integration between design teams	and contractors can set up procurement processes and integrate targets to promote waste reduction.

2.8 Climate risk reduction

Figure 14 illustrates four strategies for reducing climate risk. Project sponsors, asset managers and designer should consider these strategies in the design of all buildings and architecture assets for new and renewals projects.

Opportunities should be sought to maximise wider benefits and synergies with carbon reduction opportunities, including the use of land management techniques, Section 2.10, to enhance biodiversity. Greater awareness and involvement with new research and opportunities to collaborate with third parties will ensure these wider benefits are realised.

2.8.1 Avoid risk

Involves the elimination of a risk, for example, selecting a location for a building that is not susceptible to flood risk.

2.8.2 Reduce risk

By reducing exposure and/or reducing sensitivity of an asset to a risk. Solar shading, such as platform shelters, can reduce risk of passengers suffering heat stress, whilst using equipment that can function at higher temperatures will reduce heat-induced equipment failures.

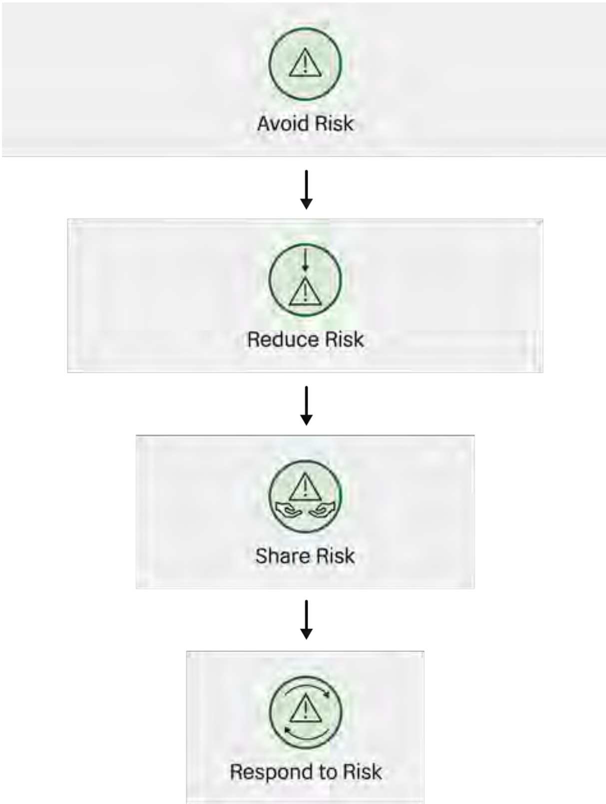
2.8.3 Share risk

Involves sharing or spreading the risks or losses, for example, participating with third parties in whole-catchment flood management plans which spread flood risk from a small number of pinch-points to a larger number of locations throughout a catchment.

2.8.4 Respond to risk

Involves planning for the materialisation of risk, by establishing robust response and recovery plans based on a climate risk assessment. Plans should be regularly reviewed, updated and communicated to all relevant stakeholders.

Figure 14. Climate risk reduction strategy. *Source: Adapted from EU Climate Adapt*[16]



[16] Adapted from EU Climate Adapt: https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-3-0

2.9 Weather and climate resilience design principles

This manual identifies seven principles for achieving a climate resilient railway.

2.9.1 Understand the risks

The vulnerability of a site to climate risks is highly dependent on local conditions such as location in the UK, proximity to water bodies, the surrounding built environment etc., and therefore climate resilience measures should be underpinned by a robust understanding of the specific levels of risk at that site, with due consideration of the latest climate projections and the site's local and regional context. The Route WRCCA Plans and the Asset Function Risk Assessment present the key risks and priorities for each Route. Risks will need to be assessed for all projects, see the Impact Assessment Guidance for further detail.

2.9.2 Prioritise a system-wide approach

Focussing on climate risks at the asset level can obscure wider factors that contribute to risk. This can limit the options for addressing it. Taking a system-wide approach has the potential to improve resilience more effectively, economically and with lower capital carbon. For example, protecting an asset from flood risk through increasing the permeability of surfaces in the wider catchment may be more effective than solutions that target that asset in isolation.

Identifying interdependencies with other infrastructure operators (e.g. power, telecoms, energy, roads) and exploring partnership funding opportunities with third parties can maximise the benefits of a system-wide approach.

After system-wide solutions have been considered, improving the resilience of assets in situ will be necessary. For example, it may be possible to allow for additional "climate headroom" that can offer capacity to cope with more frequent or severe extreme weather over the long term, with consideration of the capital carbon required to achieve it. See Section 6 for system-wide and asset-specific examples of climate resilience measures.

2.9.3 Integrate nature-based solutions

Nature-based resilience options can be attractive alternatives or accompaniments to more traditional civil engineering resilience options. They contribute to carbon sequestration efforts, and enhance biodiversity, see Section 2.10. In addition, they can be more flexible than hard engineering solutions and lead to carbon reductions where carbon-intensive civil engineering scopes are reduced or eliminated. For example, parks or green space adjacent to railway buildings can support flood alleviation, and shading from trees can address heat stress. These often represent collaborative solutions to addressing climate risks and can offer ancillary benefits.

2.9.4 Consider carbon implications and seek co-benefits

It is important to consider the implications of resilience measures on operational and capital carbon, and seek solutions that do not have a negative impact on whole-life emissions.

Good climate-resilient design can bring additional benefits for railway users and local communities in relation to other environmental, social or economic goals. Climate-resilient railway assets can support local ambitions for resilience and sustainability, but can simultaneously deliver carbon, waste reduction, biodiversity and water management benefits for Network Rail.

Mutual benefits can be realised through links between the asset design (e.g. station design) and local area (e.g. green space improvements) benefiting the wider community and not just the railway.

2.9.5 Design for future adaptability

Given the uncertainty about how the climate may change over the longer term, climate-resilient assets need to be designed for adaptability, for example, providing space for future expansion of a drainage system. This approach also helps reduce capital carbon over the long term, see Section 5.

2.9 Weather and climate resilience design principles

Adaptation pathways are an approach to identifying and planning for evolving portfolios of adaptation work for major railway assets. Network Rail Regions are developing these strategies, due to be finalised by 2029.

2.9.6 Collaborate with third parties

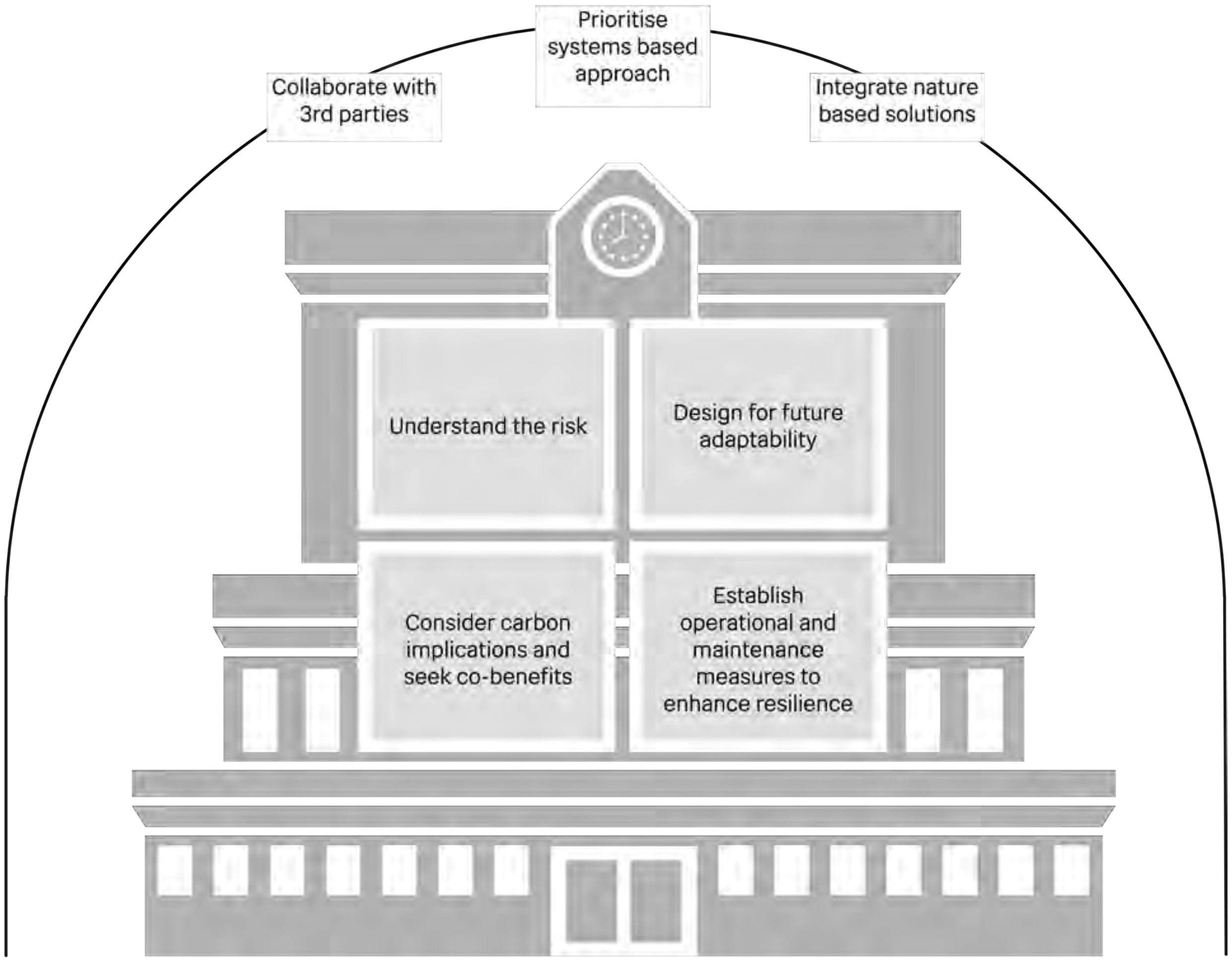
Some climate risks might be most effectively and efficiently addressed through Network Rail working in collaboration with third parties or other stakeholders. Likewise, the design of railway assets can improve the climate resilience of the local area.

For example, increasing flood risk at the railway site of interest may be reduced by changes in surface or fluvial water management upstream of that location. Or changes in vegetation management outside Network Rail's boundaries can affect the level of wind-related damage to the railway. Partnership funding opportunities can lead to greater benefits for Network Rail assets at lower investment costs.

2.9.7 Establish operational and maintenance measures to enhance resilience

Effective maintenance regimes can mitigate residual risks, reducing the damage and disruption in the event of extreme weather conditions. This includes robust early warning systems and appropriate emergency response measures, such as temporary flood barriers and strategically located pumps so train services can recover quickly.

Figure 15. Weather and climate resilience principles. *Source: © Arup*



2.10 Sustainable land use principles

2.10 Sustainable land use

Network Rail is a significant landowner. The national railway network occupies 523.5 km^2 (129,356 acres) of land, an area twice the size of Birmingham.

Land use and management influences the capacity of the soil and wider ecosystem it supports to capture and store atmospheric carbon. Improving soil quality can facilitate both climate change mitigation and adaptation.

Nature-based solutions help to reduce material use, reduce carbon emissions, create a more biodiverse environment, and increase resilience to climate change. Opportunities to integrate nature-based solutions should be sought on site and on adjacent land when undertaking renewals projects.

The built environment provides a key opportunity for enhancing biodiversity and sustainability, not only with artificial habitat creation but renewable energy generation too. By managing natural carbon flows under an appropriate regenerative land strategy, that also considers systemic land regeneration, Network Rail could contribute significantly to national carbon targets.

There are three key aspects to consider when designing land for carbon:

1. What is the impact of the asset on land degradation and how can the asset footprint be reduced as low as is reasonably practicable to ensure natural systems connectivity?

2. What is the impact of land degradation on the asset? Is there a high risk for an extreme weather event to damage the asset and can nature-based solutions and systemic thinking for environmental regeneration in the surrounding catchment be prioritised?

3. What are the implications of enabling new land use patterns and behaviours during the renewals process?

In addition to carbon and climate resilience benefits, sustainable land use measures also provide social benefits, with connections to nature offering health and wellbeing benefits to passengers, neighbours and wider communities.

The future enactment of the Environment Bill will implement a mandatory 10% biodiversity net gain for all new developments and will be part of the planning (permitting) process for new schemes.

Further information on Network Rail's biodiversity can be found on Safety Central: https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/environment/ecology-biodiversity/.

Climate Action Design Manual
for Buildings and Architecture
Climate action area summaries

3

3.1 Climate action areas for operational carbon

Summaries of the guidance provided in Sections 4, 5 and 6 are given in Table 6, Table 7 and Table 8 respectively, organised in terms of the design topics and reduction hierarchies given in Section 2. These tables are intended to be one-page quick guides for project sponsors and designers.

Table 6. Climate action areas for operational carbon

	Passive	Active	Demand	Supply
Building fabric and orientation	Specify facades with low U-value, good air tightness, openable windows, static external shading and appropriate window-to-wall ratios. Mass buildings with appropriate floor plate depths and an appropriate form factor. Design roofs to strike a balance between plant space, biodiversity gain (green roofs), daylighting, albedo and renewable energy generation. Provide occupant-level glazing in depots for daylighting and visual connection to nature.	Consider dynamic shading.	Enable occupant feedback and control.	
Heating ventilation and air conditioning	Prioritise natural ventilation, passive heating and cooling. Make passive provision for increasingly extreme temperatures.	Use radiant heating to heat people in unconditioned waiting areas. Replace boilers with heat pumps. Eliminate high GWP refrigerants. Specify high efficiency mixed-mode systems. Proactively monitor and manage energy use to achieve designed-for performance.	Specify smart metering to faciliate demand optimisation. Enable occupant feedback and control. Set appropriate temperature setpoints.	Connect to local heat networks where powered by renewable sources. Recover waste heat where possible.
Water use and heating	Specify flow restrictors and/or low-flow fittings Pipe runs should be as short as reasonably practicable. Install onsite nature-based water treatment.	Use point-of-use heating, solar thermal pre-heat. Hot water for hand washing should not be provided in small stations.	Specify smart metering and optimisation.	Install rainwater harvesting where appropriate.
Lighting	Prioritise daylighting over artificial lighting. Design artificial lighting for ease of access and maintainability. Consider wireless control technologies to reduce wiring requirements.	Select efficient lighting systems. Specify lamps providing 120lm/W or better. Incorporate Constant Light Output (CLO) control.	Specify smart metering and optimisation. Specify controls so lighting is dimmed or switched off as daylighting conditions allow.	
Embedded renewables	Integrate biodiversity where appropriate.	Install solar-thermal. Install solar PV only when all other options have been exhausted.	Provide two-way grid connections and on-site energy storage to enable smart demand management.	Install building-integrated solar PV and solar thermal. Purchase electricity from renewable sources.

3.2 Climate action areas for capital carbon

Table 7. Climate action areas for capital carbon (1 of 2)

	Renew, transform and reuse	Build less	Build clever	Build efficiently
Design for flexibility and adaptability	Exhaust renewal options before considering new build. Choose one approach between 1) multiple potential uses in one location or 2) a single use in multiple potential locations. Ensure existing assets can be adapted to changing needs. Consider at least two floorplans to show changes of use. Use stakeholder engagement to identify local needs. Use scenario planning to anticipate future needs. Use simple, rectilinear geometry. Avoid oversizing. Provide floor-to-floor heights of approx. 4m.	Choose structural loading sufficient for intended and likely future uses Design flexible spaces that meet multiple needs Reduce material need through component and material reuse.	Enable occupant feedback and control. Build in layers. Design for deconstruction.	
Design for maintenance, deconstruction and reuse	Prolong asset life with effective maintenance. Design for ease of access. Design modular assets where possible. Prepare a design for deconstruction plan for all assets.	Reduce material need through component and material reuse. Reduce the number and variation of parts and fittings.	Build in layers. Select materials suitable for upgrade, reuse, or recycling. Avoid adhesives, liquid-applied membranes and site-applied finishes.	Deconstruct and reuse rather than demolish. Create material passports and use labelling to enable reuse. Use helical reusable foundations for small structures.
Eliminating over-provision and over-specification	Choose appropriate standards when appraising existing assets (inflated specifications increase obsolescence of existing assets). Use alternative floor plans to ensure sufficient space provision.	Reduce space requirements (e.g. plant room, circulation space) and asset size by specifying sufficient space standards. In large stations use agent-based crowd modelling to assess circulation space needed.	Reduce element size and weight to enable offsite construction. Specify metering to understand actual system performance and eliminate over-sizing on future projects. Use off-site construction to justify higher execution classes and reduce partial factors.	Reduce element size and weight to reduce transport and construction impacts. Set target utilisation in design software to '1'. Report governing design criterion and utilisation for all structural elements.
Building form	Prioritise reuse of existing assets.	Set design criteria using measurements of actual user behaviour and asset performance. Use ribbed, hollow or dimpled pile forms to reduce material use. Buildings should exceed 18m in height by exception.	Avoid transfer structures. Avoid cantilevers.	Choose appropriate spans reduce element size and weight, and ensure areas for structural columns do not exceed 70sqm.

3.2 Climate action areas for capital carbon

Table 7. Climate action areas for capital carbon (2 of 2)

	Renew, transform and reuse	**Build less**	**Build clever**	**Build efficiently**
Material selection and specification	Specify pre-used structural steelwork where available. Prioritise MEP equipment suppliers with take-back schemes and product-as-a-service offerings. Collect and store information sufficient for foundations to be reused.	Eliminate hazardous materials. For long-term buildings select naturally durable (ie durable without coatings) rainscreen materials. For short-term buildings select renewable compostable rainscreen materials. In both situations specify high albedo rainscreen materials. Specify bio-based insulation materials and avoid oil-based alternatives.	Select equipment designed for upgrade, reuse, or recycling. Use engineered timber or hybrid timber-steel structures where appropriate for concourse roofs, platform canopies, facade stick systems and platforms. For deep foundations consider stone columns and recycled concrete aggregate columns (depending on ground conditions). Avoid in-situ concrete toppings and stitches. Detail connections to be reversible. Avoid steel / concrete composite slabs.	Optimise façade design by considering whole life carbon. In concrete mixes for foundations, use 70-75% GGBS or 45-50% PFA cements. Concrete strength grades should not exceed C40/50.
Design for waste efficient procurement	Identify opportunities to treat excavated soils and reuse on site. Prioritise reuse of existing assets. Where in-situ reused is not possible, removal and reuse elsewhere should be considered.	Reduce waste by designing-out finishes and site-cut components. Work to a 0.3m sub-grid to reduce the generation of offcuts.	Set clear contractual targets for waste arisings. Off-site construction techniques should be used where possible.	Develop tighter specifications to eliminate wasteful materials and processes.

3.3 Climate action areas for resilience

Table 8. Climate action areas for resilience

Risk type	Avoid risk	Reduce risk	Share risk	Respond to risks
Flood	During planning avoid high flood risk zones.	Use Sustainable Drainage Solutions (SuDS) and upstream attenuation to reduce flood peaks. Size attenuation tanks and sumps to suit future peak rainfall projections. Where possible set levels for building ground floors and for operation-critical equipment above projected flood levels.	Engage with third parties to share knowledge and risk. Paticipate in catchment-wide flood risk planning.	Understand extreme weather plans and procedures.
Extreme heat	Use passive design measures for temperature regulation only as part of mixed-mode systems.	Use solar shading and high albedo materials in façades. Use heat-resistant alternatives to asphalt. Provide cooling to control rooms. Design to temperature ranges in Network Rail climate asset risk assessment.		Understand current communication and warning systems. Understand extreme weather plans and procedures.
Extreme cold and snow	Use passive design measures for temperature regulation e.g. insulation and air tightness only as part of mixed-mode systems.	Provide frost protection for critical equipment. Specify air source heat pumps with direct heating capability. Design to temperature ranges in Network Rail climate asset risk assessment.		Understand extreme weather plans and procedures.
Wind	Select tree species able to withstand high wind speeds	Use nature-based solutions for wind management. Undertake local wind modelling during design process. Regularly complete visual inspections of roofs and station canopies.		Understand extreme weather plans and procedures. Understand vegetation management plans.

Climate Action Design Manual
for Buildings and Architecture
Operational carbon

4

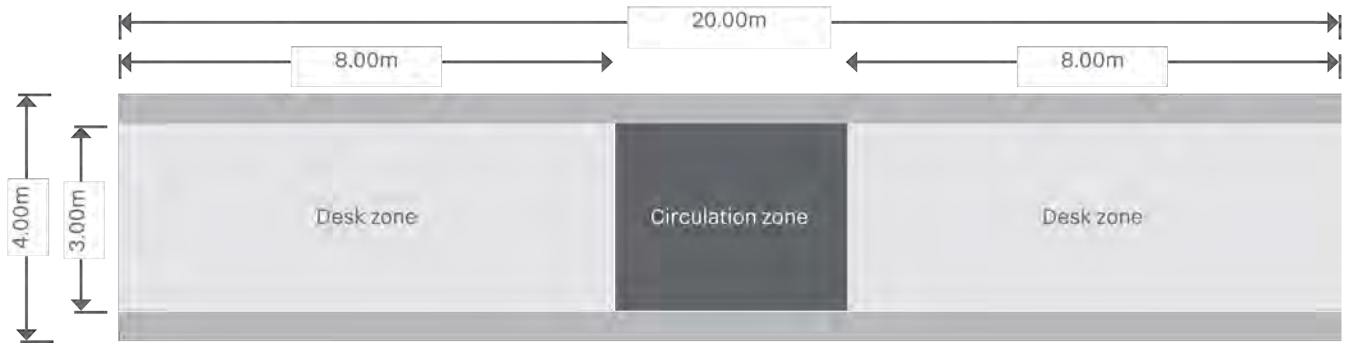
4.1 Introduction

For renewals, the hierarchy in Section 2.5 should be used, meaning the existing building fabric should be retained and upgraded with additional insulation and improved glazing before consideration is given to upgrading or replacing active systems, which in turn should be considered before installing building-integrated renewables. Only after renewals options are exhausted should new build projects be considered. For new build projects, the suggestions outlined below should be followed.

Figure 16. Form factor definition

$$\text{Form Factor} = \frac{\text{Total heat loss area of walls, roofs, floors and openings } (m^2)}{\text{Habitable floor area of all storeys } (m^2)}$$

Figure 17. Sketch showing typical short section through an office massed to allow natural ventilation and daylighting



4.2 Building fabric and orientation

The building massing should target a balance between permitting natural ventilation, controlling solar gains, maximising views and promoting natural daylight. Façade treatments and strategies will depend on orientation and expected weather conditions throughout the year. Direct views to landscape or sky also contribute to the well-being of occupants.

The following guidance is provided for buildings which are heated or air-conditioned throughout. Stations and depots comprise a combination of heated, air-conditioned spaces and unheated, unconditioned spaces. Unconditioned station circulation spaces should be massed in accordance with guidance provided in Section 5.2. Renewed unoccupied lineside buildings which are heated and cooled should follow the guidance in this section for heated and air-conditioned station buildings.

4.2.1 Massing for conditioned, multi-storey buildings

For new buildings, building form factor should not exceed 2, Figure 16.

The project team should target 100% of the building floor plate to be able to be naturally ventilated, as part of a mixed mode ventilation approach. Where possible the building should be able to achieve CIBSE TM59 summer comfort levels through natural ventilation alone.

At least 95% of workstations should be located within 8m of an external façade with a view outside.[18] Typically, this means that floor plates should not be deeper than 20m façade-to-façade, or 15m façade to a ventilated, daylit atrium.

Sufficient floor-to-ceiling clear height allows daylight to penetrate deep into the floor plate and enables effective natural ventilation. Floor-to-ceiling heights of 2.8 – 3.0m should suffice. For materials selection to reduce capital carbon, see section 5.2.5. A suggested layout is given in Figure 17.

Where these dimensions cannot be adhered to, alternative massing arrangements should still target 100% of net internal area (NIA) as able to be naturally ventilated and achieve, as a minimum, acceptable ventilation rates. This should result in a mixed mode system, with cooling only for peak summer temperatures. Buildings should aim to achieve CIBSE TM59 comfort levels with no cooling, so suitable for natural ventilation all year round.

For further information on selecting massing to ensure good daylighting and natural ventilation are possible, refer to CIBSE AM10 for natural ventilation.

For unconditioned spaces, like shelters on platforms, designers should use passive measures to provide comfort, for example orienting doorways away from prevailing winds.

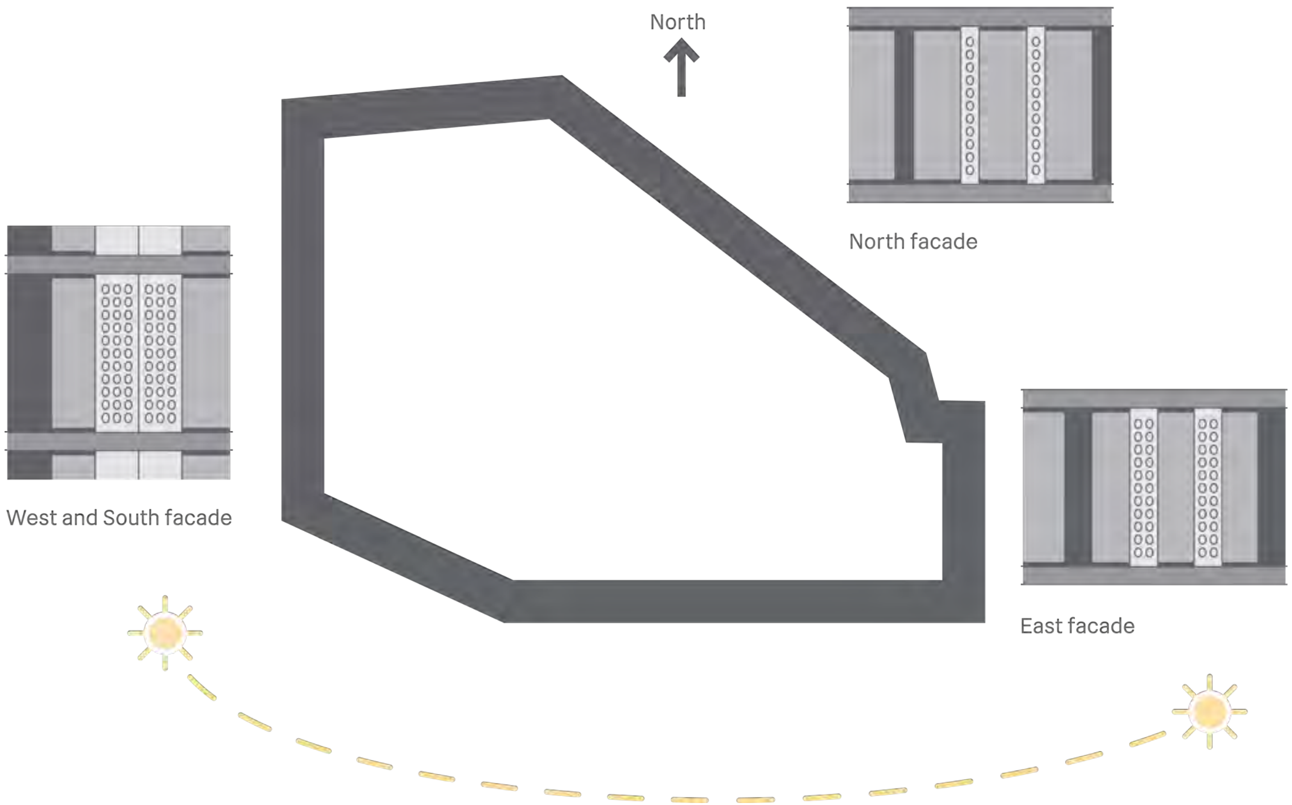
[18] For more information visit https://www.breeam.com/NC2018/#05_health/hea01_nc_a.htm#AdequateViewOut

4.2.2 Façade performance

Façade performance can be characterised by five values; window-to-wall ratio, thermal conductivity (U-value), radiative conductivity (g-value, glazing only), air tightness and thermal bridging (Y-value).

Good low emission façade design finds a balance between daylighting, solar gains and artificial lighting.

Figure 18. Varying window-to-wall ratio according to orientation *Source: Arup*



4.2 Building fabric and orientation

4.2.3 Building renewals

For building renewals the additional following principles should be adopted:

- Develop an operational energy model that accurately predicts the carbon performance of the asset in use.
- Use this model as a tool to understand actual energy demands and optimise the design and specification of equipment.
- Using the model outputs as a guide, establish a process of proactive operational energy performance management with a view to achieving operational efficiency at or close to that modelled, allowing for any differences in actual versus assumed energy usage patterns.
- If interventions are needed to improve operational performance, designers should:
    - Consider whether operational savings will exceed capital carbon required to achieve them.
    - How operational performance can also improve asset resilience.
    - Focus on improving thermal conductivity, radiative conductivity, thermal bridging and air tightness as far as is reasonably practicable to meet the values in Table 9.
    - Refer to *Design Manual NR/GN/CIV/100/04 Heritage* for heritage considerations.

4.2.4 Window-to-wall ratio

Selecting window-to-wall ratios for each elevation is a balance between achieving sufficiently low U-values to manage energy demand for heating and cooling, which demands lower ratios, with achieving optimum daylighting to reduce energy use for artificial lighting, which pushes for higher ratios.

For envelopes of spaces where U-value is not critical, for example for station concourses, designers should target a window-to-wall ratio sufficient to provide at least double the lux level normally specified for artificial lighting for the majority of daylight hours, with due consideration of glare. This is to ensure occupant perception is of adequate brightness and to do so without using artificial lighting where possible.

Provision of windows and façade glazing is also an important consideration for any regularly occupied space to provide views and a connection to the outside to occupants, promoting their well-being.

Design teams should optimise the glazing ratio to balance heat gain/loss and daylight based on scenario testing. If the design guidance and parameters in this manual have been followed (e.g. envelope performance, ventilation approach), these will reduce the complexity of optimisation calculations by fixing a number of variables. Although dependent on local conditions, in the context of mixed-mode ventilated office buildings in the south east of the UK, typically a high glazing ratio (60-75%) should be used on north facing elevations, while a lower glazing ratio (25-40%) should be used on south- and west- facing façades, with the east facing façade somewhere in between, Figure 18.

Shading devices should be provided on east, south and west façades as necessary, for example brise soleil or blind systems; an example of the former can be seen at Network Rail's new Doncaster office, Mallard House, Figure 19.

Figure 19. Mallard House in Doncaster incorporates brise soleil over south facing windows. *Source: Network Rail*

4.2 Building fabric and orientation

In depots glazing should be provided at low-level to give occupants visual connection to external environment, for example as per Jaguar Land Rover's Advanced Engine Facility near Wolverhampton, Figure 20.

Enclosed but not heated or cooled spaces, for example platform areas or train-care sheds, should provide sufficient glazing area on north, east and west facing elevations to reduce artificial lighting in daylight hours as low as reasonably practicable, for example at Blackfriars Station in London, where the east- and west- vertical walls are fully glazed. South-facing elevations should choose a glazing ratio to balance glare and summer-time heat gain.

Smaller enclosed unheated or cooled spaces like platform shelters should have sufficient glazing to reduce artificial lighting as low as reasonably practicable, without suffering overheating in summer due to unwanted solar gain.

Interior spaces which cannot be fully adequately daylit, such as underground spaces, should be provided with some daylight if possible, through light tubes, lightwells or pavement lights.

Figure 20. Jaguar Land Rover's engine manufacturing facility in the West Midlands provides views to landscape via low-level windows around the perimeter. *Source: Simon Kennedy*

4.2.5 Roof glazing

For platform canopies the glazing ratio should be chosen to provide the opportunity for roof-mounted solar PVs to be installed, see Section 4.6, without requiring artificial lighting during daylight hours to compensate.

Roofs with spans of up to 30m, for example over tracks between platforms, or depot roofs, should consider using north lights, provided by a 'sawtooth' roof profile, to allow for both solar PV installations and daylighting. Blackfriars Station provides an exemplar of how these trade-offs are managed, providing PV cells on south-facing opaque roof elements while single-glazed north-lights provide daylight to the platforms, reducing artificial lighting, Figure 21.

Typically, the glazing area should be approximately 30% of the equivalent flat roof area, evenly distributed over the area to be lit. The area should be confirmed for each project's own circumstances.

Any roof that does not have solar PV or is a green roof should have a high albedo to limit overheating. This helps overheating during extreme hot weather events, see Section 7.2.

Roofs with spans which exceed 30m should be treated primarily as a capital carbon challenge, see Section 5.

Figure 21. Platform-edge artificial lighting switched off on a bright day at Blackfriars Station thanks to north-lit platforms, without losing opportunity to generate renewable energy from south-facing solar PVs. *Credit cc-by-sa/2.0 - © Julian Osley - geograph.org.uk/p/3570690*

4.2.6 Thermal conductivity

Optimising U-values requires a balance to be struck between operational and capital carbon; capital carbon from façade materials increases as operational carbon decreases for lower U-values. Table 9 suggests U-values that strike that balance for different façade elements.

4.2.7 Windows and glazing

Target window U-values and double-glazing g-values for offices are given in Table 9. Frame materials are considered in Section 5.6.

Operational carbon reductions achieved by triple glazing do not exceed the capital carbon increase associated with the additional glass in all but exceptional circumstances. Triple glazing should therefore only be specified by exception and with justification supported by a whole life carbon analysis, see Section 2.1.2.

4.2.8 Air tightness

Achieving reduced air leakage with an improvement beyond legislative guidance (Part L) can also reduce energy consumption. An optimum value for commercial building is <1 $m^3/h.m^2$@50 Pa without compromising indoor air quality, provided sufficient ventilation is provided, see Section 4.2.9.

This is beyond typical performance delivered through traditional construction and does need a focus on design detailing and construction methodology to achieve. For renewals where this will be difficult to achieve, teams should aim to get as close to the optimum value as possible and should provide feedback to T&A on actual practice.

The specification of low-emission materials can also improve indoor air quality in highly airtight buildings.

Façade performance parameters are suggested in Table 9.

Table 9. Façade performance parameters

		Heated and cooled spaces	
Window-to-wall ratio	%	Optimise each elevation considering heating, cooling and lighting energy demands.	
Thermal conductivity (U-value)	W/m^2K	Walls: Floor: Roof: Windows: Doors	0.12 – 0.15 0.10 – 0.12 0.10 – 0.12 1.2 1.2
Radiative conductivity (g-value, glazing only)	-	0.4 – 0.3	
Air tightness	$m^3/h.\ m^2$@50Pa	<1	
Thermal bridging	-	0.04	

4.3 Heating, ventilation and air conditioning (HVAC)

Having reduced energy demands through the fabric first approach desribed in the previous section, the design and specification of HVAC systems can be considered. The HVAC system design should:

- Provide comfort using passive measures where possible.
- Support a resilient railway by preventing failure of critical equipment, for example sizing cooling systems to prevent overheating of critical equipment on extreme hot weather days, or by providing frost protection for equipment vulnerable to cold, see Section 7.2 and 7.3.
- Provide occupants with feedback and control.
- Where active measures are necessary, heat and cool air only as far as is sufficient to avoid unhealthy environments (see temperature setpoints below
- In transient, heat or cool people using long wave radiant devices, Section 4.3.1.

In addition, project sponsors, designers and asset managers should:

- Meter, monitor and report actual building performance, prioritising the optimal running and functioning of equipment over replacement.
- Embed operational energy performance metrics into the procurement process to define a measurable bottom line for building energy performance.
- Use a building management system including metering, monitoring and reporting to create benchmarks and provide feedback to inform future standard designs.
- Use a building management system including metering, monitoring and reporting to identify poorly performing assets to prioritise network-wide renewal programmes.

HVAC systems should be designed to function in temperature ranges in their expected service life, see the climate asset risk assessment. The design of the HVAC system should allow for potential future upgrades e.g. provision of space, able to cope with increasingly frequent extreme weather events in future.

4.3.1 Heating and cooling transient spaces in stations

Train stations are transient environments. As most people are passing through, broad temperature control bands should be set.

All staffed spaces —such as food and beverage (F&B) and operational kiosks— should be heated to sufficient workplace standards using long wavelength radiant heating.

For stations where interchange is unlikely and only platform shelters are provided, thermal comfort should be provided through the passive measures outlined in Section 4.2.

Where interchange is likely and waiting rooms are provided, the most energy efficient way to provide occupant comfort is high-level long wavelength radiant heating.

These spaces will be sufficiently well ventilated through natural means, so mechanical ventilation is not required. Care should be taken to orient doorways and provide staggered entranceways to reduce excessive or unwanted ventilation or draughts.

This means the only spaces in stations requiring active heating, ventilation or cooling are spaces where staff spend extended period of time sitting (i.e. not standing, on gatelines for example), namely break rooms, back offices and ticket offices.

Where available and supplied by low carbon heat sources (excluding gas-fired systems), assets should connect to district heating systems.

Where viable, secondary or reject heat sources should be investigated, for example London Underground (LU) is seeking to provide secondary heat to local businesses through its 'Cooling the Tube' programme.

In the absence of either of the above, heating (and cooling) should be provided by air source heat pumps (ASHP), with a COP of 2.8 or better[19] using low-GWP refrigerants and with a direct heating mode for cold days. Temperature setpoints should be controllable by occupants, with feedback given on energy use.

[19] See LETI Climate Emergency Design Guide

Figure 22. Three Bridges Signalling Centre. *Source: Network Rail*

4.3.2 Heat pumps

In some circumstances, ground source heat pumps are an alternative to air source heat pumps. The new Network Rail Three Bridges Signalling Centre is being heated and cooled using a ground source heat pump.

4.3.3 Behaviour change

Feedback can help facilities with high energy use adjust their behaviours to use less. For example, a display that compares energy consumption across similar buildings in the same region, can 'nudge' occupants to improve their behaviour. This intervention is most effective when paired with normative feedback (such as a smiley face for performance that is better than average), as this counteracts the effect of upwards changes in energy consumption where performance is already better than average. Figure 23 provides an example feedback display.

Figure 23. Example comparative display of Network Rail energy consumption. *Source: Arup*

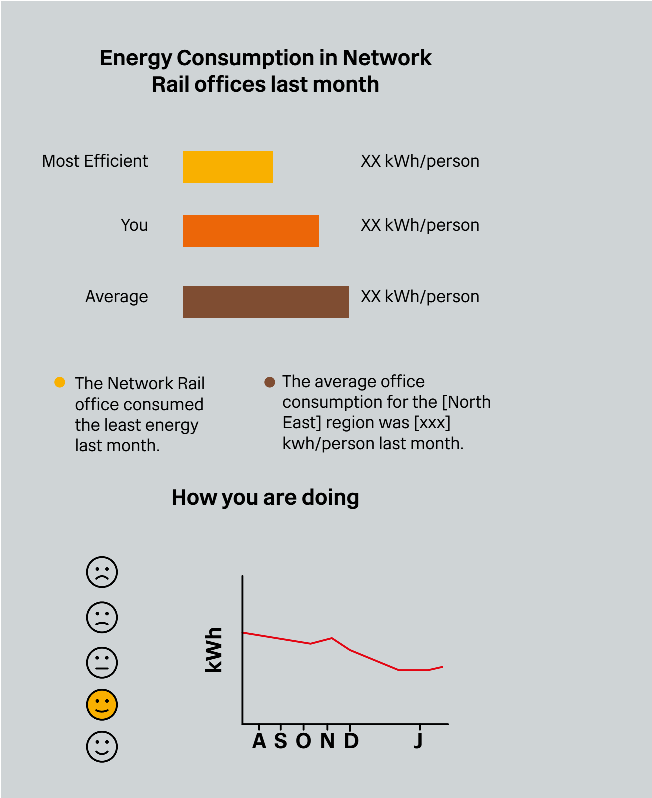


Figure 24. White Collar Factory has a mixed-mode ventilation system with user feedback as to when windows should be closed. *Source: Tim Soar*

4.3.4 Cooling systems

Most lightly occupied offices do not need air conditioning in a UK climate. Cooling systems for intensively occupied offices should meet a direct effect life cycle CO_2 equivalent emissions (DELC) of ≤100 CO_2-eq/kW, or alternatively use a refrigerant with a GWP ≤ 10, as set out in BREEAM New Construction 2018.[20]

4.3.5 Gas boilers

New gas boilers should not be installed in any Network Rail asset.

4.3.6 Ventilation

Offices and heated or cooled spaces in stations should be naturally ventilated in summer where feasible. Where this is not viable, mixed mode should be employed, and natural ventilation through openable windows should be the default mode. Manual operation of windows should be guided by an indication of outdoor temperatures; this could be achieved through for example a digital traffic light system, or more simply a wall thermometer. This should be accompanied by an interlock system to shut down mechanical ventilation when windows are open. Careful consideration should be given to the interface between the mixed mode system and building occupants, to ensure optimum performance and satisfaction.

See CIBSE Guide B2 for further design guidance, including on appropriate ventilation rates. Where mechanical ventilation is provided, it should incorporate variable flow demand control, ensuring that fresh air provision is matched to demand.

The White Collar Factory workspace uses a digital traffic light system for natural ventilation that informs occupants on optimal times to open and close windows, Figure 24. For example, on very hot days when outdoor temperatures exceed indoor temperatures, red lights discourage occupants from opening windows. The mechanical ventilation system automatically shuts down when windows are open, to improve indoor conditions.

4.3.7 Depots

Active heating and cooling (as part of a mixed mode system) should be kept to breakrooms and offices.

Radiant heating in train-care sheds can be provided at low level, for example ceiling-mounted radiant panels.

Operational procedures should ensure main doors are closed when not in use.

Table 10. Fitting maximum flow rates[21]

Shower	≤6 l/min
WC (effective flush)	≤3.5 l/flush
Urinal	3 l/bowl/hour maximum during building occupancy with user-presence activated flush.
Tap (basin)	≤4 l/min
Tap (kitchen)	≤6 l/min
Dishwasher	≤0.7 l/place setting

[20] For more information see https://www.breeam.com/NC2018/#12_pollution/pol01_a.htm%3FTocPath%3D12.0%2520Pollution%7C____1
[21] For more information see https://www.waterwise.org.uk/wp-content/uploads/2018/02/WRAP-2010_Procurement-Requirements-for-Water-Efficiency.pdf

4.4 Water use and heating

4.4.1 Water use

Setting requirements to optimise water use efficiency should be undertaken early on in the design process to achieve greater low carbon impact, and improve resilience to changing water availability and water scarcity risks.

In retrofit projects, sanitary ware can be retained if cisterns can be updated to provide dual flushing systems. If heritage concerns require retention of legacy fittings, flow restrictors should be used to reduce overall flow rates to the values in Table 10.

For fittings not listed designers should specify European Water Label (EWL) 'Green' rated outlets for domestic hot water. Designers should ensure a maximum 1 litre volume limit in system dead legs. Water heating is dealt with in Section 4.4.4.

Fitting flow rates should not exceed the values given in Table 10.

Point-of-use water heating, discussed in detail in the next section, helps reduce water use by lowering time spent waiting for hot water.

Figure 25. Gathurst station showing water butt connected to downpipe from platform shelter.
Source: Rept0n1x – Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=29590362

4.4.2 Rainwater harvesting

Rainwater harvesting reduces pressure on freshwater sources and improves resilience in face of shifting rainfall patterns and increasing likelihood of extended dry spells. It should therefore be considered for new stations, offices and particularly depots, sized to meet non-potable uses such as train washing. Renewals projects should provide where space allows, with a justification recorded if judged infeasible. For small stations a simple water butt can be adequate provision, Figure 18.

Rainwater harvesting can also contribute towards sustainable local water management, see Section 6.1.

For example, at Corkerhill Depot, Scotland (2013), train operator ScotRail installed a rainwater collection system to harvest water from 2,000 sqm of its roof. The system can store 72,000 litres and saves more than 3.5 million litres of freshwater annually[22].

4.4.3 On-site water treatment

Large sites with low occupancy densities, such as depots, lend themselves to constructed wetland water treatment for grey and black water. Such systems can have payback periods of under 10 years, are low maintenance, offer a biodiversity gain, sequester carbon and consume little to no energy. For new projects site size should assume a constructed wetland will be required, and for retrofit projects they should be provided where space allows.

4.4.4 Water heating

At small stations where the only water-using facilities would be a small number of toilets, and at individual toilets at larger stations, hot water for hand washing should not be provided. Despite building regulations stating that hot water should always be provided for sanitation there is no scientific evidence to suggest that hot water is more effective for hand washing than cold water.[23]

For offices, depots and stations with central systems, solar thermal or heat captured from other processes should be used to preheat water supply to the ASHP used to provide space heating. The central system should be used to provide hot water to areas with concentrated use, for example showers and core toilets. Installed capacity should not exceed 6W/m^2.

Pipe runs associated with central hot water plant should be circulated with any final ends of runs as short as is reasonably practicable. Run ends should be insulated to reduce heat losses and avoid risk of waterborne infections such as Legionella. The circulation system should be insulated and the distribution system sized to ensure that the temperature drop through the circulation pipework is no greater than 5°C.

Distributed and low-volume uses for hot water, for example tea points, should use point-of-use water heating.

Thermostatically controlled mixer taps should be used on all basins provided with hot water, including in retrofit projects.

Wastewater from showers should pass through a wastewater heat exchanger to pass heat to incoming supply. A trade-off may be required on pipe-run lengths given possible long distances between waste water discharge and main water feed locations; it is assumed that if the discharge and mains feed are adjacent then such a heat exchanger will be practicable, and if design teams judge it is not they should present an analysis as to why.

All water heating devices should be metered and monitored to collect and report data on energy and water use.

Teams should consider whether there is social value in providing accessible sanitary facilities at smaller stations that would otherwise not require them. Where buildings will only be served by maintenance workers no more than several times a year, teams should consider whether whether mobile welfare vans provided for maintenance visits only might be more appropriate.

[22] For more information see https://www.bbc.co.uk/news/uk-scotland-glasgow-west-23098503
[23] For more information see https://www.sciencedaily.com/releases/2017/05/170530115054.htm

4.5 Lighting

Lighting on new projects should be provided by LEDs and all renewal projects should replace legacy lighting systems with LEDs. LED lamps used should provide 120 lm/W or better. As far as possible, all lighting should incorporate Constant Light Output (CLO) control, to ensure that the target light levels are achieved throughout the life of the installation, reducing energy use and increasing the service life of the LEDs.

Lighting should be positioned with cleaning, repair and replacement in mind. For example, with easier access for more frequent cleaning, less conservative maintenance factors can be considered in the lighting design and lower wattage and output luminaires can be specified for a given task. Consideration should be given to the ability to service and replace components of the luminaires, such as LED chips and control gear, to extend their useful life and lower requirements for replacement and waste.

Appropriate lighting control technology should be employed based on the individual requirements of the installation, and whether it is new-build or a renewal. As well as traditional control protocols, such as DALI or KNX, wireless control technologies, such as Bluetooth Low-Energy (BLE), should be considered to lower wiring requirements, where appropriate. In some cases, Power-over-Ethernet (PoE) wiring and control for lighting may be beneficial. In all cases, the parasitic load of the lighting control system should be reduced as low as reasonably practicable.

Movement occupancy sensors should be used to switch off light zones when zones are unoccupied. In offices zones should be no bigger than 100 sqm. Zones should be metered and monitored to allow automated optimisation of energy consumption and accurate energy use reporting.

Lighting in daylit areas should be automatically dimmed or switched off at all times that daylight levels in the space are sufficient, using daylight-linked controls.

With regards to external lighting, buildings are part of the local community, often especially true of stations in prominent urban settings as well as heritage structures. A sustainable lighting scheme does not just focus on energy use, but also on social value. As such, carefully designed decorative lighting for façades may be appropriate in some cases.

In addition, such lighting can help to enhance visual comfort and a sense of safety, balancing overall lighting levels such that less functional lighting may be required in the associated public realm. Core hours for such installations should be identified and controls used to dim lights outside those hours, whilst maintaining minimum light levels required for safety and security purposes.

Luminaires should be specified to ensure light spilt across site boundaries complies with the Institute of Lighting Professionals (ILP) Guidance Note 1 for the reduction of obtrusive light 2020[24]. For all external lighting, designers should consult with ecologists to ensure impact on wildlife is considered.

External depot lighting should be provided at high-level where feasible, to reduce the required quantity of equipment (wider spacing of luminaires is possible where lighting is at a high level) and to reduce the potential for obtrusive light spillage (light pollution) as the light can be directed downwards more efficiently. Low-level lighting should only be used where there is no other option, and care should be taken with the design, layout and light distribution of the low-level lighting to avoid over-lighting and reduce obtrusive light.

Subway spaces should use natural daylight wherever possible through the implementation of skylights and lanterns or use of extensive glazing over staircases. The maximisation of daylight over staircases also provides an effective way to aid natural wayfinding. Where natural lighting is not possible artificial lighting should have good colour rendering and provide uniform intensity and coverage.

[24] For more information see https://theilp.org.uk/publication/guidance-note-1-for-the-reduction-of-obtrusive-light-2020/

4.6 Embedded renewables

Once energy demand has been reduced as low as reasonably practicable and energy efficiency of supply has been targeted, building-integrated solar PV should be considered, relating to the 'On-site renewables' component of the sequencing, Section 2.1.5. This can both reduce utility bills and reduce the carbon intensity of energy consumption. This can help Network Rail to achieve its target to supply 100% of non-traction electricity using renewable sources by 2030, as set out in the Environmental Sustainability Strategy 2020-2050.

Every Network Rail new build and renewal project should carry out a feasibility assessment for the installation of building-integrated solar PV, based on the considerations set out in BRE (2016) *Solar PV on commercial buildings: A guide for owners and developers*[25].

In addition to this guidance, the following should be considerationed:

- **Whole-life carbon**: the whole-life carbon savings of the proposed installation should be calculated.
- **Biodiversity:** designers should provide green roofs alongside PV systems using one of several available systems, Figure 26. For more information see BRE National Solar Centre (2014) *Biodiversity Guidance for Solar Developments*[26].
- **Access:** The installations should be designed so they can be installed and maintained without affecting train operations.
- **Deconstructability:** The installation should be designed for deconstruction, Section 5.3, facilitating pre-fabrication, modularity and the use of recycled and recyclable materials.

If after assessment it is determined that a PV installation is not suitable (i.e. on cost or other grounds) justification for its exclusion should be provided to the buildings and architecture assets team in TA.

Figure 26. Building integrated solar PV installation above a green roof. *Source: ZinCo Green Roof*

[25] Available here: https://www.solar-trade.org.uk/wp-content/uploads/2016/10/123160_nsc_solar_roofs_good_practice_guide_web.pdf
[26] To download, visit https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/National-Solar-Centre---Biodiversity-Guidance-for-Solar-Developments--2014-.pdf

4.6 Embedded renewables

Blackfriars Station: the world's first solar bridge

Improvements to Blackfriars station saw the installation of 4,400 PV panels, providing over 1MW of renewable electricity that contributes up to 50% of the station's energy demands. The installation allows Network Rail to sell excess electricity to the National Grid.

Figure 27. Solar panels on Blackfriars Station. S*ource: Volker Steven*

Climate Action Design Manual
for Buildings and Architecture
Capital carbon

5

5.1 Introduction

As outlined in the hierarchy in Section 2.5, options for renewing existing building fabric should be exhausted before new-build projects are considered. New buildings, or extensions to existing buildings, should follow the suggestions in subsequent sections, which are presented in order of precedence.

Figure 28. Kilmarnock station. *Source: Community Rail Network*

5.2 Flexibility and adaptability

Designing for flexibility and adaptability are two tactics project sponsors and designers can use to future-proof buildings and architecture assets. Flexible spaces can be used by different users during the day or week depending on demand, while adaptable assets can change function across development cycles.

5.2.1 Flexible spaces

Flexible spaces allow uses to change during the day and week in response to fluctuating demand. Many community groups have taken over abandoned station buildings to create flexible spaces for community use, for example Kilmarnock Station Heritage Trust, Figure 28.

Tomorrow's Living Station, a collaboration between Network Rail and Arup, presents some of the other uses flexible spaces in stations could be put to, including shared workspaces and parcel collection facilities[27].

Spaces should be made flexible by:

- Identifying under-utilised periods through exploration of user personas, service patterns, likely passenger demand patterns, local needs, tenancy agreements and access arrangements.
- Providing users with control over and feedback regarding services, including lighting, heating, cooling and ventilation, as discussed in Section 4.
- Building relationships with local groups and businesses in search of space.
- A common mistake is to conflate large structural spans with flexible spaces; by following the guidance in this manual project sponsors and designers can avoid the emissions penalty associated with long spans while still providing flexible spaces, see also Section 5.4.

5.2.2 Adaptable Assets

Crises such as the COVID-19 pandemic demonstrate how quickly requirements can change. Assets which can adapt to changing requirements maintain their value over time, a key principle of a circular economy.

At strategic planning stage, project sponsors and designers should decide whether, when their asset no longer meets requirements, it should:

- be adapted to new requirements in situ through renewal, or
- be relocated to another location where it can continue to meet passenger needs.

In the latter case, design for deconstruction is sufficient, as described in the next section. In the former case, further considerations are required, addressed in subsequent parts of this section.

Adaptable assets can be changed or modified for a new or updated purpose, or to respond to a changing climate, Section 6, minimising the need for unnecessary future construction. There is a long history of adapting redundant railway assets to other purposes, for example many station buildings are now private homes. There is an equally long history of dereliction in railway assets when no alternative use is found, for example Birmingham Curzon Street, the listed part of which stood unused for over 50 years[28].

[27] Available from https://www.networkrail.co.uk/news/stations-of-the-future/
[28] Huge revamp for historic Old Curzon Street Station as part of new HS2 station works, Birmingham Mail, 4 January 2021 https://www.birminghammail.co.uk/news/midlands-news/huge-revamp-historic-old-curzon-19559765 accessed 20/01/2021

5.2 Flexibility and adaptability

Buildings should be made adaptable in-situ by:

- At project inception use stakeholder engagement and scenario planning to identify alternative user groups who may find uses for a building while it is being used by Network Rail (flexible spaces), and alternative possible future functions for when it is no longer required by Network Rail. For buildings which would be removed from a site when no longer needed, refer to Section 5.3.
- In light of stakeholder engagement and scenario planning, determine spatial arrangements such that alternative users or functions can be accommodated. This can be done by sketching floorplans for alternative uses – see also Section 5.4. In multi-storey buildings particular attention should be paid to core locations, riser sizes and plant room sizes, with passive provision given as necessary.
- Adopting floor-to-floor heights of approximately 4m.
- Structural loading allowances – these do not need to be unreasonably high but should be sufficient to accommodate envisaged uses (3kPa live load sufficient for most situations).
  - NB it is a mistake to conflate over-providing structural capacity with providing flexible, adaptable spaces, see Section 5.4.
- Using rectilinear geometry and avoid complicated general arrangements.
- Designing in layers and making internal fitouts and services deconstructable to reduce as low as reasonably practicable waste arisings and cost from conversions.

Figure 29. Kiplingcotes Station, on the York to Beverley line, closed in 1965, is now a private home. *Source: Paul Glazzard / Kiplingcotes Station*

5.2 Flexibility and adaptability

Figure 30. The remains of Birmingham's Curzon Street station, opened 1838 and unused since 1965. *Source: Tony Hisgett, CC BY 2.0 <https://creativecommons.org/licenses/by/2.0>, via Wikimedia Commons*

Further discussion on the business case for flexible spaces and adaptable assets can be found in *Realising the value of circular economy in real estate*, Arup & Ellen MacArthur Foundation (2020).

Further information can be found in BS ISO 20887:2020: Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance. The next section summarises the key principles.

5.3 Maintenance, deconstruction and reuse

Designing for deconstruction allows components and parts to be reused, recycled, or recovered for energy at the end of the asset's useful life.[29] Network Rail's Environmental Sustainability Strategy 2020-2050 includes the ambition to reuse, repurpose or redeploy all surplus resources, reduce the use of resources, design out waste and embed circular economy thinking into the rail industry by 2035. This ambition will only be realised if assets are designed for deconstruction.

Designing for maintenance, deconstruction and reuse will also help Network Rail to cope with changing climate conditions in the future, thereby increasing the resilience of Network Rail's assets.

Any renewal or new construction of buildings should apply the key principles of designing for deconstruction and adaptability, including:

- Designing simple buildings using standardised, modular components, enabling offsite fabrication.
- Choosing connection details which are simple, accessible, reversible and standardised.
- Eliminating hazardous materials.
- Carefully considering a safe method of deconstruction.
- Keeping building layers separable to allow for their independent removal, for example separating building services from the structure.
- Avoid adhesives, liquid-applied membranes, and site-applied finishes.
- Select materials that are reusable and recyclable where possible, see Section 5.6.

Design teams should provide projects with material passports, documents which capture all the information required to reuse materials and components. These can be integrated into the BIM workflow. Project sponsors and designers should agree with Contractors how materials will be labelled, allowing cross-referencing to the materials passport to facilitate future identification. For example, as a minimum, marking on steel elements should include:

- Steel grade and subgrade.
- Section size.
- Weldability.
- Coatings.

For further guidance, please see BAMB (2019) *Materials Passport: Best Practice*[30] and the Steel Construction Institute's (2019) *Structural Steel Reuse: Assessment, Testing and Design Principles*[31].

For small structure such as cycle parking shelters, galvanised helical steel foundations should be used instead of mass concrete pads so that the foundations can be easily removed, reused or recycled at the end of its lifetime, see also Section 6.1.

A deconstruction plan should be prepared and disseminated to all parties at the contract stage to make sure that the construction process enables the successful execution of the plan. This should include:

- A strategy statement for the project.
- Instructions for the deconstruction of all components.
- A list of elements and suggestions as to how they will be reused, refurbished or recycled.

Further information can be found in CIRIA – *Design for deconstruction. Principles of design to facilitate reuse and recycling*, SEDA – *Design and Detailing for Deconstruction*; and WRAP – *Design for Deconstruction and Flexibility*.

[29] BS ISO 20887:2020: Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance
[30] Available from: https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf
[31] Available from: https://steel-sci.com/assets/downloads/steel-reuse-event-8th-october-2019/SCI_P427.pdf

Olympic and Paralympic Games Village, Stratford

The design of the temporary accommodation for the 17,000 athletes competing in the 2012 London Olympics and Paralympics closely considered design for deconstruction and adaptation principles, including for example using movable partitions that were easy to reconfigure, off-site manufacturing of many building components including bathrooms, kitchens, façades and balconies, off-site preparation of wiring, and interchangeable cladding panels.

Figure 31: Olympic and Paralympic Games Village, Stratford. *Source: 120416 LOCOG Aerials_038*

Workington North station

In response to the Cumbrian floods in 2009, Network Rail provided a temporary station at Workington North. Design for deconstruction principles were used for the temporary platforms to maximise recovery of the materials for future uses. Initially built to serve 2-car trains, the temporary station was sufficiently popular to merit 3-car services, requiring a further extension to be built, shown in Figure 32.

Figure 32. Workington north platforms. *Source: Network Rail*

5.4 Eliminating over-provision and over-specification

5.4.1 Space criteria

Instead of sizing for forecasted passenger needs in 60-120 years, and therefore introducing spare capacity for many years, it is preferable to design adaptable concourses and circulation spaces that can accommodate other uses (e.g. retail) now, and can be converted in the case that forecasted growth is realised or exceeded. For more information see Section 5.2 on Flexibility and Adaptability. Other techniques to avoid over-sizing stations include:

- Using agent-based modelling software such as Mass Motion[32] to consider likely passenger behaviour at larger stations, ensuring sufficient space is provided for circulation, waiting etc.,
- Creating floor plans showing multiple different anticipated uses, so that only sufficient space for alternative uses is provided and no more. For more information see Section 5.2.

5.4.2 Design criteria

Project sponsors should ensure design criteria are sufficient to meet code requirements for safety, as well as project outcomes, using statistical assessments of cost and risk, user behaviour and asset performance. Design teams should dimension elements and specify materials sufficient to meet the criteria; client- or code-dictated, whichever is more onerous; and no more.

Over-specification occurs when the project sponsor sets design criteria in excess of what might be reasonably considered appropriate, for example requiring a suspended station slab to resist lateral loads from 4 trains coming to a stop at the same time in a station with a throat that could only ever allow 2 trains to enter the station at a time.

Over-provision occurs when a design team provides a solution which conservatively exceeds the design criteria, for example providing 90 minutes of fire resistance when 30 minutes is required; or providing 1000kN column capacity when the calculated design loads (accounting for all load conditions, durability etc) require a column with 500kN capacity.

Surveys of building structures and structural engineering professionals have found the practice of over-provision to be common.[33,34] Research into the origins of loading allowances suggest over-specification also happens.[35]

Measures project sponsors and designers can take to avoid over-provision and over-specification are suggested in Table 11.

Tuning up buildings in advance of renewals works can improve existing energy performance, see section 4.2.3. Introducing metering into existing buildings and understanding a building's performance can inform targeted renewals. Building management systems could be used to collect data on actual heating and cooling demands enabling better specification of equipment that is better suited to actual energy demands in a building e.g. smaller boilers or chiller systems.

[32] For more information see https://www.oasys-software.com/products/pedestrian-simulation/massmotion/
[33] Muiris C. Moynihan and Julian M. Allwood, Utilization of structural steel in buildings, Proceedings of the Royal Society A – Mathematical, Physical and Engineering Sciences, 2014. https://royalsocietypublishing.org/doi/10.1098/rspa.2014.0170 accessed 15/01/21
[34] Minimising Energy in Construction (https://www.meicon.net/), EPSRC research project led by University of Cambridge supported by industry partners.
[35] J. A. Austin, Over-design: fact or fiction?, Institution of Structural Engineers, 1998.

Table 11. Suggestions to avoid over-provision and over-specification

Discipline	Over-provision	Over-specification
Building structures	At early design stages use likely (not conservative) allowances. Allowances 'just to make sure' there will be 'more than enough' capacity should not be used, as these allowances set expectations and budgets and can be carried through detailed design to construction. Set target utilisation in calculation tools to '1.' Use automated calculation software to design each element for actual loads, rather than rationalising elements. Use offsite construction methods to justify higher execution class structures thereby reducing partial factors (e.g. for reinforcement placement). Identify governing design criterion and report utilisation against it for all elements.	Specify likely maximum loads (for images of what different live loads amount to in practice visit https://www.meicon.net/floor-loading). Specify appropriate deflection criteria by considering how likely and how severe the consequences would be if deflection criteria were exceeded. Consider using structural monitoring to understand how structures actually behave and provide feedback into future requirements setting.
Building services	Plant capacities derived from rules-of-thumb should be refined at the earliest opportunity to avoid oversizing central plant which then impacts on the size distribution networks, HVAC components and operational efficiency. 'Right-sizing' plant at an early stage also reduces installation costs, reduces material usage and hence capital carbon. Analysis should be carried out using dynamic simulation software that appropriately accounts for the thermal response of the building, models part-load system performance accurately and more accurately accounts for the impacts of solar gain. A combination of reduced peak capacity and differential sizing of main plant can have a particularly transformative effect on performance at low part loads resulting in operational energy savings.	Lighting and small power loads can often be over-specified beyond what is needed by occupants. There are significant opportunities to reduce system capacities, system cost and capital carbon by discussing appropriate values with clients and stakeholders at an early project stage. In-use monitoring often shows that operational small power loads are significantly lower than those originally specified. Similarly, 'wider' control bands for space temperature and humidity should be considered to reduce installed design capacities as well as operational energy use. The design team should carefully consider the best means of providing appropriate redundancy in plant provision, balancing greater redundancy against capital carbon and resilience.
Façades	Provision of façade elements with no other function than to provide novel form	Including in project briefs requirements for 'iconic' forms

5.5 Building form

Designers from all relevant disciplines should work together from project inception to ensure selection of building form accounts for emissions sources at all lifecycle stages to create optimised low emission buildings. Recommended floor plate depths and floor-to-ceiling heights are given in Section 4.2 and considerations for ensuring buildings are resilient to future climate change are given in Section 6.

Buildings should not exceed 18m in height only by exception.

Structural grids should be rectilinear and regular. Tributary area for an internal structural column should not exceed 70sqm. This facilitates the use of lower carbon structural solutions, discussed further in the Section 5.6.

Transfer structures and cantilevers should be avoided.

Pile forms other than planar cylinders, for example, ribbed, hollow or dimpled, offer equivalent capacity with reduced material use. Pile designers should therefore consider whether alternative pile forms can be used to reduce material use in pile designs. In some ground conditions stone or recycled concrete aggregate columns can be used in lieu of reinforced concrete piles, see next Section.

5.6 Material selection and specification

5.6.1 Building structures

Materials should be selected that are non-toxic, low-carbon, renewable, reused and reusable, recycled and recyclable. In some cases there are additional climate adaptation measures to be considered, see Section 6.

Engineered timber (cross-laminated timber (CLT) and glulam) solutions for structural floors and columns should be used. Hybrid CLT-structural steel solutions are acceptable if a suitable source of reusable structural steelwork can be sourced. In-situ concrete/steel composite floors (with welded shear studs) are not deconstructable and should be avoided. Non-composite steel beam and precast concrete hollowcore plank floors may be used, provided in-situ toppings are avoided, as at Arup Campus.[36]

Similarly, CLT shear-wall stability systems, typically placed around cores, risers and stairs, should be used.

If engineered timber or hybrid timber-steel structures are deemed inappropriate, the reason should be reported to the Building and Architecture team in the TA. Reinforced concrete structures may be considered as alternatives provided they are precast and deconstructable, see Section 5.3, through the use of cast-in mechanical connections, Figure 33.

Care should be taken to avoid the use of high-strength grouted stitches in precast solutions, as these can prevent deconstruction.

For exceptional buildings where minimum structural depth is demanded, optimised-form precast concrete solutions (without in-situ toppings) such as waffle slabs should be used. Digital fabrication techniques can achieve up to a 56% reduction in material use compared with flat solutions, for example the Smart Slab by ETH Zurich, Figure 34.

Where loading, ground conditions and climate risk allows (see next paragraph), stone columns should be used instead of in-situ reinforced concrete piles. Where ground conditions permit, columns should be made from recycled concrete aggregate (RCA), particularly if excess site-won material is available.

Where flooding is identified as a risk, neither shallow reinforced concrete foundations nor stone columns should be used. Where loading and ground conditions allow, reusable helical screw piles should be used, see also Section 6.1.

Figure 33: Precast concrete structures should be used only where other materials have been ruled out. Reversible mechanical connections should be used and high strength grouted stitches should be avoided[37]. *Source: Peikko*

[36] For more information see https://www.architectsjournal.co.uk/archive/candid-campus and http://www.wrap.org.uk/sites/files/wrap/Refurbishment%20Resource%20Efficiency%20Case%20Study_Office_Arup%20Campus.pdf
[37] For more information visit https://www.peikko.com/blog/what-does-it-take-to-reuse-a-concrete-element/

5.6 Material selection and specification

Figure 34. Digitally fabricated, precast and post-tensioned slabs allow limited depth solutions for constrained sites. The Smart Slab is a proof-of-concept requiring further development prior to widespread adoption. *Source: Andrei Jipa, Digital Building Technologies, ETH Zurich*

Foundations should be made of low-Portland-cement content concrete, for example 70-75% Ground Granulated Blastfurnace Slag (GGBS) or 45-50% pulverised fuel ash (PFA) mixes should be default. Designers should select the lowest grade sufficient to provide necessary performance. Grades should only exceed C40/50 by exception unless a reduction in whole life carbon can be demonstrated. Designers should identify implications of high replacement rates in terms of curing times so that this can be built into the programme from the outset where applicable.

GGBS and PFA mixes are not a long-term solution to eliminating Portland cement from concrete. Alkali-activated and geopolymer cements are among the technologies best placed to replace Portland cement. Network Rail is undertaking work in this area and further guidance will be provided.

Designers and Contractors should retain and transfer to Network Rail information sufficient to ensure foundations can be reused in future. This information will typically include design calculations, site investigations and, where relevant, pile logs. For further information please refer to *A short guide to reusing foundations*, IStructE, 2020.[38]

[38] Accessible here: https://www.istructe.org/journal/volumes/volume-98-(2020)/issue-11/a-short-guide-to-reusing-foundations/

5.6.2 Other station structures

Platforms should be engineered timber structures with composite panels, per the platform extensions at Hampton Court station, Figure 35.

Platform canopies should be in engineering timber, with careful detailing to avoid water pooling, excessive exposure to wind-blown rain and to protect column bases. The timber canopies at Manchester Oxford Road are a good example, Figure 36.

Train shed or concourse roofs should be in engineered timber. Consideration should be given to the form which allows the space to spanned most efficiently – the timber shells at Manchester Oxford Road are a good example as they also provide for natural daylighting through a sawtooth profile and north-lights, Figure 37 and 38, unlike the new Abbey Wood station roof, also in engineered timber, Figure 39, next page.

Figure 35. Engineered timber and composite platforms at Hampton Court. *Source: NOV Fiber Glass Systems*

Figure 36. Engineered timber platform canopies at Manchester Oxford Road. *Source: Giles Rocholl Photography*

Figure 37. Manchester Oxford Road station roof, an engineered timber shell. *Source: Giles Rocholl Photography*

Figure 38. Ariel view showing north lights at Manchester Oxford Road. *Source: Network Rail*

5.6 Material selection and specification

Figure 39. Abbey Wood station roof, an engineered timber beam grid which requires continuous artificial lighting as natural daylighting has not been provided for. *Source: Network Rail*

Design of surface water drainage systems should use recycled materials where possible. New innovations such as the Rigidrain[39] thermoplastic structured walled piping systems are 100% recyclable without compromising durability. Suppliers which offer lightweight composite manhole covers should be favoured e.g. Structural Science Composite's Limited[40] and NAL Ltd[41].

For guidance on the use of concrete, see section 5.6.1.

[39] Accessible here: https://www.polypipe.com/civils/surface-water-drainage?range=95339
[40] For more information see https://www.polypipe.com/civils/surface-water-drainage?range=95339
[41] For more information see https://www.structuralscience.net/composite-manhole-cover/

5.6.3 Façades

When considering the building façade, operational carbon, capital carbon and climate resilience must be considered together. Improving the thermal performance of the façade often involves adding more material, increasing capital carbon. A solution should be developed that optimizes whole life carbon, see triple glazing example in Section 2.1.2.

Stick systems using engineered timber for internal structural elements with aluminium or similar external cap plates should be used. Example products include RAICO and STABLUX. Alternative, off-site manufactured timber cassette systems should be used, Figure 40.

Specification of rainscreen or external finishing materials should follow one of two approaches:

1. Choose inherent durable materials which do not rely on coatings for durability, for example fired clay (brick, terracotta, faience), stone, glass; this approach is better suited to prominent buildings in public view.
   a. where fixings are required, for example terracotta tiles, aluminium or stainless steel should be used.
2. Choose low carbon materials, such as biobased materials which are 100% compostable and can be composted and replaced as required, for example treated softwoods like Accoya, or biocomposites, Figure 41.

Figure 40. Timber cassettes can be delivered to site in large sizes with insulation, internal and external finishes already fixed, accelerating construction programmes. *Source: Arup*

Figure 41. High Performance, Economical and Sustainable Biocomposite Building Materials, a €7.5m research project, explored the potential for biocomposites to reduce capital carbon in façades. For more information see https://cordis.europa.eu/project/id/285689/reporting. *Source: Lichtzelt*

No reversible membrane or vapour barrier products are known on the market, otherwise they would be suggested. Well-sealing membranes are important for achieving good airtightness. Membrane materials should therefore be chosen for their recyclability, with suppliers offering take-back schemes preferred.

Insulation materials should be natural or biobased, for example cork, wool, stonewool or hempcrete. Oil-based (plastic) insulation materials should be avoided.

5.6.4 Building services and lighting

Designers should refer to CIBSE guides TM65[42] and TM56[43] to specify mechanical plant with low capital carbon.

Suppliers which offer product-as-a-service, or performance procurement, routes with demonstrable capacity for collecting and remanufacturing product, and with equipment designed for deconstruction, upgrade or recycling, are preferred. Examples include Kaer and Signify[44]. Suppliers with equipment take-back and refurbishment schemes are preferred. Second-hand plant which has been refurbished and re-warrantied should be sourced where available.

Figure 42. Lighting-as-a-service by Signify, Schiphol Airport, Amsterdam. *Source: iStock*

[42] Available here: https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000IPZOhQAP
[43] Available here: https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7fO
[44] For more information see https://www.enterprisesg.gov.sg/inspiring-stories/kaer and https://www.signify.com/global/case-studies/schiphol-airport

5.7 Design for waste efficient procurement

Good practice means adopting a design approach that focuses on materials efficiency to eliminate waste and ensure wastes are cascaded at their highest possible value – first reuse, then remanufacture, then recycling.

Clear contractual targets should be set to ensure all potential construction waste has been identified and steps are in place to eliminate its generation. Development of tighter specifications should be drafted during the early design stages to ensure the implementation for designing for waste efficient procurement.

Designers should work to a 0.3m sub-grid for setting out of structural grids, façades, services and internal partitions, to reduce ensure cutting and jointing of materials and reduce the generation of offcuts. Designers should work to a palette of standard designs and details to allow the supply chain to adopt consistent and optimised manufacturing processes. For more information see BS ISO 21723:2019 Buildings and civil engineering works - modular coordination - module.

For example, at London Bridge Station, waste arising from demolition was crushed and re-used within the station. Plasterboard offcuts from fitout were returned to suppliers for recycling or reuse. Modular and pre-fabricated components were used for the bridge decks, platform units, lifts, escalators, station furniture and station glazing, eliminating waste from site.

At Bedford station, reclaimed steel tubular piled foundations were used. This reduced the volume of concrete used by 320 tonnes and the volume of material requiring excavation by 115m^3, therefore decreasing carbon emissions, shortening the construction programme and reducing disruption to the local community[45].

[45] For more information please see: https://safety.networkrail.co.uk/wp-content/uploads/2017/06/TLP-Programme-Sustainability-Best-Practice-Reducing-Waste-Reducing-Cost.pdf

5.8 Station footbridges

5.8.1 Design for maintenance, deconstruction and reuse

When no longer required existing station footbridges should be deconstructed, restored and reused, for example Alton station footbridge was salvaged for use on a heritage railway, Figure 43.

Rail structures can be designed to be deconstructable, enabling simpler deconstruction and/or upgrade.

- Use bolted connections instead of welded connections to the extent appropriate for deconstruction.
- Ensure connections are accessible.
- Make sure that all bearings are accessible for inspection and maintenance.
- If concrete is used (see Section 5.8.3), precast concrete is preferred, for example modular, precast parapet units that are removable individually without damage.
- If in-situ concrete is used, eg. to provide mass on a footbridge, a membrane should be provided between the in-situ concrete and deck.

Offsite construction methods are particularly suited to footbridge construction. Staircase and overbridge elements are often suitable dimensions to be delivered to site as a complete element and lifted into place. This minimises disruption.

The use of engineered timber should be considered ahead of structural steelwork, see Section 5.8.3.

Figure 43. Alton station footbridge was deconstructed, restored and reused. © *Stephen Lewis of FAS*

Figure 44. Footbridges at Sittingbourne and West Drayton station. *Source: Network Rail*

5.8 Station footbridges

5.8.2 Eliminating over-provision and over-specification

Concerns regarding over-provision and over-specification apply to station bridges. These should be addressed by:

- Choosing from optimised, standardised designs where possible.
- Reviewing structural monitoring data for actual bridge performance, where available.
- Reporting governing design conditions and structural element utilisations for all elements.
- Over time replacing standards based on empirical observations with versions based on testing and analysis.

5.8.3 Material selection and specification

Station bridges should be made from engineered timber. Typical construction elements include:

- Triangulated timber trusses for bridge, stairs and lift-shaft, with glulam members jointed with steel plates where necessary.
- Enclosed to keep structure dry and shelter passengers.
- A steel deck.

Norway has been pioneering the use of engineered timber bridges for some time; examples include an accessible footbridge at Råde Station, constructed in 2013 and one of several such bridges at Norwegian stations, Figure 45, next page.

Where other structural materials are under consideration for footbridges, a lifecycle assessment covering life cycle stages A-C and covering sub-structure, super-structure, cladding and finishes should be used to determine the lowest whole life carbon option, which should then be chosen.

An alternative to engineered timber is fibre reinforced polymer (FRP) composites, which are less dependent than engineered timber on good detailing to provide durability. Challenges exist for FRP structures regarding construction waste, end-of-life recycling and microplastics. Modular designs should be considered to facilitate mould reuse, reduce construction waste and offer greater reuse options at end-of-life. FRP cannot be recycled; research is needed into equally durable yet recyclable alternative resins. There is also limited research into the contribution made by the thermoset resins used in FRP structures to ocean microplastics.

5.8 Station footbridges

5.8.4 Design for waste efficient procurement

Design, form and layout should be simplified without compromising the design concept. Where possible standardisation of structures should be sought to avoid excess cutting of materials to eliminate waste.

Development of tighter specifications early on in design can ensure work procedures are developed to avoid waste and facilitate the use of recycled materials.

When designing structures determining similar elements that can be standardised should be encouraged to generate efficiencies in the design and construction process.

Figure 45. Råde Station Footbridge, Norway

Climate Action Design Manual

Climate resilience

6

6. Climate resilience

This section provides examples for approaching climate resilience in response to the climate risks facing Network Rail's building's and architecture assets. It covers the key features of resilient design set out in Section 2.8. It should be read in conjunction with Network Rail's Climate change adaptation strategy, risk and adaptation documents and climate change projections guidance.[10.]

Vulnerability to climate risks can be local environment specific, and appropriate measures for resilience must be considered on a project-by-project basis in response to the specific risks that are relevant. In order to determine which resilience measures are appropriate for a given project, refer to Network Rail's WRCCA Impact Assessment Guidance Note (2020)[46], which provides a basic process to identify, quantify and mitigate weather and climate change risks. The WRCCA decision making tool[47] is an economic appraisal tool that can also help to prioritise actions that enhance weather resilience of assets, based on Schedule 4 & 8 payments as well as maintenance and repair costs.

Measures intended to build climate resilience can have positive or adverse impacts on mitigation efforts (addressed in Sections 4 and 5). The principles presented in Section 2.8 aim to address climate resilience and whole life carbon together. As part of the design process, potential trade-offs should be identified, and an appropriate balance should be sought with consideration to cost, safety and carbon. Furthermore, combined assessment of climate risk reduction and whole life carbon impact can allow the lowest carbon, most risk-reducing interventions to be prioritised.

There is a wide range of measures available to protect assets against climate change risks. The examples provided in this section, drawn from industry documents such as the TRaCCA report[48], are not intended to be exhaustive; instead they are intended to provide ideas and stimulate innovation in the design process. They address the highest priority risks described in Network rail route, asset and other climate change risk assessment documentation.

Climate risks will grow progressively over this century; therefore, it is critical for designers to adopt the Layers approach (see Section 2.1.3). In many cases, building systems installed today will become obsolete and be replaced before certain thresholds are exceeded. For those systems not expected to require replacement or upgrade, passive provision should be prioritised now. This will ensure these systems are resilient to extreme events expected to emerge towards the end of their service life. Systems where obsolescence can be anticipated, for example active cooling systems, should be designed for the criteria projected to be experienced during their expected service life.

While this section is structured by individual risks, designers should consider the likelihood of multi-risk events, for example flooding, high winds and lightning concurrently.

[46] For more information see https://safety.networkrail.co.uk/wp-content/uploads/2020/11/Weather-resilience-and-climate-change-impact-assessment-issue-2.pdf
[47] For more information see https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/wrcca/wrcca-decision-making-tool/
[48] Compendium of climate and weather resilience measures of potential benefit to future operation of GB railway system, RSSB 2015,

6.1. Flood risk reduction measures

The following measures should be considered to enhance flood resilience of Network Rail's buildings and architecture.

During the planning phase, avoid locating stations, offices and depots in flood risk zones. Where this is not possible consider the following:

- For new build projects: set ground floor levels above projected future flood levels.
- For renewals or enhancements projects: use landscaping features where feasible to direct flows away from entrances or vulnerable assets.

For example, the Greener Grangetown project in Cardiff used permeable paving, rain gardens and tree planting to absorb and treat surface water before directing it to a nearby natural water body whilst also enhancing the social value of the community. These measures could be used outside station entrances or near vulnerable assets to direct flood waters away as part of a renewals or enhancement scheme.

The Greener Grangetown project team worked closely with third party infrastructure providers including Welsh Water and Natural Resources Wales to realise benefits for interdependent infrastructure, whilst also improving the social value of community assets.

Engagement with the Local Authority, Environment Agency, SEPA or Natural Resources Wales is recommended to understand the role of upstream interventions under a catchment-based approach to reduce flood design criteria for building and architecture assets. These can offer co-benefits, including net biodiversity gain, see Section 2.10.

Teams should consider the location of standalone equipment and elevate equipment above projected flood levels where necessary.

Attenuation tanks and sumps should be sized to suit future projections of peak rainfall in relevant Network Rail climate change projections guidance[49]. Recent Network Rail examples include the attenuation system installed at Dalmarnock Station and the flood site including new pipe work and an attenuation pond at Drem Station.

For existing assets vulnerable to flooding, operation-critical assets like signalling, and moisture sensitive equipment like wall sockets, should be relocated within the building to sit above flood levels where possible, while fabric and finish materials should be selected which are water resistant, with reference to Section 5.6 as appropriate.

Figure 47. Permeable paving used for the Grangetown Project in Cardiff. *Source: © Arup*

[49] For more information visit https://safety.networkrail.co.uk/

6.1 Flood risk reduction measures

Figure 48. Rain garden used to enhance flood resilience for the Grangetown Project in Cardiff. *Source: © Arup*

Teams should consider Sustainable Drainage System (SuDS) interventions to reduce flood risk by increasing the permeability of surfaces, increasing their ability to absorb, store, and transport water. SuDS should be designed such that water flow across the site can be planned. Some examples include:

- Green or blue roofs and walls.
- Swales, per example in Figure 48.
- Artificial wetlands or protection of surrounding wetlands.
- Rain planters and rain gardens.

A flood risk reduction project at Stebonheath School utilised SuDS interventions to alleviate flooding of the school playground. A swale, bio-retention basin, downpipe timber planters, planting beds and pond system were created to slow down and treat surface water runoff during heavy rainfall events. The increased absorption allows water to drain more slowly, reducing flood risk across the school playground.

6.1 Flood risk reduction measures

Construction of helical piles to increase foundation stability should be used in preference for shallow pad foundations, see also Section 5.6.

In locations with high flood risk:

- Physical flood barriers such as flood protection walls and watertight doors may be suitable.
- Automatic switch-off of electrical equipment during flood events should be installed for high risk assets.
- In coastal areas measures may include sea walls and storm surge protection measures.
- Materials should be selected which can withstand flooding to ensure rapid recovery, for example water resistant partitions.

The Network Rail Operational Weather Management Standard NR/L2/OPS/021 provides further detail for managing assets in adverse and extreme flood events. Furthermore, the Network Rail Drainage System Manual (2018) included guidance to prevent slips, trips and falls in railway buildings.

The Network Rail Weather Service[50] should be used in all Network Rail buildings to provide forecast data and alerts when weather thresholds or triggers are forecast to be exceeded.

Emergency flood procedures should be regularly reviewed and updated.

Figure 49. The SuDS system at Stebonheath School. Source: © Arup

[50] Accessible here: https://www.nrws.co.uk/site/htdocs/

6.2 Adapting to extreme heat

Renewing assets and designing new buildings using the fabric first approach described in Section 4.2 also serves to improve climate resilience:

- Well insulated, highly air-tight, mixed-mode buildings with passive solar shading and carefully considered window-to-wall ratios are less reliant on active services (which might fail in periods of disruption) for providing comfortable internal conditions during both extreme hot and cold events.
- Mixed-mode buildings offer both energy-savings during benign weather and the ability to cope with infrequent yet extreme temperature weather events.

Specific additional measures addressing extreme heat include:

- Renewing assets to include passive cooling measures, including shading deep eaves or brise soleil as discussed in Section 4.2, as well as pale-coloured wall and roof finishes.
- In addition to shading considered in Section 4.2, site planning and landscape design should allow for tree planting to further reduce the solar irradiance on buildings.
- Active cooling should be specified in control rooms for all renewals and new projects to reduce the likelihood of equipment failure from overheating, with due consideration to the guidance in Section 4.3.
- Project sponsors should ensure project scopes include due consideration of and contribute to climate communication and warning systems.
- Consider heat-resistant alternatives to traditional asphalt, for example FRP for platform surfaces (see Section 5.6.2), or polymeric asphalt for public realm areas surrounding stations and offices.
- For structures (i.e. station footbridges) which will experience full environmental temperature ranges, designers should consult the design and compare with the latest climate change projections to attain the most appropriate temperature ranges for thermal loading. A balance between climate resilience and carbon mitigation factors should be sought by considering the guidance on over-specification in Section 5.4 and 5.8.2.
- Design of mechanical ventilation systems should embed future climate adaptation into replacement and upgrade cycles to ensure newer systems include temperature thresholds based on the latest climate change projections data and are replaced with assets that are resilient to future climate change.
- With due consideration of the guidance in Section 4, high albedo roofs should be used to mitigate urban heat island effects, Figure 50.
- Follow CIRIA (2019) guidance on carrying out concrete pours in high temperatures.[51]

Teams should refer to the Network Rail Operational Weather Management Standard NR/L2/OPS/021 for procedures to manage assets during extreme heat events.

Teams should also make use of the Network Rail Weather Service[52] tool which provides forecast data and alerts when weather thresholds or triggers are forecast to be exceeded. These documents should be used to inform and update extreme weather communication and management procedures in all Network Rail buildings.

[51] Report C766: Early age thermal crack control in concrete, CIRIA, 2019
[52] Accessible here: https://www.nrws.co.uk/site/htdocs/

Figure 50. White roofs can help cool buildings. *Source: Nasa*

6.3 Extreme cold and snow measures

During winter there is high confidence in climate change projections that daytime and night-time temperatures are likely to increase, and the frequency and severity of snowfall is likely to decline. However, present-day snowfall events and minimum temperatures will still be possible.

Asset managers, designers and project sponsors should ensure design of building assets still accounts for these thresholds and have procedures in place to respond even if these events are likely to become less frequent in future.

The Network Rail Weather Service[53] tool should be used to manage cold extremes when they arise and ensure measures are in place, for example, alternative routes to stations and planning for use of salt or grit in public realm areas adjacent to buildings.

Designers should provide frost protection capable of withstanding projected extreme cold temperatures in otherwise unheated plant rooms housing temperature-sensitive critical equipment, see also Section 4.3, whilst ensuring this does not increase risk of overheating in summer.

Air source heat pumps should always be specified with direct heating capability sized to provide appropriate indoor temperatures during extreme cold, see also Section 4.3.

For structures which will experience full environmental temperature ranges, for example station footbridges, designers should consult the relevant Network Rail climate asset risk assessment for appropriate temperature ranges for thermal loading, with due consideration of the guidance on over-specification in Section 5.4 and 5.8.2. Care should be taken to ensure this does not increase risk of overheating in summer.

Project teams should follow CIRIA (2019) guidance on carrying out concrete pours in low temperatures[55].

Figure 51. Frost protection for space heating. *Source: https://www.turnbull-scott.co.uk/heating/industrial-space-heating/plant-frost-protection/*

[53] Accessible here: https://www.nrws.co.uk/site/htdocs/
[54] Accessible here: https://safety.networkrail.co.uk/
[55] Report C766: Early age thermal crack control in concrete, CIRIA, 2019

6.4 Resilience to high winds

Climate projections for wind speeds are mixed, but it is likely that they will show increases in the second half of the century. Increased wind speeds are likely to be localised in scale and ensuring resilience to high winds should be considered on a case-by-case basis.

Project sponsors should include climate change projections in the project scope for assets that may be at risk of wind impacts i.e. platform canopies and train-shed roofs. Further information can be found in the Network Rail WRCCA Climate Projections Guidance Note[56].

Roofs and platform or station canopies should be designed to correct wind tolerance thresholds. For locations where risk of high winds is likely, local wind modelling should be completed for design of these assets. This will also inform decisions around siting and orientation of the building as well as those for building massing, see Section 4.2.

Nature-based solutions for wind management should be prioritised, for example selecting tree species that are able to withstand high wind speeds coupled with appropriate vegetation management plans. Wider benefits of this approach include:

- Vegetation is a useful buffer for noise and pollution.
- Biodiversity impacts should be carefully considered, and options that protect and enhance ecosystems should be prioritised.
- Stabilisation of slopes if properly implemented.
- The potential for vegetation to fall onto building roofs should be analysed and closely managed.

Setting down points should be covered to provide protection from adverse weather[57].

Visual inspections of roofs and station canopies should be completed annually, and detailed inspections should be completed every five years to manage potential wind damage to building assets.

The Network Rail Operational Weather Management Standard NR/L2/OPS/021 explains how to manage assets in adverse and extreme weather and the Network Rail Weather Service[58] provides forecast data and alerts when weather thresholds or triggers are forecast to be exceeded.

[56] Accessible here: https://safety.networkrail.co.uk/
[57] For more information see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918425/design-standards-accessible-stations.pdf
[58] Accessible here: https://www.nrws.co.uk/site/htdocs/

Glossary

Albedo	The proportion of light or radiation that is reflected by a surface
Capital carbon	The greenhouse gas emissions associated with the creation, refurbishment and end of life treatment of an asset
Carbon sequestration	The process of capturing and storing carbon dioxide from the atmosphere
Circular economy	Circular economy is a systemic approach to economic development that aims to decouple economic activity from the consumption of finite resources and the emission of waste
Climate change mitigation	Efforts or actions to reduce or prevent emission of greenhouse gases
Climate change resilience	The capacity for a system or asset to absorb stresses and maintain its functionality in response to external climate hazards and their associated impacts
Climate hazard	A physical process that can cause harm to human health or an asset or system
Life cycle assessment	Assesses the environmental impacts associated with a product, process or service over its entire life cycle, across materials extraction, production, construction and transportation, use, and end-of-life treatment
Nature-based solutions	Actions to protect, sustainably manage and restore natural or modified ecosystems to address societal challenges and provide benefits for climate resilience, climate mitigation, biodiversity and human well-being
Operational carbon	The greenhouse gas emissions associated with the operation of an asset
Solar irradiance	The output of energy from the sun measured at the Earth's surface
Urban heat island	An urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities
Whole life carbon	The carbon emissions arising from a project across all its life cycle stages
Whole life costing	The total cost of a project over the course of its lifetime, from concept through to disposal including purchase, hire or lease, maintenance, operation, utilities, training and disposal
Whole life value	The total social, economic and environmental value delivered by a project over the course of its lifetime

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