DELIVERING NET ZERO IN USE

A guide for architects

by AHMM and IEDE

INTERACTIVE READING

UCL IEDE

The Institute for Environmental Design and Engineering is part of The Bartlett, ÇUCL's global faculty of the built environment. IEDE aims to pursue a deeper understanding of the interactions between the built environment and health, human wellbeing, productivity, energy use and climate change.

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Allford Hall Monaghan Morris is an architecture practice committed to the design of buildings of economy, elegance and delight: buildings that reflect a continuing belief in the ability of outstanding architecture to last through time; buildings whose success is defined not just by the use for which they were commissioned, but by their ability to adapt to different uses; buildings that aim to make a positive and lasting contribution to the city around them; buildings that form the backdrop to the city and the theatre of everyday life, but that can be, in themselves, extraordinary.

UCL
THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Central House
14 Upper Woburn Place
London WC1H 0NN
www.ucl.ac.uk/bartlett/environmental-design

ALLFORD
HALL
MONAGHAN
MORRIS

Morelands
5-23 Old Street
London EC1V 9HL
T +44 (0)20 7251 5261
F +44 (0)20 7251 5123
www.ahmm.co.uk
www.ahmm.co.uk/profile/sustainability-and-building-performance-at-ahmm

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DELIVERING NET ZERO CARBON IN USE

Prepared on behalf of AHMM by Dr Simon Hatherley for the UCL Institute for Environmental Design and Engineering (IEDE)

With support and guidance from Dr Craig Robertson of AHMM, Matthew Murphy of AHMM, Professor Dejan Mumovic of IEDE, and Dr Esfand Burman of IEDE. Support for the section on the Embodied Carbon Performance Gap was provided by Ceyda Davidson of Elementa Consulting, Sefa Keles of Department of Energy Efficiency in Buildings (Turkey) and Dr Yair Schwartz of IEDE. Additional support with data collection and modelling was provided by Juila Yao, Martina Pacifici, Barbora Vanek, Valentina Baldini and Rosie Ashbourne. Graphics by Pablo Jorge with additional images by Ella Smith. Edited by Shelley Smith.

Thanks to British Land for the use of Canada Water Plot F as a case study and the Canada Water Plot F design team for acces to their analysis.

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This document is one output from a Knowledge Transfer Partnership between AHMM and IEDE. KTP is a UK-wide programme that has been helping businesses for the past 40 years to improve their competitiveness and productivity through the better use of knowledge, technology and skills. The KTP research described here was a match-funding initiative with contributions from AHMM and Innovate UK.

Timeline of contents

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KEY

- Contents
- Main chapter
- Sub-chapter
- Key point — key points for delivering net zero in use
- Project example

INTERACTIVE READING

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STYLE
MORE
JOY
YOU
LIFE
SOUL

Simon Allford
Founding Director of AHMM, President of the Royal Institute of British Architects 2021-2023

Our world of architecture and infrastructure must adapt - and fast. 38% of the world's CO_2 emissions are the responsibility of the built environment. We have tough targets and 2030 is just eight years away, so we must urgently address the great problems we face: problems that demand great thinking from us all. Charles Darwin said 'The species that survives is the one that is best able to adapt to… the changing environment in which it finds itself.'

These are exacting times but they are also exciting times. We are now designing for **longer life**, **looser fit**, and **lower carbon**.

I welcome this guide as it sets out to establish the common ground: the **how** not the why. In our dynamic world, where we are taking actions every day, it is essential that we record, report and share knowledge.

And that we continually assess and reassess our measures and standards – in design and in use. We need to establish a fertile ground for technological and cultural review of what we are doing and how it is working. We must also accept that we will make mistakes, so must learn from and share these lessons.

The guide works in four parts. First by defining criteria to assess in the journey to **net zero**. Then by outlining the key considerations of the changing contexts which you must continuously review. Then by offering key resources to tool up a team; and finally by offering case studies for guidance. If it is to fulfil its potential as a tool for practice it will itself be subject to an ongoing critical review.

Introduction

From macro to micro, this guide takes you through the key considerations, practicalities, concepts, resources and strategies to deliver net zero in use.

We have written this guide to share our experiences of the challenge of designing net zero carbon buildings. It is presented as a guide for architects but we also welcome anyone interested in reducing carbon emissions in the built environment to take a look.

We all know that reducing our carbon emissions is a matter of urgency and we hope that this guide will improve your knowledge, distil your thinking, and ultimately change your design process.

Background to the guide

This guide is one output from a collaborative Knowledge Transfer Partnership (KTP)[1] between Allford Hall Monaghan Morris (AHMM)[2] and University College London's (UCL) Bartlett Institute for Environmental Design and Engineering (IEDE).[3] The KTP is a two-year programme researching the opportunities and implications of developing net zero carbon large scale, mixed use, urban, commercially driven and densely occupied buildings. Our aim is that discussions arising from this publication will contribute to the ongoing research and inform further revisions of this guide.

How to use the guide

Designing net zero carbon buildings is incredibly complex with many considerations. We have broken the guide into four parts and invite you to jump in where you need the most support and research:

- Overleaf you will find our summary of the 10 essential points architects should consider, with links to further information on each point within the guide. (This is a good starting point if you are new to net zero carbon design.)
- In part **ONE** we break down the definition of 'net zero carbon' into its component parts and the influence architects have over each. We have also included snapshots of AHMM projects that apply the principles of net zero carbon design in practice.
- In part **TWO** we proceed chronologically through the lifecycle of a building and identify the issues involved at each stage.
- In part **THREE** we look at the relevant international standards, frameworks and guides available to architects.
- In part **FOUR** we have included a detailed case study of a project that puts into practice a lot of the issues and considerations described in parts ONE and TWO.

We include a brief definition of each new term and concept as we go, but we have also included a glossary at the end of the guide for quick reference.

When researching and writing this guide we benefited from the many excellent guides to net zero carbon design freely available (see part **THREE** for links). We hope that this guide will take its place among these resources as a contribution to ongoing discourse about the nature and scope of zero carbon development.

Further reading

We have included many links to essential and informative resources for readers who wish to explore the issues and concepts presented in more detail. As you read the guide, you will find footnotes with external links in the right hand column. For quick reference, we have also included all footnotes at the end of the guide.

1 More information about KTPs and the role of the programme in developing innovation in UK industries.

2 Allford Hall Monaghan Morris is a UK architecture practice commitment to the design of buildings of economy, elegance and delight: buildings that reflect a continuing belief in the ability of outstanding architecture to endure.

3 IEDE aims to pursue a deeper understanding of the interactions between the built environment and health, human wellbeing, productivity, energy use and climate change. For more infomation about IEDE.

Net zero in context

Net zero carbon is often referred to as 'carbon neutrality', which is the global aim of keeping the emissions of carbon within the limits of what the Earth's natural systems can sequester.

A macro-level definition of carbon neutrality recognises the need to reduce carbon emissions from human activities to achieve a balance with the connected systems of the natural world. As a minimum this means striking a balance between the natural and built environments to ensure that human systems do not overwhelm natural processes. Going beyond the minimum, it means reversing the harm previously and currently caused to natural systems[4].

There are complex and diverse natural systems with critical relationship between constituent parts, like peatlands[5] or natural forests[6], which absorb vast quantities of carbon. As architects we need to recognise that the human systems which develop, support, and inhabit the built environment are, like these natural systems, complex and diverse.

At a micro-level, this guide highlights that the structures supporting development, (whether they are systems extracting and processing materials to provide resources for construction and refurbishment or supplying energy to provide controlled environments), are as tied to a definition of net zero carbon as the direct emissions that come from a building. And within this definition we cannot exclude the social and economic systems underpinning a development even if as architects, we may have limited influence over them.

The natural world is made up of complex connected systems that emit, absorb and ultimately neutralise carbon emissions. The built environment and human society are also complex and diverse systems within the natural world, but we have become disconnected.
To achieve net zero carbon neutrality the enormous challenge for architects is to mitigate the harm humans have already caused and redress the balance and connections between the systems of the built environment and the natural world.

Sources, collaborations and contributions

The guide has been prepared on behalf of AHMM by Dr Simon Hatherley for the UCL Institute for Environmental Design and Engineering (IEDE) with support and guidance from Dr Craig Robertson and Matthew Murphy of AHMM. AHMM benefited from our KTP collaboration with Professor Dejan Mumovic and Dr Esfand Burman of IEDE. Some members reviewed early drafts, plus excellent dissertation research by IEDE Environmental Design and Engineering MSc students supported the section on the embodied carbon performance gap.

The UCL and AHMM collaboration provided a framework to engage with the construction industry. In the course of preparing this guide a series of workshops were held with dozens of industry consultants and AHMM architects in order to understand their perceptions of the obstacles to, and opportunities for, achieving net zero carbon developments.

The case study

As part of the KTP, the project chosen for the case study is Plot F at Canada Water in south London. This high density mixed use development was designed by AHMM for British Land and received planning permissions in summer 2022. The client established net zero as an aspiration and this case study has provided an excellent opportunity to explore what adopting net zero carbon principles means in practice and also offers guidance for the future. The reader is taken from first principles to examining more nuanced decision making identifying some of the trade-offs required to drive down whole life carbon on a live commercial project.

We wish to thank our KTP partners and collaborators, and our project client and design team, for their ambition, knowledge, cooperation and support in the production of this guide.

4 More information about creating Buildings with Positive Impacts.

5 An overview of the relative contributions of different British habitats to carbon sequestration.

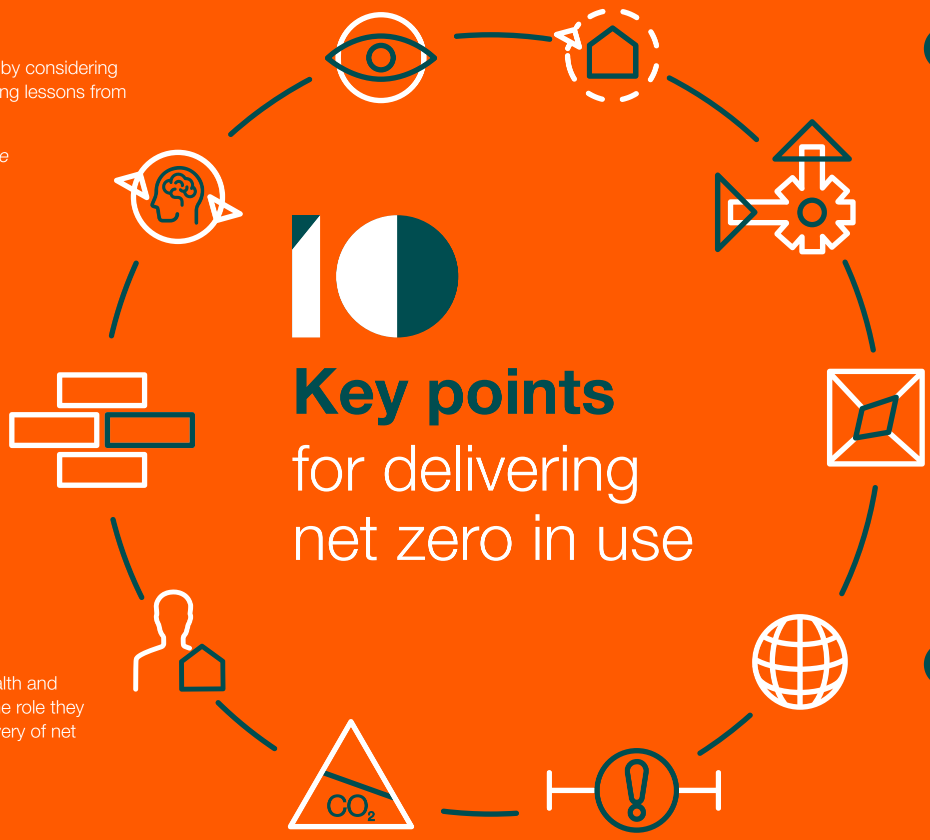
6 An interesting report about the role of British forestry in mitigating climate change

How to deliver net zero carbon in use

Here are ten essential points architects should consider in order to deliver net zero carbon in use. For each point we have referenced the section where you can find more detailed information and advice.

10 Key points for delivering net zero in use

10 Key points for delivering net zero in use



1 Whole life carbon approach

A whole life carbon approach should be taken when designing net zero carbon buildings encompassing operational carbon, upfront embodied carbon and lifetime embodied carbon.

ONE › *Defining net zero*

2 Operational energy

Operational performance should be a key consideration of net zero carbon development - monitoring and tracking operational carbon is essential for delivering and verifying net zero.

ONE › *Operational carbon*

3 From golden triangle to carbon square

Carbon must be viewed alongside time, cost and quality as one of the key constraints when designing buildings.

TWO › *From a golden triangle to a carbon square*

4 Design principles

Economy, efficiency and elegance should be the design principles that drive architects to reduce the carbon intensity of a new development, by eliminating superfluous material.

ONE › *Embodied carbon - architects' influence*

5 Performance gap

A whole life carbon approach extends the scope for a performance gap and awareness of this should be a critical consideration in net zero carbon design.

TWO › *The performance gap*

6 Decarbonisation and flexibility

The role of decarbonisation of the grid and grid flexibility should be considered in the development of net zero strategies.

TWO › *Grid decarbonisation and net zero carbon buildings*

7 Building users

It is important to consider the health and wellbeing of building users and the role they play in the development and delivery of net zero carbon strategies.

TWO › *Grid flexibility*

8 Save, substitute and sequester

When considering embodied carbon, architects should, where possible, save existing materials, substitute highly carbon-intensive materials with less intensive ones, and use the building to sequester carbon.

ONE › *Embodied carbon - architects' influence*

9 Cyclical thinking

Net zero design requires cyclical thinking, by considering the sourcing and reuse of materials, learning lessons from POE, and iterative design approaches.

ONE › *Carbon neutral to climate positive*

10 Architects' influence

It is important to recognise how much influence architects have; we can steer and shape ambitions and expectations to deliver net zero carbon in use.

ONE › *Embodied carbon - architects' influence*
ONE › *Carbon offsetting - architects' influence*
ONE › *Carbon neutral to climate positive*

ONE
Understanding net zero

QUICK INDEX

Defining net zero

To achieve net zero carbon, we first need to understand how carbon is generated in the construction, operation and eventual demolition of the buildings we design.

Throughout this guide we define carbon emissions generated from the construction, operation and demolition of buildings as 'whole life carbon', which is broken down further into the following:

Upfront embodied carbon
Upfront embodied carbon, or 'upfront carbon' is generated from the extraction, processing and manufacturing of materials used to make, maintain, run and repair buildings.

Operational carbon
Operational carbon is a product of energy generated for the use of electrical power, heating and cooling systems for the benefit of a buildings' users.

Lifetime embodied carbon
Lifetime embodied carbon includes maintenance and replacement of materials and replacement of components throughout the life of the building, and the eventual demolition and disposal of a building at the end of its life.[7]

Carbon offsetting
Carbon offsetting is sometimes required for a building project to meet net zero carbon commitments. Where residual carbon emissions are unavoidable, methods such as carbon sequestration and financing renewables offsite can be applied although this is not without risk.

Carbon neutral
'Net zero carbon' and 'carbon neutral' are often used interchangeably, but the two are not technically the same. Carbon neutrality is achieved when an organisation delivers zero direct and indirect carbon emissions. However to achieve 'net zero carbon' an organisation must also account for other indirect emissions outside of their direct control, such as those generated by suppliers.

Climate positive
Climate positive (or carbon negative or regenerative design) means taking actions that go beyond achieving net zero carbon emissions to actually create environmental benefits and reverse the harm previously and currently caused to natural systems by humans.

Key points for delivering net zero in use

Whole life carbon approach

7 RIBA Embodied and whole life carbon assessment for architect

8 The UKGBC Net Zero Whole Life Roadmap outlines the whole life carbon emissions across the built environment and describes emissions pathway reductions to achieve net zero.

Whole life carbon

Total carbon emissions associated with a building are expressed as whole life carbon (WLC). This is the total embodied and operational carbon created through the total lifespan of a building.[8] WLC includes emissions from manufacturing products and materials assembled into a building, the transportation of these products to site and construction activities to assemble a building. During the life of a building WLC will account for the maintenance and replacement of components and all operational energy. Finally, at the end of a building's life WLC accounts for the disposal or recycling of materials.

Understanding whole life carbon

A useful starting point for understanding WLC is the Royal Institute of Chartered Surveyors (RICS) Whole Life Carbon Assessment for the Built Environment Guidance [9] (which draws on The Sustainability of Construction works - EN 15978:2011).

The RICS framework separates emission into sets of modules:

Modules A1- A5 include the upfront carbon. A1-A3 deal with extraction and material supply along with the transportation and manufacture of materials and products. A4 deals with the transportation of those materials and products to site and A5 with the construction and installation processes.

Modules B1-B7 deal with the use stage and include emissions from building elements, like refrigerants (B1), maintenance (B2) and repair and refurbishment (B3-B5). Operational energy use is included in Module B6 and water use is accounted for in Module B7.

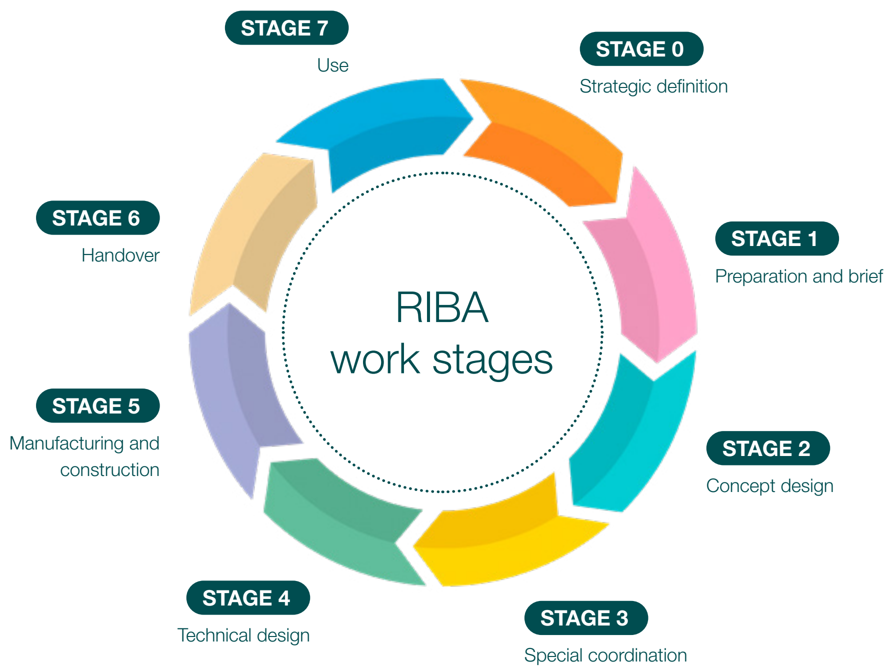
Modules C1-C4 deal with the end of life stage. This includes demolition (C1), transport to a disposal facility (C2), waste processing (C3) and disposal of a building (C4).

Module D is considered separately. It includes the potential benefit of savings in future energy and carbon from the recovery, reuse, and recycling of a building's materials.

The RICS framework can be overlaid on other development frameworks such as the RIBA Plan of Work [10], as shown in figures 1 through to 5. The RIBA Plan of Work separates the design and delivery of a building into eight separate work stages each with clear tasks and outputs:

9 A link and further information on this key document can be found in Part 2 - Key processes.

10 The RIBA Plan of Work organises the process of building development into stages. It is a framework for all disciplines on construction projects and should be used solely as guidance for the preparation of detailed professional services and building contracts.



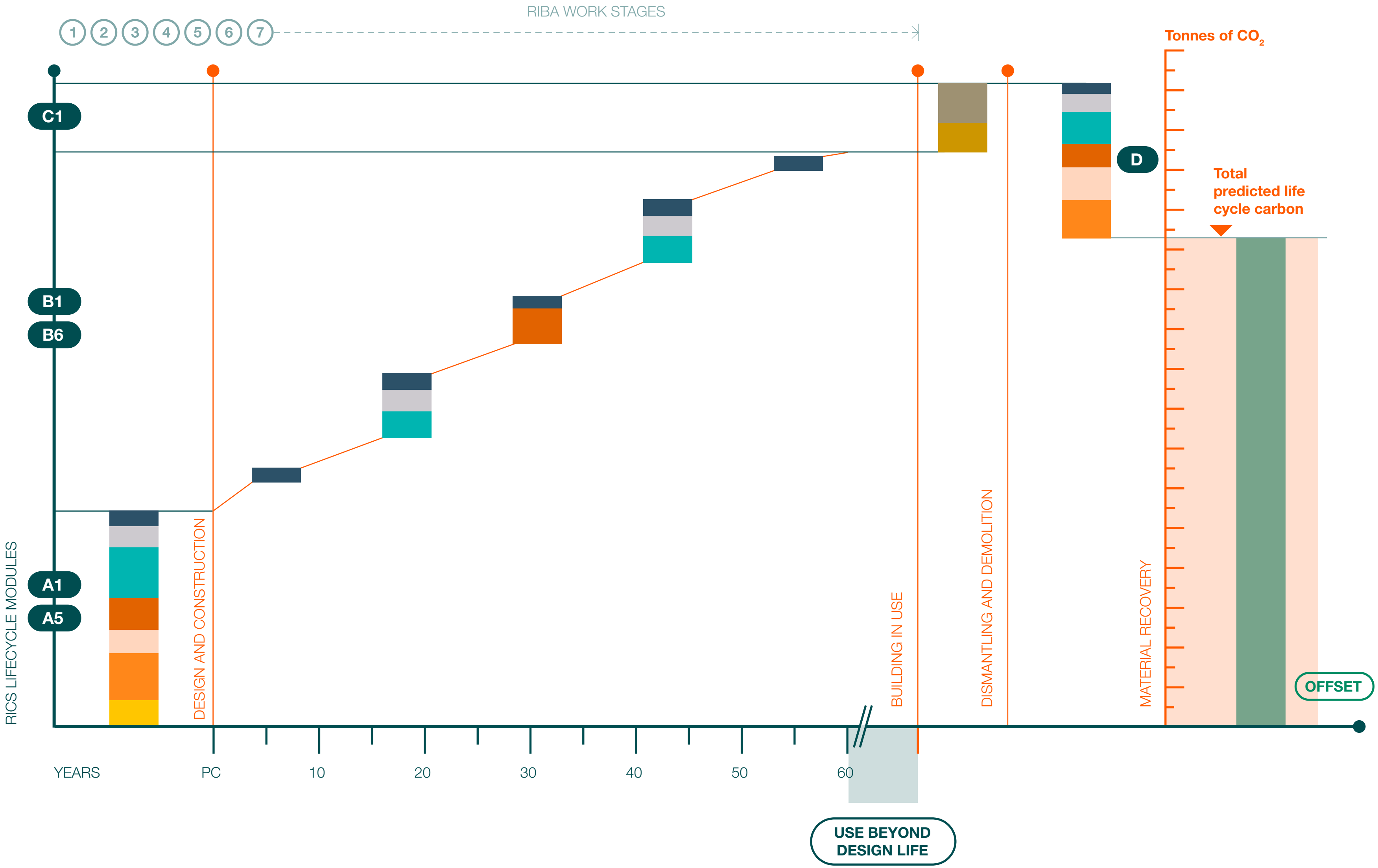


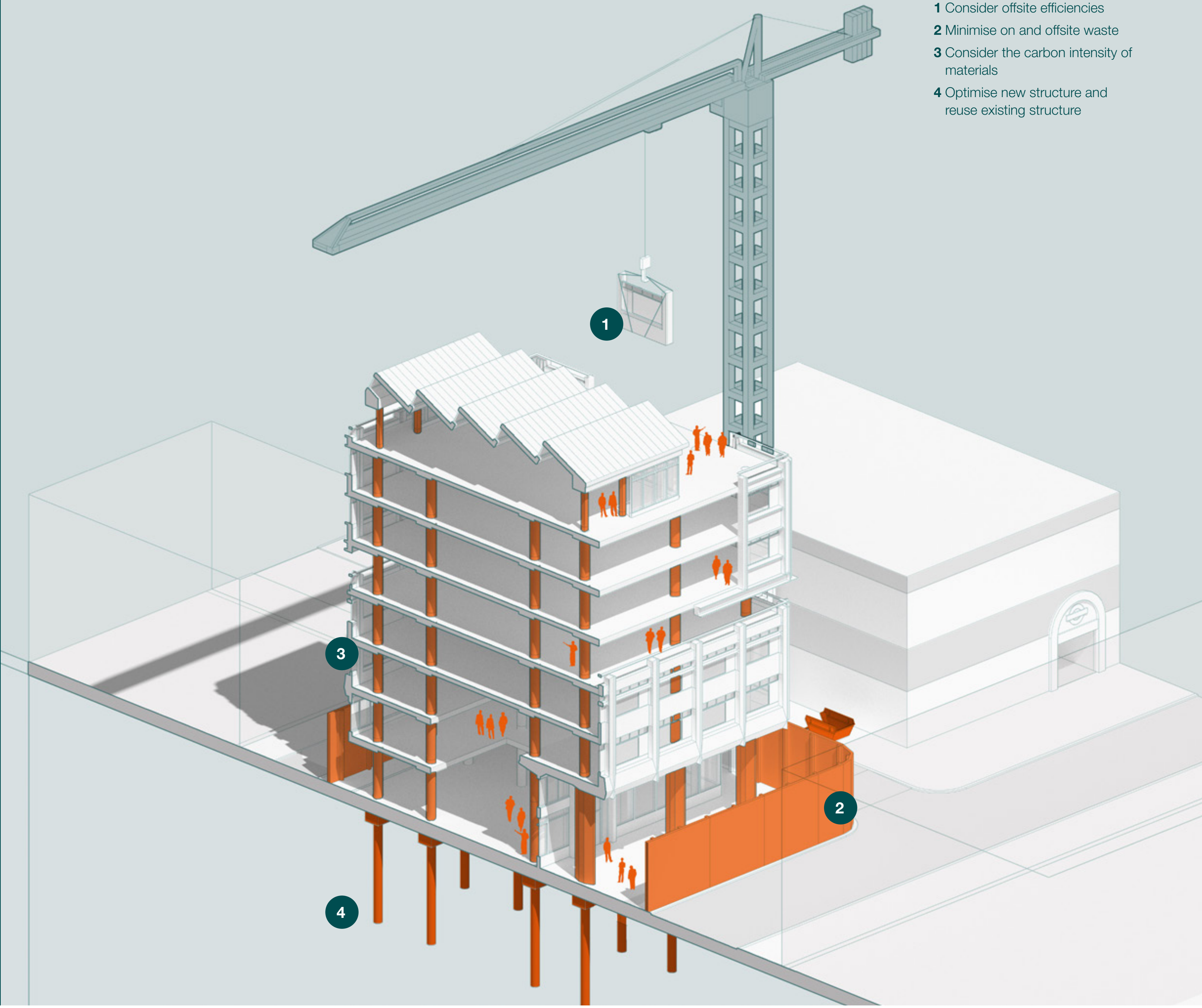
FIGURE 1
A lifecycle chart showing the whole life carbon emissions over the life of a building and their relationship to RIBA work stages and RICS lifecycle modules.

KEY

- services
- stairs
- internal construction
- external walls
- roof
- superstructure
- substructure
- operational energy

Upfront embodied carbon

Architects have considerable influence over the upfront embodied carbon of a building through design and construction methodologies, and specification of materials.



1 Consider offsite efficiencies
2 Minimise on and offsite waste
3 Consider the carbon intensity of materials
4 Optimise new structure and reuse existing structure

Upfront embodied carbon
Definitions in detail

Making a building takes energy and resources. Material is extracted, harvested or gathered, then processed and assembled offsite and onsite.

Upfront embodied carbon is the carbon footprint of a building before it becomes operational and, as architects, we are responsible for specifying many of the products and materials that are used in construction.

RICS breaks down the definition of upfront embodied carbon as:

- The building products used to construct the initial building, including extraction, transportation to manufacturer and manufacturing (RICS Modules A1-A3).
- The transportation of those materials to the site (RICS Module A4).
- The construction practices employed (RICS Module A5).

Other technical terms referred to in this section include:

Form factor
Form factor, or 'heat loss form factor' is a measurement used in Passivhaus and high performance building design. The ratio of thermal envelope surface area to treated floor area (often referred to as the wall:floor ratio) is used to determine how energy efficient the building will likely be once it is operational.[11]

Carbon sequestration
Carbon sequestration describes the process of storing carbon in a pool or 'carbon sink'. It can be a natural or artificial process and is described in greater detail later in carbon offsetting.

Key definitions

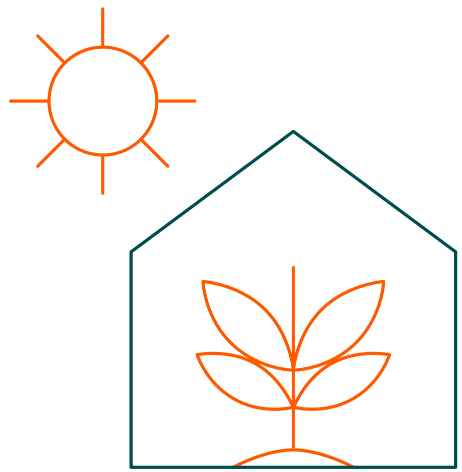
Passivhaus is a rigorous energy efficiency standard developed by the Passivhaus Institute in Germany where buildings are designed to maintain a constant temperature without additional heating or cooling systems (i.e. minimal to no operational carbon emissions).[12]

Key metrics

Embodied carbon is usually expressed as kilograms (kg) of carbon dioxide (CO_2), or equivalent (e), per metre squared (m^2) or $kgCO_2e/m^2$.

[11] Green Building Design: Materials & Techniques.

[12] Passivhaus Institute website.



13 The Global Status Report for Buildings and Construction is a reference document published by the UN Environment Programme (UNEP). It is published annually and tracks the impact of the construction sector and the built environment on global carbon emissions.

14 GLA Construction Scope 3 (Embodied):

UN carbon emissions

“The UN Global Status Report for Buildings and Construction[13] identifies that the buildings and construction sector accounted for 36% of final energy use and 37% of energy and process-related carbon dioxide emissions in 2020, 10% of which are from manufacturing building materials and products such as steel, cement and glass...[14]”

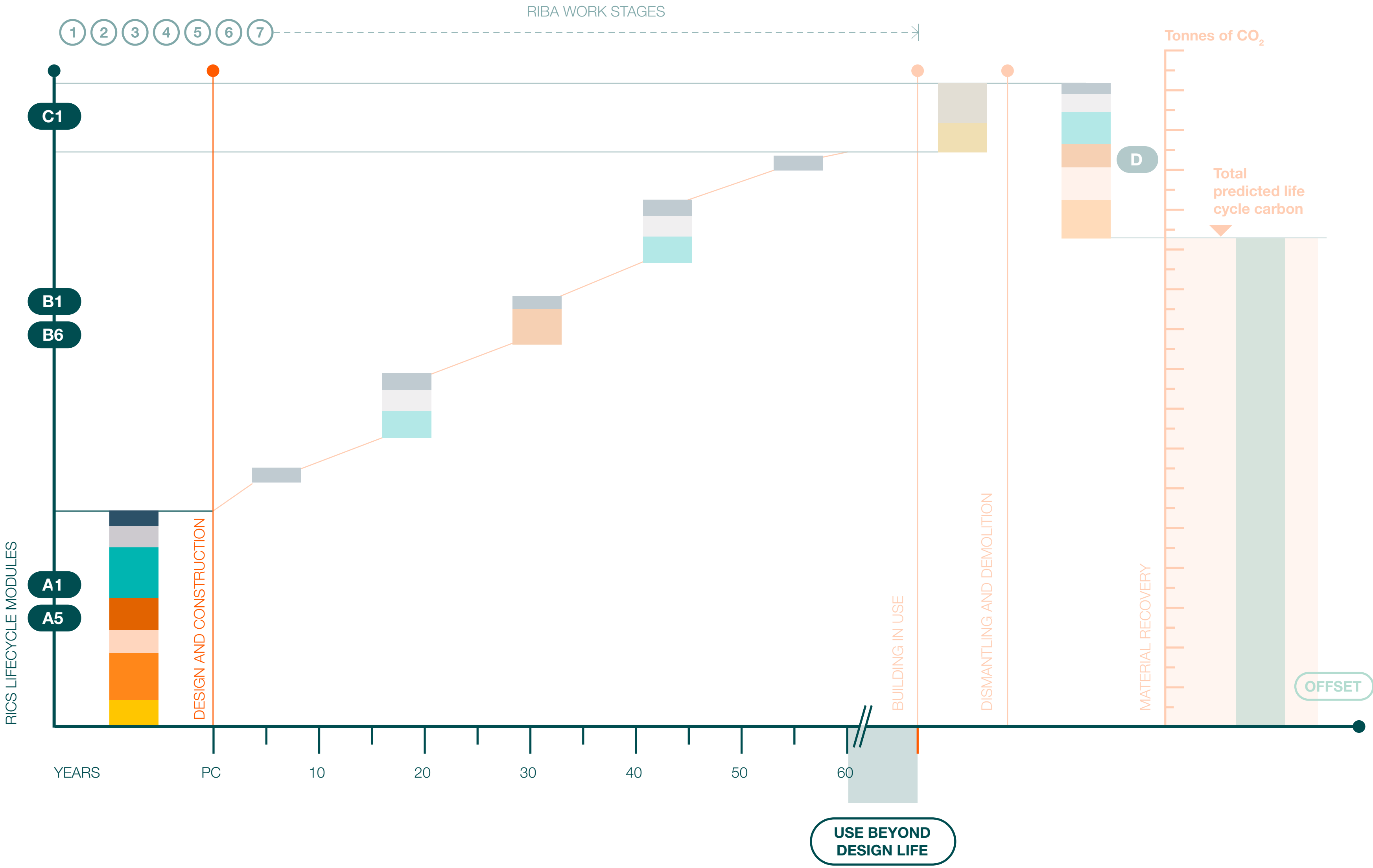


FIGURE 2

A lifecycle chart showing the ufront embodied carbon emissions over the life of a building and their relationship to RIBA work stages and RICS lifecycle modules.

KEY

- services
- stairs
- internal construction
- external walls
- roof
- superstructure
- substructure
- operational energy

Upfront embodied carbon
Architects' influence

Architects have considerable influence over the upfront embodied carbon of a building through design and construction methodologies, and specification of materials.

Application of design principles and consideration of building elements are key to reducing upfront embodied carbon:

Structure
The sub and superstructure of a building is often the most carbon intensive component; according to LETI[15] the structure accounts for around 65% of the embodied carbon of a typical commercial office and 67% for a typical large residential development. Resources used for the substructure of large scale buildings can account for a fifth of embodied emissions and those used for the superstructure nearly half.

The specification of the structure sits with the structural engineer, but it is often part of the architectural expression. Collaboration across the design team is key to understanding and optimising the carbon contained in the structure and ensuring structural efficiency.

Façades
Building façades have a significant effect on every element of whole life carbon; upfront embodied carbon, operational carbon and lifetime embodied carbon.

The configuration of façade components plays a key role in moderating internal and external temperatures and by extension the operational carbon emissions of a building.

There is a balance to be struck between reductions in operational carbon moderating the internal environment and the embodied carbon used to construct the façade which provides an environmental buffer.

Façades are also components which are subject to replacement during the life of a building. Their initial configuration and design can facilitate removal and replacement to positively affect lifetime embodied carbon.

Services
The embodied carbon of M&E equipment is difficult to quantify because it comprises multiple components made from various materials and involves complex installation, maintenance and replacement regimes. However, CIBSE TM65[16] has defined a methodology for this calculation.

Services can be a relatively small proportion of upfront embodied carbon (circa 15% in offices according to LETI), however the complexity and replacement cycles of mechanical services systems increases their contribution to lifetime embodied carbon over time. Architectural decisions to increase passive conditioning can reduce the need for servicing equipment and replacement and, by extension, reduce total embodied carbon over the life of a building.

Space and volume
The spatial configuration of a building impacts whole life carbon. For example, reducing a building's form factor, i.e. the internal area relative to external surface area, is typically associated with savings in operational energy by reducing the volume required for heating and the surface area from which heat is lost. A compact form not only saves operational carbon, but also reduces the quantity of material, and by extension, the embodied carbon required of a project.

Avoiding excessive material at both general arrangement (GA) plan level and building detail level, can also reduce total embodied carbon.

10 Key points for delivering net zero in use

Architect's influence

15 The LETI Embodied Carbon Primer provides an overview of embodied carbon in buildings and provides breakdowns of embodied carbon by building element.

16 CIBSE TM65 outlines an approach to assess embodied carbon of products linked to mechanical, electrical and public health (MEP) systems.

Efficiency, economy and elegance[17]

Efficiency, economy and elegance are core design principles that can be applied to reducing the upfront embodied carbon emissions of buildings:

Efficiency
The principle of using the minimum amount of material required to meet present need and future flexibility can be applied to reducing emissions.

Economy
The careful management of resources is an approach to avoiding excessive carbon emissions in the design, construction, operation and decommissioning of a building.

Elegance
Recognising when the attractive appearance of materials in their finished state reduces, or even eliminates the need to add more materials solely for aesthetic reasons.[18]

The application of efficiency, economy and elegance can affect architecture through the expression of building elements such as structure and services, and often means leaving these aspects of the design exposed. This approach ensures that the right materials are in the right place when and where required, and recognises that the treatment of surfaces and finished materials is a factor in reducing the use of excessive materials.

Save, substitute and sequester

These three core principles address the carbon intensity of materials directly in order to reduce upfront embodied carbon:

Save
This principle applies to the entirety of a development; specify reused materials and give precedence to saving, refurbishing and reusing existing buildings onsite over demolition and rebuild, wherever possible.

Substitute
Encourage the substitution of less carbon-intensive materials, for example ground granulated blast furnace slag (GGBS) in place of cement or recycled steel beams in place of new.

Sequester
Specify materials that have carbon locked into their physical make-up, such as cross laminated timber (CLT).

17 AHMM's Founders' Statement, published in 2018, describes the aims, values and ambitions which underpin the practice and describes how 'a commitment to buildings of economy, elegance and delight' is at the core of the approach of the practice.

18 An interesting essay entitled: 'E4: Efficiency, Economy, Elegance, and Ecology' on the benefits of efficiency, economy and elegance for ecological design.

81-87 Weston Street

Bermondsey, London 2018
Client: Solidspace

A mansion block of eight tessellating, split-section apartments on a backlands site.

AHMM applied the design principles of elegance, economy and efficiency at the Weston Street residential development, in Bermondsey, south London.

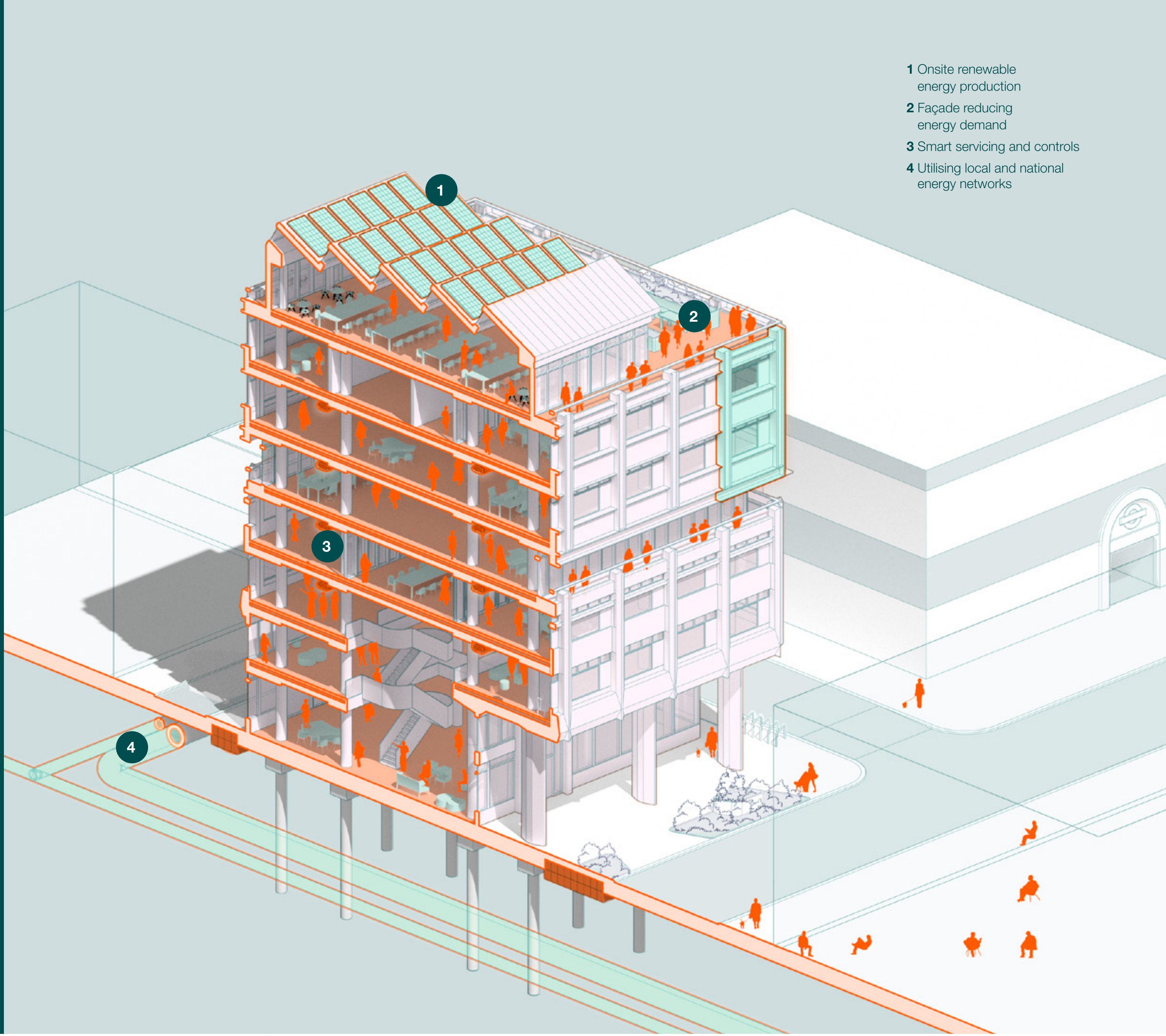
A combination of exposed concrete surfaces (GGBS mostly replaced cement), and timber to windows and wall linings reduced the need for superfluous material. These materials also provide thermal mass, warmth and texture to the internal spaces of these apartments.

More about this project

LINK

Operational carbon

Architectural design affects operational carbon through its response to the site and client brief, the design of building components and the development of environmental design strategies.



Operational carbon
Definitions in detail

Buildings are designed to create a comfortable safe internal environment, so operational energy is usually the starting point when considering carbon consumption.

According to RICS (module B6) operational carbon encompasses energy used for space conditioning (ventilation, heating and cooling), hot water, lighting and appliances. Operational energy affects carbon emissions in three distinct ways:

Direct emissions: The burning of fossil fuels onsite (e.g. a gas boiler).

Indirect emissions: When fossil fuels are burnt at a source away from the site and the energy is transferred to the building (e.g. a gas or coal fired power station providing electricity to the building).

Leakage: The release of greenhouse gases onsite (e.g. refrigerants used in air-conditioning systems).

Calculating operational carbon

Buildings are environmental modifiers that essentially create an internal environment more comfortable and safer than the external one. The configuration of architectural components plays a key role in determining the energy required to maintain optimum internal conditions.

The **energy use intensity (EUI)** [19] of a building is determined by the energy balance from external heat losses and gains, internal heat gains, heating and cooling requirements, lighting, power use for equipment and other uses.

Other technical terms referred to in this section include:

Thermal envelope

The thermal envelope of a building provides the insulation to prevent heat loss and keep the conditioned interior at the required temperature. An air-tight layer prevents conditioned air from leaking from the building (conditioned air has had an ‘investment‘ of energy and carbon).[20]

Thermal bridges

A ‘thermal bridge’ describes a localised area of intense heat loss in the thermal envelope of a building, where heat escapes due to structure, fixings or service penetrations.[21]

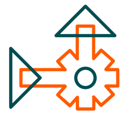
Key definitions

The **active buildings** concept [22] identifies that it is possible for many buildings to be operationally zero carbon, generating a surplus of renewable energy, through the considered application of renewable technologies and storage (such as batteries and heat stores). However, this approach requires balancing the operational demands of the building with the demands of the grid, and balancing uplifts in embodied carbon with operational savings.

Key metrics

Operational energy (and EUI) is usually expressed as KiloWatt Hours (kWh) per metre squared (m^2) per year (yr) or kWh/m^2.yr. This can be converted to CO_2 emissions or Green House Gas (GHG) Intensity (kg/CO_2e/m^2.yr) using carbon conversion factors available for each fuel type.

Key points for delivering net zero in use



Operational carbon

19 This High Performance Buildings article provides an informative and useful critique of EUIs.

20 A Carbon Trust guide to building fabric is available here.

21 A Zero Carbon Hub guide to thermal bridges.

22 More information about active buildings including a link the active buildings design guide is available here.

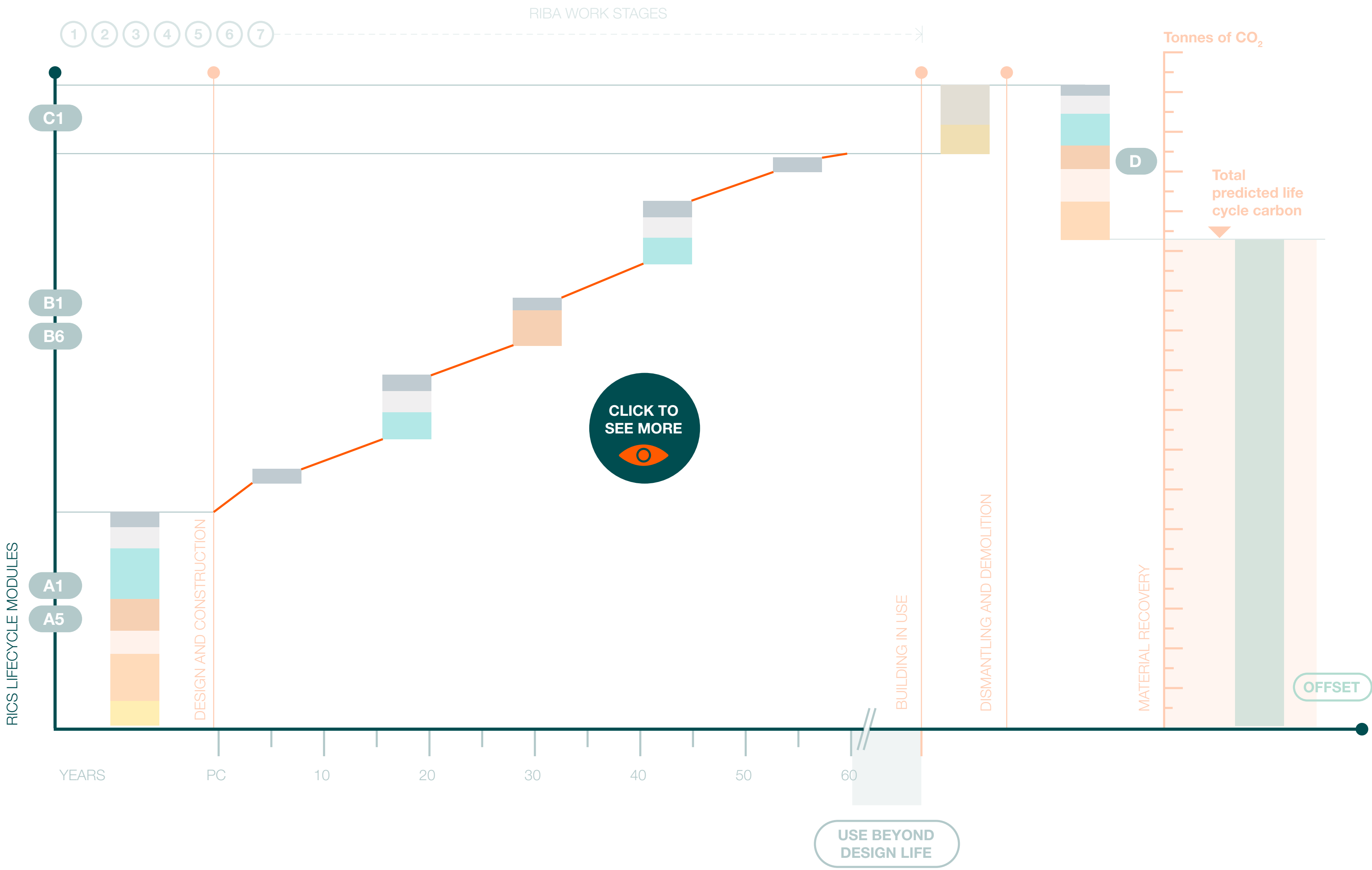


FIGURE 3
A lifecycle chart showing the operational carbon emissions over the life of a building and their relationship to RIBA work stages and RICS lifecycle modules.

KEY

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Operational carbon
Architects' influence

Architectural design affects operational carbon through its response to the site and client brief, the design of building components and the development of environmental design strategies.

These design decisions influence operational carbon as follows:

Site layout

How the building responds to the limitations and opportunities of the site can affect the net zero strategies. Site level analysis should identify the nature of the regional climate, how overshadowing will affect daylighting, solar gains, and the application of renewable technologies such as PV. Other micro-climate considerations will be the impact of the building on its surroundings, such as the urban heat island effect, and down-draughts from tall buildings.

Building form

The form of a building can affect its operational energy performance by reducing the need for artificial lighting and mechanical ventilation. In addition, reducing a building's external surface area also reduces the area subject to heat loss.

Form factor, while important should not be considered in tandem with how the scale and mass of the building is organised to optimise daylight, control solar gains and facilitate natural ventilation.

The thermal envelope

Within the thermal envelope of a building windows and glazed areas offer less thermal resistance and, as well as allowing in light and useful solar gains, they also let heat out, increasing heating loads, and can increase cooling loads if not carefully designed. Balancing the solid and glazed sections, understanding heat loss and gain, thermal bridges, other conductive losses and radiative gains, all help to manage the energy balance.

Infiltration and 'leaky' buildings - small gaps in the fabric that are a result of construction tolerances and/or poor quailty construction - can add to operational energy requirements because air that has been conditioned through energy intensive heating or cooling leaks through the façade and must be replaced.

Ventilation, heating and cooling

A healthy internal environment is comprised of fresh and often tempered air. Current guidance is for around 10 litres of fresh air to be supplied per person per second – although post-Covid responses may increase this provision .

Moving air around a building can require energy (e.g. fans etc.) as does conditioning air as it enters a building – in heating, cooling and/or (de)humidification. In order to help reduce energy requirements architects can consider means of ventilating spaces naturally, either through simple opening windows or by more advanced

The design and performance of the thermal envelope fall within the architect's design remit. Thermal envelope design has a profound impact on the user experience, operational carbon emissions and aesthetics of a building.

Key points for delivering net zero in use

Save, substitute and sequester | Design principles

23 This is a summary of ventilation actions to mitigate the risk of COVID-19 by the SAGE Environment and Modelling Group.

methods of buoyancy and fabric tempered air (using thermal mass). These measures have implications for the form, spatial efficiency, and expression of the building's architecture.

Plan depths and spatial configuration can facilitate natural ventilation and reduce the energy required to move air around a building. These are within an architect's remit but may conflict with other architectural aspirations, the client brief or commercial viability.

Solar gain

The location and the orientation of glazing on a building façade can affect the heating and cooling requirements of a building, provision of daylight and the risk of overheating. In the northern hemisphere summer solar gains through glazing on the south façade can be moderated through the provision of solar shading. These features can be orientated to allow in winter sun which will reduce heating requirements. East or west facing glazing may be more difficult to shade because of the low incidence of the sun but can be partially controlled through vertical solar shading or adjusting the depth of window reveals.

Occupant density

The number and density of people in a building can influence EUI. Building users are the reason a space is heated, cooled and ventilated. Their use of equipment within a building is one reason why an electricity supply is required. The heat gains generated by people, their activity and equipment adds to cooling loads (or reduces heating loads).

Control and demand response

How ventilation, heating and cooling systems are controlled by users (occupants and inhabitants) and operators (facilities and building managers) can affect energy performance.[24] Control mechanisms can change occupants' perception of internal conditions and lead to reductions in energy use. From how windows are opened to the ease with which people can control their heating, human interaction with a building and its systems should be an important consideration in the development of an environmental strategy.

Giving people control over their environment and ensuring they understand how their building works can also positively affect wellbeing by boosting mood, improving happiness and reducing the need for cooling and heating.[25] The adaptive comfort model can allow for more relaxed thermal conditions within a building and save energy.[26]

Review of performance/post occupancy evaluation

Investigating the operational energy performance of the building in use, and the general performance and suitability of the design, should be considered part of the design process.[27] Post Occupancy Evaluation (POE) of performance provides opportunities for:

- Gathering data on building performance to provide lessons for use on future projects with a view to bridging the performance gap.
- Data analysis which can help the building achieve its anticipated design performance.
- Working with building operators and users to aid their understanding of the environmental design of the building.

24 Berkeley Labs provide a useful introduction to thermal comfort and its relationship to minimising energy use.

25 The UK Green Building Council document Health and Wellbeing in Homes outlines the benefit of quality of environment on health and wellbeing.

26 TM52 The limits of thermal comfort: Avoiding overheating in European buildings is about predicting overheating in buildings.

27 RIBA guidance on Post Occupancy Evaluation is available here.

Integration of renewable technologies

The starting point for decreasing carbon emissions should be reducing energy demand. However, it is not possible to bring a building's energy demand down to zero. Complete electrification of a building offers one approach to reducing carbon emissions but it is reliant on decarbonisation of the grid to reach operational carbon neutrality.

Onsite generation where a building generates some or all of its own energy (or even a surplus) provides an opportunity for a building to meet its own demand. Typically, onsite generation will use such technologies as PV and solar thermal.[28]

Other technologies include heat pumps, which require electricity to operate, but which utilise the ambient energy of the environment (the thermal mass of the ground, the surrounding air temperature differences or local bodies of water like rivers or lakes) to extract heat from these sources to increase efficiency.

In some cases these renewable technologies will be combined into local energy networks providing heat or electricty to a district which a new development can utilise.

Renewable technologies and energy storage are key components of the design of net zero carbon buildings in the 21st Century.

In-use optimisation

Optimisation starts before a building is handed over to the users through robust and intensive commissioning to ensure that systems are operating at their optimal performance and then it continues beyond practical completion to ensure that environmental systems are correctly interfacing with users and operators.

This approach is reflected in many net zero carbon building standards, having a period after practical completion (typically one to five years after PC) where a building is expected to perform at the level required to achieve accreditation.

Storage

Energy can be stored in a building passively by using the thermal mass of the building structure and fabric, or actively through thermal heat stores and batteries[29]. Area for active storage should be considered at the planning stage of the design process. To facilitate passive storage thermal mass should be considered in the design of structure and finishes to ensure that the mass is thermally tied to the space.

> "I do not like ducts, I do not like pipes. I hate them really thoroughly, but because I hate them so thoroughly, I feel that they have to be given their place. If I just hated them and took no care, I think that they would invade the building and completely destroy it."[30]
>
> **Louis Kahn**

Architects should take the same care with the integration of renewable technologies as Kahn did with mechanical building services.

28 A Carbon Trust guide to renewable technologies is available here.

29 A Carbon Trust guide to energy storage is available here.

30 Louis I. Kahn in World Architecture, 1964

Dagenham Park School

Dagenham, London 2012
Client: London borough of Barking and Dagenham / Dagenham Park Church of England School

A new school with a central atrium and modular façades designed with the contractor.

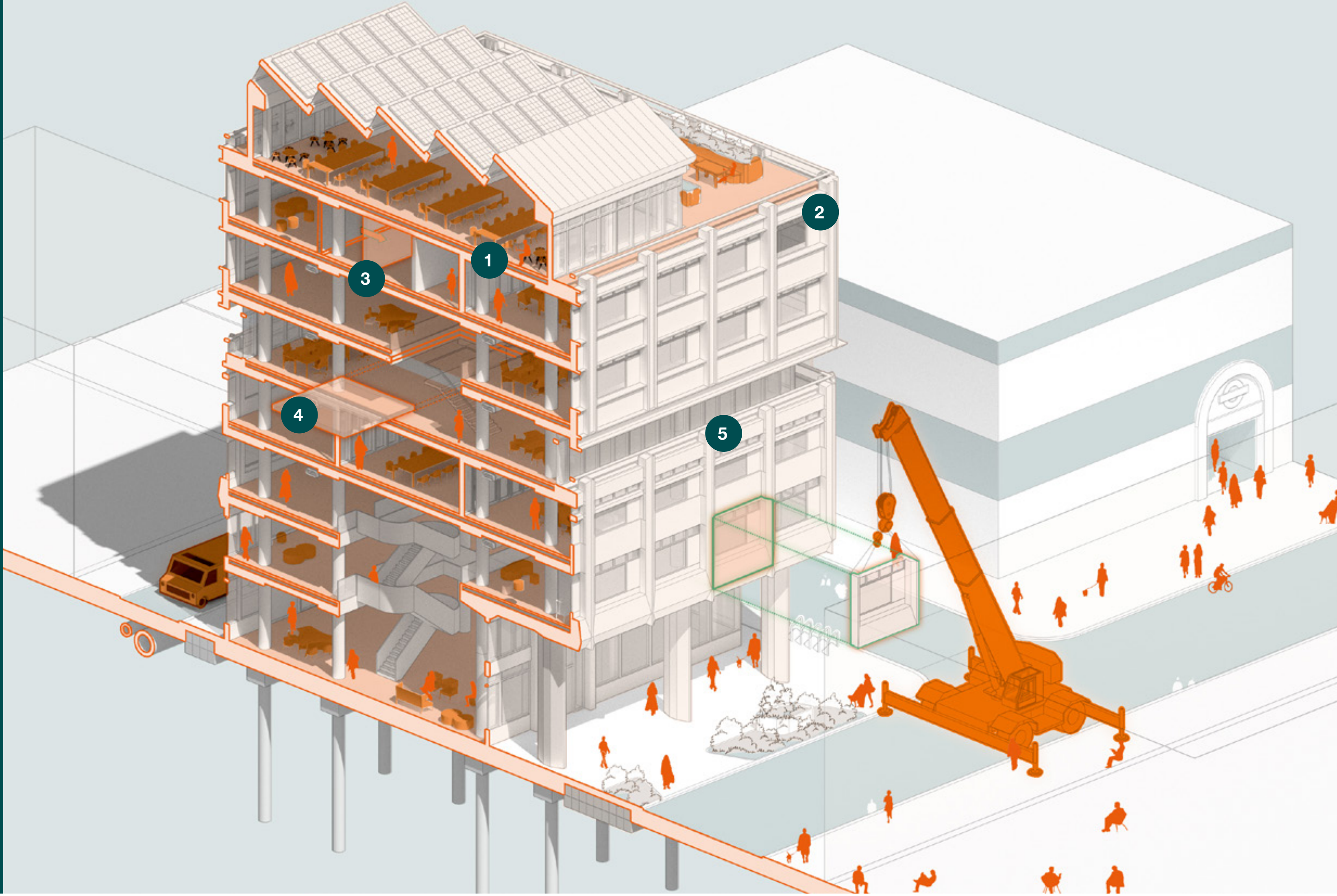
Solar control and ventilation strategies are a feature of AHMM's design of Dagenham Park Church of England School in London. Key components of the external façade are brightly accented, orientation specific solar shading, and ventilation mesh grilles. The building façades are composed of layers of storey-high load-bearing panels, finished in pre-cast concrete that was developed as part of a prefabricated manufacture and assembly solution.

More about this project

LINK

Lifetime embodied carbon

Recognising that buildings change and considering demolition at the design stage necessitates a degree of humility on the part of the architect.



1 Recognising the values of the building as a material bank

2 Materials passports providing information about products and materials

3 Flexible partition systems

4 Soft spots in the slab to enable adaptation across floor plates

5 Demountable building elements

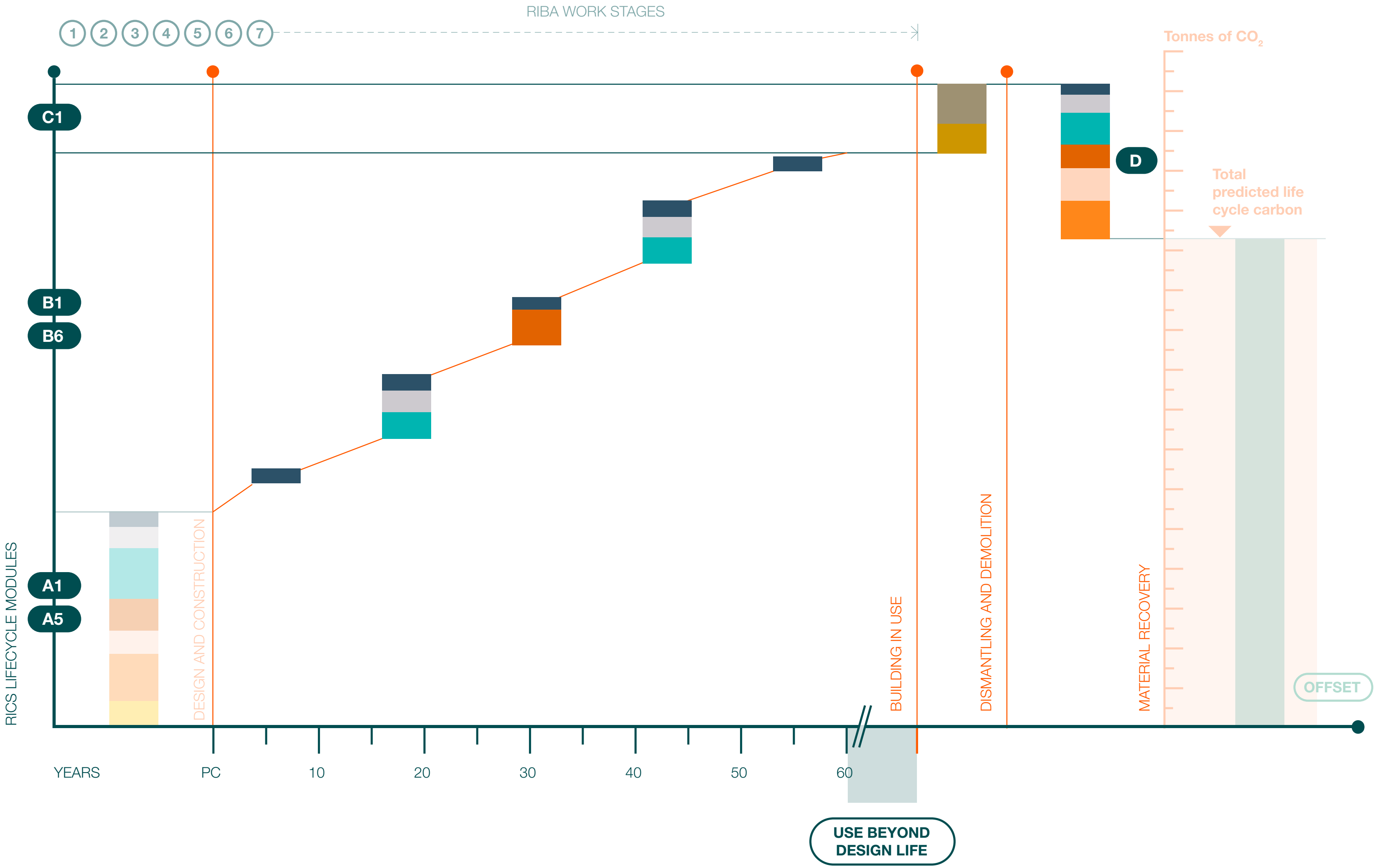


FIGURE 4
A lifecycle chart showing the life-time embodied carbon emissions over the life of a building and their relationship to RIBA work stages and RICS lifecycle modules.

KEY
- services
- stairs
- internal construction
- external walls
- roof
- superstructure
- substructure
- operational energy

Lifetime embodied carbon
Definitions in detail

To deliver net zero, architects must design for future flexibility to reduce the carbon impact of adaptations made to buildings during their lifetime.

After they are built, buildings continue to change, evolve and adapt to new uses.[31] Lifetime embodied carbon describes the in use and end of life emissions resulting from the adaptation and replacement of parts of a building over its entire life (RICS Modules B1 to B5), along with its demolition and disposal (RICS Modules C1 to C4) and material recovery (RICS Module D).

Calculating lifetime embodied carbon

The WLC methodology captures embodied and operational carbon and the carbon associated with changes over time, climate and emerging technology. There is a degree of speculation in calculating lifetime embodied carbon, but RICS have set out some assumptions for the replacement and maintenance rates of building elements and components.[32]

Key definitions

The **circular economy** is a model of production and consumption based on natural systems that prioritises reuse, regeneration and recycling, over single use materials and disposal.[33]

Key definitions

Design for disassembly is a strategy that ensures buildings are designed in ways that aid dismantling and every component can be recycled or reused at the end of the building's lifespan.[34]

Key definitions

Materials passports record the characteristics of building materials and components and assign a value for their present use, recovery, and reuse.[36]

Key metrics

Lifetime embodied carbon is usually expressed as Kilograms (kg) of Carbon Dioxide (CO_2), or equivalent (e), per Metre Squared (m^2) or $kgCO_2e/m^2$.

31 Stewart Brand's book How Buildings Learn: What Happens After They're Built is a good primer on the evolution of buildings and how buildings adapt to changing requirements over long periods.

32 RICS guidance outlining a whole life approach to reducing carbon emissions within the built environment is available here.

33 A Mayor of London Design For A Circular Economy Primer is available here.

34 This article offers a good overview of design for disassembly.

35 A guide to the reversible buildings concepts is available here.

36 An ORMS guide to materials passports can be found here.

Lifetime embodied carbon

Architects' influence

Recognising that buildings change and considering demolition at the design stage necessitates a degree of humility on the part of the architect.

A design approach that considers lifetime embodied carbon will make a significant contribution to delivering net zero in use:

Replacement, repair and maintenance

Materials, components and building elements, (façades, services, finishes etc), need to be maintained and, in many cases, replaced over the life of a building. This can add up to make a significant contribution to whole life carbon. Designing to minimise replacement and maintenance, and eliminating the need to change components can reduce WLC emissions .

Adaptation and reuse

When buildings adapt and change it can affect both operational carbon use and lifetime embodied carbon emissions.[37] Efforts should be made to ensure that buildings can accommodate changes of use by designing for future flexibility. For example designing modular units and partition walls that can be moved, disassembled and reassembled depending on future accommodation needs.

Dismantling

Inevitably some buildings will need to be dismantled. The investment of embodied carbon should be treated as a future resource bank to ensure that the materials in the building can be recovered and recording the characteristics of building components will facilitate their recovery. This material recovery could happen during planned replacement, repair and maintenance programmes, as well as at the end of a building's life.

There are established procedures which support the recovery of the materials and help realise their residual value, such as Design for Disassembly, Reversible Buildings and the development of Material Passports to track the material through its life.

Lifespan

Generally components should be designed so that the embodied carbon (and other constituents of the components) can be given a useful life for as long as possible. The lifespan of buildings is generally assumed to be 60 years but many components may require replacement before then and many buildings (or parts of buildings) can last longer than this.

There are relationships between embodied carbon and life span and circular economy. Carefully designing buildings to maximise the lifespan of carbon intensive elements either onsite or to be removed and reused elsewhere will reduce lifetime embodied carbon.[38]

Speculating on how buildings might be used in the future and how they might be adapted spatially, structurally and materially is key to designing adaptable buildings. Interrogating the impacts on operational energy and carbon into the analysis of the adaptation process is crucial for the delivery of net zero carbon buildings.

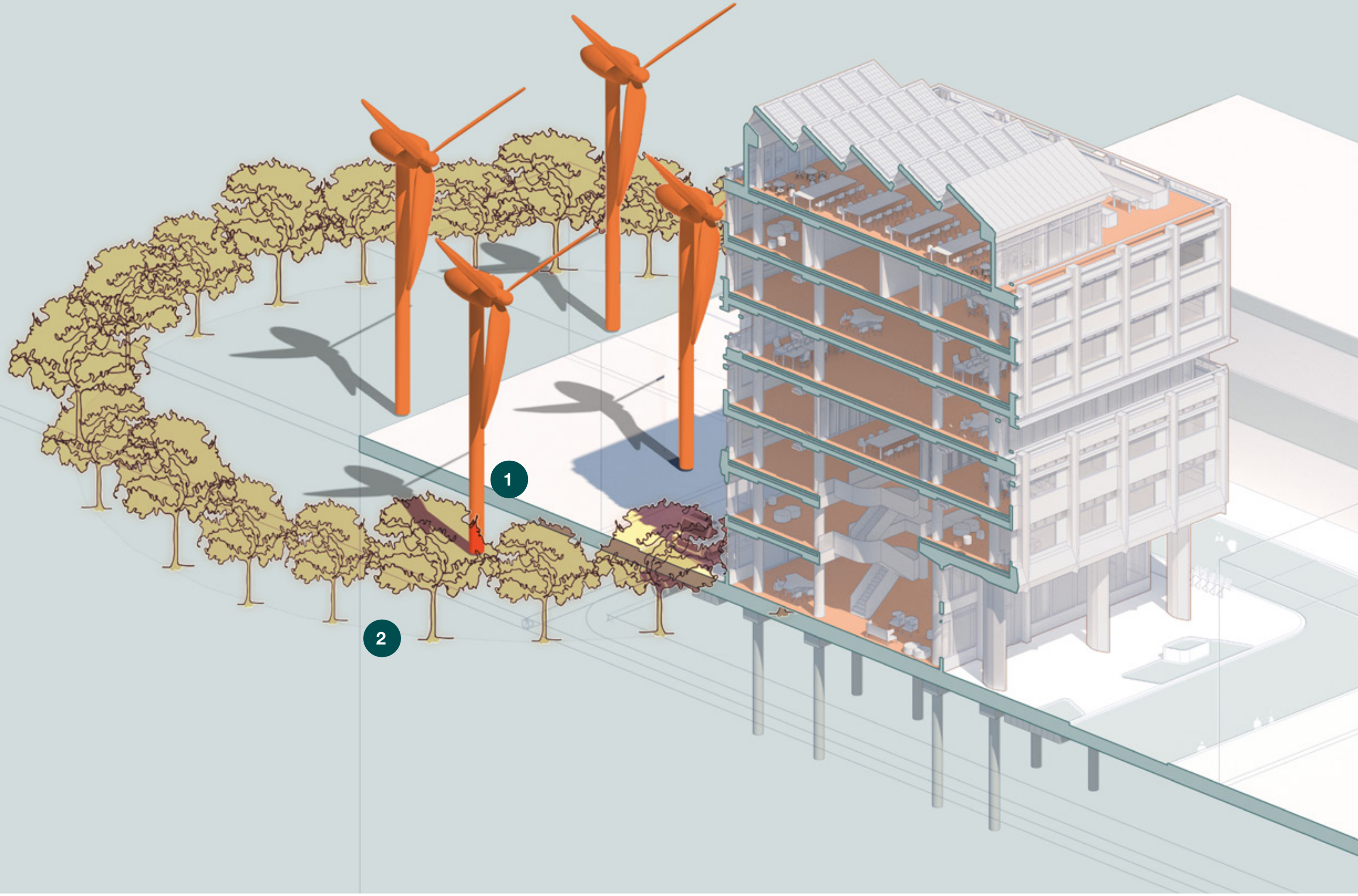
37 The AIA provide an informative guide on designing for adaptability, deconstruction, and reuse.

38 An interesting article on the Circular Economy and a link to the academic paper supporting it is available here.

Carbon offsetting

It is not preferable, but likely that carbon offsetting will be a component of large-scale, net zero carbon developments in the immediate future.

1 Offsite renewable technologies
2 Offsite sequestration (tree planting)



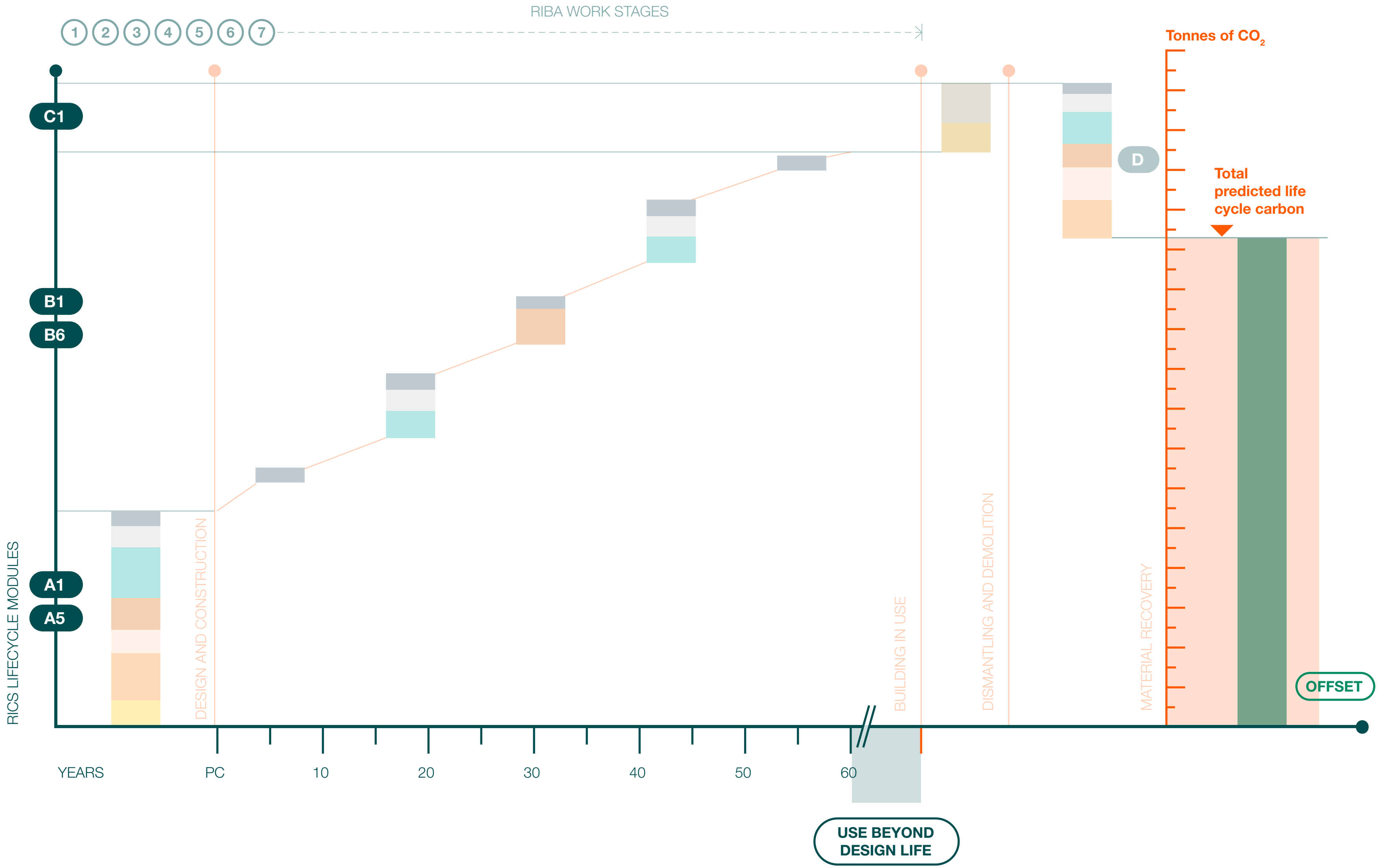


FIGURE 5

A lifecycle chart showing the compensatory aspect of net zero and the use of carbon offsets over the life of a building and their relationship to RIBA work stages and RICS lifecycle modules.

KEY

- services
- stairs
- internal construction
- external walls
- roof
- superstructure
- substructure
- operational energy

Google Pancras Square

Kings Cross, London 2016
Client: Google

Fit-out of offices for 2,500 Google staff, using a modular meeting room system.

Zero carbon certification was achieved on Google's headquarters at King's Cross, London. The building is certified to the International Living Futures Institute Zero Carbon Standard. Recognising that fit-outs can be wasteful in both material use and lifespan, AHMM's design embraced the inevitable need for the fit-out to adapt and evolve, to be reused, to reinvent itself and, importantly, to be a living and breathing space for Google to overlay its own creativity over time.

As an example, the modular meeting room unit, Project Jack, originally designed for the HQ fit-out, has since been rolled out to Google's other international offices.

More about this project

LINK

Carbon offsetting
Definitions in detail

Offsetting is an accounting process and its place in an architects' guide could be questioned, however it will likely affect design decisions.

Carbon offsetting describes the process of compensating for unavoidable embodied and operational carbon emissions through reduction and removal elsewhere:

Offsetting upfront embodied carbon

An expulsion of upfront embodied carbon at the outset of a new development, also known as an 'emissions burp',[39] will necessitate a balance of sources and sinks, (i.e. emissions with removal) to achieve net zero. Approaches such as 'the building as a carbon sink' and zero emissions products (where carbon is removed at source) will reduce or mitigate this initial carbon expulsion. Currently, however, the most common way to address these initial emissions is by offsite carbon removal.

Offsetting operational carbon

For operational emissions there are two possible carbon neutral end states:

- The building will be emitting no carbon during its lifetime (e.g. a building may achieve operational carbon neutrality through demand reduction measures, energy storage, renewable technologies and grid decarbonisation).[40]
- The building will be emitting carbon and actions will be necessary to balance those emissions, for example, by removing them from the atmosphere elsewhere.

Key definitions

A **carbon sink** describes anything that absorbs and stores more carbon from the atmosphere than it releases. In construction engineered timber is a carbon sink, as opposed to cement and concrete which are carbon intensive to produce. For example, the building as a carbon sink concept turns buildings into long term carbon stores through use of engineered timber.[41]

Key definitions

Biogenic carbon emissions are produced by the natural world, i.e. plants and trees. **Biogenic sequestration** describes the natural process plants have developed to remove these carbon emissions from the atmosphere by fixing it within carbohydrates (for plant growth) in their tissues.[42]

Key metrics

Offsets are expressed as tonnes (t) of carbon dioxide (CO_2) equivalent (e) or tCO_2e for sequestered carbon and kilowatt hours (or kWh) for offsite renewable energy capacity.

39 A phrase borrowed from Architecture Foundation article.

40 An energy positive approach can be used to address the embodied carbon emissions of a new development. Here a building 'pays back' it's production emissions through an energy surplus. For a building standard based on this approach see DGNB Climate Positive and examples of buildings achieving this standard are available via this link.

41 For more information about the concept of buildings as carbon sinks.

42 More information can be found in this article.

Carbon offsetting
Architects' influence

It is not preferable, but likely that carbon offsetting will be a component of large-scale, net zero carbon developments in the immediate future.

Priority should always be given to reducing or eliminating operational emissions at source: onsite renewables should be prioritised over offsite and the sequestration of carbon onsite (e.g. structural timber) is preferable to biogenic sequestration offsite.[43] However, it is important for architects to understand the main approaches to carbon offsetting:

Offsite renewable energy

If there is insufficient space onsite to deploy renewable technologies to meet the energy requirements of a building one response is to deploy them offsite. A quantity of renewable energy capacity is purchased from an energy provider to compensate for the residual operational energy of the building. Unless a cable links the renewable energy sources to the site, the energy produced will be provided to the grid by the purchaser. The purchaser will buy extra capacity from an energy provider and this is called an **Additionality**,[44] that is, the additional energy capacity provided, in solar, wind power etc. equivalent to the residual operational energy of the building.

Avoided emissions

Avoided emissions are payments to others to apply technologies or processes to reduce their emissions. Examples include the installation of PV in the global south or providing a means to reduce the carbon intensity of an existing process like providing cooking stoves to replace open fires.[45]

The payment to others to reduce their emissions on the project's behalf is, according to the **Oxford Offsetting Principles**[46], the least robust form of offsetting because of the difficulties of demonstrating additionality (i.e. that the deduction would not have happened otherwise). Indeed, this approach has been compared to the practice of selling of indulgences[47] by the Church of England in the 15th and 16th Centuries.

Sequestration

Sequestration is the capturing of carbon at source or from the air. Biogenic capture is the locking up of carbon through natural processes like tree planting or soil management. Carbon can be sequestered through engineered solutions which include capturing carbon in rock formations. However engineered approaches to carbon removal are currently expensive and not readily available. Carbon offsets based on sequestration can be applied to the upfront embodied carbon emissions or operational emissions.

The robustness, and in many cases cost, of sequestration for offsetting is tied to the following:

- **Institutional factors:** These include third-party verification and ongoing monitoring.
- **Physical properties:** The method of sequestration and length of time that the carbon will be locked away (whether it is years, decades or millennia).
- **Risk of reversal:** This is the risk that carbon stored will be emitted. For example, reversal of biogenic storage might arise from disease, fire or changes in land management.[48] If a building is used as a carbon sink the risk of reversal would be the premature release of carbon through early demolition combined with a failure to reuse carbon sequestering materials.

Just as a building's form is driven by the economics of development and commercial viability, so in a net zero environment the design space available to architects is affected by the treatment of residual carbon emissions. For example, a business-as-usual net zero paradigm is currently viable because of the availability of cheap carbon offsets, which do not factor in the risk and uncertainty associated with this approach.

Key points for delivering net zero in use

Architects' influence

43 See this UCL article on the true cost of carbon offsets.

44 UKGBC guidance on the procurement of renewable energy and carbon offsets for net zero buildings is available here.

45 The Moral Economy of Carbon Offsetting: Ethics, Power and the Search for Legitimacy in a New Market - a PhD thesis providing a critique of offsetting.

46 The Oxford Offsetting Principles provide guidelines to ensure offsetting is aligned to achieve a net zero society and provide a key resource for the design and delivery of rigorous voluntary net zero commitments by government, cities and companies.

47 The practice of purchasing an indulgence was a means by which an individual could reduce the length and severity of punishment that heaven would require as payment for their sins and has been compared the purchase of carbon offsets in the present day.

48 A paper highlighting the risk of forest carbon offset reversal because of climate change.

Alconbury Weald Club

Alconbury, Cambridgeshire 2015
Client: Urban & Civic

Flexible office and community building within the Alconbury Weald masterplan.

A carbon sequestering timber superstructure is on show at the Alconbury Weald Club near Huntington, just north of London. AHMM reduced the need for carbon offsetting by utilising the building to store carbon. The CLT frame has aesthetic, sustainable and - most notably - construction benefits. Generous volumes, multi-functional auxiliary spaces and exposed finishes of this enterprise campus ensure that the building is flexible and robust enough to adapt to new uses as the mixed-use work community continues to grow.

More about this project

LINK

Key points for delivering net zero in use

Cyclical thinking

Architects' influence

Carbon neutral to climate positive

Defining the difference between net zero and carbon neutrality is necessary to understand how architects can deliver net zero in use.

Although 'net zero' and 'carbon neutral' are often used interchangeably, at this point we need to draw a distinction between them.

Carbon emissions for an organisation are grouped into three categories based on greenhouse gas protocols:

Scope 1 Direct emissions
Direct emissions from the activities of an organisation or under their control including fuel combustion onsite (e.g. gas boilers, fleet vehicles and air-conditioning leaks).

Scope 2 Indirect emissions
Indirect emissions include emissions created during the production of the energy and eventually used by the organisation (e.g. electricity purchased and used by the organisation).

Scope 3 Other indirect emissions
Other indirect emissions from activities of the organisation, occurring from sources that they do not own or control and can include emissions generated by employee travel and from the entire value chain, including suppliers.

Carbon neutrality is defined by the PAS 2060[49] standard and ISO14068 (which is due to be published in 2022) and is applied to direct and indirect emissions (scope 1 and 2) of an organisation. These standards allow residual emissions that are particularly difficult to eliminate to be addressed by purchasing offsets.

At present there is no agreed internationally recognised standard for net zero, however a body of work around the definition describes it as 'not adding new emissions to the atmosphere.' These definitions of net zero agree that scope 3 emissions are included, which indicates that net zero is harder to achieve than carbon neutrality.

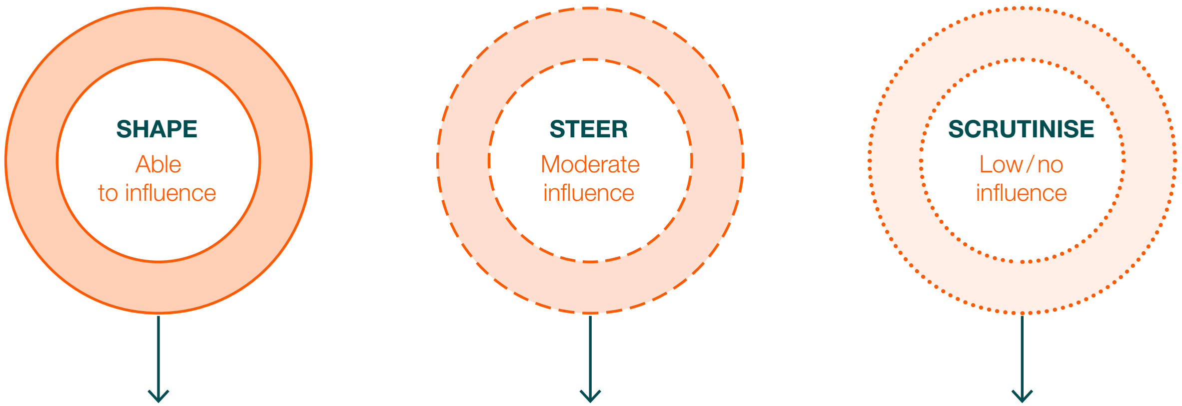
49 More information on PAS 2060 is available here.

Indirect emissions in the built environment (scope 3)

The previous sections describe how an architect can influence the direct and indirect emissions from a building. However, scope 3 indirect emissions linked to the building but not accounted for in its development, present a particular challenge. It is likely that these emissions will be linked to other human systems like transport, food production or the broader economy. There is no method for defining scope 3 emissions, with identification and consideration undertaken on a project by project basis.

Some scope 3 emission will be considered in relation to a project's broader sustainability objectives; others the architect might address through user and client engagement; and, finally, there are other emissions an architect will have little or no direct control over.

Scope 3 emissions can be categorised as follows:



Examples might be the building materials supply chain where, through the processes of investigation and specification, the architect can influence the development and market viability of low carbon products and materials.[50]

Examples might relate to buildings users[51] activities like travel to and from the building. An architect might support low carbon travel options by recommending the provision of resources like cycling facilities or electric car charging points.

These might be emissions relating to the economic activities of an organisation using a building.

50 This Royal Academy of Engineering outlines the scope of the construction industry and the importance of procurement and supply chains on decarbonisation.

51 This document provides case studies where measures to encourage sustainable behaviour have been implemented.

This guide addresses the challenges architects face to deliver net zero in use, however the climate positive movement has more ambitious aims.

Climate positive (or carbon negative) means taking actions that go beyond achieving net zero carbon emissions to actually create environmental benefits. As we mention in the introduction, the objective is to reverse the harm previously and currently caused to natural systems. There is a growing body of opinion, sometimes described as the climate positive or regenerative movement, with several initiatives offering proposals for climate positive development:

Climate positive buildings

The Blekinge Institute of Technology research project 'Making Climate-Positive Buildings and Building Systems Sustainable' considers climate positive development at a building and district level.[52] Its framework is characterised by an approach that compensates for historic greenhouse gas emissions, oil spills and chemical releases, loss of productive surfaces and biodiversity and deteriorating health and discrimination.

Climate positive design

The Buildings as Materials Banks initiative guide to 'Creating Buildings With Positive Impacts'[53] advocates 'improving the economic, social & ecological quality of materials, energy and life' and going beyond 'minimizing negative impacts of buildings to include [an] approach of healthy abundance'.

With regard to landscape design the Climate Positive Design Initiative was established with the mission 'to provide a significant contribution to reversing global warming through the exterior built environment'.[54]

Climate positive design projects are defined as providing net positive climate outcomes that provide environmental, social, cultural, and economic co-benefits, beyond mitigating the negative impact of development.

Climate positive design is closely connected to the concept of buildings as a carbon sink. Mid-rise mass-timber buildings have the capability to store more carbon per m^2 than many forests and research based on widespread use of this approach indicates that the carbon stored in mass timber could be one-tenth of that stored in living forests worldwide.[55] To realise these reductions changes would be required to regulation, expanding markets for timber products, ensuring that sequestration is captured in embodied carbon calculations and ensuring that these buildings are long lived.

52 A link to a report by Blekinge Institute of Technology within the project Energy Making Climate-Positive Buildings and Building Systems Sustainable is available here.

53 A link to the Buildings as Materials Banks guide to 'Creating Buildings With Positive Impacts is available here.

54 Further information about the Climate Positive Design initiative and the Climate Challenge is available here.

55 Papers on the potential for buildings and built environment include:

Buildings as a global carbon sink on the potential for the built environment to be a carbon sink is available here.

A paper on the potential of cities to act as carbon sinks is available here.

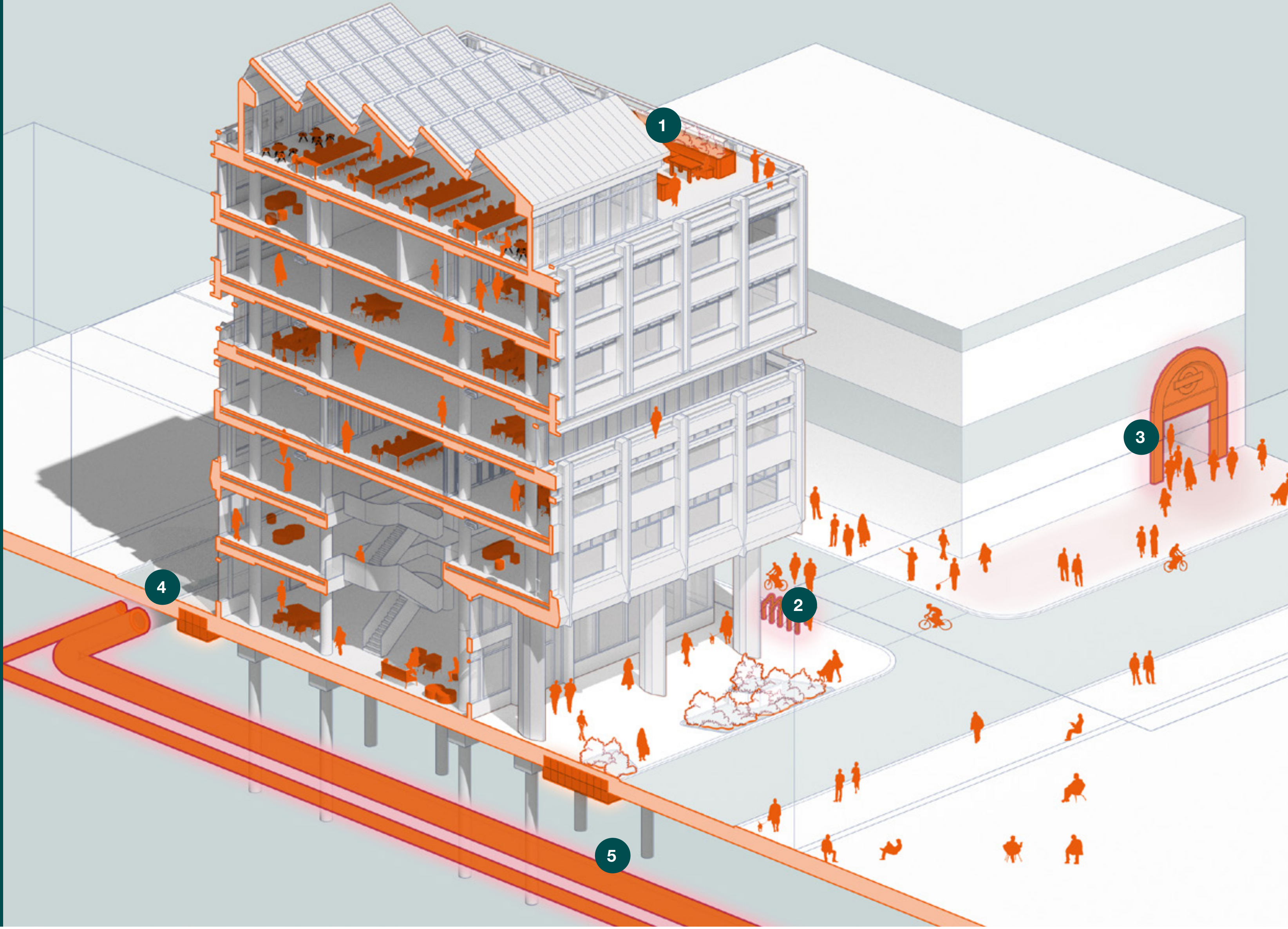
A paper on the limits and feasibility of buildings as a global carbon sink is available here.

Net zero carbon systems

How the building relates to other systems

To achieve net zero, the relationship of the building to natural and human systems beyond the scope of the site must be considered. For example, the building's proximity to public transport and provision of low carbon travel options will have an impact on the carbon emissions of the users.

On the next few pages are a series of system diagrams (loosely based on Odum diagrams) charting energy and resource flows for a net zero carbon building.



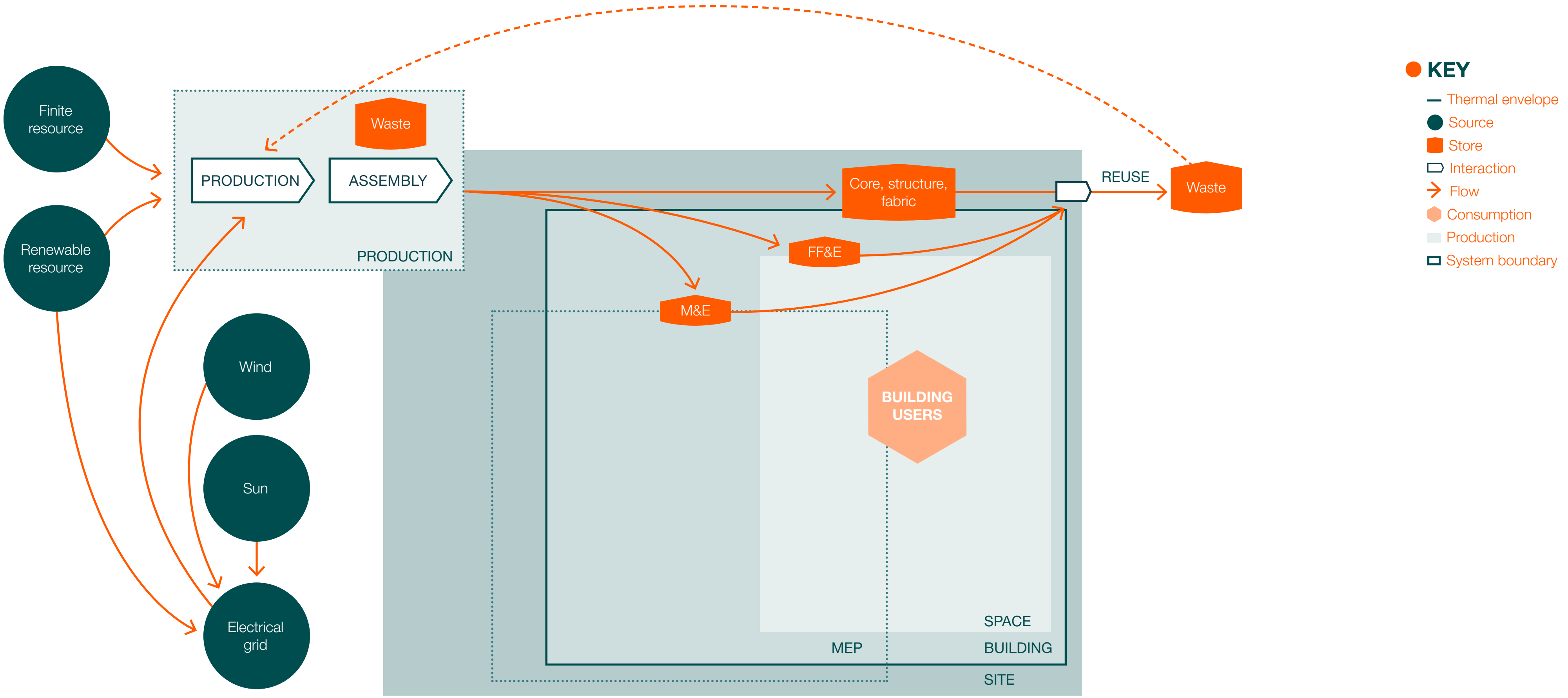


FIGURE 6

This diagram highlights the systems of production for a development and illustrates how the resources are stored within the structure, fabric and services of the building; and then released for reuse at the end of the building's life.

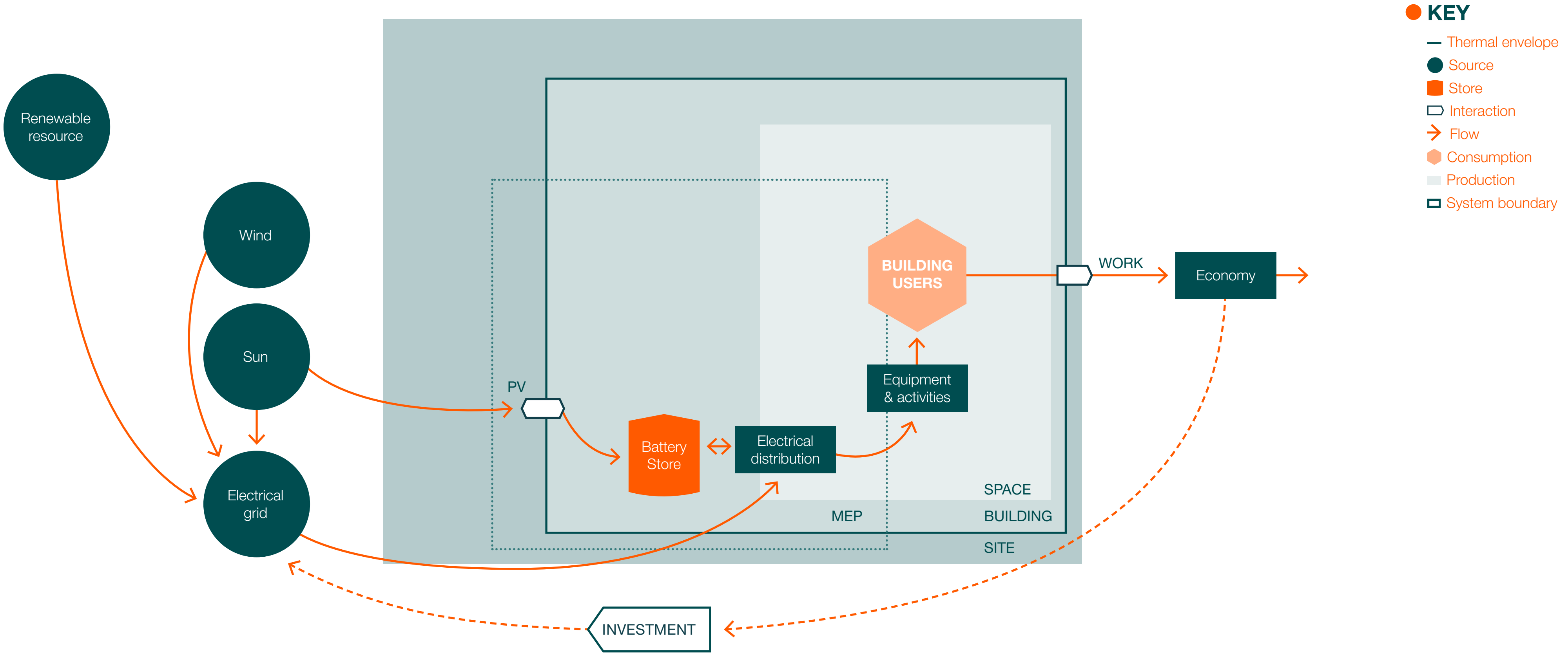


FIGURE 7

This diagram shows the interaction of a net zero building with systems of electricity production and supply. It highlights how sources of electricity on a development could be direct (onsite production provided by renewable technologies), or could be delivered by a decarbonised grid.

It also illustrates how the economic activities of the building users might feed back into a decarbonised grid by providing investment (as in the case of additionality for offsite renewables).

White Collar Factory

Shoreditch, London 2017
Client: Derwent London

Innovative city campus and office tower designed to long life, loose fit principles.

A mixed-mode ventilation system and user centred design were AHMM's key approaches to reduce operational carbon at the White Collar Factory; a speculative office development on Old Street Yard in London.

Windows can be opened throughout the building and a digital traffic light system provides guidance on optimal times to open and close them. Booster cooling for very hot days is provided and controlled by occupants rather than pre-set by a central system.

More about this project

LINK

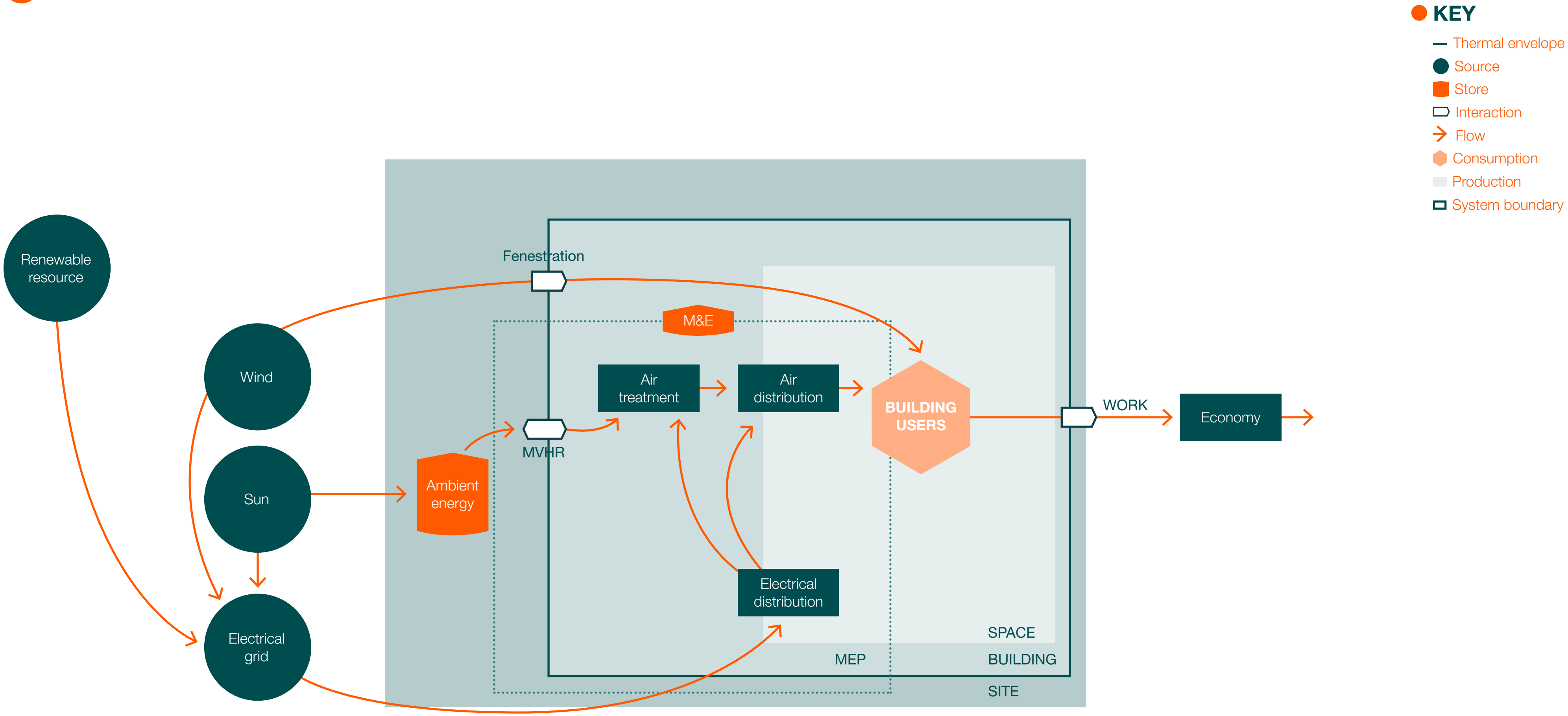


FIGURE 8

This diagram shows the interaction between energy and resource flows required for ventilation. As with many heat systems, these flows can be reversed to provide cooling.

Kentish Town Health Centre

Kentish Town, London, 2008
Client: Camden Primary Care Trust / James Wigg Practice

Community health centre and GP practice, shortlisted for the 2009 Stirling Prize.

Housing a large GP practice, a wide range of community health services, office space, staff facilities, a library and meeting rooms, Kentish Town Health Centre - and the process in which it was championed, procured, designed and delivered - set new standards for the NHS. Consultation rooms are organised around a wide, daylit street on the perimeter of the building. This allows for secure natural ventilation and high levels of daylight to reduce operational energy demand. The project, initially won in an RIBA competition, was shortlisted for the RIBA Stirling Prize in 2009.

More about this project

LINK

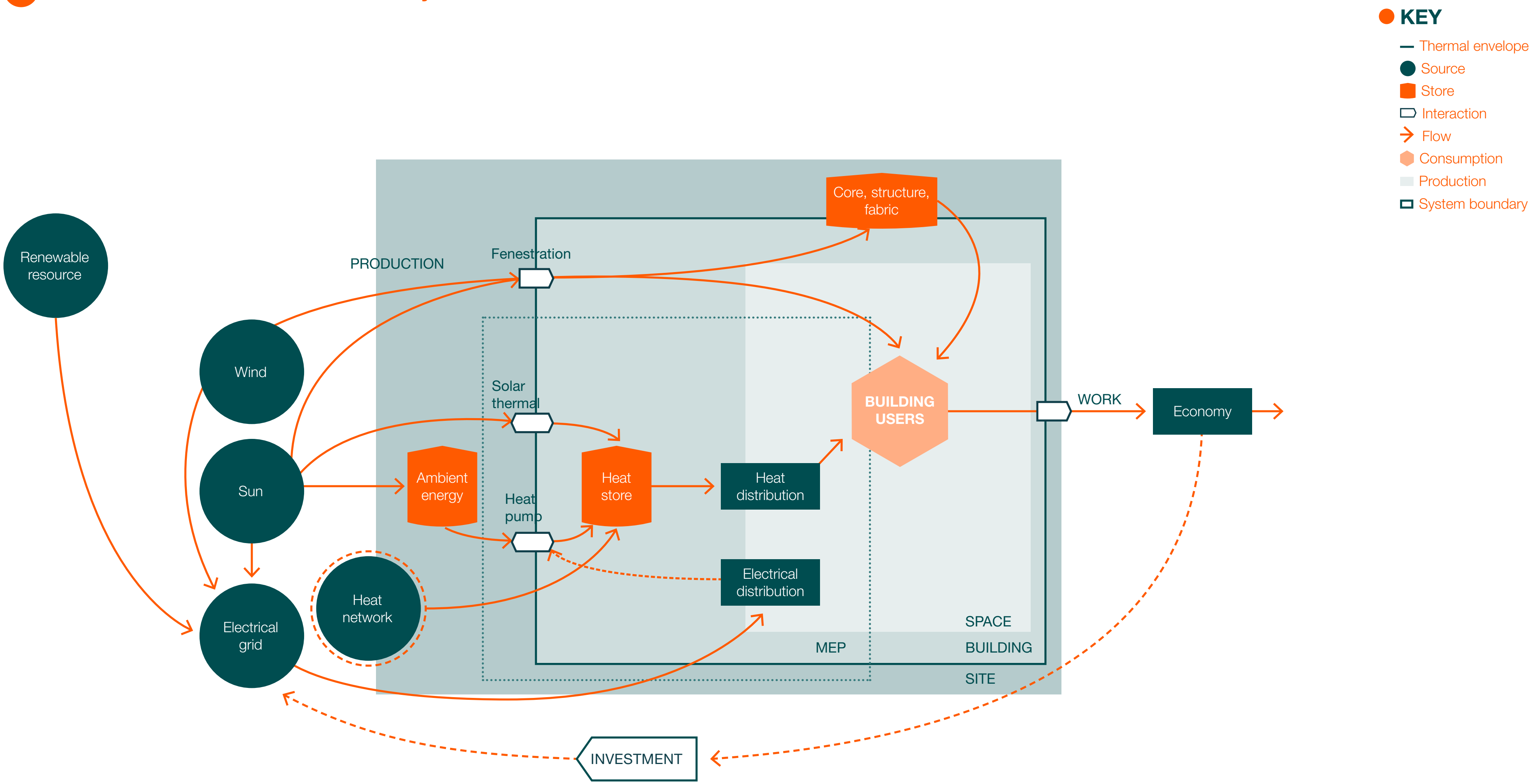


FIGURE 9

This diagram highlights the delivery and storage of heat in a building. It shows how heat from the sun enters the building via fenestration will directly warm building users, or be stored in the building fabric.

Ambient heat energy utilised by heat pumps can be kept in a dedicated store. In some cases there is scope for these flows to be reversed to provide cooling depending on the season.

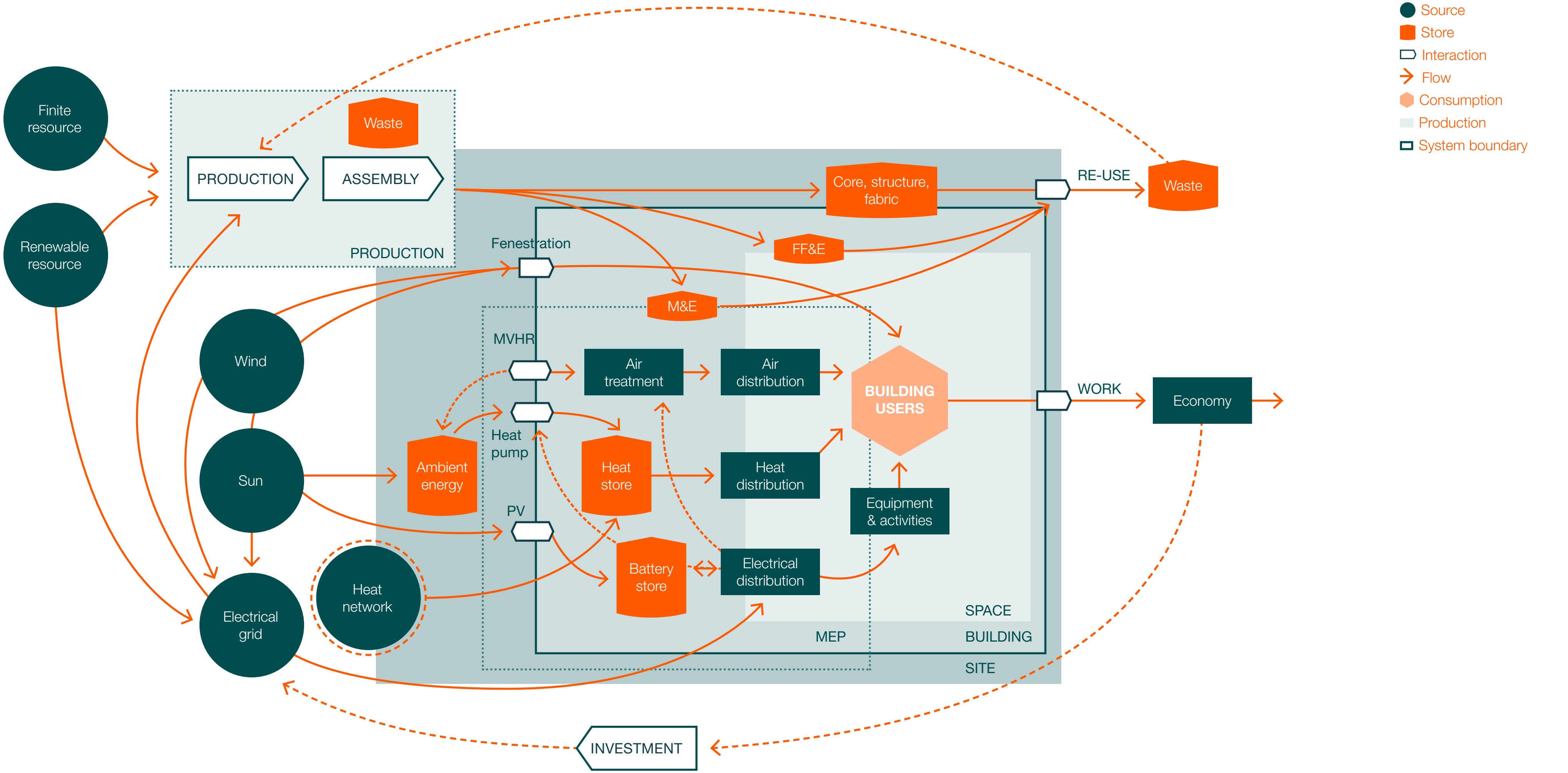


FIGURE 10

Drawing on the previous system diagrams, this diagram highlights the complex synergy of systems of a net zero carbon building with the building's users at its core. As designers we should ensure that processes are closed loops, where possible, rather than linear processes.

Architects cannot overlook the role of a building's users in the success (or failure) of a net zero approach, including and their connection to other human systems such as the transport, communication, water, food and economic production.[56]

56 This IPCC report on the role of buildings in global decarbonisation outlines the role that economics, behaviour change and improvements in consumer electronics will have on the building sector.

Plow Building

Oklahoma City, USA 2014
Client: Rock Island Plow LLC

Bricktown warehouse refurbished as incubator offices, shops and restaurants.

AHMM reinvented this robust but disused warehouse in Oklahoma City into flexible new office space. To exploit the essence of its character, the Plow Building was stripped back to its heavy timber frame and structural brick shell. Lightwells were cut into the floor slab which, combined with new sawtooth rooflights and large perimeter windows, draw natural light deep into the office bays across all four floors to create a user centred environment.

More about this project

LINK

TWO

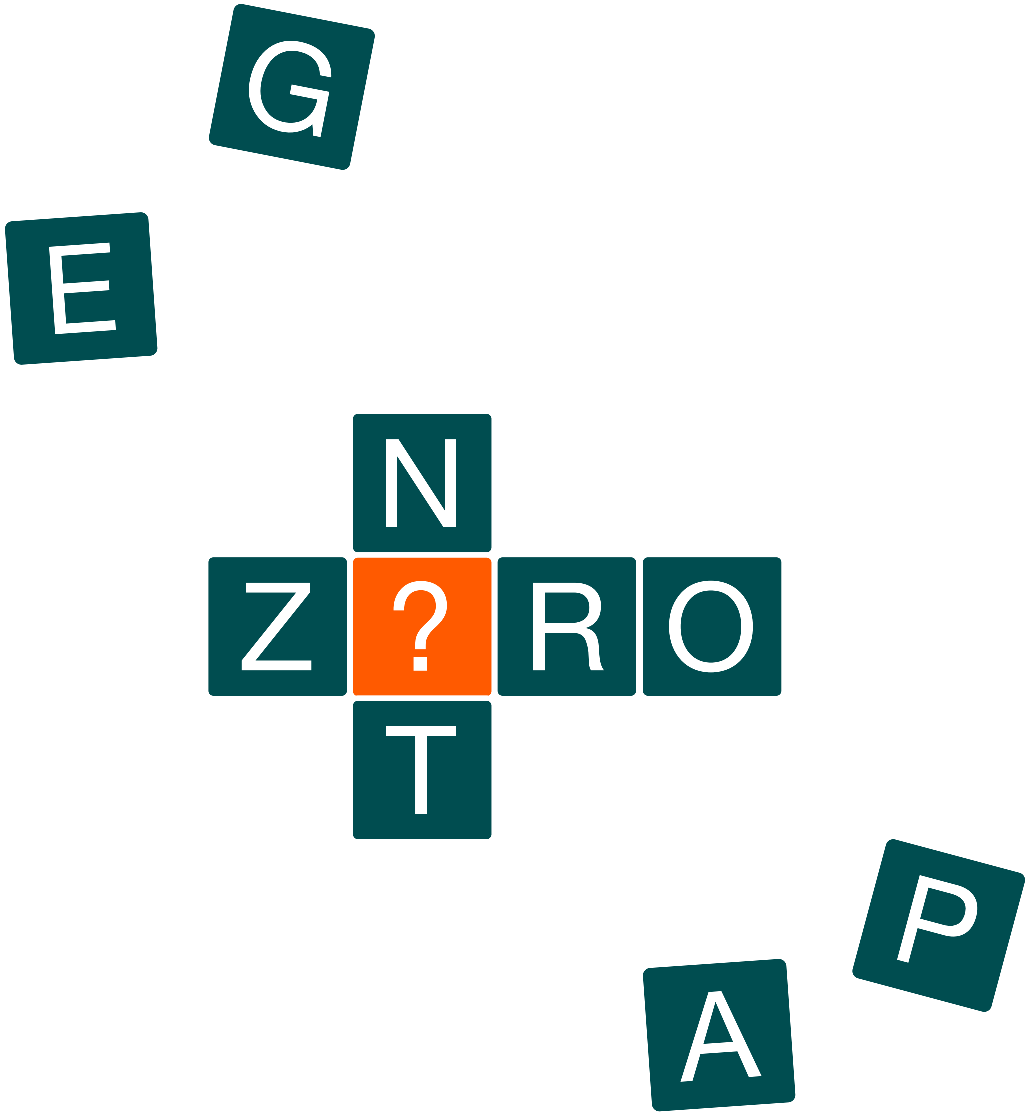
Key considerations

The net zero performance gap

The performance gap describes the discrepancy between the designed and anticipated performance of a building and its actual performance in use.

The performance gap is a well established phenomenon typically applied to the operational energy of a building.[57]

The net zero performance gap
When net zero is set as a goal, the scope for discrepancies between designed performance and as-built performance extend beyond the operational performance of the building. The net zero performance gap can include discrepancies in upfront embodied carbon used to develop the building and issues and uncertainties around carbon offsets. A net zero performance gap also includes changes in use affecting the energy performance of the building, failures to fulfil the circular economy principles, and inaccuracies in predicting replacement rates.



Key points for delivering net zero in use

Performance gap

57 There are several documents describing the operational performance gap:

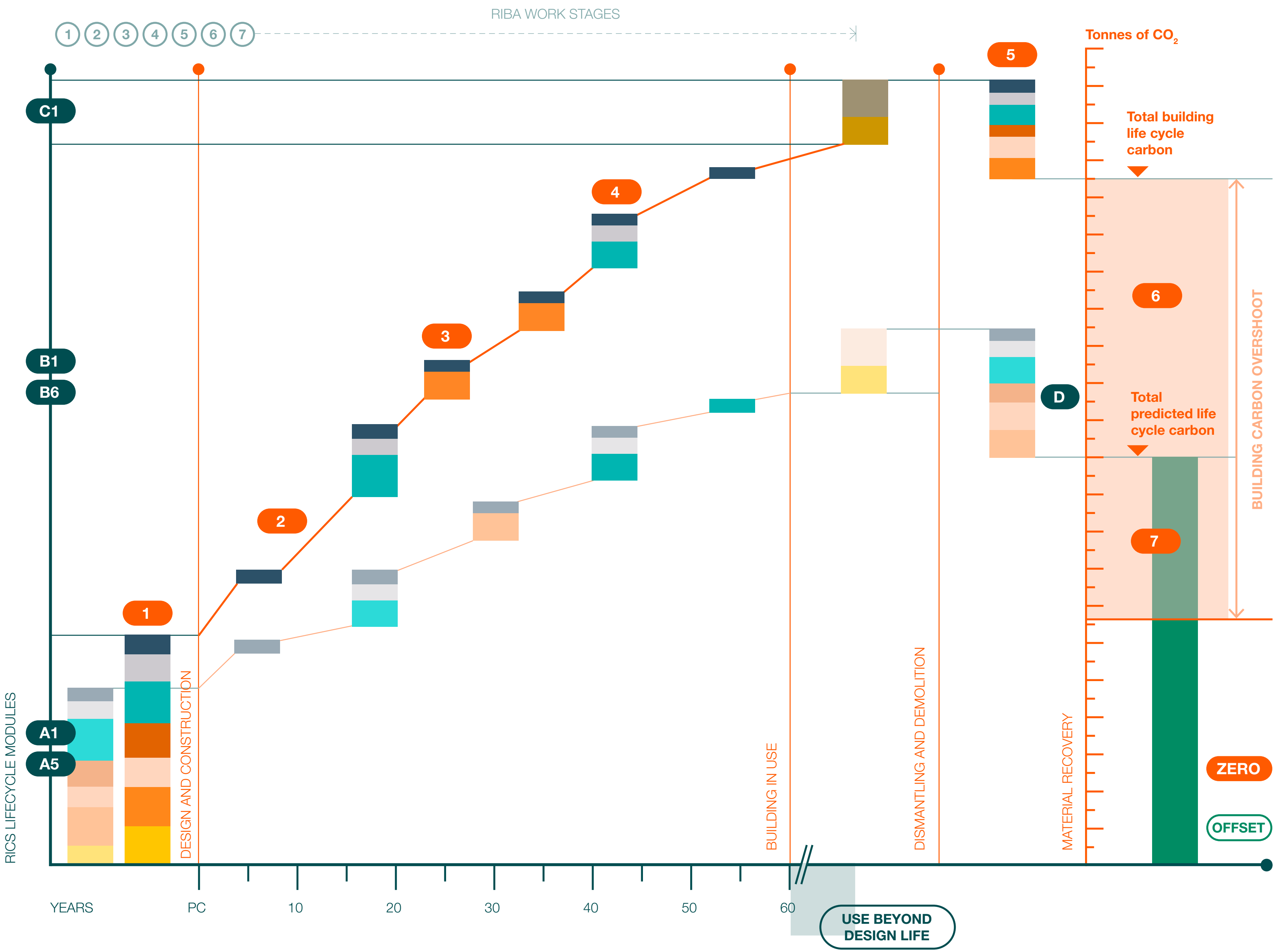
The Probe project, which started in 1995, undertook post-occupancy surveys of new commercial and public buildings, typically 2-3 years after completion.

Findings from the Innovate UK Building Performance Evaluation Programme for non-domestic projects are available here.

And findings from the Innovate UK Building Performance Evaluation Programme for domestic projects are available here.

An important paper outlining the underlying causes for the performance gap.

The net zero performance gap



1 Embodied Carbon Performance gap
2 Operational Carbon Performance gap
3 Higher than anticipated replacement rates
4 Change of use afecting performance
5 Lower than anticipated recovery of materials
6 Failure to provide additionality
7 Reversal of offsets i.e. stored carbon being emitted
8 Net Zero Carbon Performance Gap

The operational carbon performance gap

The operational carbon performance gap is relevant throughout the life of the building.

CIBSE TM61 divides it into four key phases: design; construction; commissioning and handover; and operation.[58] Below are examples of some of the actions contributing to the operational performance gap at each phase.

Design

- A lack of focus and understanding on the implications of design decisions relating to form, orientation, materials, use of renewables and passive strategies.
- A lack of design team consideration for simple workable solutions that can affect building performance. Issues related to the complexity of the design and systems can extend beyond the design and construction phases.
- Uncertainty at the early design stage can affect predicted energy use. Assumptions used to address uncertainty often turn out to be unrealistic. In addition, designers faced with stringent targets might opt for optimistic values when dealing with uncertainty.
- Human-introduced errors in modelling due to the complexity of building energy simulation and tools.
- Energy 'predictions' that do not reflect the reality of the finished building due to the limitations of the modelling process and simplified assumptions.

Construction

- Operational performance can be affected by poor onsite workmanship due to a lack of training for increasing levels of complexity in building construction.
- Value engineering that affects building performance not being fed back to the design team for evaluation against the required performance standards.
- Site changes to the design, not integrated with, or tested against, the original design can lead to inconsistencies.

Commissioning and handover

- Poor commissioning, or a tick-box exercise mentality (i.e. 'fill-in and forget'), can result in reduced system efficiency, compromising design strategies.
- A focus on visible defects and overlooking functional defects (energy performance and indoor environmental quality). Functional defects might only be addressed after complaints from occupiers which could be some years after handover.
- Poor or incomplete handover information such as user guides, building log books, and operation and maintenance (O&M) manuals.

Operation

- Users have a substantial influence on operational energy performance. People are very different in their behaviour through culture, upbringing and education, making their influence on energy consumption highly variable.
- In design calculations, occupancy profiles are simplified, based on the average behaviour of the occupants, neglecting variations based on personal preferences.
- Complex systems, specified at the design stage, may confuse building users and operators.
- Factors affecting the ability to monitor performance like equipment calibration, installation errors or large amounts of data confusing operators may undermine efforts to address issues.

58 A link to CIBSE document TM61 providing further details on the scope and nature of the operational energy performance gap is available here (purchase required).

The embodied carbon performance gap

An embodied carbon gap occurs when the lifetime embodied carbon emissions are discovered to be greater than design stage projections.

The concern around the embodied carbon performance gap is about both individual buildings and the cumulative effect; if many buildings miss their targets there will be serious implications for emission targets generally.

At present UK building regulations address operational carbon, but do not cover embodied carbon. It is anticipated that when this omission is rectified it will help to resolve some of the issues listed here. [59]

Extent of an embodied carbon performance gap

The scope for an embodied carbon performance gap encompasses the design, construction and use of a building:

- Differences between calculation methodologies and carbon intensity databases can lead to discrepancies, for example the use of the ICE database as compared to Environmental Product Declarations (EPDs). [60]
- Differences between measurements of quantities on a project is another source of discrepancy, for example the use of the cost plan as compared to the BIM model for acquiring material and volumetric data about a design.
- Differences between software-based calculation methods.
- A lack of oversight from a regulating authority to review and verify calculations.
- Issues around product verification and oversight of EPDs.
- Site level evaluation, review and verification.
- Differences to what is built on site as compared to the WLC model (e.g. changes to design intent) and complexities, around tracking incoming material and outgoing waste on site.
- Issues around end-of-life use and disposal, and review and verification of material replacement over the life of a building.

Impact of the embodied carbon performance gap

Inconsistencies in operational performance can be identified through end-point verification such as post occupancy evaluation (POE) and reference to metered data. By contrast end-point verification of the embodied carbon of a material or product is challenging. Whilst documentation can be collected, the scope for non-conformity with certification and calculations has the potential to extend down the entire supply chain including everything from method of delivery to site to the extraction of raw materials.

A lack of robustness and reliability around embodied carbon analysis and verification can have lasting impacts on net zero carbon buildings.

An undercount of embodied carbon will be mirrored by an equivalent shortfall in carbon offsets. The untracked overspend of carbon combined with the lack of compensation could result in a doubling of lifetime embodied carbon emissions

59 A campaign to introduce a Building Regulations amendment, 'Part Z', would make mandatory the assessment of whole life carbon emissions, and limits on embodied carbon emissions

60 An Environmental Product Declaration (EPD) is an independently verified document providing information about a product's environmental impacts, EPDs, which last 5 years, provide a basis of Life Cycle Assessment (LCA) calculations, and quantitative basis for comparison of products and services. Further information on EPDs can be found in this ASHP briefing paper here.

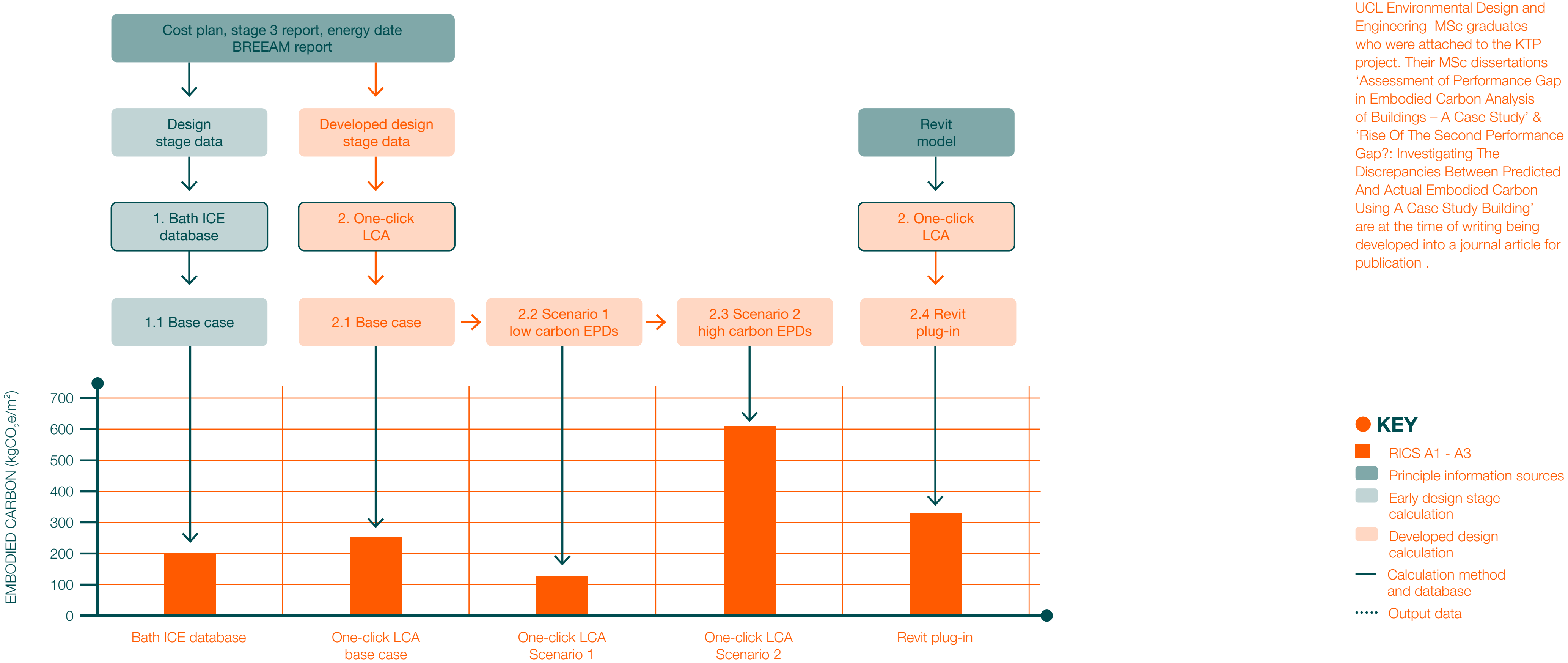


FIGURE 11

This diagram is reproduced from UCL EDE MSc student research examining the range of results from an embodied energy analysis based on differences in input data and calculation methodology.[61] The case study was a completed AHMM four storey office development with a GIA of 2249 m^2 and in all five instances the building remained the same.

The differences between result 1.1 and result 2.1 are from the use of ICE database as compared to One-Click LCA. The differences between result 2.1 and result 2.4 arise from sources of input data (the cost plan etc. versus the Revit model and One-Click LCA plug-in). The differences between result 2.2 and result 2.3 are a product of EPD sources.

This highlights the significant discrepancies that can occur from differences in database, sources of material and volumetric data and treatment of EPDs. The difference between the highest and lowest EPDs demonstrates how the selection of EPDs can have a significant impact on perception of building carbon intensity. This is particularly important early in the design process when product selection might not be finalised. In some instances speculative selection of low carbon products combined with incomplete models may contribute to a perception of a negative carbon story (where the carbon intensity of the building increaes in response to greater detail as the design progresses).

61 This work examining the potential for an embodied carbon performance gap is informed by the work of two UCL Environmental Design and Engineering MSc graduates who were attached to the KTP project. Their MSc dissertations 'Assessment of Performance Gap in Embodied Carbon Analysis of Buildings – A Case Study' & 'Rise Of The Second Performance Gap?: Investigating The Discrepancies Between Predicted And Actual Embodied Carbon Using A Case Study Building' are at the time of writing being developed into a journal article for publication .

Grid decarbonisation and net zero carbon buildings

Reducing the emissions of the National Grid accounts for around half the UK's overall carbon emission reductions.

Since the 1990s significant progress has been made in the UK to reduce the carbon emissions of the National Grid[62] due to a substantial reduction in coal-fired power stations and a corresponding increase in the contribution of renewables. The proportion of electricity from coal in the UK has declined from 40 per cent in 2012 to less than 1 percent in 2019 [63] and renewable energy production has gone from 2 percent in 1990 to 37 percent in 2019. Decarbonisation of the grid is ongoing and the deployment of new renewables (i.e. wind farms and solar farms), nuclear power plants and continental connectors will continue to drive down the carbon intensity of grid electricity.

What does this mean for the built environment?

Decarbonisation of the grid is reducing the climate change impact of grid connected electrical systems and devices. Looking forward, a significant impact of a decarbonised grid will be on heat by eliminating the combustion of fossil fuels onsite for heating via gas boilers. Decarbonisation of the grid permits electrification of heat, whether directly or indirectly via a heat pump (which is preferable due to high coefficients of performance).[64]

How will this affect new building development?

The decarbonisation of the grid will affect the development of new net zero carbon buildings in the following ways:

Context

It provides an energy context for the development of net zero carbon buildings. For example, a fully decarbonised grid would mean that fully electrical buildings connected to this system would be considered operationally zero carbon. However, buildings solely dependent on grid decarbonisation to achieve net zero will be competing with other systems taking this approach to decarbonisation (such as transport) and will be at risk of higher running costs.

Opportunity

It provides opportunities for future developments to reduce their emissions by using this process of decarbonisation through a 'net zero carbon ready approach' whereby a building is fully electric. This approach is discussed overleaf.

Materials

Decarbonisation of energy is happening at a global scale and, combined with the electrification of manufacturing processes, will reduce embodied carbon of construction products. Global decarbonisation of energy will impact the embodied carbon of materials in the future. However, some industries will be better placed to take advantage of this than others.

Balance

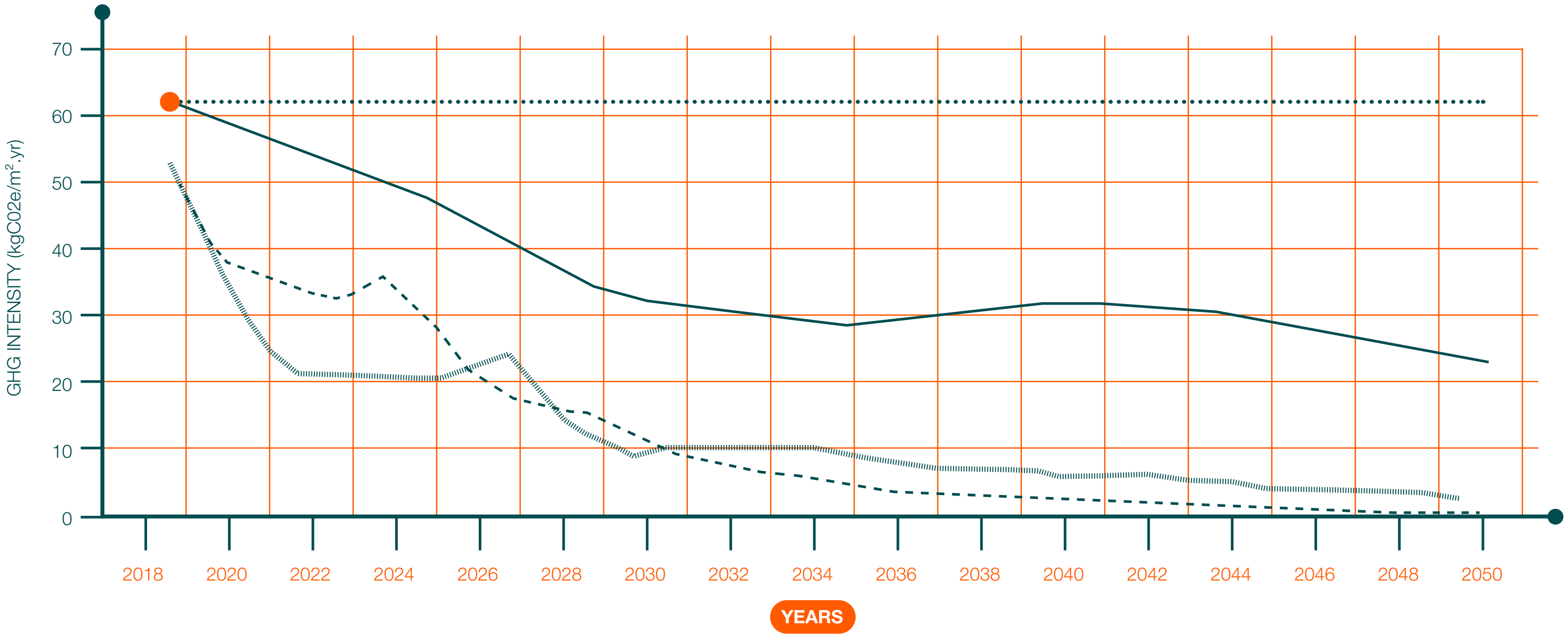
One consequence of renewable energy in the energy production mix is a requirement to balance onsite renewable generation against grid production. Onsite renewables should be matched to building demand and not provide excess power to the grid when it is not required. Maintaining a balanced grid is vital in order to avoid power cuts and ensure that electrical equipment operates correctly and efficiently.

Later in this section there is a description of how the decarbonisation of national and global electrical grids can be utilised in a strategic approach to achieving carbon neutrality.

62 Department for Business, Energy & Industrial Strategy one page green house gas emissions summary available here.

63 Carbon Brief interactive article explaining how the UK has transformed its electricity supply in a decade – and how things are expected to continue changing.

64 An interesting paper on decarbonising heating in buildings is available here.



KEY
- 2019 Performance
- Baseline asset performance
- CRREM Climate and grid connected asset performance
- BEIS Energy and emissions projections
- FES Steady progression projection

FIGURE 12
Graph showing the declining carbon intensity of an all electric hypothetical building with a an EUI of 225 kWh/m^2.yr based on outputs from the CRREM Tool.

This diagram illustrates the impact of several grid decarbonisation scenarios on the emission of an individual building. It shows a hypothetical building with an operational energy EUI of 225 kWh/m^2.yr and a greenhouse gas (GHG) intensity of 64 kg/CO_2e/m^2.yr in 2019. The building is all electric and so all emissions are indirect via the grid and emissions from leakages of gases have not been included in this calculation.

This also demonstrates that a building with no interventions to improve building performance (i.e. building fabric improvements) or upgrade of building services will reduce its GHG intensity by about 40 kg/CO_2e/m^2.yr by 2050, based on projections of grid decarbonisation from the Carbon Risk Real Estate Monitor (CRREM) tool.[65] These reductions are a product of the building's connection to a decarbonising energy system, i.e. the energy grid.

There are other projections of grid decarbonisation such as the National Grid Future Energy Scenarios [66] and the Department for Business, Energy and Industrial Strategy (BEIS) Energy and Emissions Projections[67] which offer even greater estimates for grid decarbonisation. These scenarios highlight the important role that the National Grid will have in reducing emissions from the built environment.

65 The Carbon Risk Real Estate Monitor (CRREM) risk assessment tool for assessing stranding risk is available here.

66 Information about the National Grid Future Energy Scenarios is available here.

67 The BEIS Energy and Emissions Projections are available here.

Grid flexibility

Challenges for net zero carbon buildings

A flexible power grid maintains a balance between generation and consumption by moderating demand on the system.[68]

The development of flexible grids is being driven by several factors:

- A supply side shift from fossil fuel-burning plants, which have provided a constant base-load power, to renewables with more intermittent production.
- Extensive electrification across sectors (e.g. replacement of petrol cars with electric vehicles and gas boilers with heat pumps) is complicating demand as each sector has its own point of peak demand.
- Increasing sophistication of the grid itself allows supply and demand devices to speak to each other in ways not possible previously.
- Decentralised networks, and local and micro grids are adding increased complexity to a system which was historically one single centralised network.

These changes present new challenges to the management of energy systems because of increased variability in supply and demand, at both a diurnal and seasonal level, and limited controllability. Variability in supply could result in energy prices becoming more volatile and an increased risk of power shortages.

What does this mean for the built environment?
The design and management of buildings will be affected by a shift to flexible grids[69]. The built environment can respond to this challenge by increasing the intelligence and flexibility of its energy use to address misalignments in supply and demand. In addition, increased resilience of an asset will help reduce the risks posed by this energy transition.

Flexible and intelligent buildings will be able to respond to volatility of supply and price of energy by controlling the time that they draw energy from the grid. Load shifting is the process of moving peak demand to periods when tariffs are cheaper or where there is increased supply. The ability of a built asset to load shift will become increasingly important to reduce running costs and ensure security of operation.

Resilient net zero carbon buildings will ensure reliability of energy supply for building users and maintain comfortable conditions despite volatility. They will also ensure continuity of operation without recourse to fossil fuel based systems, like backup diesel generators. Resilient net zero carbon buildings will rely on energy stores, local generation and an energy efficient building fabric to ensure continuity of operation faced with volatility of supply or price.

Key points for delivering net zero in use

Building users

68 Read more about flexible grids here.

69 A Carbon Brief article about the potential challenges and benefits of a flexible grid is available here.

Designing buildings for flexible grids

Designing net zero carbon buildings for flexible grids will require building designers to consider the integration of energy flexible buildings in future energy systems. This demands a holistic approach that harmonises building fabric and energy systems with energy markets and occupant demand. To support this approach energy scenario modelling can assess the impact of changes in energy supply energy based on reference scenarios.[70]

Increased provision of energy storage is important for ensuring resilience and facilitating load shifting. Methods of storing heat include: in the building fabric, thermal stores or inter-seasonal energy storage for large buildings or clusters and electricity in batteries. In addition, energy efficient buildings will allow some systems (like heating) to be switched off completely for short periods over peak times without causing discomfort to users.

Finally, flexibility will be delivered through smart building electrical systems. These systems will intelligently load shift and optimise demand profiles, often in the background without user engagement. Smart systems could automatically respond to price signals from time of use tariffs to shift electricity demand away from peak periods.

Centre the building users

Building users are key to the success of net zero carbon strategies and sit at the centre of a web of systems and interactions, as shown in the systems diagrams in the previous section. However, it is easy to overlook the importance of the user in favour of technological and technocratic solutions.

A user-centred approach to net zero considers the interactions of the building with users at the design stage to ensure that it operates for their benefit.

A definition of 'building user' should extend to include anyone affected by the development alongside operators, occupants and/or inhabitants. To a greater or lesser extent a new building has an impact on its locality and on people in that locality, for example by contributing to the urban heat island effect or by contributing to, or avoiding surface water flooding.

An evidence-based approach should correlate the user and the building with trends (e.g. global and local climatic changes etc.), the architectural proposals, and hypothetical outcomes that represent plausible futures. Exploring these scenarios will encourage designers to consider how the development can enhance wellbeing and resilience as well as achieving carbon reduction targets.

A flexible grid calls for efficient, smart and adaptable buildings. It requires **efficient** buidlings which minimise energy loads generally and peak demand specifically. It also asks that buildings are **smart** and able to communicate with both the grid and users to respond to changes in supply and demand. Finally, a flexible grid calls for **adaptable** buildings able to utilise storage and self-generation to reduce, shift and modulate demand as required.

70 Methodology for modelling changes in grid supply was introduced by IEA EBC Annex 67. The methodology quantifies the amount of energy a building can shift in response to external factors without compromising the occupant comfort conditions.

What is climate resilience?

Climate resilience refers to the ability of the building to maintain its function and support its users in a changing climate. Climate resilience can be considered in terms of exposure, adaptability, sensitivity, and vulnerability[71] of the building and users. Consideration of climate resilience should recognise:

- The complex interaction of a development with societal infrastructure and the hazards of climate change.
- The scope of the hazard and the people and buildings, affected by a climate hazard.
- The resources available within an organisation, community, or society to manage and reduce risk and strengthen resilience.
- The capacity for an asset, individual or community to adjust, recognising that some groups (the elderly, children and disabled people) can be more sensitive to the impacts of hazards.

A poorly designed building can increase the vulnerability of groups sensitive to climate hazards. Good design and robust risk assessment play a critical part in ensuring the benefits of net zero carbon buildings are maximised, and negative aspects (such as longer heat decay times in summer) are minimised.[72]

Incorporating wellbeing

In contrast to resilience, which is focused on mitigating hazards, wellbeing in the built environment refers to the development of environments that positively support and or encourage improvements in building users' physical and mental health.

For example, a building might:

- Support active modes of transport (e.g. with cycle storage, showers).
- Optimise access to daylight and fresh air.
- Provide access to outdoor green space and support biophilia.
- Provide multi-purpose rooms supporting the wellbeing of users.
- Support healthy nutrition.[73]

Many of these approaches connect to broader (scope 3) net zero strategies, and other significant human systems like transport and food production.

> Putting the user at the centre of delivering net zero design challenges designers to consider climate resilience and occupant wellbeing alongside energy supply and demand. Climate change brings significant hazards and demands that designers consider how their buildings will respond to extreme weather events. Incorporating wellbeing involves recognising the role a building can have on physical and mental health of occupants. In both cases a key part of a response will be consideration of the building in relation to other human systems.

71 This Tyndall Centre for Climate Change Research paper provides a conceptual framework for understanding climate change risk.

72 A World Green Building Council report outlines a Health & Wellbeing Framework (Six Principles for a Healthy, Sustainable Built Environment), which is available here.

73 A European Academies' Science Advisory Council report Decarbonisation of buildings: for climate, health and jobs is available here.

The carbon thread

Linking design to use (and back)

Net zero in use requires that strategies and calculations developed at design stages be effectively applied to the occupied building.

Design, construction and commissioning teams, along with building operators and users, all have a collective part to play to ensure net zero operating performance is achieved. And for this to happen, it is necessary to maintain a thread that ties design strategies to the actions of building users and operators. Equally important is taking the lessons from the users and operators and feeding them back into the design process, turning a linear thread into a loop.

Linking net zero design to net zero operation

Operations and maintenance (O&M) manuals provide a link between the design team, commissioning team and facilities teams.

On net zero carbon projects this documentation needs to be supplemented with circularity information providing guidance on how to disassemble the building, material passports and digital twins (described later in this section). These documents along with the whole life carbon calculations will provide an insight into the 'carbon account' [74] of a project.

For some net zero developments the carbon account will have been paid upfront in the form of offsets and offsite renewable technology capacity. Any deviations from the design over the life of the building risk overspending this budget and will require corrective measures. However for other net zero developments, planned decarbonisation interventions over an extended time frame will need to be managed.

The carbon action plan

Strategic approaches for identifying and managing the CO_2 budget of a building should be set out in net zero carbon specific project documentation. An example is the Climate Action Roadmap of the DGNB Climate Positive Standard. [75] This strategic documentation might include the following:

- Programmes that identify the time frame and actions required for an existing building or estate to reduce carbon emissions.
- A plan for an asset to achieve climate neutrality based on a specific target year. This might be derived from a corporate ESG target to achieve carbon neutrality by a set date.
- A record of design team decisions that affect the carbon emissions of current and future building users, plus predictions for the long term financial benefits of the efficiency measures and the risk of asset devaluation for a project which fails to achieve carbon neutrality.
- For a long term decarbonisation project, effective carbon measures will be put in a sequence accounting for the technical aspects (buildability, disruption to users and planned re-optimisation of systems), financing and the CO_2 budget ascribed to the building.

Ongoing contributions to the carbon thread

Strategic documentation for implementing net zero carbon strategies should periodically be supplemented with data gathered over the life of a building, such as post occupancy evaluation studies, monitoring and meter readings. This will chart the life of the building from inception to end-of-life, capturing the effectiveness of implemented carbon reduction measures and verifying emissions against values identified at design stage.

Scope of services and delivering net zero in use

The requirements of net zero indicate services over and above those typically provided by design teams. At the design stage these include detailed modelling and analaysis. As the project progresses these duties might inculde the development of digital twins and carbon action plans.

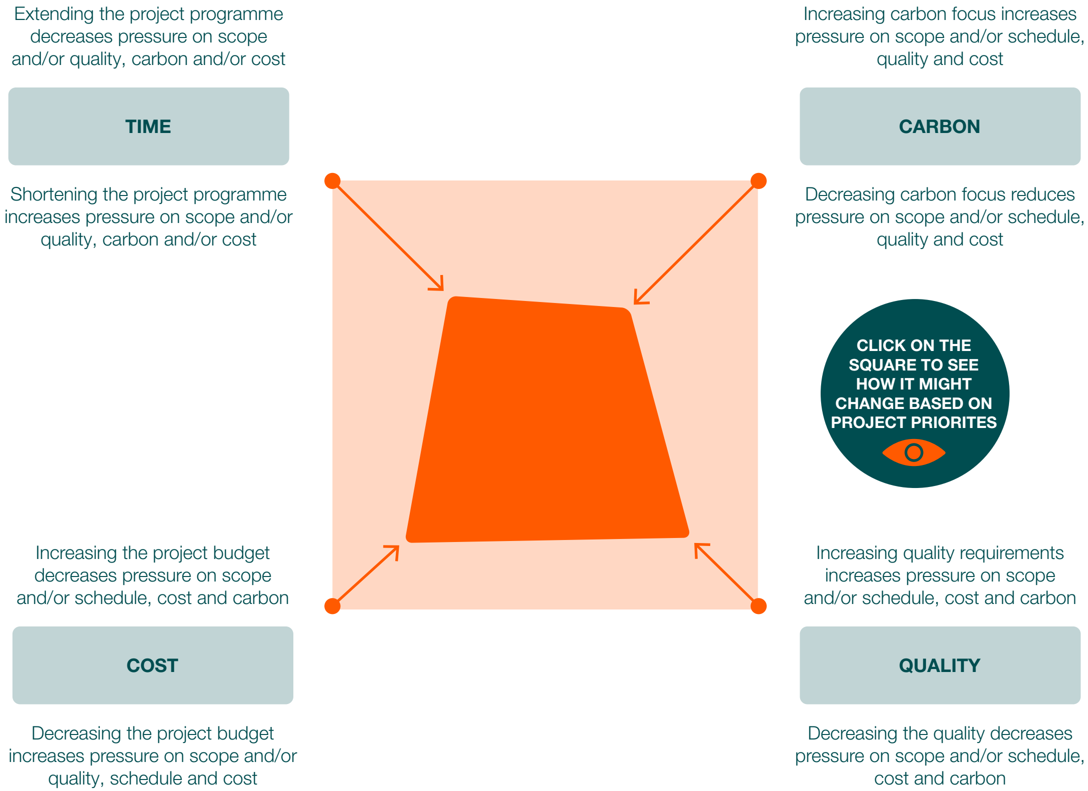
The scope of architectural responsibility and services, as defined by contractual agreements, will have to adapt for delivering net zero. These arrangements will have to recognise the increased processes of communication, creation and management required for net zero design. In addition contractual arrangements will have to facilitate ongoing engagement with building users and operators after practical completion to ensure the building achieves a net zero level of performance in use.

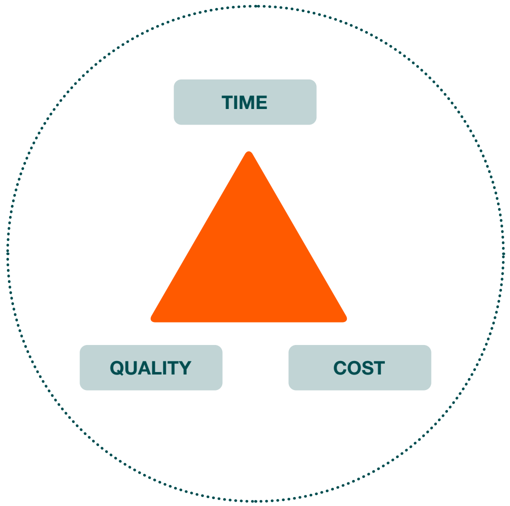
74 For more on carbon accounting.

75 The DGNB carbon neutral buildings and sites framework provides a comprehensive, practically rules for accounting the CO2 emissions of buildings and sites.

From a golden triangle to a carbon square

What happens when we introduce the impact of climate change and carbon emissions to the golden triangle development model?

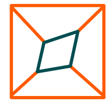




The golden triangle is a popular means to highlight the trade-offs that arise between time, cost and quality for a project to be realised. [76]

In this diagram the time-cost-quality triangle is re-envisioned as a time-cost-quality-carbon square to re-think the trade-offs required to deliver a net zero carbon development. [77]

Key points for delivering net zero in use



From golden triangle to carbon square

76 Constructing Excellence briefing paper on procurement.

77 A report for the Committee on Climate Change by Currie and Brown and AECOM on the costs and benefits of tighter standards for new building.

FIGURE 13
The net zero carbon square.

Carbon risk register

Carbon reduction measures can have implications for cost, programme and quality. By identifying these risks their impact can be managed and minimised.

A risk register is an industry tool used to identify, assess and review risks associated with a project. Identifying potential negative impacts and opportunities early in the design process when net zero carbon targets are set will help to mitigate risks to programme, cost, quality and buildability.

The example shown here is an RIBA Stage 1 Carbon Risk Assessment that highlights consideration of the risks and mitigation measures around the specification of materials on a net zero carbon project.

	CARBON POSITION	CARBON SAVING (Kg/CO_2/m^2)	RISK	COST RISK	PROG. RISK	ACTIONS / MITIGATION
STRUCTURE	Concrete reinforcement	-45 to -55	Single source supply risk for manufacturers / mills and rebar suppliers	M/H	L	• Establish list of manufacturers / suppliers able to deliver the required embodied CO_2 rate • Identify opportunities for early orders • Specification to define maximum embodied CO2 rate for reinforcement • Cost plan validation
STRUCTURE	Increased GGBS content (cement replacement)	-15 to -25	Increased programme durations due to increased formwork cycle times (particularly in winter)	L/M	H	• Review extent precast solutions can be adopted to mitigate site programme risk • Precast to assist site programme constraints however reduced factory production output will increase costs • Market test programme, building sequence and critical path • Cost plan validation
STRUCTURE	Low Carbon Steel	-25 to -35	Frequency of rolling of required sections	M/H	L	• Possible requirement for early order placement due to programme risk • Cost plan validation
FACADE	Aluminium from Hydro Sources	-20 to -30	Single source supply risk	M/H	M	• Confirm modelling assumptions are based on hydro aluminium • 'Register' the project with hydro, via CRM system so we can position the project to use hydro aluminium • Establish cost uplift for hydro sourced aluminium and ensure factored into cost plan • Timing of façade contractor procurement to allow early order placement of aluminium billet once quantity is known

Two net zero strategies

At an early stage in the design process it needs to be decided whether a development should aim to achieve net zero either at practical completion, or some future assigned date, between the completion of the development and 2050. These two choices correspond to two principal net zero strategies:

Net Zero Now

Net Zero Now requires the setting of challenging benchmarks for operational energy and embodied carbon at the outset of the project, with carbon offsets earmarked to compensate for any residual emissions. This is an approach where a building is considered net zero at, or shortly after, practical completion (assuming the project meets its assigned performance targets).

This approach is advocated by accrediting organisations like the International Living Futures Institute Zero Carbon Standard[78] and represents the preferred option for decarbonising most buildings. It does however, have the disadvantage of relying on models and design stage prediction rather than the actual performance of the built asset, which can lead to in-use performance gaps (described earlier in this section). Many zero carbon standards address the performance gap issue by basing accreditation on measured data from the building in-use (typically one to five years after practical completion) rather than design stage modelling.

Further scope for uncertainty and shortfalls in offsets may arise from this approach because of, for example, changes in building occupancy after the evaluation period.

Planned Pathways Approach

A Planned Pathways Approach involves identifying a series of steps to progressively reduce the carbon intensity of a building.[79] These measures should be pre-planned interventions; however, they could also include upgrades to equipment and other building components as part of an ongoing replacement cycle.

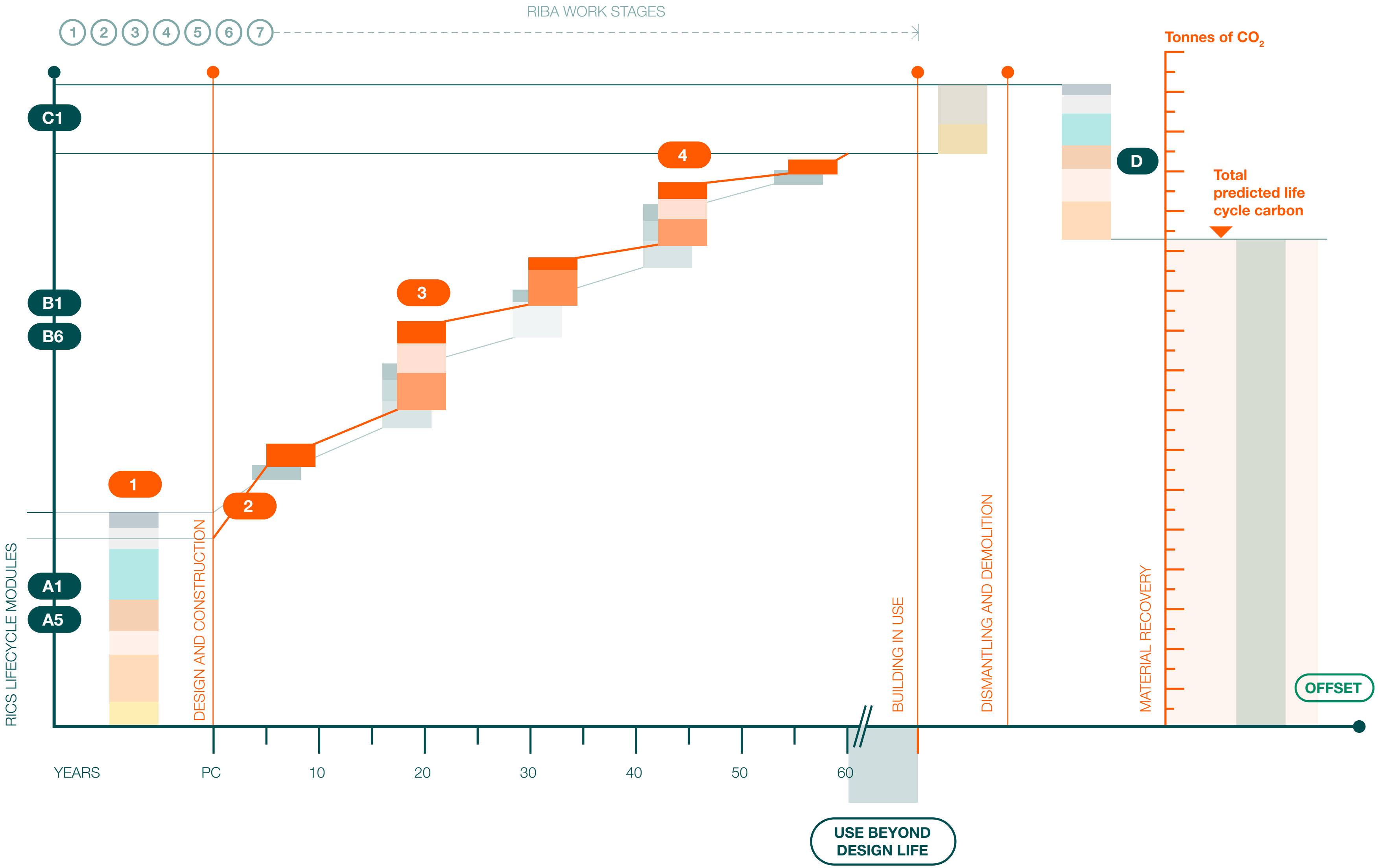
One advantage of this approach over Net Zero Now is that it can take advantage of future grid decarbonisation to reduce initial capital outlay. However this advantage comes at the expense of benefits from operational savings from demand reduction and onsite energy production (i.e. renewable technologies).

There are, of course, difficulties inherent in this approach arising from uncertainty associated with a development programme that could extend to decades and it relies on factors outside the designers' control (i.e. grid decarbonisation). In addition, decarbonisation measures, even if carefully planned, could cause disruption to occupants, and re-optimisation of the building could impact the adaptability and resilience of the initial design.

As a general rule Net Zero Now should take precedence over the Planned Pathways Approach but there are situations where a Planned Pathways Approach might be preferable (for example, the implementation of estate level strategies, heritage buildings and refurbishments). This further highlights the importance of establishing high level strategic approaches to decarbonisation at the outset of a project.

78 Information on the ILFI Zero Carbon Standard is available here.

79 For one definition of a pathways based approach see the UKGBC Paris Proof Method - information available here.



1 The pathways building would be expected to have lower upfront embodied carbon.

2 The pathways approach will initially have higher operational emissions.

3 Interventions would have higher embodied energy but more significant impact reducing operational emissions.

4 Successive interventions will further reduce the operational energy.

FIGURE 14
A lifecycle chart showing the whole life carbon emissions associated with a Planned Pathways Approach, (with Net Zero Now shown faded), and their relationship to RIBA work stages and RICS lifecycle modules.

KEY
- Net zero now
- Planned pathways approach
- NZN perational energy
- PPA operational energy

Whole life carbon information requirements

Thermal, BIM and WLC models are critical for evaluating net zero designs. Coordinating, communicating and reviewing data should be established early on.

The importance of model coordination

The incorporation and management of data is critical for the delivery of large scale net zero carbon buildings. Dynamic thermal, BIM and WLC models are all required for evaluating net zero carbon building designs against targets established at the outset of the project. Supporting these primary models will be iterative secondary models investigating singular aspects of the design (see the case study section for examples analysing daylighting, thermal gain, and façade embodied carbon).

Progamme and data exchange

Coordination and integration of models, their input and output data, and the results of analysis undertaken using primary and secondary models is crucial. Processes for the exchange of data between the main models and integration of data and results from iterative models should be established early in the design process. Data exchange will include programmed data drops at key project stages, alongside task-based exchanges of information.

It is critical that deliverables and responsibilities are clear to all parties, the format data will be exchanged with modellers is understood, and how results from analysis will communicated to the client and the design team is agreed in advance.

The benefits and limitations of early calculation

Early calculation of the embodied carbon and environmental performance are a feature of large scale net zero carbon development. For initial embodied carbon assessments databases such as the Inventory of Carbon and Energy (ICE)[80] can be used. However, as highlighted earlier in this section on the embodied carbon performance gap, a degree of uncertainty should be factored into early calculations and the limitations of the databases recognised.

Early calculations should be flexible and iterative, recognising that this analysis will be contributing to progression of the design rather than providing final answers. The data drops from this early analysis will facilitate later, in-depth assessment based on more accurate sources of information such as environmental product declarations (EPDs), increasing the quality of the primary models.

In contrast to digital twins which are developed near the end of the design process, early and iterative models support decisions aimed at reducing carbon impacts, rather than as true reflections of the performance of the building.

BIM and embodied carbon assessment

The process of data extraction from the BIM model for an embodied carbon assessment should be considered. More detailed modelling will be required earlier in the design process to support this analysis.

Data validation and information sharing should be a consideration and efforts should be made to ensure the accuracy of information transferred whilst recognising the limitations of BIM modelling at each work stage. For example, correction factors might need to be applied to aluminium sections that recognise the void in a window frame modelled as a block. As the design progresses data continuity, compliance, completeness and veracity should be evaluated against the project protocols.

Peer and independent review

Finally, the benefit of peer review and independent quality assessment should not be overlooked. Where this capacity exists within the team it should be utilised for checking and improving model quality.

80 The Circular Ecology website provides a link to the ICE database.

Net zero and digital twins

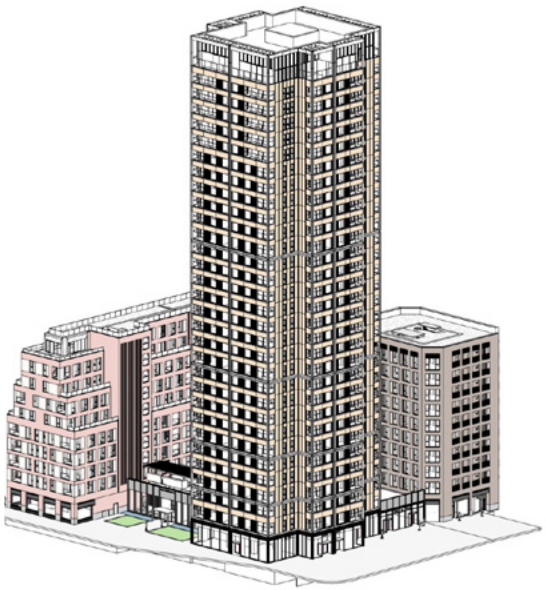
A digital twin connects physical and digital systems.[81] It can fulfil several functions: it can provide a record of the building at the point of practical completion - a record of the net zero carbon strategies; and it can be a tool for evaluating and optimising the performance of the building in use.

To fulfil these functions the digital twin will be comprised of the following models:

- **BIM model** providing spatial and material information supporting a materials passport database.
- **WLC model** providing a carbon picture of the development incorporating final design operational and embodied carbon calculations (including upfront, in-use and end of life predictions).
- **Dynamic thermal in-use energy model** calibrated to installed systems and occupancy patterns.
- **FM digital operation model** drawing on real time data on the internal environment and performance of automated systems facilitated by building management systems.

Developing the digital twin

For a new build project the digital twin will be developed towards the end of the design process. However, for a refurbishment project the initiation of a digital twin might be the starting point to facilitate the sophisticated testing of design approaches.



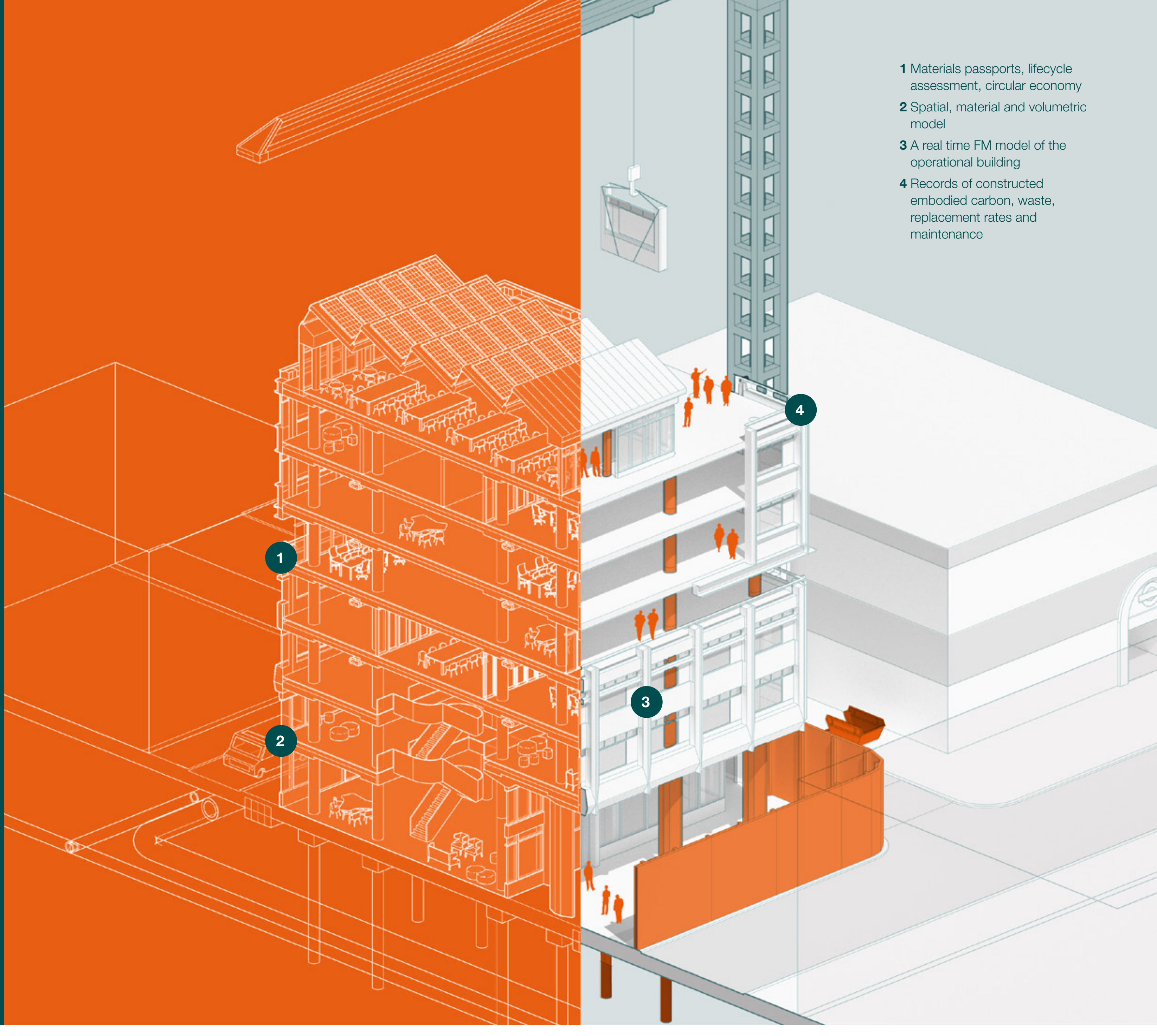
WEST GROVE
Elephant & Castle, London. Stage 4

81 A useful primer is the Institution of Engineering and Technology document: 'Digital twins for the built environment: An introduction to the opportunities, benefits, challenges and risks'.

Net zero and digital twins

It is necessary to identify the additional work required for the development of a net zero specific digital twin in the appointments and scope.

Early in the design process contractual issues will also need to be addressed around responsibility for delivery of the digital twin models and the incorporation of as-built information.



1 Materials passports, lifecycle assessment, circular economy

2 Spatial, material and volumetric model

3 A real time FM model of the operational building

4 Records of constructed embodied carbon, waste, replacement rates and maintenance

THREE

Key resources

International net zero carbon building standards and frameworks

Presented here are a selection of net zero carbon building standards. This is not an exhaustive list, for example Brazil, India and South Africa have regional net zero carbon standards; however, it does highlight the standards most relevant for projects in Europe or North America.

NAME	BODY	COUNTRY	IDENTITY		EST.	ASSESSMENT	NOTES
Minergie A	Minergie	Switzerland	MINERGIE-A®		2011	In-use operatioal performance only WEB	This standard is currently only available in Switzerland and Liechtenstein. Energy independence and on site production of electricity is a feature of this standard.
Energie Positive & Reduction Carbone	Alliance HQE-GBC France	France	E+ C- Bâtiment à Énergie Positive & Réduction Carbone		2017	Design and in-use operational performance WEB	Described on the website as a trial scheme it is not clear if this certification scheme has been more widely applied to industry.
Zero Carbon Building Standard	Canada Green Building Council	Canada	ZERO CARBON BUILDING INITIATIVE Canada Green Building Council		2017 Rev. 2020	Option of design or operational performance WEB	This building standard provides two routes for certification (1) based on design performance; and (2) based on in-use building performance.
Leadership in Energy and Environmental Design (LEED) Zero Carbon	United States Green Building Council	USA	LEED Zero		2018	In-use operational performance only WEB	This standard can only be used in conjunction with other LEED Certificatation. This is a performance only standard.
Zero Carbon Certification	International Living Futures Institute	USA	ZERO CARBON CERTIFICATION		2018	Design & in-use perf. one year post PC WEB	Carbon offsetting is only permitted for upfront embodied energy. The operational energy assessment period is 1 year after PC.
NABERS Climate Active Carbon Neutral	National Australian Built Environment Rating System	Australia	NABERS		2018	In-use operational performance only WEB	A full range of NABERS products, is not currently available in the UK. This is a performance only standard.
Climate Positive Buildings	German Sustainable Building Council (DGNB)	Germany	Climate Positive		Oct 2019	Design and in-use operational performance WEB	This building standard requires the embodied energy to be offset by on or off-site renewables over the life of a building.
LETI Climate Emergency Design Guide	Low Energy Transformation Initiative (LETI)	UK	LETI Climate Emergency Design Guide		Dec 2019	No assesment WEB	This is a guidance only; however, there are opportunities for a scheme to be a demonstration project. The evaluation period for operational energy is 5 years post PC.
RIBA 2030 Climate Challenge	Royal Institute of British Architects (RIBA)	UK	RIBA 2030 CLIMATE CHALLENGE		2019 Rev. 2021	No assesment WEB	This standard is currently guidance.
Noll CO_2	Sweden Green Building Council	Sweden	NollCO2		2020	Design and perf. 5 years post practical completion WEB	The assessment period for a project built to this standard is 5 years post PC.

Explanatory notes

A Some standards are guidance only, however, others provide certification and verification of performance.

B Most standards presented here are international; however, some are specific to countries or regions.

C Net zero carbon building standards can be based on operational performance (i.e. energy use post practical completion) or (predicted) design performance - see notes for assessment period.

D Continuing debate about the validity of carbon offsetting and offsite renewables means that most standards only allow these approaches under specific circumstances (i.e. to offset upfront embodied carbon) whilst others do not permit their use at all.

The majority of net zero carbon building standards are based on operational performance rather than (predicted) design performance.

KEY

- Ⓒ [A] Certification standard
- Ⓖ [A] Guidance
- [B] international standard
- Transport emission of users considered
- Embodied energy included
- [C] In-use performance evaluation
- [D] Carbon offsetting permitted
- [D] Offsite renewables permitted

An overview of zero carbon guides

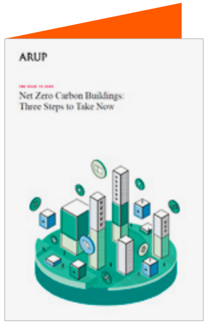
This selection of net zero carbon guides offers a deeper insight into the principles and application of net zero design in the built environment.

We have limited the selection to one entry per organisation. For LETI and UKGBC this means that the document shown is a representative entry and a gateway to a suite of documents supporting the development of net zero carbon buildings provided by these organisations.

Our aim is to support the development of a broad knowledge base so the guides we have included here range from broad overviews to detailed technical guides and strategic documents. Some guides, such as Active Buildings Design Guide and the RICS Whole Life Carbon Assessment, are not explicitly net zero carbon guides but they contain useful information on the subject.

The Active Building Design Guide
Specific
LINK

The Active Building Guide provides an introduction to approaches enabling energy positive buildings. The guide provides and insight into integration of on site renewables, the inclusion of electric vehicles and energy storage along with Intelligent controls essential for grid balancing Active Buildings.



Net Zero Carbon Buildings: Three Steps to Take Now
Arup
LINK

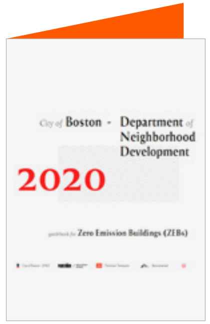
This publication outlines steps to ensure the delivery of buildings that contribute to a net zero carbon world. It outlines incentives to support asset owners and developers to get their portfolios on a net zero trajectory and a whole life carbon approach to achieving net zero carbon.

Unlocking the Delivery of Net Zero Carbon Buildings
UKGBC
LINK

This sets out strategies for the delivery of net zero carbon buildings. Other UKGBC net zero guides include Building the Case for Net Zero, Delivering Building Performance, Circular Economy Guidance and Renewable Energy Procurement & Carbon Offsetting Guidance.

Climate Emergency Design Guide
LETI
LINK

An essential guide that outlines the requirements and processes for new net zero buildings. This document is the first of several useful guides by LETI which include the Client Guide for Net Zero Carbon Buildings, The Embodied Carbon Primer and Embodied Carbon Target Alignment.



Guidebook for Zero Emission Buildings (ZEBs)
City of Boston
LINK

This guide utilises analysis using parametric modelling to identify ZEBs to highlight development strategies and requirements based on a range of typologies. The guide explores the trade-offs necessary for the delivery of ZEB projects at no net or minimal cost increase.

Beyond Net Zero: A Systematic Design Approach
Design Council
LINK

This document provides a high level overview of the process of design, in the broadest sense, considering the challenges of delivering net zero. It highlights the role of the designer as a thought leader, decision maker and storyteller in delivering carbon reduction measures.

Designing for Net Zero
Helical
LINK

This is a design guide from the developer perspective which aims to aid professional teams in the development of net zero projects. The guide covers the entire development process from design and construction through to operation and occupation.

Net Zero Carbon Guide
Max Fordham
LINK

This guide is a collection of articles assembled in a framework covering the inception, design and lifetime of a building. It provides a mix of background knowledge, design guidance, key considerations and tips to assist the delivery of a net zero carbon buildings.

The Building Decarbonisation Practice Guide
AIA California
LINK

This is a comprehensive guide to the development of net zero carbon buildings. The specifics of the document relate to US but it covers embodied carbon and the impact of grid decarbonisation.

Whole life carbon assessment for the Built environment
RICS
LINK

This guidance provides a whole life approach to reducing carbon emissions within the built environment. The guide establishes the principles and supporting guidance for the interpretation and implementation of a whole life carbon methodology and has provided a reference for the industry.

FOUR

Case study

QUICK INDEX

Introduction to the case study

Our Knowledge Transfer Partnership project case study aims to develop a model for the design of net zero high density, mixed use developments.

This case study plays a key part in the Knowledge Transfer Partnership between AHMM, Innovate UK, and the Bartlett School of Environment, Energy and Resources at UCL. AHMM's project design team are applying many of the principles and processes described in this guide to deliver the client's ambitious net zero in use targets, described in more detail overleaf.

At the time of publication, the project is at RIBA Stage 3 and has achieved planning permission, which means that we have not implemented in use performance assessments yet. We aim to update the case study in future editions of this guide as the project progresses.

Project overview

AHMM was appointed by British Land to design a high density, mixed use development at Canada Water; a post-industrial area of south London. The development, known as Plot F, is part of the client's 21ha masterplan for the site and will provide residential, commercial and retail spaces within two 33 and 36 storey towers, plus 11 storeys of offices at the base of tower 1 (all areas quoted are GIA);

- 410 residential units split between the two towers of approx. 24,300m^2 for tower 1 and 18,450m^2 for tower 2.
- 10 storeys of office space with an area of 38,925m^2 in the tower 1 offices.
- 1800m^2 of retail space on the ground floor of the tower 1, tower 2 and the offices.

The towers are separated by a pedestrian walkway, but connected underground by a shared basement level containing residential cycle storage, office and residential refuse stores and other commercial space.

Key definitions

The **Knowledge Transfer Partnership** (KTP) and the data generated by the design team is being used to assist in developing a tool for delivering high density, mixed use, net zero carbon developments. The client brief includes targets that are significantly more onerous than the planning requirements, targeting ambitious operational energy metrics which result in a blended 53 percent improvement over Part L, an embodied carbon target of 550-600kg/CO_2/m^2 for commercial uses (A1-A5) and a 450-650kg/CO_2/m^2 (A1-A5) for residential uses, BREEAM Outstanding, HQM 4 Stars and NABERs 5*.

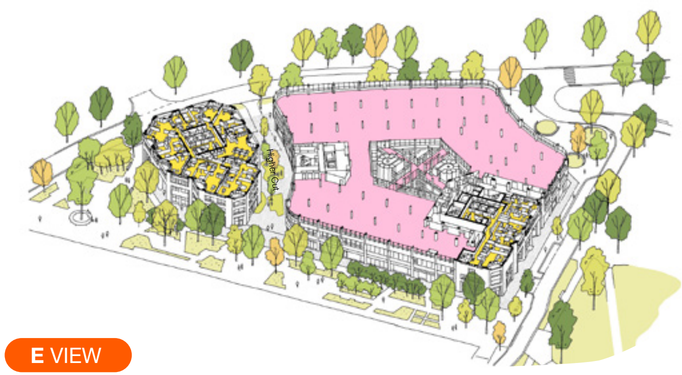
Net zero targets

The net zero targets for the project operate on three levels:

- Project aspirations established by the client at the evaluation stage which included identifying that the development would be net zero in use.
- Primary targets (or client strategic targets) established by the team and the client based on industry benchmarks for achieving the ambitious aspirations of the scheme, such as the specific embodied energy and operational targets.
- Secondary targets (or design team strategic targets) supporting the delivery of the primary targets which are informed by team experience and other industry benchmarks.

Project design team

Architecture AHMM
MEP engineering Sweco
Structural engineering AKT II
Construction advisor Mace
Fire consultant OFR
Facade engineer AKT-E
Access consultant David Bonnett Associates
Cost consultant Gardiner & Theobald
Sustainabilty and WLCA Sweco
Specialist lighting Speirs and Major
Landscape Townsend and Campbell Cadey
Acoustic consultants Sandy Brown Acoustics



E VIEW
Lower level

E VIEW
Ground level

E VIEW
Typical upper level

NE VIEW
Roof level

PLOT F
Cutaway isometric views.

Plot F

Canada Water Plot F, London, UK
In progress
Client: British Land

Canada Water Plot F includes a significant office building and 410 residential units across two towers of 10, 34, 36 storeys including ground. The towers share the same design language, and are positioned at 45 degrees to one another to respond to the street pattern and create a varied skyline within the context of the 21ha site masterplan. The commercial office building is flexible in its construction and form, in response to the streets and public spaces it addresses.

The development includes shared landscaped roof terraces for residents and workers, biodiverse green roofs, plus new trees and landscaping along the adjoining streets.

Client aspirations

The client's challenging net zero carbon aspirations for Plot F are ambitious, unambiguous and measurable.

Net zero aspirations

The client's high level aspiration was for the development to have the lowest feasible whole life carbon dioxide emissions, at the time of development, for a large-scale building of this type.

To achieve this aspiration, the client envisaged that whole life embodied carbon savings would be driven by setting challenging targets and the use of a carbon offsetting transition fund.

Targets

Targets aligned with RIBA's 2030 Challenge[82] were intially established to chart the success of the project. These targets were subject to review as the project progressed. The ambitious, unambiguous, and measurable targets are based on key building performance metrics. Monitoring of operational carbon in use will support the embodied carbon metrics.[83]

Wider sustainability aspirations

The client's net zero aspirations were one part of a wider sustainability drive on the project which includes targets to minimise waste and water consumption, and maximise community benefit and social engagement. However, the challenging nature of the net zero targets dominated sustainability discourse within the design team.

Key project appointments were made to facilitate the delivery of the project's net zero carbon targets. These included a sustainability lead drawn from within the client organisation to manage the sustainability brief process, allocate resources, and manage performance data reporting. Sweco was enlisted from within the design team to formulate the net zero carbon strategy and develop the WLC model. They also coordinate and compile the whole life carbon assessment with support from other design team members.

"The project should be driven by an ambitious and innovative sustainability strategy going beyond minimum compliance standards aiming for genuine in-use performance improvements. This should include verifiable and tested performance metrics established at design stage and evaluated in use."

Client aspiration from the strategic environmental report

82 Information on the RIBA 2030 Challenge can be found here.

83 Available resources and sustainability outcomes.

Operational and embodied carbon primary targets

Developing and setting robust targets was a significant feature of the early stages of the project.

Upfront embodied carbon targets

The upfront embodied carbon targets were based on the RIBA 2030 Challenge (see part **THREE** for details). These targets were 500kgCO_2e/m^{2}GIA for the commercial and 450kgCO_2e/m^{2}GIA (RICS stages A1-A5 the production and construction stages) for the residential.

The client's carbon offsetting transition fund[84] provided an additional incentive to reduce the upfront embodied carbon of the development. The incorporation of the fund payments help to raise awareness of the cost and carbon implications of specification decisions.

Lifetime embodied carbon targets

Embodied carbon emissions targets relating to in use and end of life carbon were also established (RICS Stages B1-B5 & C1-C4) at 275kgCO_2e/m^{2}GIA for the commercial and 250kgCO_2e/m^{2}GIA for the residential.

Materials passports and design for disassembly were client requirements. To facilitate the use of material passports, minimum data requirements were established based on provenance, certification (EPDs, BBAs etc.), weight/mass/volume, lifespan, carbon emissions and end of life routes.

Operational carbon targets

Operational carbon targets were set by the client's development team in consultation with the design team. Each specific target was developed based on team experience, industry benchmarks (such as LETI and UKGBC guidance) [85] and the client's environmental, social and governance (ESG) goals.

Operational energy targets were aligned with UKGBC targets for commercial buildings. Total building energy targets were set at 90 kWh/m^2.yr for commercial space and 35 kWh/m^2.yr for residential units. Recognising the landlord/tenant split in commercial property, the base building landlord energy in design and operation was 55 kWh/m^2.yr and tenant energy in design and operation 35 kWh/m^2.yr.

In-use operational performance will be addressed by implementing Design for Performance and CIBSE TM54 processes. Later in the development of the project, the performance-based standard NABERS will be implemented with a four and a half star target to be set. Applying this standard brings with it a requirement for a detailed dynamic thermal model and digital twin.

84 More information on British Land's transition fund is available in their sustainability report 'Places People Prefer: Pathway to Net Zero'.

85 UKGBC energy performance targets for commercial offices aiming to achieve net zero carbon in operation can be found here.

Carbon offset commitments

The client made a commitment that every tonne of upfront embodied carbon produced through construction would trigger a £60 per year payment used to purchase accredited offsets and contribute to a client transition fund that provides capital to retrofit their existing assets to achieve zero carbon. It should be noted that this fund doesn't fully align with the Oxford Principles described in part **ONE** of the guide because it was established by the client before this document was published.

The transition fund was instrumental for informing material strategies on the project and was incorporated into the cost plan. This mechanism allowed any uplifts in costs associated with lower embodied carbon materials to be considered against savings in contributions to the transition fund. With regard to operational offsetting the client committed to the purchase of offsite renewable energy and required that this offsite renewable energy demonstrate additionality.

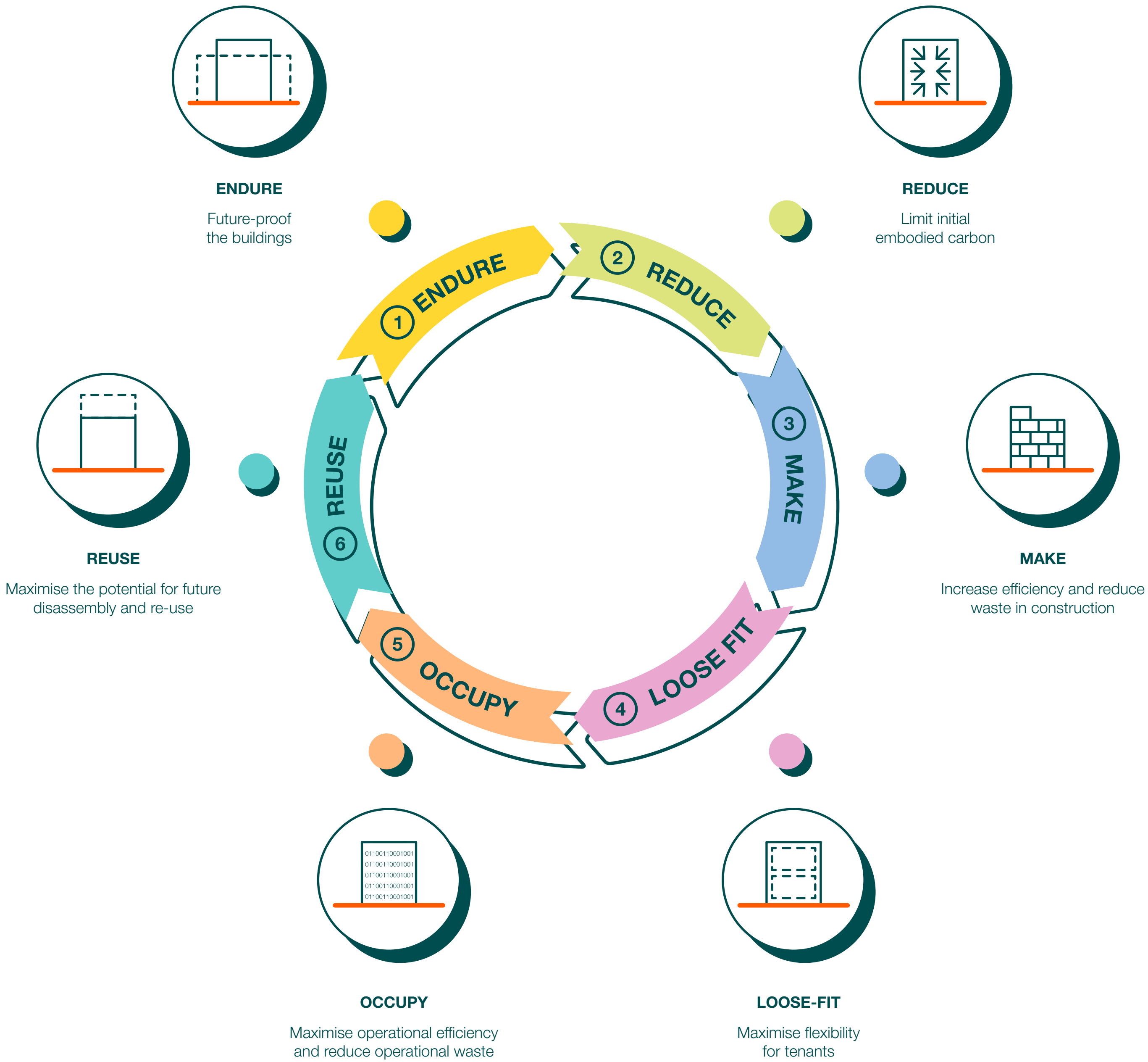


FIGURE 15
Diagram describing the principles applied to reduce the embodied carbon of the case study.

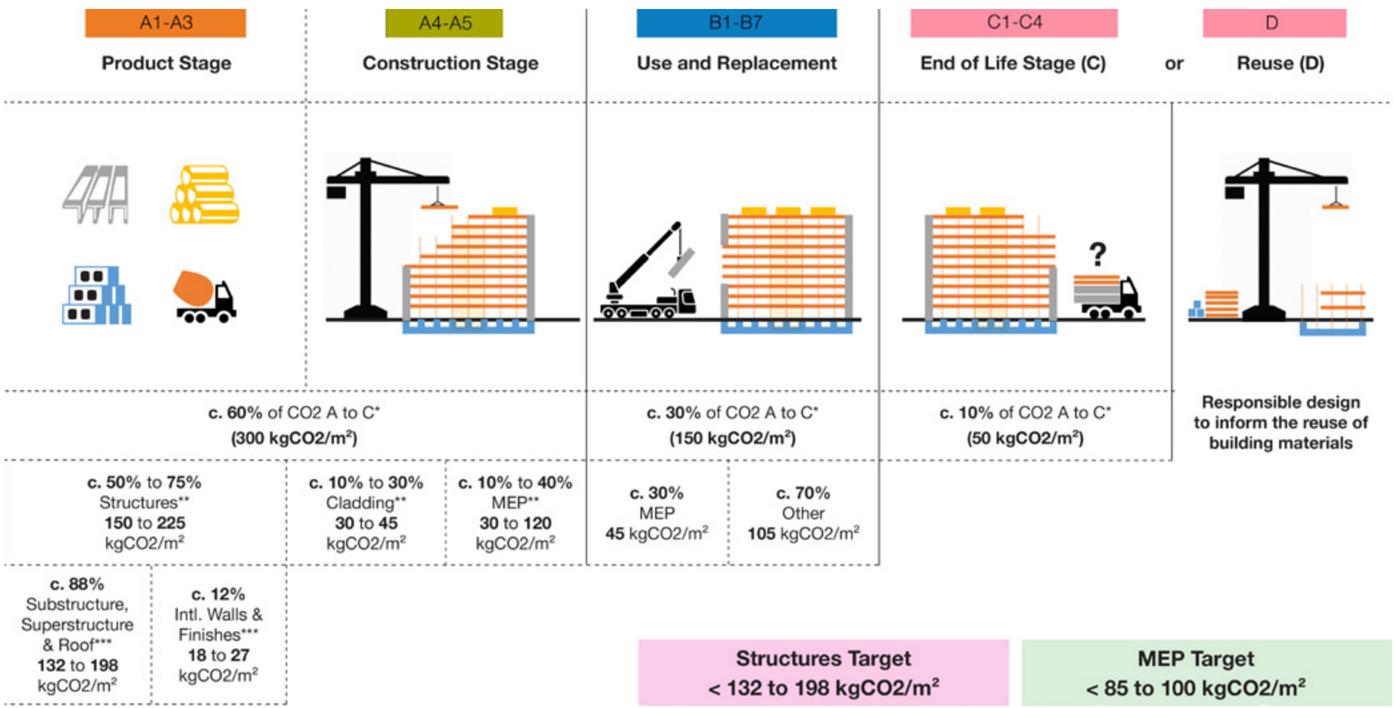


FIGURE 16

Embodied carbon targets for Primary Structure:500 $kgCO_2/m^2$ Stage A to C.

Design team strategic targets supported coordination between the disciplines by identifying and communicating common objectives.

The design team's strategic targets, or secondary targets, were derived from the strategies and principles identified as necessary to achieve the embodied and operational carbon targets. These targets also supported design team coordination by identifying common objectives that intersected design disciplines.

Upfront embodied carbon secondary targets

The most ambitious primary project target for embodied carbon was set at 500 $kgCO_2e/m^2$ for the office building (this initial target was later revised to 550-600 $kgCO_2e/m^2$). This high level target was evaluated by the design team who collectively arrived at upfront embodied carbon targets for several key components of this building:

Structure target = <132 to 198 $kgCO_2/m^2$
MEP target = <85 to 100 $kgCO_2/m^2$
Cladding target = <30 to 45 $kgCO_2/m^2$
Target for remaining items = <30 to 45 $kgCO_2/m^2$

More detailed targets were informed by the LETI Climate Emergency Design Guide (see part **THREE** ›) for details) and other documents providing elemental breakdowns of embodied carbon.

Operational carbon secondary targets

An operational energy road map was developed by Sweco, which included targets for power loads, equipment efficiencies, system pressures, and other end uses. The design team set a notable secondary target to limit peak solar gain to less than or equal to 40W/m². This is beyond the British Council for Offices requirements to limit solar gain to 50-65W/m².

In order to reduce the need for mechanical services to provide cooling, and instead facilitate free cooling through natural ventilation, it was planned to utilise solar gain, effective natural ventilation and thermal mass. It should be noted that the design team targets would sometimes override other industry targets.

Applying first principles

The starting point for the project's net zero strategy was to apply key principles, rules of thumb, professional experience and previous analysis.

These first principles, (laid out in part **ONE**), were communicated across the design team through drawings, reports and presentations, and were instructive in establishing initial assumptions. For example; minimum floor to ceiling heights to facilitate natural ventilation, and plan layouts to residential apartments that facilitated cross-ventilation.

Modelling based analysis

These assumptions would later be supported and/or challenged by modelling based analysis, which became a fundamental part of the design process. Iterative models investigating one or two key metrics of the net zero targets allowed for rapid investigation of singular aspects of building performance. Early RIBA Stage 1 and 2 models investigated the role of massing and solar capacity at a site level and the embodied carbon of a building component (i.e. a typical façade bay).

As the project progressed, iterative models were used for testing approaches to meeting performance targets, informing architectural principles, and identifying areas for further exploration. However, this type of investigation was not always possible using the heavier (in terms of data size), primary whole life carbon and dynamic thermal models. Within the architectural team environmental modelling was undertaken by AHMM's dedicated building performance team.[85] AHMM for architecture, and AKT for structures, used bespoke tools for modelling and analysis.

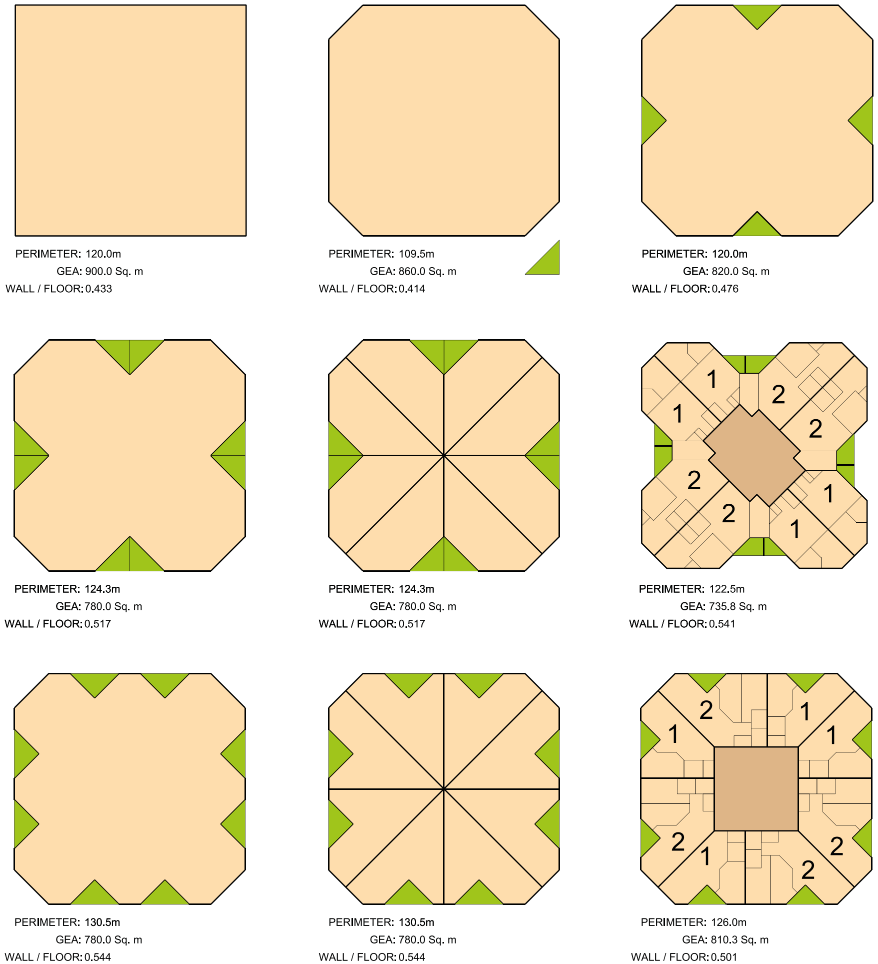


FIGURE 17
Diagram showing the development of the plan form for residential towers ventilation. It shows the development of a residential tower typology based on optimising wall to floor ratios to ensure the efficiency of material use and allowing through ventilation to all units to reduce the need for mechanical cooling.

86 More information on AHMM's building performance team is available here.

Operational carbon roadmap

After establishing first principles, an operational energy road map was developed by the MEP engineers, with input from the design team.

RIBA Stage 2
During RIBA Stage 2, Sweco, the project's MEP engineers and sustainability consultants, prepared an operational energy roadmap to 2030 to enable the project team to explore energy saving options as the design progressed. This roadmap helped to drive the direction of design and decision making, starting with a fabric first approach, and then considering services equipment locations, reducing ductwork and pipework runs, focussing on system pressures and equipment efficiencies, demand control optimisation and energy sharing.

RIBA Stages 3 and 4
Most of the items identified in the roadmap were embedded into the RIBA Stage 3 design. As the project progressed Design for Performance and digital twin modelling became more significant as drivers for delivering in use operational energy reductions. RIBA Stage 4 detailed design for performance modelling will continue to target energy demand reductions and find potential further operational energy savings.

Roadmap to 2030
As the project progresses it will be important for contractors, other specialists (such as commissioning agents), incoming tenants and their design consultants, and the facilities management team to engage with the operational energy roadmap. Extended compliance monitoring will be required from the MEP consultant, to ensure that the savings identified in the roadmap are understood and delivered by the buildings in use.

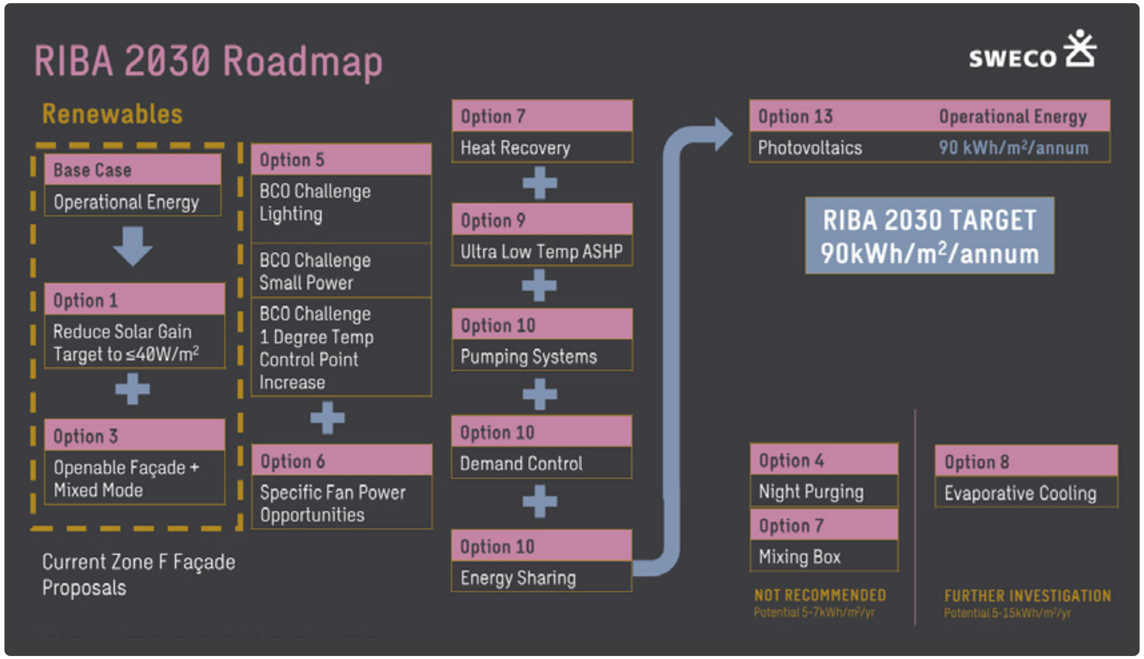


FIGURE 18
Diagram showing the roadmap identifying a series of measures to reduce the operational energy from a baseline to the project target.

Parametric solar gain analysis

A peak solar gain target of 40W/m^2 was identified by the mechanical engineers within the operational energy roadmap for the commercial aspect of the development. Achieving this target affected the architectural design through window to wall ratios, the depth of window reveals and provision of solar shading.

Detailed solar radiation analysis was conducted by the AHMM building performance team, using a Grasshopper tool at Stage 2, modelling which was progressed by the mechanical engineers at Stage 3 to inform the broader energy model. Initial modelling examined the massing of the building to identify façade bays at risk of exceeding the target based on context (e.g. overshadowing from surrounding buildings) and orientation.

This analysis was followed by detailed parametric studies using another Grasshopper tool examining mitigation measures to individual bays. The parametric modelling identified conditions that would allow this target to be achieved on an individual bay based on the following:

- Solar shading including: angle from horizontal and orientation (vertical or horizontal); number; location (horizontal or vertical distance from the window reveal); depth (distance of the end of the shading from the face of the glass);
- Depth of window recesses (location of the glazing plane relative to the outside face of the wall);
- G-value[86] (the glass's ability to transmit solar energy).

This parametric modelling mapped out options for the architects and design team to achieve the 40W/m^2 target.

FULL BASE CASE RESULTS TABLE

	L02	L05	L08/9
E1	25.6	29.7	
E2	32.5	41.4	59.4
SE Corner	55.2	69.6	115.3
S	25.1	26.4	45.7
SW Corner	89.4	92.5	161.8
W1	21.3	26.5	32.7
W2	18.4	30.4	40.6
W3	39.9	40.5	54.7
NW Corner		55.5	63.0
NW	8.3	8.3	10.0
N Corner			17.1
N	16.7	16.9	19.9

Peak Internal Solar Gain W/m^2

< 15 | 15-30 | 30-45 | 45-60 | > 60

L02/05 of SW Corner and W3 show very similar results so only L05 has been tested in the next section.

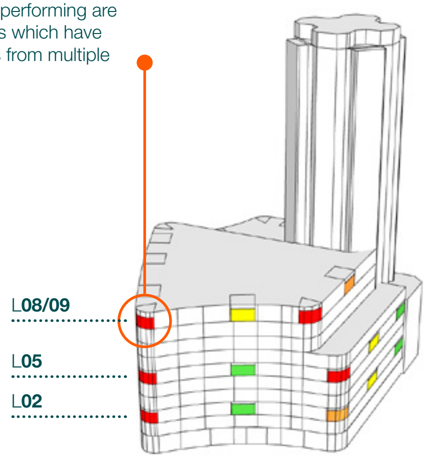
In general the higher floors have high solar gains due to proportionally higher glazing ratios.

400mm recesses has been applied to these areas in the optimisation section.

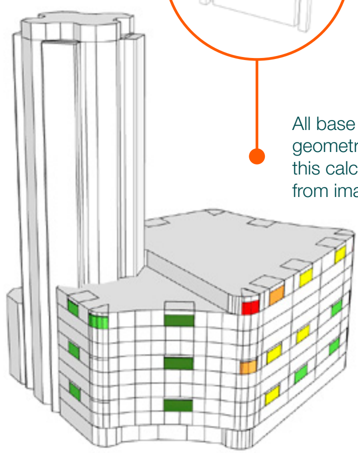
These areas are well below the target solar gain so current shading could reduce.

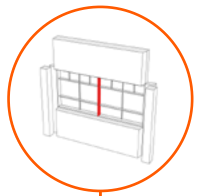
SE VIEW

The worst performing are the corners which have solar gains from multiple directions.



NW VIEW





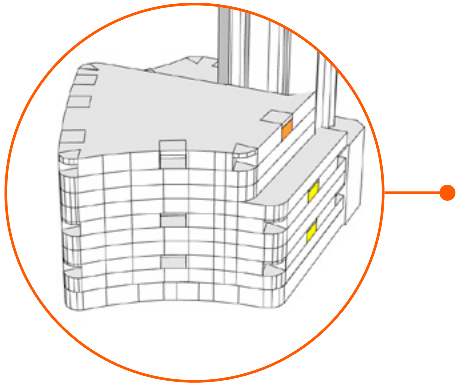
All base case facade geometry are included in this calculation. Removed from images for clarity.

87 This blog post provides a useful overview of U-values, Psi-values and G-values for windows.

Diagram and tables façade comparison

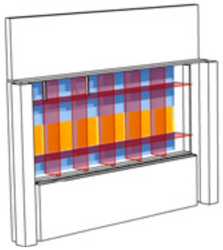
- The diagram on the left shows the peak internal gains for the base case facade of the commercial development (without the second tower).
- The areas with the highest gains require additional shading strategies to reach comfortable levels.
- All areas in green appear to meet the target solar gain so the following pages in section 3 only show interventions for all other areas.
- These are just suggestions and other architectural options can be explored to achieve similar performance.

EAST FAÇADE



L09 E2 façade

- Recess 400mm
- 5 x vertical shades
- Increase depth of vertical and horizontal shades

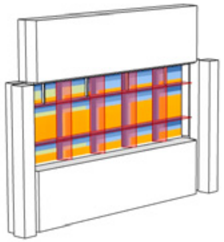


Level 09 E2

- Internal solar gain - 30w/m²
- G-value - 0.3
- Vertical shade depth - 675mm
- Horizontal shade depth - 800mm

L05 E2 façade

- 4 x vertical shade, rotate 45 deg
- Increase depth of vertical and horizontal shades

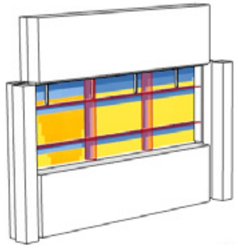


Level 05 E2

- Internal solar gain - 29.2w/m²
- G-value - 0.3
- Vertical shade depth - 400mm, 45deg acw
- Horizontal shade depth - 400mm

L02 E2 façade

- 2 x vertical shade, rotate 45deg
- Increase depth of vertical and horizontal shades



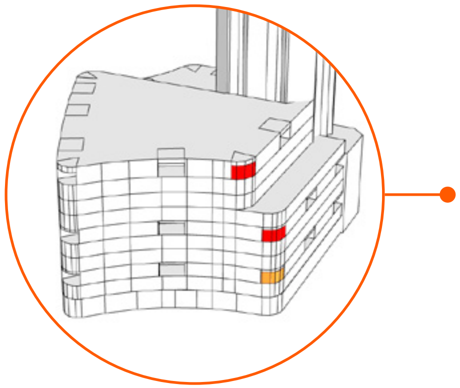
Level 02 E2

- Internal solar gain - 29.2w/m²
- G-value - 0.3
- Vertical shade depth - 275mm, 45deg acw
- Horizontal shade depth - 275mm

Diagram and tables
Façade comparison

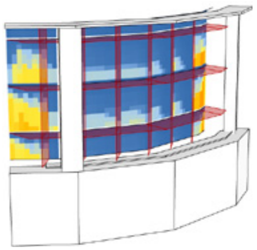
The diagram on the left shows the peak internal gains for three bays on the East and South East facade of the case study presenting various options to reduce the solar gain to an individual bay.

SOUTH EAST FAÇADE



L09 SE corner façade

- Recess 400mm
- 6 x vertical shades, rotate 45deg
- 3 x horizontal shades
- Increase depth of vertical and horizontal shades

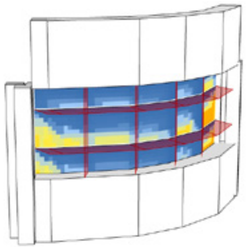


Level 09 SE corner

- Internal solar gain - 30w/m²
- G-value - 0.3
- Vertical shade depth - 800mm, 45deg acw
- Horizontal shade depth - 750mm

L05 SE corner façade

- 4 x vertical shade, rotate 45deg
- Increase depth of vertical and horizontal shades

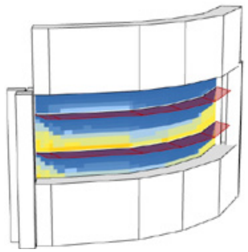


Level 05 SE corner

- Internal solar gain - 29.8w/m²
- G-value - 0.3
- Vertical shade depth - 650mm, 45deg acw
- Horizontal shade depth - 775mm

L02 SE corner façade

- Increase depth of horizontal shades



Level 02 SE corner

- Internal solar gain - 29.1w/m²
- G-value - 0.3
- Vertical shade depth - 0mm, 0deg
- Horizontal shade depth - 650mm

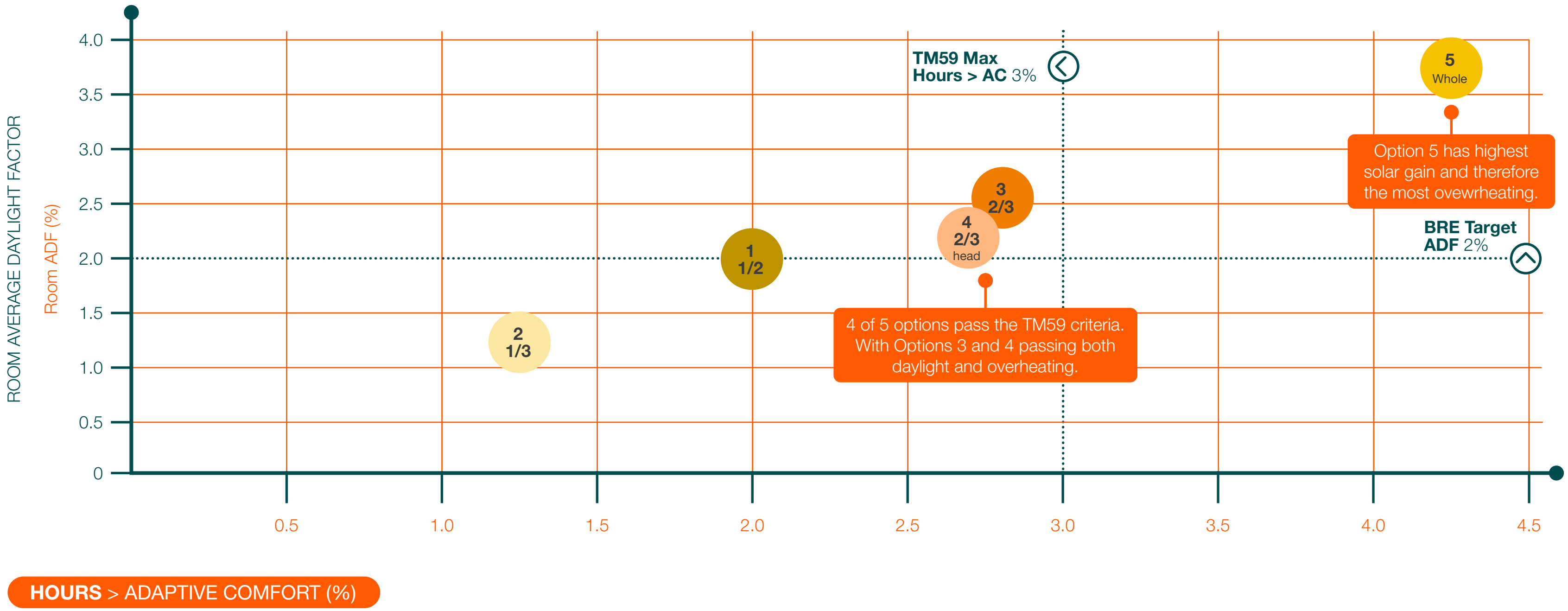
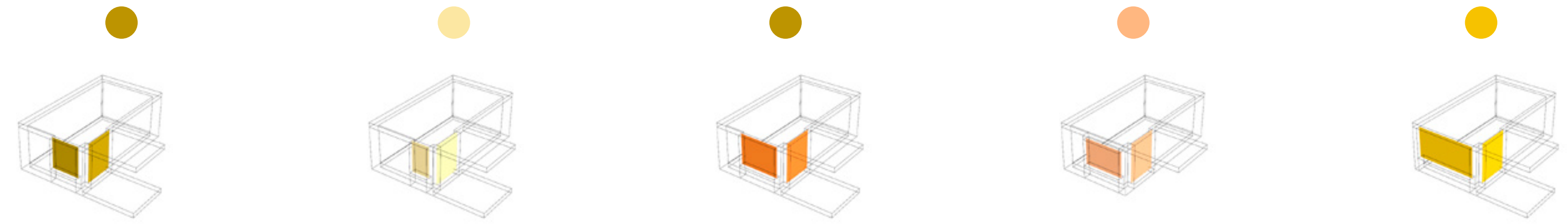


FIGURE 19

The diagram on the left shows a study examining the trade-off between daylighting (average daylight factor above 2%) and overheating (the number of hours which the operative temperature is one degree or more above the adaptive comfort threshold for more than 3% of occupied hours). Options 3 and 4 provide sufficient daylight without exceeding overheating requirements.



Option 1 1/2
Hrs > AC 2.0%
ADF 1.9%

Option 2 1/3
Hrs > AC 1.2%
ADF 1.2%

Option 3 2/3
Hrs > AC 2.8%
ADF 2.5%

Option 4 2/3 with head
Hrs > AC 2.7%
ADF 2.2%

Option 5 Whole wall
Hrs > AC 4.1%
ADF 3.7%

In the residential apartments a delicate balance had to be struck between solar gain, daylighting and the risk of overheating. A user centred approach[87] to net zero carbon design recognises the necessity to consider the occupant experience and comfort alongside carbon reduction targets. This approach was at the core of the net zero strategy for this project.

Thermal comfort iterative modelling studies of the tower apartments explored plan and window layouts, supporting cross ventilation, minimising solar gain and maximising daylight. Parametric studies examined how fenestration size and position, window to wall ratios and solar shading would affect occupier comfort.

A TM59 methodology for the assessment of overheating risk in homes was carried out on a typical floor of the residential towers and individual apartments. This assessed thermal comfort based on adaptive thermal comfort principles. Parametric analysis explored the relationship between daylight, overheating, window size and solar gain, on thermal comfort. This analysis carried out by the AHMM building performance team, informed the options available to the design team, and supported analysis undertaken by the MEP engineers using the energy and daylight models.

88 This CIBSE Journal article provides information about the use of TM59 to address overheating risk for apartments.

Embodied carbon approach

Addressing the embodied carbon of the project was especially important given the scale of the development.

The whole life carbon assessments for the project revealed that upfront embodied carbon emissions would be as important as operational energy emissions over the life of the building.

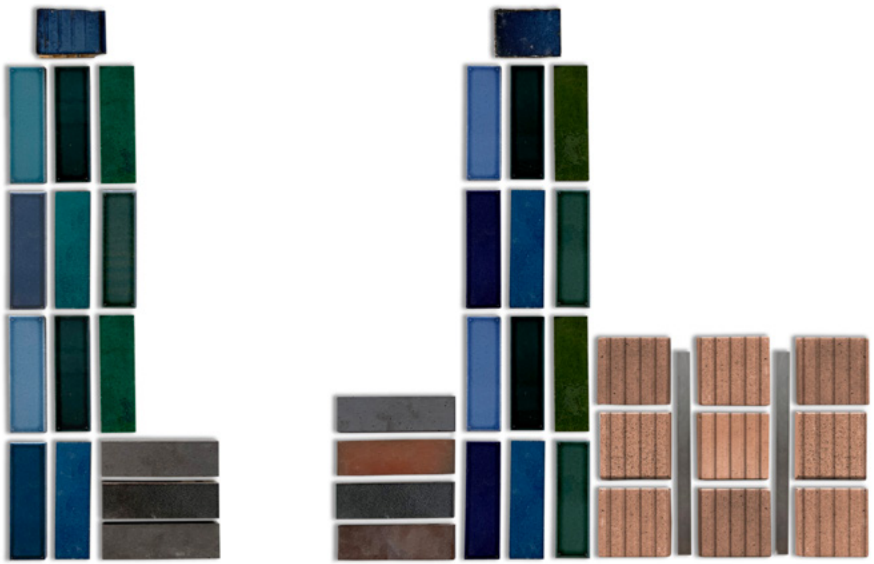
Two key studies exploring approaches to the upfront embodied carbon of the project were carried out:

Embodied carbon of the structure

The first study explored reducing the embodied carbon of the structure of the commercial element of the development. Much of the focus of this analysis was on a typical structural bay. This process began with a range of options which, through detailed analysis, were reduced to one option at the end of RIBA Stage 2. With early contractor input at RIBA Stage 3, another option was explored which eventually superseded the RIBA Stage 2 preferred option.

Embodied carbon of the façade

The second significant embodied carbon study was of the façade. A broad evaluation of options was considered with detailed evaluation of key carbon intensive elements like windows. By the end of RIBA Stage 2 a preferred option was identified. With early contractor engagement and sub-contractor input at RIBA Stage 3, detailed proposals will be developed for RIBA Stage 4.

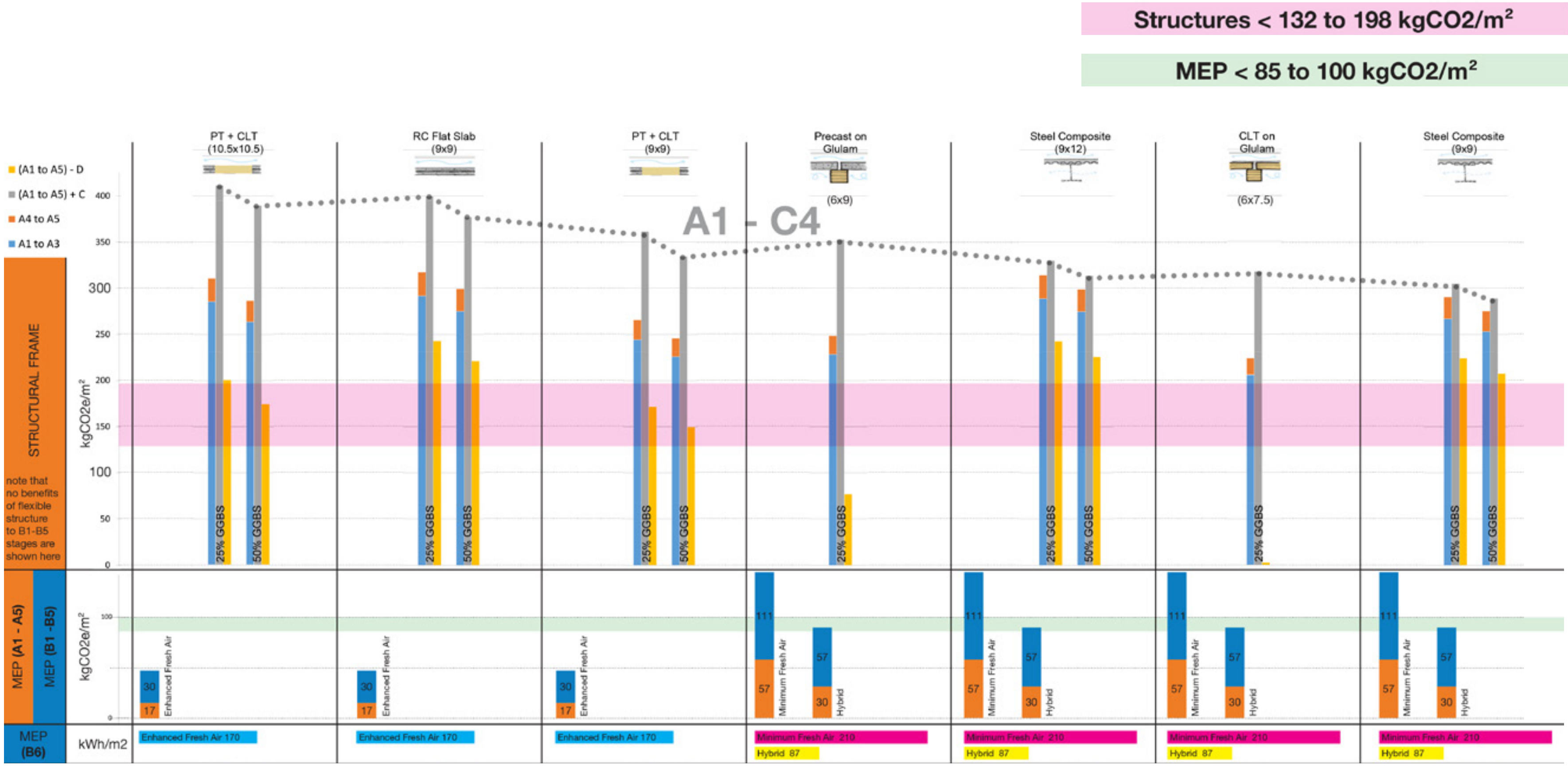


PLOT F

Plot F façade material concept samples.

Structural embodied carbon calculations

Stages A1 to C4

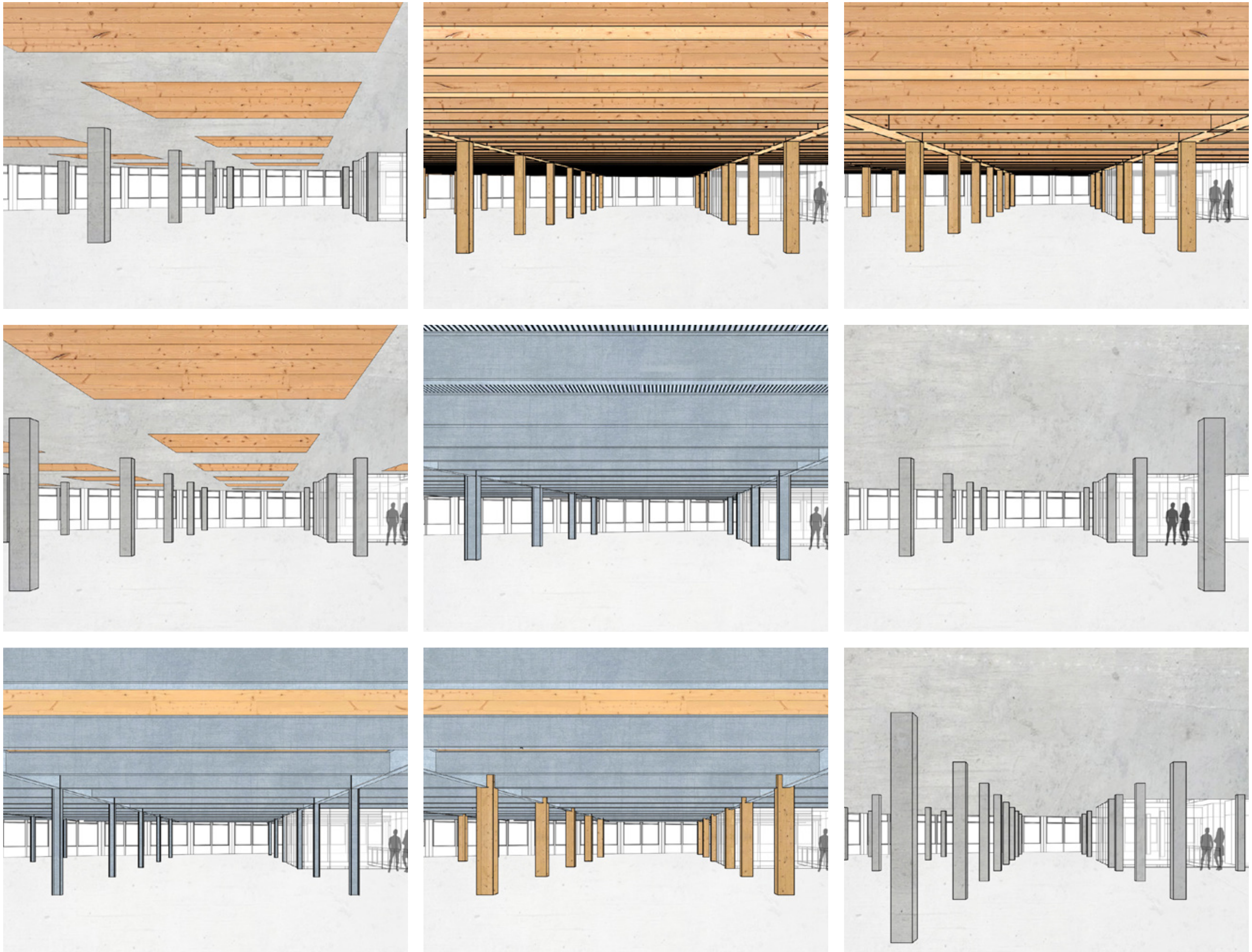


A broad range of structural systems were analysed during RIBA Stage 2 and evaluated against the project's net zero targets. Each option was costed for financial and procurement appraisal, and design risk and user experience were also considered.

As a result of the studies it was decided that the 9x9m post-tensioned slab with CLT infills and concrete columns, coupled with an enhanced fresh air ventilation strategy would be taken forward into the coordinated design.

The post-tension slab with CLT with infill panels was developed over a full timber structure because it was perceived by the design team as providing the optimal carbon performance in relation to other project risks, such as insurance and fire risk. This decision highlights the impact of current regulatory frameworks and other industry factors, like insurance, have on the capacity of design teams to deliver large scale development with a significant sequestration component (i.e. buildings as carbon sinks) in the UK.

4 CASE STUDY **Structural embodied carbon calculations**



Visual analysis of various structural bay options ranging from full CLT to concrete with cement replacement.

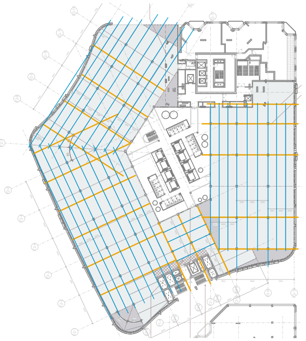
Contractor engagement on the project supported the continued development and evaluation of embodied carbon reduction strategies. The contractor was able to consult the supply chain and provide alternative options and, as part of their modern methods of construction (MMC) proposals, the contractor introduced the design team to a low carbon precast concrete cassette system they had developed as part of an Innovate UK research grant.

The design uses conventional prefabricated building systems with low carbon components to reduce the carbon footprint of the building structure. Analysis by the team was required to ensure that the grid system was compatible with the current design, considering section heights, fresh air strategy and integration of the structure with façade systems. At the beginning of RIBA Stage 3 two principal options were available: an in-situ with CLT infill or cement-free precast panels combined with recycled steel beams.

The comparison of these systems included quantitative analysis with and without sequestration but also other aspects such as appearance, coordination of services, the effect of the change on the ventilation strategy, the ability to reuse components for end of life recovery and other issues such as insurance.

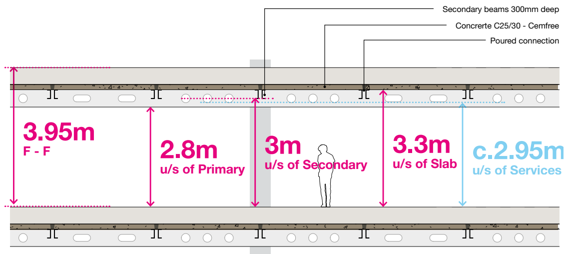
Diagram and tables

Comparison of typical structural bay options, RIBA Stage 2 and contractor's proposal considering embodied carbon, alignment with the ventilation strategy and appearance.



Typical floor RCP

Typical view through floorplate



Typical floor section

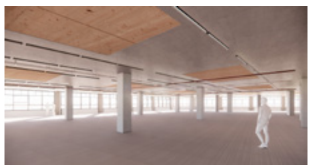
Concrete C25/30 - Cemfree
Secondary beams 300mm deep

Material		Units	Carbon (kgCO2e / kg)	Carbon (kgCO2e / m2)	Total carbon (A1-A3) kg	Carbon/m2	% of total
Cemfree precast concrete	26006.4	kg	0.023		598.1		10.3
Insitu stitches concrete	1209.6	kg	0.11		133.1		2.3
Rebar	648.0	kg	0.79		511.9		8.8
Steel sections (rolled)	3411.0	kg	0.842		2872.1		49.3
Column Steel	812.9	kg	0.842		684.5		11.7
Steel connections	170.6	kg	2.48		423.0		7.3
Shear studs	113.4	kg	2.48		281.2		4.8
Intumescant paint	81.0	m^2		4	324.0		5.6
Weight (bay)	32371.8	kg			5827.8	71.9	100.0

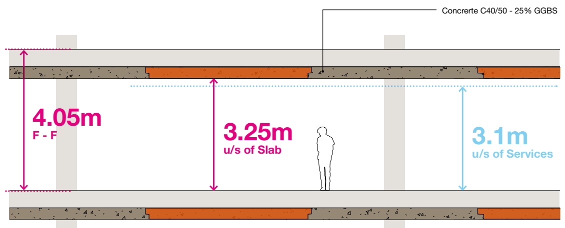
Embodied CO2 calculation

Precast Concrete Cassette

Typical floor RCP



Typical view through floorplate



Typical floor section

Concrete C40/50 - 25% GGBS

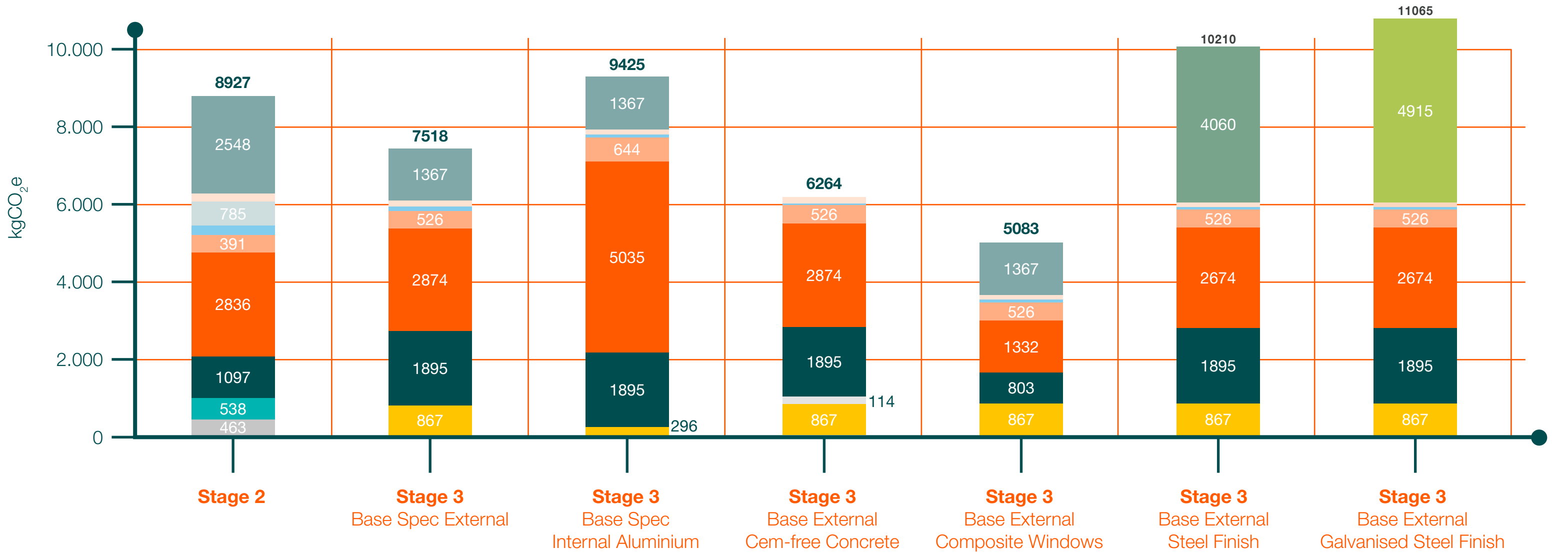
Material		Units	Carbon (kgCO2e / kg)	Total carbon (A1-A3) kg	Carbon/m2	% of total
Slab Concrete	36114.6	kg	0.138	4983.8		58.5
Slab Reinforcement	1655.3	kg	0.79	1307.6		15.4
PT tendons	376.2	kg	1.5	564.3		6.6
Column concrete (C50/60 70% GGBS)	3469.6	kg	0.076	263.7		3.1
Column reinforcement	506.0	kg	0.79	399.7		4.7
CLT	2024.6	kg	0.365	739.0		8.7
Gifa	758.7	kg	0.308	233.7		2.7
Formwork area	61.4	m2	0.432	26.5		0.3
Weight (bay)	44905.0	kg		8518.4	105.2	100.0

Embodied CO2 calculation

In-situ PT slab with CLT infill

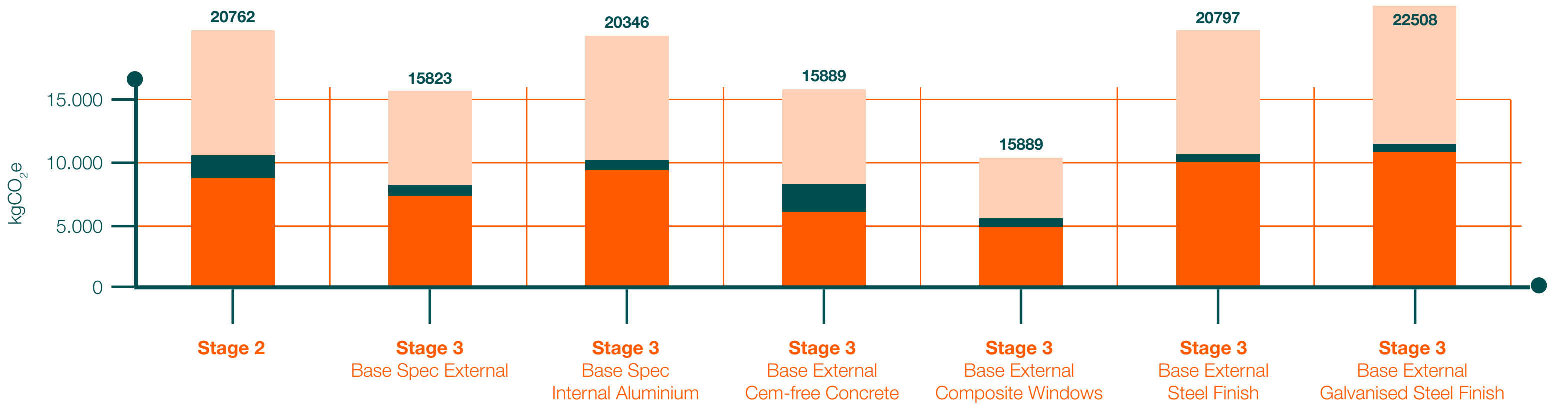
Typical office façade bay studies

FIGURE 20
Embodied carbon comparison for typical façade bay A1-A3 product stage.



KEY
- facade support structure
- glass (double glazing)
- cold rolled steel framing
- cement free concrete
- aluminium ~33% RC
- precast component
- composite window (aluminium and timber)
- mineral wool
- electrogalvanized steel
- plasterboard
- hot rolled coil steel
- common handset brick
- hot dip galvanised steel

FIGURE 21
Whole life embodied carbon comparison.



KEY
- A1-A3 product stage
- A4 transport stage
- B4 replacement stage sum A1-A3, A4 and B4

As the façade design developed, iterative modelling was used to investigate the whole life carbon of various façade options.

These studies of façade embodied carbon took into account unitised and panelised construction systems alongside earlier RIBA Stage 2 designs.

This investigation of the embodied carbon of a façade bay was not an isolated example but one part of a wider analysis considering the environmental design of the façade, as described earlier in relation to solar control.

Façade embodied carbon analysis and lifecycle analysis

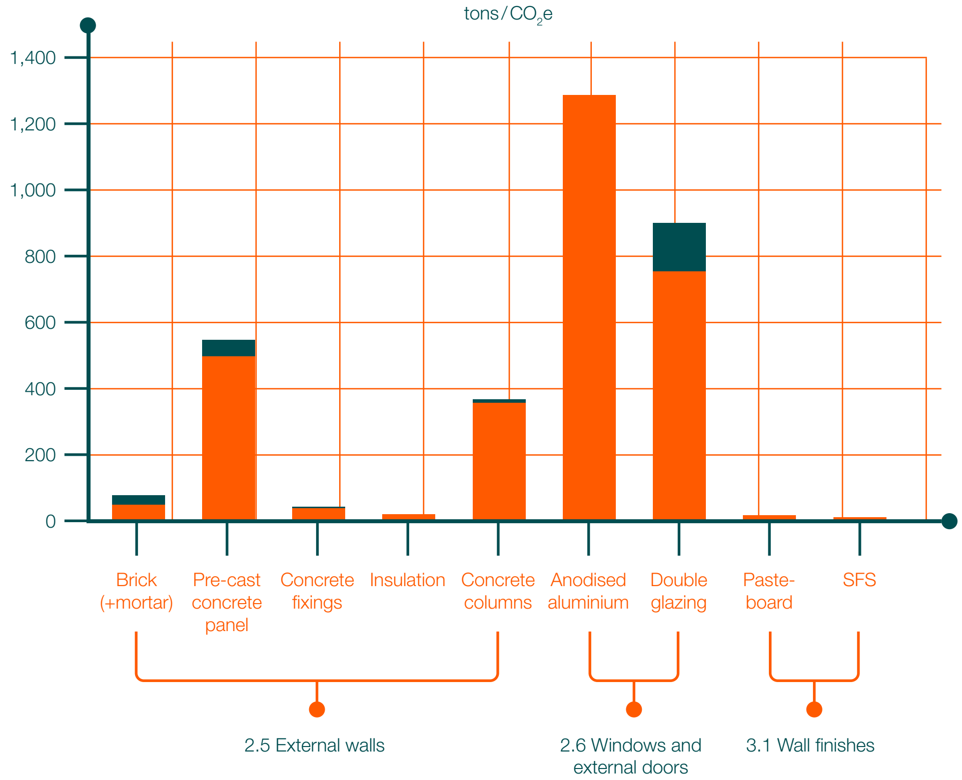
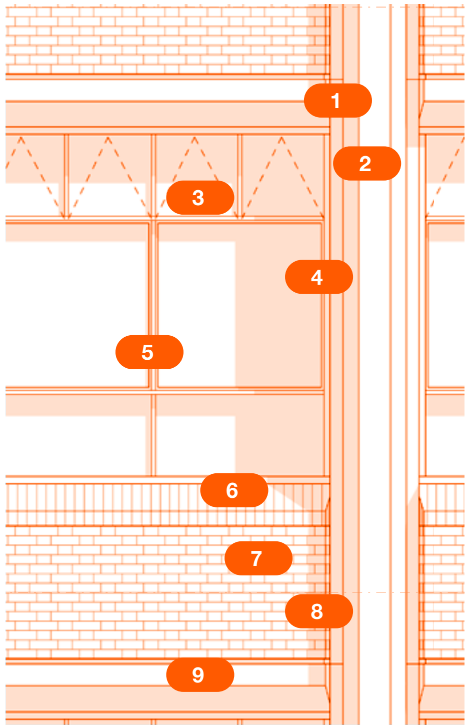


FIGURE 22
Embodied carbon comparison analysis of the carbon intensity of various elements of the commercial office façade based on a typical bay.

KEY
- (A1-A3) tCO_2e
- (A4)



1 Expressed rebated joints between precast concrete column, location of joint illustrative only.
2 Profiled precast concrete column.
3 Outward opening, projecting top hung windows, manually operated by handle at centre of sill.
4 Aluminium window.
5 Clip-on aluminium fin.
6 Angled brick sill.
7 Precast concrete spandrel panel with brick slip or half brick facing.
8 Profiled corner to brick panel.
9 Precast concrete lintel.

Elemental breakdowns helped the architects to understand the most carbon intensive elements of façade construction and focus on lower carbon alternatives.

Secondary embodied carbon targets were established for building components, such as a typical façade or structural bay based on LETI benchmarks. The AHMM building performance team carried out an embodied carbon analysis of a typical façade bay early in Stage 3 using a Grasshopper based tool which used volumetric data from Revit models.

The tool corrected for the characteristics of building elements (e.g. recognised the voids in aluminium window frames) and applied the ICE database.

This analysis provided an elemental breakdown of the carbon intensity of a façade bay. The results highlighted that, for example, the commercial building's façade had an embodied carbon 88.5 $kgCO_2e/m^2$ based on RICS A1-A3. This value was almost double the LETI benchmarks for RIBA 2030 target, which is estimated to be 46.8 $kgCO_2e/m^2$.

Benchmarking the façade and elemental breakdowns allowed the architects to identify and understand the most carbon intensive elements of the facade construction and focus their efforts on seeking lower carbon alternatives.

The breakdown in RICS categories of the facade at this stage indicated that the most embodied carbon intensive element of a typical façade bay was the window frame and glazing. At this stage pre-cast concrete panels account for 51% of the embodied carbon contained in the external walls (i.e. excluding the glazing) and the structural columns 35%.

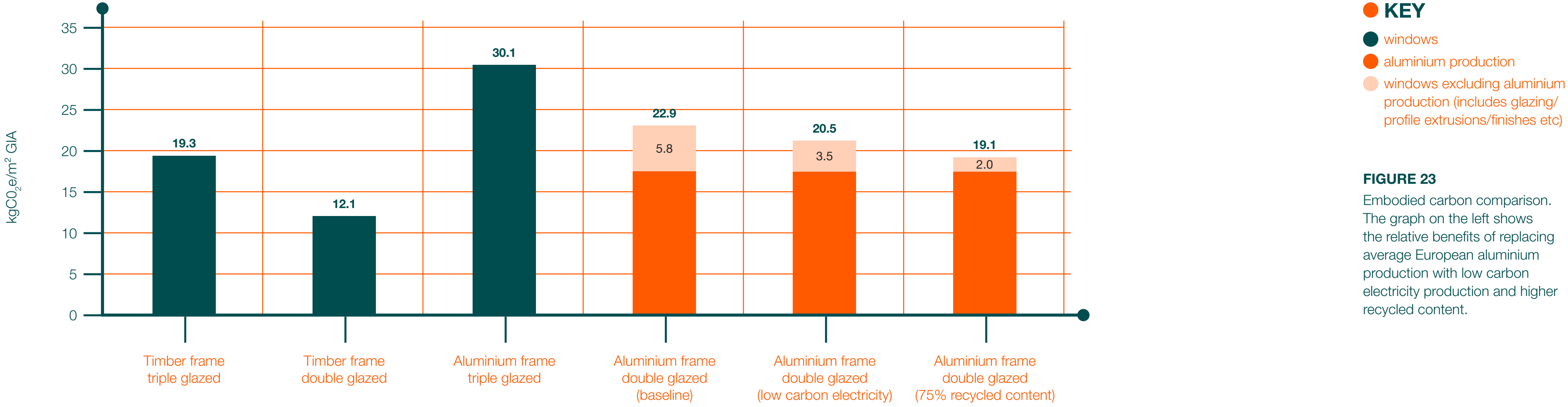


FIGURE 23

Embodied carbon comparison. The graph on the left shows the relative benefits of replacing average European aluminium production with low carbon electricity production and higher recycled content.

The façade bay analysis highlighted that the anodised aluminium windows and external doors accounted for most of the embodied carbon of the façade. This finding directed the design team to examine options for reducing embodied carbon of these elements. For example, one detailed study focussed on windows, but the results informed consideration of other aluminium façade elements.

EPDs were utilised for a detailed investigation of embodied carbon rather than materials databases. The study evaluated the benefit of low-carbon production aluminium (e.g. using hydro electricity) and recycled aluminium[88] for windows alongside timber alternatives in order to reduce the carbon intensity of the façade.

NOTES	The figure listed below assumes the world average recycled content of 31%	Aluminium production using renewable energy such as electricity produced by hydroelectric plants can reduce carbon emissions by 40% compared to average European production	Typical European aluminium profiles have recycled contents of 20-40%. Although increasing the RC is possible, it may affect the effectiveness of applying certain finishes. Eg. PPC is better suited to aluminium with high RC compared to anodising
EMBODIED CARBON ($kgCO_2e/kg$ aluminium)	6.7	4.0	2.3
LINKS TO PRODUCTS		Alcoa Ecolum LINK Hydro Reduxa LINK	Hydro Circal 75r LINK

89 For information on the use of low-carbon aluminium and its place in the life cycle assessment see this whitepaper here.

Whole life carbon model and assessment

Iterative WLC modelling was essential for detailed analysis of various options to reduce the total carbon emissions of the project.

The WLC model was developed by a whole life carbon specialist in collaboration with the design team. The model was based on RICS guidelines using the software platform One Click LCA[89] in line with London Plan recommendations. This was the main reference point for understanding the embodied carbon emissions (upfront, in use, and end of life) of the whole development and their relationship to operational energy emissions. Most importantly it brought the various studies described earlier together to consider their collective impact on reducing the total carbon emissions of the project.

Development of the whole life carbon model

The model was developed and updated using several data sources:

- The cost plan providing quantities and an evaluation framework.
- Consultant Revit models providing materials and volumetric information.
- Results from operational energy calculations from the dynamic thermal model.
- The results of iterative analysis by the consultants.
- Product and material information such as EPDs.

Regular fortnightly meetings were held with the design team and the whole life carbon specialist to support data drops and to address gaps in information.

While One Click LCA incorporates a database of EPDs there were instances where there was no qualifying data on a material or product. In these cases an equivalent or similar carbon product or material was used. Geographically and technologically appropriate data was selected based on the project location and the anticipated supply chains.

Early contractor engagement supported the development of the WLC model. The contractor was able to:

- provide information about site activities (e.g. the extent to which site activities could be electrified and how often formwork could be re-used);
- provide information about base values for demolition and deconstruction;
- provide opportunities to engage with supply chains.

Distribution of results

The results from One Click LCA, with all modules collated and calculated were processed and issued at the end of each RIBA work stage to the design team and client. However, the importance of regular updates necessitated the release of interim reports between work stages to support decision making. The size of the WLC model and challenges around bringing together information from numerous sources prevented the release of information more frequently than this.

Interaction of the WLC model with the architecture

It was important that the data from the architecture models were not simply volumes from the BIM models but that this information provided correction factors considering the qualities of a material or component. The façade data, based on the latest working RIBA Stage 3 design proposal, was provided separately by AHMM, which included the office and the residential façades.

This information was taken from the architectural BIM model operated by AHMM, and was split into material volumes, some of which were assigned conversion factors to derive accurate volumes for input into the model. AHMM also provided data for the residential façades.

Challenges around co-ordinating the WLC model

Careful programming was needed to co-ordinate the release of the WLC reports. This was becuase the WLC model was, in part, based on cost modelling, the timing of which typically sits outside of the design team release schedule. As a result it was not always possible to co-ordinate the release of the full WLC assessment with the latest design at times appropriate to fully support the further development of the design.

90 One Click LCA is lifecycle assessment software used to calculate and reduce the environmental impacts of buildings and products.

RICS WLC Modules	**IMPACT** (kg C02e)	**PROPORTION** (%)	**INTENSITY** (kg C02e/m2 GIA)
A1-A5	52,707,632	60%	598
B1-B5	32,671.624	38%	371
B6	12,743,577	12%	145* (1016 without grid decarbonisation)
B7	6,409,401	6%	72
C1-C4	1,181,611	2%	21

FIGURE 24
This table provides an overview of the whole life carbon of the whole project.

*Operational carbon includes grid decarbonisation based on BEIS projections.

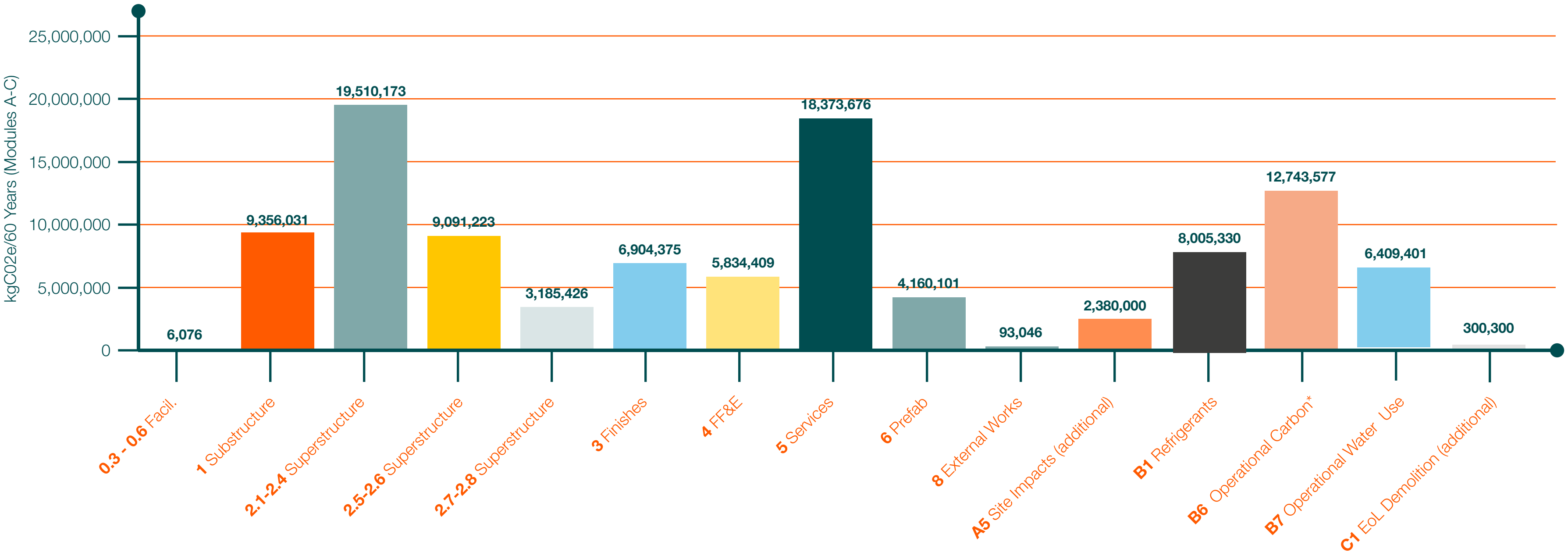
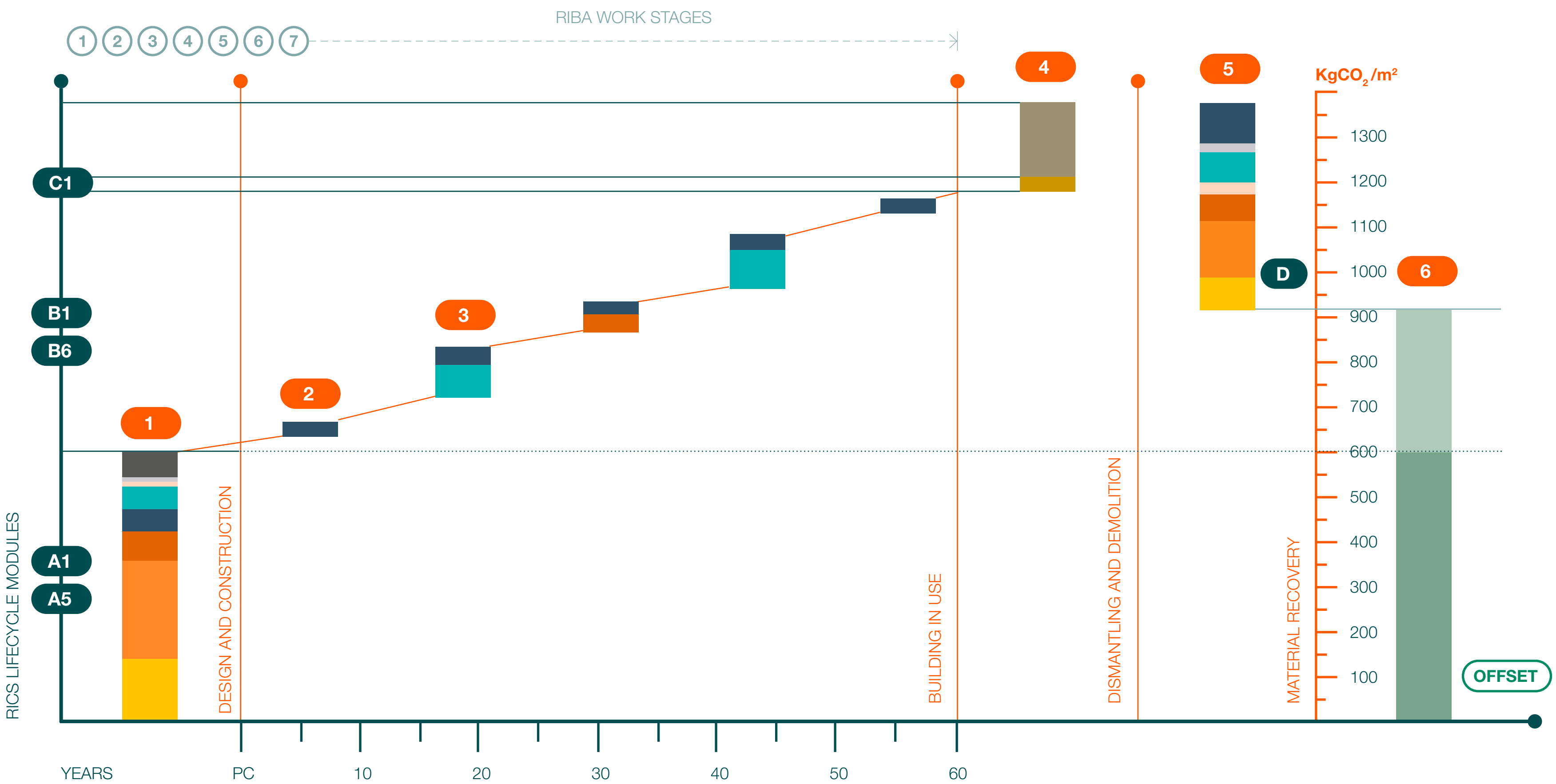


FIGURE 25
The chart provides a breakdown of the upfront embodied carbon of the case study project.

These results are from the draft RIBA Stage 3 WLC model and provide an overview of the carbon emissions of the project. The analysis is based on a sixty year building life and breaks down the emissions by RICS stage and building component.

The results indicate that embodied carbon (and upfront carbon in particular) will form the bulk (60%) of the project's emissions.



1 Embodied carbon minimised in the base design

2 Operational carbon minimised in the base design with digtial twins to help identify and address performance gaps.

3 Long life, loose fit appproach to support change over the life of a building.

4 Incorporating design for dissassembly principles to minimise material loss.

5 Materials passport to maximise opportunities for end of life recovery of resources.

6 Power purchase agreements to match operational carbon and transition fund to compensate for embodied carbon.

KEY

- substructure
- sequestration
- superstructure
- services
- stairs
- transition fund offsetting
- external walls
- roof
- other
- offsite renewables
- internal construction
- lifecycle carbon
- demolition
- material loss
- operational carbon

FIGURE 26

The chart provides a breakdown of the whole life carbon of the case study project.

Material passports and digital twins

Two key elements of the client's net zero strategy for this project were the use of materials passports and the development of digital twins.

Materials passports

The client's aim to fully realise the residual value of the development at end of life was incorporated into the sustainability brief which required the development of materials passports and end of life reuse scenarios for all materials. The design team followed circular economy principles which optimised the design for longevity and design for disassembly. Materials passports will be developed with subcontractor input as part of the Stage 4 design.

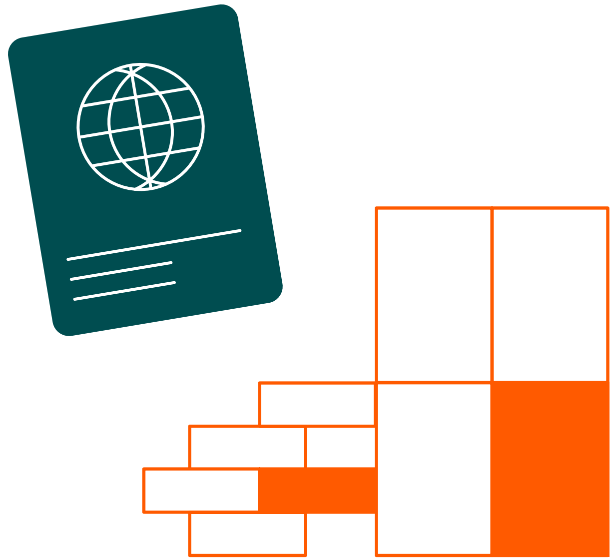
The digital twin

At an operational level the digital twin was tied to the implementation of a performance-based standard, NABERS. This involved a detailed dynamic simulation model incorporating low energy systems, IT equipment, HVAC systems. The intention is that this model should replicate the building as it is expected to operate using best practice inputs and principles. [90]

Regarding embodied carbon, it was anticipated that this aspect of the digital twin would be tied to the database created through the Madaster platform. [91]

91 Handbook for estimating NABERS ratings.

92 Madaster is an online registry for materials and products that provides information about circularity.




3

Case study summary and key lessons

The case study provides a number of key lessons for the development of net zero carbon buildings.

1 Carry out iterative performance based modelling

The design of the case study followed a pattern, typical for a project of this nature, of exploring a range of options and then narrowing these down, at the same time undertaking ever more detailed analysis. However, it is significant that overlaid on this process was the interrogation of the approaches based on the use of iterative performance-based modelling, analysing the progress of the design in meeting key metrics.

2 Set clear and ambitious targets

It was essential to set clear and ambitious targets for the net zero carbon requirements of the development. These targets were realistic, based on industry benchmarks representing best practice, but challenging. It is also significant that at the outset of the project it was decided that the operational energy performance targets should be based on in-use performance.

3 Appointments to support delivery

Ensure that the appointments to support the delivery of project net zero ambitions are sufficient. Significant work is required to meet the challenge of delivering net zero carbon buildings and it is important that the project teams understand their responsibilites and are appropriately resourced.

4 Communication is key

It was important that the setting of net zero as a project aspiration was communicated at the outset rather than considered as an afterthought or relayed later in the design process. This approach allowed for the development of secondary targets to meet this aspiration.

5 Early contractor involvement

Early contractor involvement (at RIBA Stage 3) brought new options to the design process and opportunities for sub-contractor engagement.

6 Team coordination

Team coordination was a critical part of the design process. It was necessary for each consultant to bring their own analysis skills to the embodied carbon calculations. It was also important that this analysis could be brought together in the whole life model to chart the progress of the design against the carbon reduction targets.

7 Design team capabilities

The capability of the design team to support the client aspiration was essential for delivering carbon reductions on this project. The architects, with the support of the building performance team, were able to conduct detailed embodied carbon analysis.

Dr Craig Robertson
Head of Sustainability
at AHMM

This guide has been nearly three years in the making, conceived by Matt Murphy and me as we took part in the Climate Strike march to Parliament Square in 2019. Initially, it was intended to address what we saw as a gap in zero carbon guidance to address the kinds of projects that we are working on at AHMM.

We are launching the guide into a very different context. Since 2019, our industry has gone through a sea change in focus. The prominence of carbon in both public discourse and design team meetings is unrecognisable compared to three years ago.

This is exciting to those of us who have been pushing the sustainability boulder up a seemingly Sisyphean hill for most of our careers – there might be a summit! But it also speaks to the seriousness of climate emergency and the urgency with which we must act. I hope this guide can help our industry move to zero carbon and regenerative architecture with the required rapidity.

At AHMM, we are constantly learning more as we apply this new zero-carbon framework to our range of complex and varied projects. For that reason, this digital guidance will be a live document, updated as we learn. It will soon be accompanied by tools to help calculate and communicate a carbon story.

We welcome feedback and comment, as well as the opportunity to discuss and collaborate to develop our thinking together.

zerocarbon@ahmm.co.uk

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GLOSSARY AND REFERENCES

Glossary

A

Active buildings The active buildings concept identifies that it is possible for many buildings to be operationally zero carbon, generating a surplus of renewable energy, through the considered application of renewable technologies and storage (such as batteries and heat stores). However, this approach requires balancing the operational demands of the building with the demands of the grid, and balancing uplifts in embodied carbon with operational savings.

Additionality A form of offsetting where the purchaser will invest in extra grid capacity from an energy provider and this is called an Additionality, that is, the additional energy capacity provided, in solar, wind power etc. equivalent to the residual operational energy of the building.

B

Biogenic sequestration Biogenic sequestration describes the natural process plants have developed to remove these carbon emissions from the atmosphere by fixing it within carbohydrates (for plant growth) in their tissues.

C

Carbon accounting, or 'greenhouse gas accounting', refers to the methods used to estimate the carbon emissions of a business.

Carbon offsetting is sometimes required for a building project to meet net zero carbon commitments. Where residual carbon emissions are unavoidable, methods such as carbon sequestration and financing renewables offsite can be applied.

Carbon neutral 'Net zero carbon' and 'carbon neutral' are often used interchangeably, but the two are not technically the same. Carbon neutrality is achieved when an organisation delivers zero direct and indirect carbon emissions. However to achieve 'net zero carbon' an organisation must also account for other indirect emissions outside of their direct control, for example those generated by suppliers.

Carbon sequestration describes the process of storing carbon in a pool or 'carbon sink'. It can be a natural or artificial process and is described in greater detail under carbon offsetting.

Carbon sink describes anything that absorbs and stores more carbon from the atmosphere than it releases. In construction engineered timber is a carbon sink, as opposed to cement and concrete which are carbon intensive to produce. The building as a carbon sink concept turns buildings into long term carbon stores e.g. through use of engineered timber.

Circular economy is a model of production and consumption based on natural systems that prioritises reuse, regeneration and recycling, over single use materials and disposal.

Climate positive Climate positive (or carbon negative or regenerative) means taking actions that go beyond achieving net zero carbon emissions to actually create environmental benefits and reverse the harm previously and currently caused to natural systems by humans.

Climate resilience refers to the ability of the building to maintain its function and support its users in the changing climate.

D

Design for disassembly This strategy ensures that buildings are designed in ways that aid dismantling and every component can be recycled or reused at the end of the building's lifespan.

Digital twin A digital twin connects physical and digital systems to provide a record of the building at the point of practical completion, and a record of the net zero carbon strategies; and it can be a tool for evaluating and optimising the performance of the building in use.

E

Embodied Carbon Refers to the material that is extracted, harvested or gathered, then processed and assembled offsite and onsite to construct, refurbish or repair a building.

Energy use intensity (EUI) The energy use intensity (EUI) of a building is determined by the energy balance from external heat losses and gains, internal heat gains, heating and cooling requirements, lighting, power use for equipment and other uses expressed as kWh/m^2.yr.

Environmental product declaration (EPD) An EPD is an independently verified document providing information about a product's environmental impact. EPDs, which last 5 years, provide a basis of Life Cycle Assessment (LCA) calculations, and quantitative basis for comparison of products and services.

F

Form factor, or 'heat loss form factor' is a measurement used in Passivhaus and high performance building design. The ratio of thermal envelope surface area to treated floor area is used to determine how energy efficient the building will be once it is operational.

G H I

Inventory of Carbon and Energy (ICE) database The ICE database details the embodied carbon found in building materials.

J K L

Lifetime embodied carbon Lifetime embodied carbon includes maintenance and replacement of materials and replacement of components throughout the life of the building, and the eventual demolition and disposal of a building at the end of its life.

M

Madaster is an online registry for materials and products that provides information about circularity.

Material passports record the characteristics of building materials and components and assign a value for their present use, recovery, and reuse.

N O

Net zero carbon is an approach to acheiving a balance of carbon emissions with mitigation measures based on identifying and reducing direct and indirect emissions associated with a building where possible.

One click LCA is life cycle assessment software used to calculate and reduce the environmental impacts of buildings and products.

Operational carbon is operational energy associated with the use of electrical power, heating and cooling systems for the benefit of a buildings' users.

Oxford Offsetting Principles The Oxford Offsetting Principles provide guidelines to ensure offsetting is aligned to achieve a net zero society and provide a resource for the design and delivery of rigorous voluntary net zero commitments by government, cities and companies.

P

Passivhaus is a rigorous energy efficiency standard developed by the Passivhaus Institute in Germany where buildings are designed to maintain a constant temperature without additional heating or cooling systems (i.e. minimal to no operational carbon emissions).

Performance gap describes the discrepancy between the designed and anticipated performance of a building and its actual performance in use.

Q R

Reversible buildings This concept essentially applies the circular economy model to construction, with buildings designed to be adapted, transformed and disassembled for reuse.

S T

Thermal envelope The thermal envelope of a building provides the insulation to prevent heat loss and keep the conditioned interior at the required temperature and the air-tight layer that prevents conditioned air from leaking from the building (conditioned air has had an 'investment' of energy and carbon).

Thermal bridges A 'thermal bridge' describes a localised area of intense heat loss in the thermal envelope of a building, where heat escapes due to structure, fixings or service penetrations.

U

Upfront embodied carbon or 'upfront carbon' is generated from the extraction, processing and manufacturing of materials used to make buildings.

V W

Whole life carbon (WLC) Total carbon emissions associated with a building are expressed as whole life carbon (WLC). This is the total embodied and operational carbon created through the total lifespan of a building. WLC includes emissions from manufacturing products and materials assembled into a building, the transportation of products to site and construction activities to assemble a building. During the life of a building WLC will account for the maintenance and replacement of components and all operational energy. Finally, at the end of a building's life WLC accounts for the disposal (or recycling) of materials.

X Y Z

References

1 **More information about KTPs and the role of the programme in developing innovation in UK industries** *https://www.ktp-uk.org/*

2 **Allford Hall Monaghan Morris is a UK architecture practice commitment to the design of buildings of economy, elegance and delight: buildings that reflect a continuing belief in the ability of outstanding architecture to endure.** *https://www.ahmm.co.uk/*

3 **IEDE aims to pursue a deeper understanding of the interactions between the built environment and health, human wellbeing, productivity, energy use and climate change. For more infomation about IEDE.** *https://www.ucl.ac.uk/bartlett/environmental-design/*

4 **For more information about creating Buildings with Positive Impacts see the link below:** *https://www.bamb2020.eu/wp-content/uploads/2019/02/Creating-Buildings-with-Positive-Impacts.pdf*

5 **This article provides a overview of the relative contributions of different British habitats to carbon sequestration:** *https://www.iucn-uk-peatlandprogramme.org/news/carbon-storage-and-sequestration-habitat-2021-nerr094*

6 **For an interesting report abut the role of British forestry in mitigating climate change see the link below:** https://cdn.forestresearch.gov.uk/2022/02/fcrp018-4.pdf

7 **RIBA embodied and whole life carbon assessment for architects:** *https://www.architecture.com/-/media/gathercontent/whole-life-carbon-assessment-for-architects/additional-documents/11241wholelifecarbonguidancev7pdf*

8 **The UKGBC Net Zero Whole Life Roadmap outlines the whole life carbon emissions across the built environment and describes emissions pathway reductions to achieve net zero. The roadmap is available here:** *https://www.ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-A-Pathway-to-Net-Zero.pdf*

9 **A link and further information on this key document can be found in Part 2 - Key processes**. *https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf*

10 **The RIBA Plan of Work organises the process of building development into stages. It is a framework for all disciplines on construction projects and should be used solely as guidance for the preparation of detailed professional services and building contracts. Further information is available here:** *https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work*

11 **Further reading on form factor - Green Building Design: Materials & Techniques on** *https://www.greenspec.co.uk/*

12 **Find out out more on the Passivhaus Institute website:** *https://passivehouse.com/*

13 **The Global Status Report for Buildings and Construction is a reference document published by the UN Environment Programme (UNEP). It is published annually and tracks the impact of the construction sector and built environment on global carbon emissions:** *https://globalabc.org/resources/publications/2021-global-status-report-buildings-and-construction*

14 **GLA Construction Scope 3 (Embodied):** *https://www.london.gov.uk/sites/default/files/gla_construction_scope_3_embodied_greenhouse_gas_accounting_and_reporting_guidance_vfinal_1.pdf*

15 **The LETI Embodied Carbon Primer provides an overview of embodied carbon in buildings and provides breakdowns of embodied carbon by building element:** *https://www.leti.uk/ecp#:~:text=The%20Embodied%20Carbon%20Primer%20offers,carbon%20reduction%20strategies%20and%20calculations.*

16 **CIBSE TM65 outlines an approach to assess embodied carbon of products linked to mechanical, electrical and public health (MEP) systems:** *https://www.cibse.org/knowledge-research/knowledge-portal/embodied-carbon-in-building-services-a-calculation-methodology-tm65*

17 **AHMM's Founders' Statement, published in 2018, describes the aims, values and ambitions which underpin the practice and describes how 'a commitment to buildings of economy, elegance and delight' is at the core of the approach of the practice:** *https://www.ahmm.co.uk/assets/uploads/AHMM_The_Founders_Statement.pdf*

18 **An interesting essay on the benefits of efficiency, economy and elegance for ecological design:** *https://www.block.arch.ethz.ch/brg/files/2019_BLOCK_Design_E4-efficiency-economy-elegance-ecology_1548554587.pdf*

19 **This High Performance Buildings article provides an informative and useful critique of EUIs and is available here:** *https://www.hpbmagazine.org/content/uploads/2020/04/10Su-Building-Energy-Use-Intensity.pdf*

20 **A Carbon Trust guide to the building fabric is available here (note: registration required):** *https://prod-drupal-files.storage.googleapis.com/documents/resource/restricted/Building%20Fabric%20Guide%20-%20GBF%20Carbon%20Trust.pdf*

21 **A guide to thermal bridges can be found here (the focus of the document is on domestic construction):** *https://www.labc.co.uk/sites/default/files/resource_files/zch-thermalbridgingguide-screen.pdf*

22 **More information about active buildings including a link the active buildings design guide is available here:** *https://www.specific.eu.com/what-are-active-buildings/*

23 **This is a summary of ventilation actions to mitigate the risk of COVID-19 by the SAGE Environment and Modelling Group:** *https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2017/12/05152120/Healthy-Homes-Full-Report.pdf*

24 **Berkeley Labs provide a useful introduction to thermal comfort and its relationship to minimising energy use:** https://www.osti.gov/servlets/purl/1169480

25 **The UK Green Building Council document Health and Wellbeing in Homes outlines the benefit of quality of environment on health and wellbeing:** *https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2017/12/05152120/Healthy-Homes-Full-Report.pdf*

26 **TM52 The limits of thermal comfort: Avoiding overheating in European buildings is about predicting overheating in buildings:** *https://www.cibse.org/knowledge-research/knowledge-portal/tm52-the-limits-of-thermal-comfort-avoiding-overheating-in-european-buildings*

27 **RIBA guidance on Post Occupancy Evaluation is available here:** *https://www.architecture.com/knowledge-and-resources/resources-landing-page/post-occupancy-evaluation#available-resources*

28 **A Carbon Trust guide to renewable technologies is available here:** *https://prod-drupal-files.storage.googleapis.com/documents/resource/restricted/Renewable%20energy%20guide%20-%20GBF.pdf*

29 **A Carbon Trust guide to energy storage is available here:** *https://prod-drupal-files.storage.googleapis.com/documents/resource/restricted/Energy%20storage%20guide%20-%20GBF.pdf*

30 **Louis I. Kahn in World Architecture, 1964**

31 **Stewart Brand's book How Buildings Learn: What Happens After They're Built is a good primer on the evolution of buildings and how buildings adapt to changing requirements over long periods:** *https://en.wikipedia.org/wiki/How_Buildings_Learn*

32 **RICS guidance outlining a whole life approach to reducing carbon emissions within the built environ-**

LINKED CONTENT

Full URLs for all footnotes and external links can be found here.

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CONTACT HERE

ment is available here: https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf

33 **A Mayor of London Design For A Circular Economy Primer is available here:** *https://www.london.gov.uk/sites/default/files/design_for_a_circular_economy_web_2.pdf*

34 **This article offers a good overview of design for disassembly:** *https://www.archdaily.com/943366/a-guide-to-design-for-disassembly*

35 **A guide to the reversible buildings concepts is available here:** *https://www.bamb2020.eu/wp-content/uploads/2019/05/Reversible-Building-Design-Strateges.pdf*

36 **An ORMS guide to materials passports can be found here:** *http://orms.co.uk/~ormscouk/wpo/wp-content/uploads/2021/05/Orms-Materials-Passports_flipbook-correct-QR.pdf*

37 **The AIA provide an informative guide on designing for adaptability, deconstruction, and reuse:** *https://content.aia.org/sites/default/files/2020-03/ADR-Guide-final_0.pdf*

38 **An interesting article on the Circular Economy and a link to the academic paper supporting it is available here:** *https://www.linkedin.com/pulse/building-lifespan-function-sustainability-yes-really-rob-marsh/*

39 **A phrase borrowed from Architecture Foundation article:** *https://www.architecturefoundation.org.uk/writing/so-what-does-a-building-that-has-burped-70-less-carbon-in-its-creation-look-like*

40 **An energy positive approach can be used to address the embodied carbon emissions of a new development. Here a building 'pays back' it's production emissions through an energy surplus. There are questions about the benefit of an energy surplus if storage is not used and the excess is not balanced with electricity grid requirements (offloading surplus energy into the grid when it is not required is not considered net zero carbon). For a building standard based on this approach see DGNB Climate Positive and for examples of buildings achieving this see here:** *https://www.dgnb.de/en/topics/climatepositive/index.php*

41 **For more information about the concept of buildings as carbon sinks see the article below:** *https://sustainabilitycommunity.springernature.com/posts/59221-buildings-as-a-global-carbon-sink*

42 **More information can be found in this article:** *https://journal-buildingscities.org/articles/10.5334/bc.46/*

43 **See this UCL article on the true cost of carbon offsets:** *https://www.ucl.ac.uk/news/2021/jun/ten-fold-increase-carbon-offset-cost-predicted*

44 **UKGBC guidance on the procurement of renewable energy and carbon offsets for net zero buildings is available here:** *https://www.ukgbc.org/ukgbc-work/renewable-energy-procurement-and-carbon-offset-guidelines/*

45 **The Moral Economy of Carbon Offsetting: Ethics, Power and the Search for Legitimacy in a New Market - a PhD thesis providing a critique of offsetting:** *https://www.research.manchester.ac.uk/portal/files/55558851/FULL_TEXT.PDF*

46 **The Oxford Offsetting Principles provide guidelines to ensure offsetting is aligned to achieve a net zero society and provide a key resource for the design and delivery of rigorous voluntary net zero commitments by government, cities and companies:** *https://www.smithschool.ox.ac.uk/sites/default/files/2022-01/Oxford-Offsetting-Principles-2020.pdf*

47 **The practice of purchasing an indulgence was a means by which an individual could reduce the length and severity of punishment that heaven would require as payment for their sins and has been compared the purchase of carbon offsets in the present day:** *https://www.monbiot.com/2006/10/19/selling-indulgences/*

48 **A paper highlighting the risk of forest carbon offset reversal because of climate change:** *https://www.sciencedirect.com/science/article/pii/S0006320721002767*

49 **More information on PAS 2060 is available here**: *https://knowledge.bsigroup.com/products/specification-for-the-demonstration-of-carbon-neutrality-1/standard*

50 **This Royal Academy of Engineering outlines the scope of the construction industry and the importance of procurement and supply chains on decarbonisation:** *https://nepc.raeng.org.uk/policy-work/net-zero/decarbonising-construction*

51 **This document provides case studies where measures to encourage sustainable behaviour have been implemented:** *https://raeng.org.uk/media/lvpisgkr/built-for-living.pdf*

52 **A link to a report by Blekinge Institute of Technology within the project Energy Making Climate-Positive Buildings and Building Systems Sustainable is available here:** *https://www.diva-portal.org/smash/get/diva2:1609764/FULLTEXT01.pdf*

53 **A link to the Buildings as Materials Banks guide to 'Creating Buildings With Positive Impacts is available here:** *https://www.bamb2020.eu/wp-content/uploads/2019/02/Creating-Buildings-with-Positive-Impacts.pdf*

54 **Further information about the Climate Positive Design initiative and the Climate Challenge is available here:** *https://climatepositivedesign.com/challenge/*

55 **Papers on the potential for buildings and built environment include:**

Buildings as a global carbon sink on the potential for the built environment to be a carbon sink is available here: *https://www.usablebuildings.co.uk/UsableBuildings/ProbeListAll.html*

A paper on the potential of cities to act as carbon sinks is available here: *https://www.ukri.org/publications/non-domestic-buildings-best-practice-and-what-to-avoid/*

A paper on the limits and feasibility of buildings as a global carbon sink is available here. *https://www.frontiersin.org/articles/10.3389/fmech.2015.00017/full*

56 **This IPCC report on the role of buildings in global decarbonisation outlines the role that economics, behaviour change and improvements in consumer electronics will have on the building sector:** *https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter9.pdf*

57 **There are several documents describing the operational performance gap and links to some of these are provided below: The Probe project, which started in 1995, undertook post-occupancy surveys of new commercial and public buildings, typically 2-3 years after completion - further information is available here:** *https://www.usablebuildings.co.uk/UsableBuildings/ProbeListAll.html*

Findings from the Innovate UK Building Performance Evaluation Programme for non-domestic projects are available here: *https://www.ukri.org/publications/non-domestic-buildings-best-practice-and-what-to-avoid/*

And findings from the Innovate UK Building Performance Evaluation Programme for domestic projects are available here: https://www.ukri.org/publications/low-carbon-homes-best-strategies-and-pitfalls/

An important paper outlining the underlying causes for the performance gap: *https://www.frontiersin.org/articles/10.3389/fmech.2015.00017/full*

58 **A link to CIBSE document TM61 providing further details on the scope and nature of the operational energy performance gap is available here (purchase required):** *https://www.cibse.org/knowledge-research/knowledge-portal/operational-performance-of-buildings-tm61*

LINKED CONTENT

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59 **A campaign to introduce a Building Regulations amendment 'Part Z' and Approved Document Z which would make mandatory the assessment of whole life carbon emissions, and limits on embodied carbon emissions. More information is available here:** *https://part-z.uk/proposal*

60 **An environmental Product Declaration is An Environmental Product Declaration (EPD) is a independently verified document providing information about a product's environmental impact. EPDs, which last 5 years, provide a basis of Life Cycle Assessment (LCA) calculations, and quantitative basis for comparison of products and services. Further information on EPDs can be found in this ASHP briefing paper here:** *https://asbp.org.uk/wp-content/uploads/2019/12/ASBP-Briefing-paper-EPD-Part-1.-An-Introduction.pdf*

60 **This work examining the potential for an embodied carbon performance gap is informed by the work of two UCL Environmental Design and Engineering MSc graduates who were attached to the KTP project. Their MSc dissertations 'Assessment of Performance Gap in Embodied Carbon Analysis of Buildings – A Case Study' & 'Rise Of The Second Performance Gap?: Investigating The Discrepancies Between Predicted And Actual Embodied Carbon Using A Case Study Building' are at the time of writing being developed into a journal article for publication.**

62 **Department for Business, Energy & Industrial Strategy one page green house gas emissions summary available here:** *https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2020*

63 **Carbon Brief interactive article explaining how the UK has transformed its electricity supply in a decade – and how things are expected to continue changing:** *https://interactive.carbonbrief.org/how-uk-transformed-electricity-supply-decade/*

64 **An interesting paper on decarbonising heating in buildings is available here:** *https://www.creds.ac.uk/wp-content/uploads/CREDS-decarb-transitions-brief-2020.pdf*

65 **The Carbon Risk Real Estate Monitor (CRREM) risk assessment tool for assessing stranding risk is available here:** *https://www.crrem.eu/tool/*

66 **Information about the National Grid Future Energy Scenarios is available here:** *https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021*

67 **The BEIS Energy and Emissions Projections are available here:** *https://www.gov.uk/government/collections/energy-and-emissions-projections*

68 **Read more about flexible grids here:** https://www.carbontrust.com/resources/briefing-flexible-energy-systems

69 **A Carbon Brief article about the potential challenges and benefits of a flexible grid is available here:** *https://www.carbonbrief.org/in-depth-how-smart-flexible-grid-could-save-uk-40-billion/*

70 **A methodology for modelling changes in grid supply was introduced by IEA EBC Annex 67. The methodology quantifies the amount of energy a building can shift in response to external factors without compromising the occupant comfort conditions, Further information is available here:** *https://annex67.org/media/1470/position-paper-energy-flexibility-as-a-key-asset-i-a-smart-building-future.pdf*

71 **This Tyndall Centre for Climate Change Research paper provides a conceptual framework for understanding climate change risk:** *https://www.ipcc.ch/apps/njlite/srex/njlite_download.php?id=5463*

72 **A World Green Building Council report outlines a Health & Wellbeing Framework (Six Principles for a Healthy, Sustainable Built Environment), which is available here:** *https://worldgbc.org/health-framework*

73 **A European Academies' Science Advisory Council report Decarbonisation of buildings: for climate, health and jobs is available here:** *https://easac.eu/publications/details/decarbonisation-of-buildings-for-climate-health-and-jobs/*

74 **For more on carbon accounting**; *https://corporatefinanceinstitute.com/resources/esg/carbon-accounting/*

75 **The DGNB carbon neutral buildings and sites framework provides a comprehensive, practically rules for accounting the CO2 emissions of buildings and sites:** *https://www.dgnb.de/en/topics/climate-action/framework/index.php*

76 **Constructing Excellence briefing paper on procurement:** *https://constructingexcellence.org.uk/wp-content/uploads/2015/03/procurement.pdf*

77 **A report for the Committee on Climate Change by Currie and Brown and AECOM on the costs and benefits of tighter standards for new buildings:** *https://www.theccc.org.uk/wp-content/uploads/2019/07/The-costs-and-benefits-of-tighter-standards-for-new-buildings-Currie-Brown-and-AECOM.pdf*

78 **Information on the ILFI Zero Carbon Standard is available here:** *https://living-future.org/zero-carbon-certification/*

79 **For one definition of a pathways based approach see the UKGBC Paris Proof Method - information available here:** *https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2020/01/05150328/UKGBC-Net-Zero-Carbon-Energy-Performance-Targets-for-Offices.pdf*

80 **The Circular Ecology website provides a link to the ICE database.** *https://circularecology.com/embodied-carbon-footprint-database.html*

81 **A useful primer is the Institution of Engineering and Technology document: 'Digital twins for the built environment: An introduction to the opportunities, benefits, challenges and risks':** *https://www.theiet.org/media/8762/digital-twins-for-the-built-environment.pdf*

82 **Information on the RIBA 2030 Challenge can be found here:** *https://www.architecture.com/about/policy/climate-action/2030-climate-challenge/resources*

83 **Available resources and sustainability outcomes:** *https://www.architecture.com/knowledge-and-resources/resources-landing-page/sustainable-outcomes-guide#available-resources*

84 **More information on British Land's transition fund is available in their sustainability report 'Places People Prefer: Pathway to Net Zero':** *https://www.britishland.com/sites/british-land-corp/files/sustainability/reporting/latest-reporting/pathway-to-net-zero.pdf*

85 **UKGBC energy performance targets for commercial offices aiming to achieve net zero carbon in operation can be found here:** https://www.ukgbc.org/ukgbc-work/*net-zero-carbon-energy-performance-targets-for-offices/*

86 **More information on AHMM's building performance team is available here:** *https://www.ahmm.co.uk/profile/sustainability/*

87 **This blog post provides a useful overview of U-values, Psi-values and G-values for windows at:** *https://www.greenbuildingstore.co.uk/understanding-windows-u-values-psi-values-g-values/*

88 **This CIBSE Journal article provides information about the use of TM59 to address overheating risk for apartments:** *https://www.cibsejournal.com/technical/using-tm59-to-assess-overheating-risk-in-homes/*

89 **For information on the use of low-carbon aluminium and its place in the life cycle assessment see this whitepaper here:** *https://content.comms.euromoneyplc.com/rs/376-KVV-177/images/Rusal-Microsite-Low-carbon-alumin-*

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ium-key-to-sustainable-construction.pdf

90 **One Click LCA is life cycle assessment software used to calculate and reduce the environmental impacts of buildings and products:** *https://www.oneclicklca.com/*

91 **The Handbook for estimating NABERS ratings is available here:** *https://www.nabers.gov.au/file/1941/download?token=Qi0PXBBO*

92 **Madaster is an online registry for materials and products that provides information about circularity.** *https://madaster.com/*

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THE BARTLETT
INSTITUTE FOR ENVIRONMENTAL DESIGN AND ENGINEERING

Central House
14 Upper Woburn Place
London WC1H 0NN
www.ucl.ac.uk/bartlett/environmental-design

ALLFORD HALL MONAGHAN MORRIS

Morelands
5-23 Old Street
London EC1V 9HL
T +44 (0)20 7251 5261
F +44 (0)20 7251 5123
www.ahmm.co.uk
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