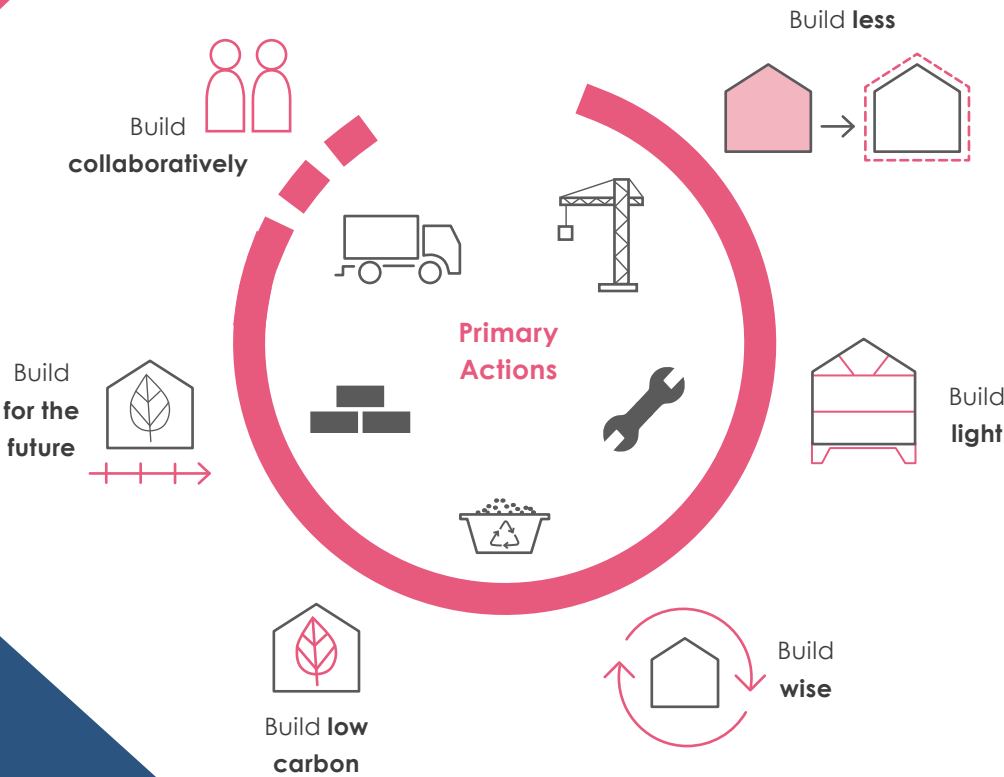


LETI Embodied Carbon Primer

Supplementary guidance to the Climate Emergency Design Guide



About LETI

The London Energy Transformation Initiative (LETI) was established in 2017 to support the transition of the capital's built environment to net zero carbon, providing guidance that can be applied to the rest of the United Kingdom (UK).

We do this by:

- **Engaging with stakeholders** to develop a robust and rapid energy reduction approach, producing effective solutions to the energy trilemma of security, sustainability, and affordability;
- **Working with local authorities** to create practicable policy alterations to ensure the regulatory system is fit for purpose, placing verified performance at its core;
- **Encouraging and enabling collaboration** within a large, diverse group of built environment professionals; and
- **Providing technical advice to support exemplar developments**, enabling leaders who want to deliver net zero carbon buildings.

LETI is a network of over 1,000 built environment professionals who are working together to put London on the path to a zero carbon future. The voluntary group is made up of dedicated and passionate developers, engineers, housing association professionals, architects, planners, academics, sustainability professionals, contractors, and facilities managers, with support and input provided by

the Greater London Authority (GLA) and London boroughs. LETI was established for these groups to work collaboratively to put together evidence-based recommendations for two pieces of policy – the new London Environment Strategy and the rewrite of the London Plan (planning policy guidance published by the GLA). Many of the recommendations that LETI put forward to the GLA have been included in emerging London policy and Energy Assessment Guidance.

Over the last year LETI has focused on providing this guidance on defining what 'good' looks like in the context of the climate emergency for new buildings. This report is the culmination of these efforts. These ideas will inevitably refine and evolve over time.

For more information on LETI, please see: www.LETI.london





Acknowledgements



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Executive summary

The climate emergency - a call to action

We are in a climate emergency, and urgently need to reduce carbon emissions. Here in the UK, 49% of annual carbon emissions are attributable to buildings (see Figure 1.1). Over the next 40 years, the world is expected to build 230 billion square metres of new construction – adding the equivalent of Paris to the planet every single week¹ – so we must act now to meet the challenge of building net zero developments.

LETI, along with others such as the World Green Building Council and Architecture 2030, believe that in order to meet our climate change targets all new buildings must operate at net zero carbon by 2030 and all buildings operate at net zero carbon by 2050. This document provides practical solutions to set out a definitive journey, beyond climate emergency declarations, into a net zero future. To this end, the solution to meeting our climate change targets must be:

- **Scalable:** Energy consumption targets are set so that there is enough renewable energy to power all buildings in the UK.
- **Achievable:** A comprehensive modelling study has been undertaken, and in-use data from buildings analysed, so that the targets, while ambitious to achieve, are deemed achievable for most projects.
- **Verifiable:** Targets are measured in-use.
- **Whole Life:** Embodied carbon and operational carbon must both be considered.

For this document Net Zero Carbon means Whole Life Carbon. **Whole life carbon** is formed of two key components:



Operational Carbon: A new building with net zero operational carbon does not burn fossil fuels, is 100% powered by renewable energy, and achieves a level of energy performance in-use in line with our national climate change targets.



Embodied Carbon: Best Practice targets for embodied carbon are met, and the building is made from re-used materials and can be disassembled at its end of life in accordance with circular economy principles.

The built environment industry, together with current regulations and practices, are seriously lagging behind the carbon trajectory required to protect life on planet earth. Everyone's future is at stake. As an industry we must be absolutely confident that all new buildings can operate at net zero carbon from 2030.

Embodied Carbon : The carbon emissions emitted producing a building's materials, their transport and installation on site as well as their disposal at end of life.



Products



Transport



Construction



Maintenance and replacement



End of life disposal



In order to achieve this, LETI believes that by 2025, 100 percent of new buildings must be designed to deliver net zero carbon, and the whole construction industry will need to be equipped with the knowledge and skills necessary.

To set us on this trajectory, LETI believes that in 2020, 10 percent of all new buildings need to be designed to deliver net zero carbon (see Figure i). This allows time for lesson learning, knowledge transfer, and market uptake – but only if we all act now.

This document represent LETI's understanding of how we need to be designing to meet our climate change targets in 2020. This primer will evolve over time reflecting changes in carbon budgets, technologies and the capability of industry. LETI is collaborative by nature and is very interested in your feedback, go to the LETI website (<https://leti.london>) to find a general feedback form on the primer.

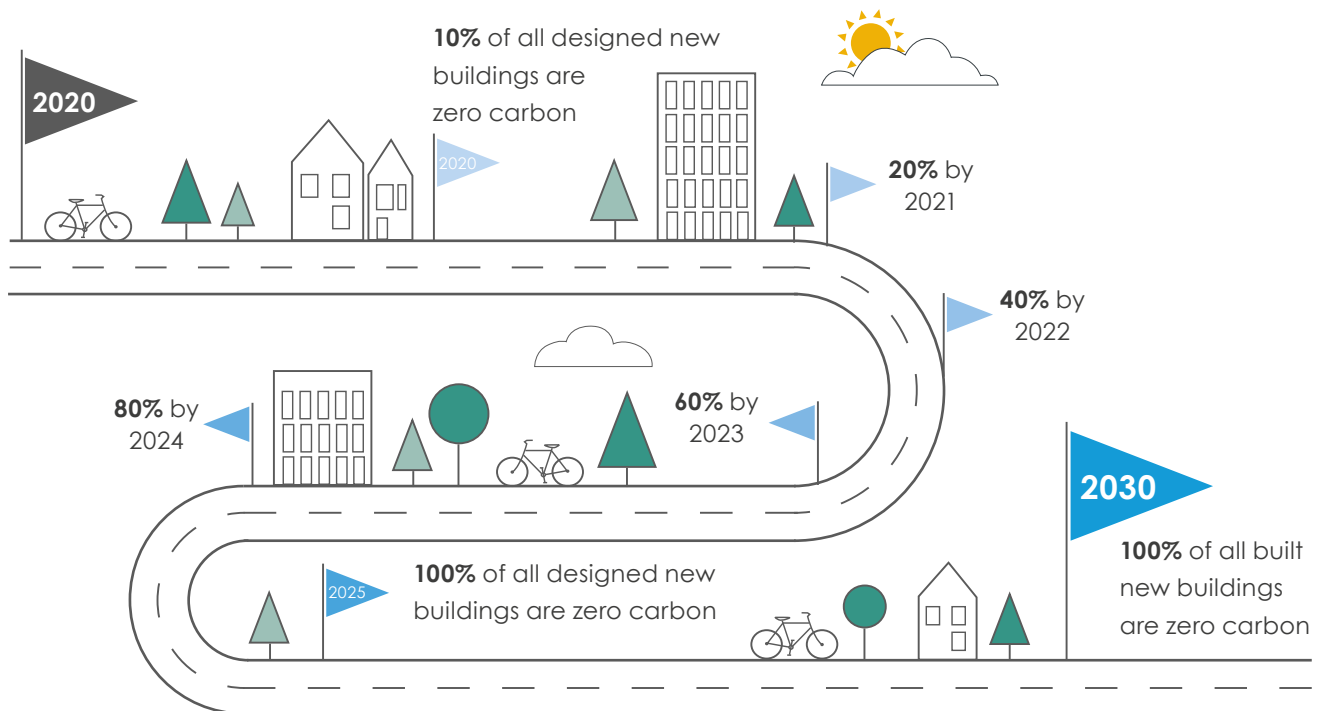


Figure i - LETI – Getting to Zero

Executive Summary

Every stakeholder working in the built environment has a part to play, and all must work together, with the same collective ambition, for net zero carbon to be delivered at scale.

The most aspirational designer can be limited by a client with a narrow strategic vision, and the most aspirational client can be limited by design teams unskilled in delivering net zero carbon. Regulation and policy must be implemented quickly so that the minimum standards are set to deliver net zero carbon.

The LETI Climate Emergency Design Guide

To help industry understand and deliver net zero carbon new buildings, LETI recently published the Climate Emergency Design Guide. The Guide is specifically targeted towards developers, designers and policy makers. It helps to define 'good' and sets clear and achievable targets. It contains five chapters that provide detail on delivery and implementable solutions, with each chapter addressing a key component towards a zero carbon future. Chapter 2 of the Climate Emergency Design Guide addresses embodied carbon.

The LETI Embodied Carbon Primer

This Embodied Carbon Primer offers supplementary guidance to those interested in exploring embodied carbon in more detail. There is lack of knowledge in

the built environment industry surrounding embodied carbon reduction strategies and calculations. Therefore LETI has produced the 'LETI Embodied Carbon Primer', to support project teams to design buildings that deliver ambitious embodied carbon reduction.

Structure of this report

The introduction outlines in further detail the magnitude and challenges that this industry faces, as well as the approach taken by LETI to establish guidance. The introduction also summarises the actions that must be taken at each RIBA design stage as well as the requirements of four key UK building archetypes in relation to embodied carbon reductions.

The diagrams aside show the emissions breakdown of a building lifecycle both in terms of operational carbon and embodied carbon, this makes up whole life carbon.

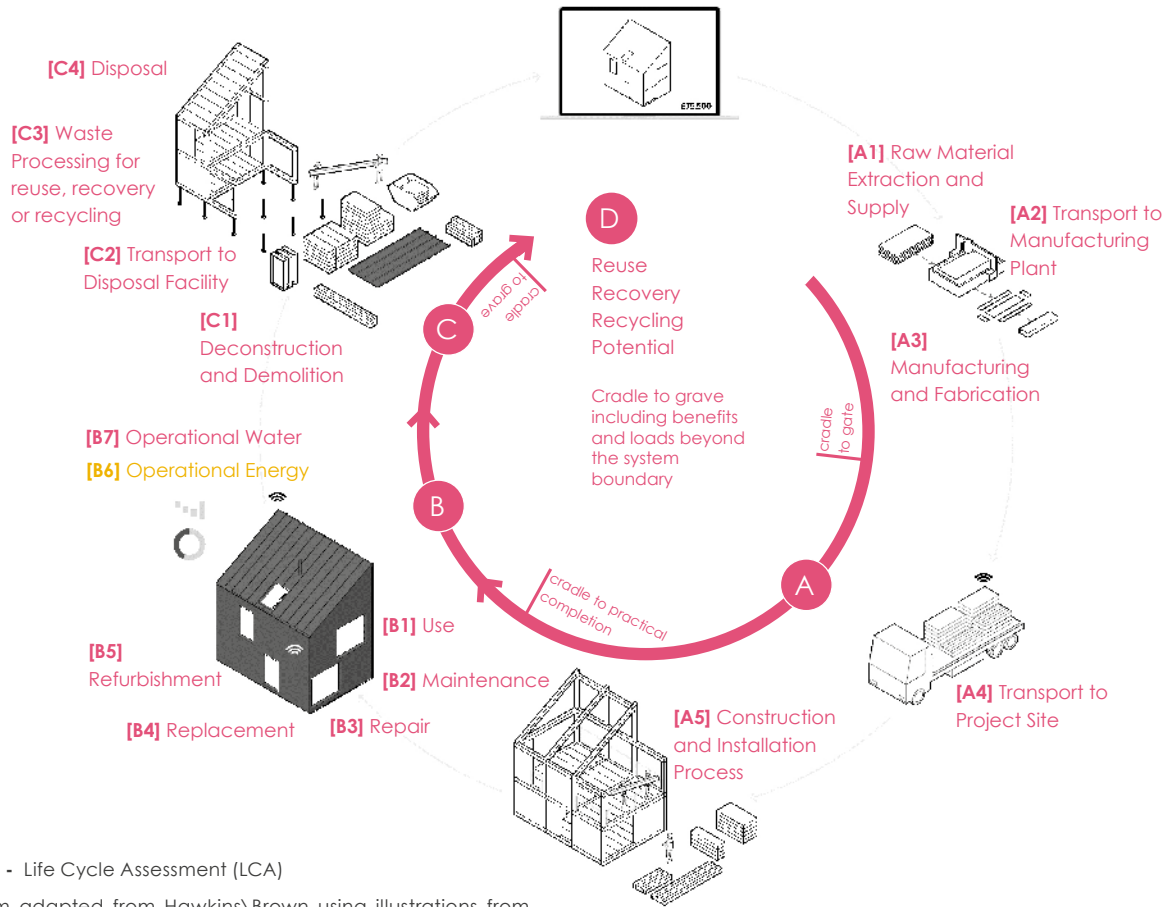


Figure ii - Life Cycle Assessment (LCA)

Diagram adapted from Hawkins\Brown using illustrations from Open Systems Lab 2018 licensed under Creative Commons CC-BY-ND

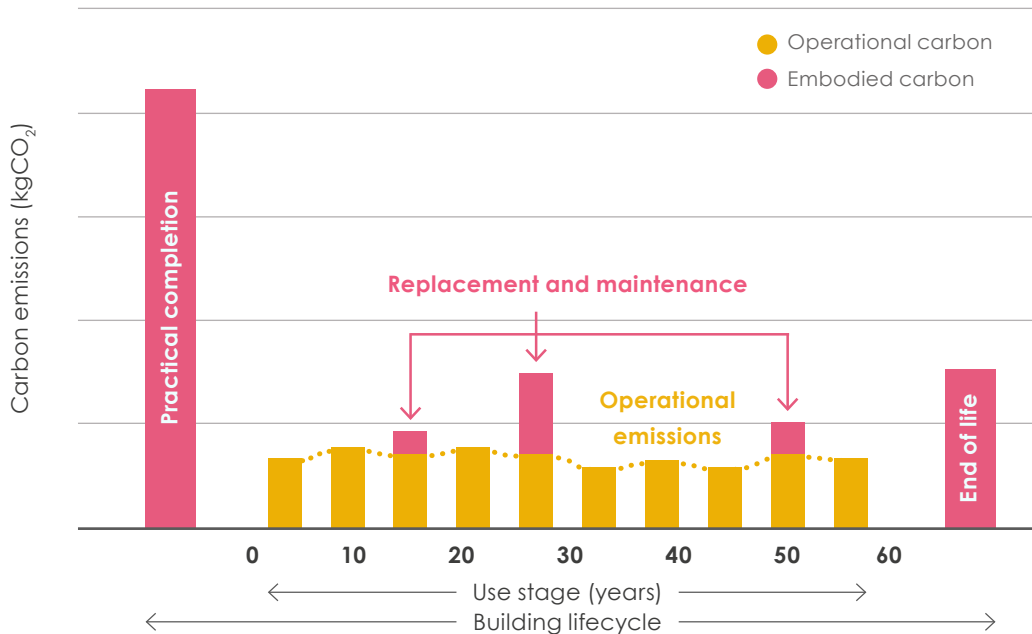


Figure iii - Emission breakdown of a building's life cycle

1. Introduction

We are in a climate crisis and the construction industry is responsible for 49% of carbon emissions in the UK, (see Figure 1.1). Therefore we must take rapid action to decarbonise the building industry.

In order to limit climate change, the UK government is committed to achieving net zero carbon emissions by 2050. LETI along with other organisations believe that this is not sufficient. Global warming is predicted to be limited to 1.5°C only if drastic changes are made, Figure 1.2 shows the magnitude of the change needed to reach net zero carbon.

1.1 Scope of this document

This document is intended to provide designers including architects, engineers, interior designers, urban designers with easy-to-follow best practice and toolkits for reducing embodied carbon in buildings. The document can also aid planners to be aware of strategies available to designers to reduce embodied carbon in building design, and how planning recommendations on materials, massing and treatment of sites may affect embodied carbon. For everyone working in the construction of buildings the leap of knowledge and skill required to be able to fulfil this goal is still relatively large, but far from insurmountable.

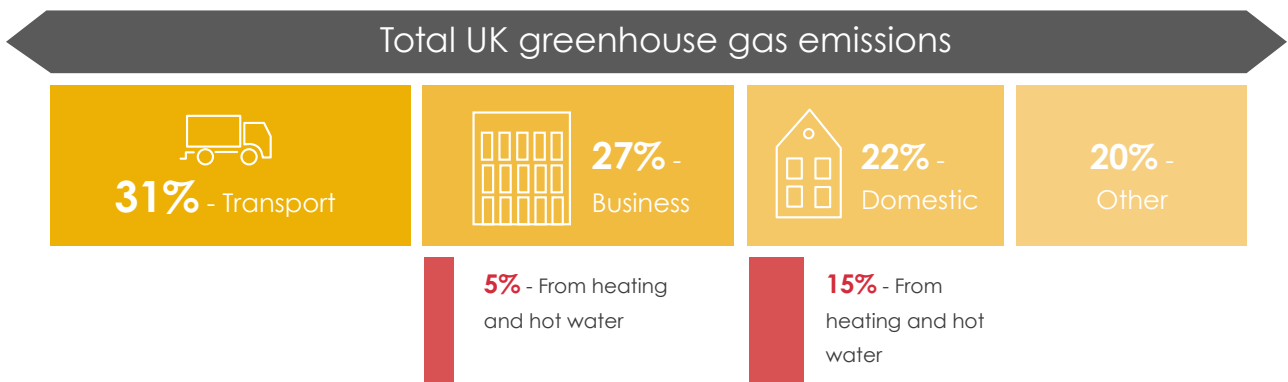


Figure 1.1 - The UK's carbon footprint

Source: Information in figure 0-01 has been developed from a variety of sources. 1. National Statistics, Annex: 1990-2017 UK Greenhouse Gas Emissions, Final Figures by End User, Issued 28/03/19. 2. Committee on Climate Change, UK housing: Fit for the future? February 2019. 3. Committee on Climate Change, Reducing UK Emissions - 2019 Progress Report to Parliament. 4. Environmental Change Institute, 40% House, 2005



Due to the rapidly evolving nature of emerging knowledge in this field this guide should always be read in conjunction with the latest guidance and technical toolkits available, including (but not limited to) those by the UKGBC, RICS, CIBSE and the RIBA, as listed in 'Further Reading'. We hope this document offers easy-to-follow guidance for designers and 'city-makers' (e.g. planners, developers, land-owners) to better understand how to reduce whole life carbon in the design and construction of buildings.

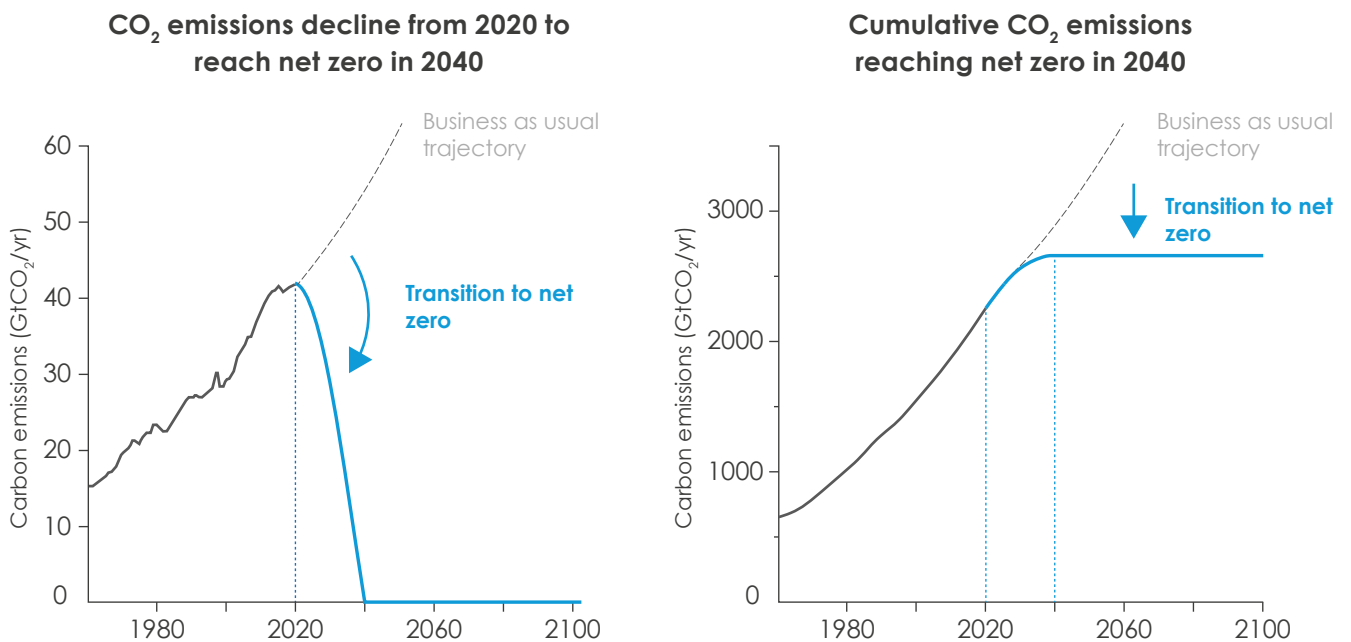


Figure 1.2 - Magnitude of global carbon emission reductions required to limiting warming to 1.5°C. Intergovernmental Panel on Climate Change.

2. The elements of whole life carbon

Net Zero carbon needs to be considered in the context of whole life carbon. Whole life carbon includes operational and embodied carbon, and these need to be understood, and considered, very differently.

2.1 Operational - zero carbon balance

A new building with net zero operational carbon does not burn fossil fuels and is 100% powered by renewable energy, and achieves a level of energy performance in-use in line with our national climate change targets. This means that an operational carbon balance is met, see Figure 2.1. LETI has carried out extensive consultation on the key requirements for net zero operational carbon for new buildings (see Appendix 0.1 of the Climate Emergency Design Guide). No carbon offsets can be used to achieve this balance.

For some building types, such as small scale residential, 100 % of the energy consumption can be met on-site with roof mounted PV panels. Taller buildings have a smaller proportion of roof area to floor area, therefore investment in 'additional' renewable energy off-site will be required. Such investment into additional renewables is not considered an offset.

As well as achieving the 'zero carbon balance' at a building level, it is important that this balance is also achieved at a national level (see Figure 2.2). To meet the UK's climate change targets all buildings must achieve net zero operational carbon. Because the amount of renewables that the UK can produce is limited, to achieve operational net zero carbon at scale in the UK, developments must not exceed their Energy Use Intensity target, and their 'energy budget'.

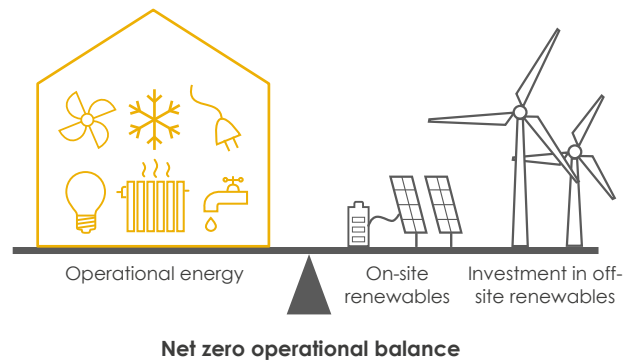


Figure 2.1 - Net zero operational balance - at the building scale

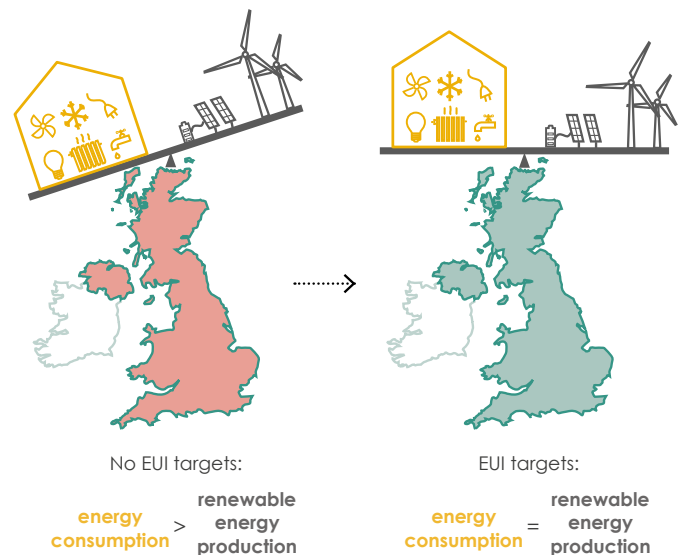


Figure 2.2 - Net zero operational balance - at UK scale



2.2 Embodied carbon – not just about emissions: Building as material resource banks

Operational carbon is based on the flow of energy and needs to be generated through renewables. Constructing buildings uses energy as well as resources, and once a building has come to the end of its life, these resources are still potentially available for use. Thus in addition to reducing embodied carbon we must consider the resources as a 'store' rather than a 'flow' and buildings should be thought of as 'material resource banks'.

The embodied carbon emissions need to be considered within national and regional carbon budgeting. This means the carbon emissions themselves need to be reduced which is why LETI has set embodied carbon targets for the upfront embodied carbon emissions (Building Life Cycle Stage A1-A5). In addition, the material resources used need to be kept in the circular economy. This means the building re-uses materials and products from demolished buildings, and is designed for disassembly, so that materials and products within the building can be re-used in future buildings.

LETI defines 'Whole Life Carbon Best Practice' as a building that meets the operational zero carbon balance, and meets best practice targets for embodied carbon, including upfront embodied carbon targets, proportion of materials from re-used sources and proportion of materials that can be re-used in future buildings.

2.3 Whole life net zero carbon

One school of thought is that offsetting can be used to achieve net zero embodied carbon. However, offsets are a controversial subject, with significant issues related to transparency and effectiveness. LETI have taken a view that circularity is more relevant than offsets for the design team and for policy makers. However as offsets can be seen as means to reduce residual emissions of embodied carbon Appendix 10 gives a dispassionate review of offsetting, looking at the advantages, disadvantages and technical and societal challenges to its effective implementation.

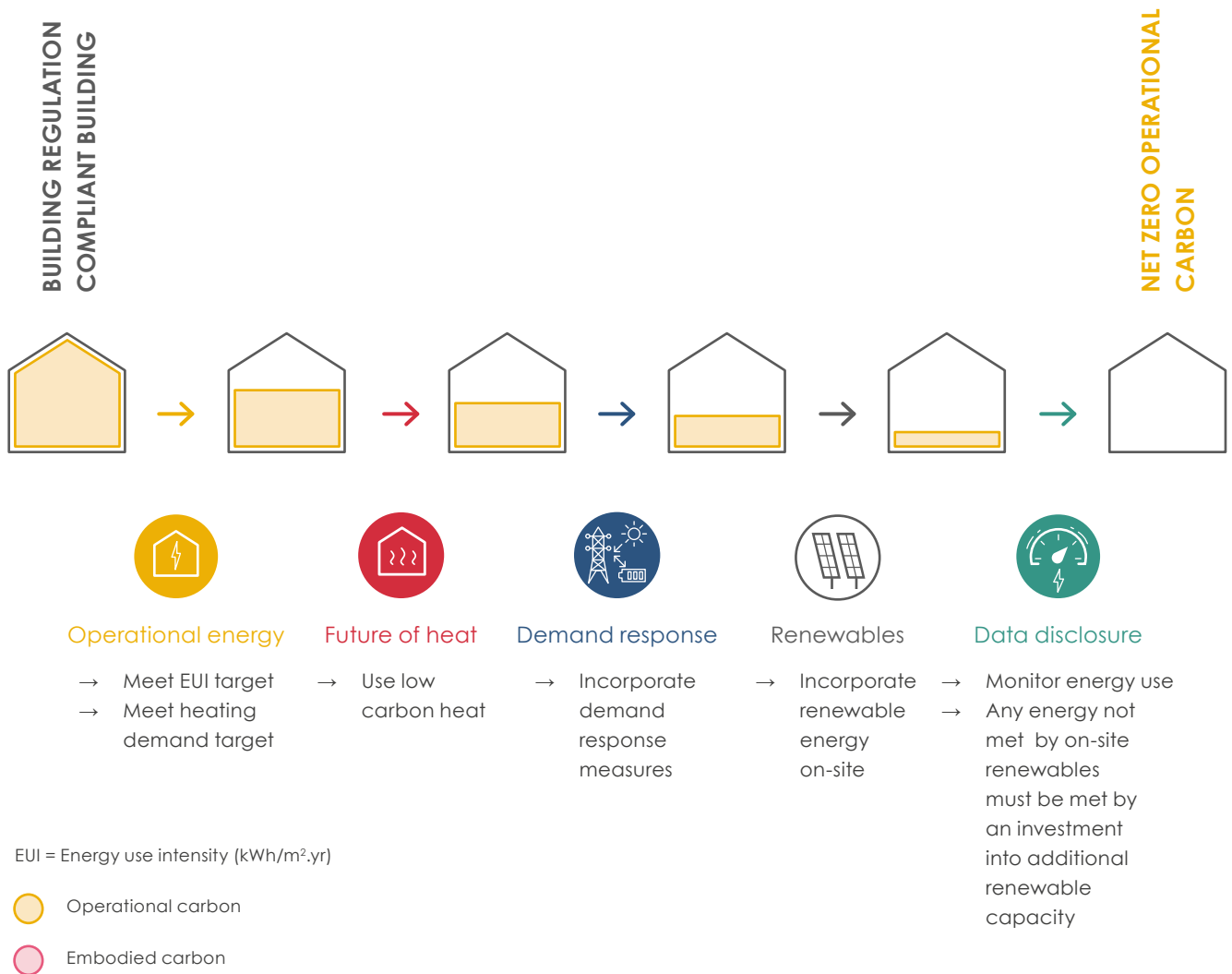
 **SIGNPOST** Appendix 10 – Offsetting

A building that is whole life net zero carbon meets the operational zero carbon balance and is 100% circular, this means that 100% of its materials and products are made up of re-used materials and the building is designed for disassembly such that 100% of its materials and products can be re-used in future buildings. When construction, transport and disassembly are carried out with renewable energy there will be zero carbon emissions associated with the embodied carbon.

2.4 Whole life carbon reductions

Whole life carbon encompasses all carbon emissions that arise as a result of the energy used in the construction, operation, maintenance and demolition phases of a building.

Figure 2.3 shows the operational carbon reduction stages on the left, and the embodied carbon reduction stages on the right.





Whole life carbon = Operational carbon + Embodied carbon

A new building that meets net zero operational carbon does not burn fossil fuels, is 100% powered by renewable energy, and achieves a level of energy performance in-use in line with our national climate change targets. See Appendix 0 of the Climate Emergency Design Guide.

Best Practice targets for embodied carbon are met, the building is made from re-used materials and can be disassembled at end of its life - in accordance with the circular economy principles.

SIGNPOST LETI Climate Emergency Design Guide

SIGNPOST LETI Embodied Carbon Primer

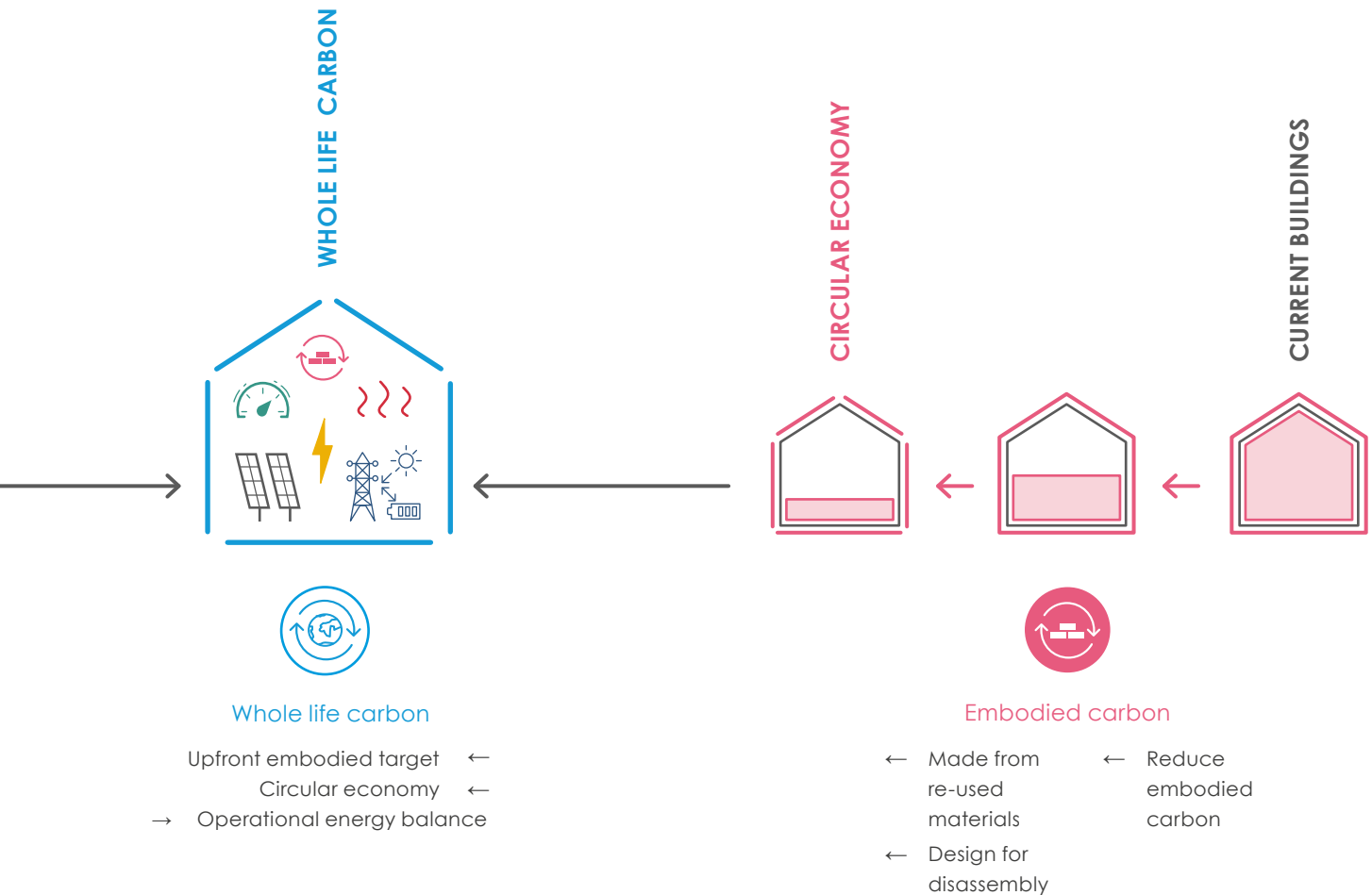


Figure 2.3 - Whole life carbon

3.0 Key terms

Embodied Carbon: Carbon dioxide and other greenhouse gases associated with the following stages:

- **Product:** extraction and processing of materials, energy and water consumption used by the factory or in constructing the product or building, and transport of materials and products
- **Construction:** building the development
- **Use:** maintenance, replacement and emissions associated with refrigerant leakage
- **End of life:** demolition, disassembly waste processing and disposal of any parts of product or building and any transportation relating to the above.

Operational Carbon: Carbon dioxide and other greenhouse gases are associated with the in-use operation of the building. This includes the emissions associated with heating, hot water, cooling, ventilation, and lighting systems, as well as cooking, by equipment and lifts.

Whole Life Carbon (WLC): This includes both embodied and operational carbon as defined above.

Circular Economy: A circular economy is an industrial system that is restorative or regenerative by intention and design. A circular economy replaces the linear economy, and its 'end-of-life' concept with restoration and regeneration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals and aims for the elimination of waste through the design of materials, products and systems that can be repaired and reused. The circular economy concept shown in the bottom part of Figure 3.1 illustrates an evolution of the current Linear Economy (top part) to the Circular Economy (bottom part) which is achieved through the application of principles: maintain, repair, reuse, remanufacture and recycle, as well as leasing and servicing.

Life Cycle Assessment

Life Cycle Assessment (LCA): A multi-step procedure to quantify carbon emissions (embodied and operational) and other environmental impacts (such as acidification and eutrophication) through the life stages of a building. The EN 15978 standard is typically used to define the different life cycle stages A1-3 ('Cradle to Gate'), A1-3 + A4-5 ('Cradle to Practical Completion of Works'), B1-5 ('Use'), C1-4 ('End of Life'), D ('Supplemental'). In the case of whole life carbon, an LCA assesses greenhouse gas emissions measured in carbon dioxide equivalent to evaluate Global Warming Potential (GWP). Thus the use of predicted CO₂e data across the Life Cycle Stages relevant to the particular development allows comparisons of different options in relation to impact on whole life carbon as well as demonstrating that a certain level of carbon emission reductions have been met at design stage ¹.

Environmental Product Declaration (EPD): An independently verified and registered document that communicates transparent and comparable information about the life cycle environmental impact of a product ².

Linear Economy



Circular Economy

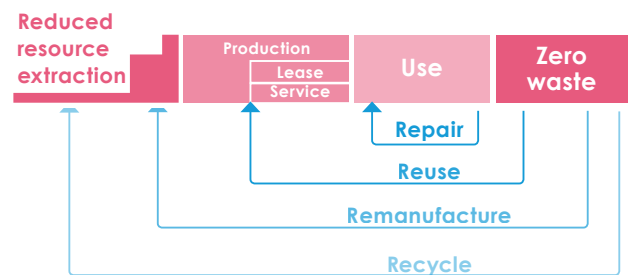


Figure 3.1 - Circular Economy Principles, compared to existing Linear Economy



4.0 Building archetypes

This guide focuses on 4 building archetypes that make up the majority of new buildings in the UK. Taken together they represent 75% of the new buildings likely to be built between now and 2050.

Archetypes detailed in this report:

- **Small scale residential:** terraced, semi-detached or detached homes, up to three floors
- **Medium and large scale residential:** four floors and above
- **Commercial office**
- **School:** Primary or secondary



Figure 4.1 - Building Archetypes

1 - Athena, Sustainable Material Institute definition
2 - Environdec - International EPD System

5.0 Contribution to Zero Carbon

In the UK, buildings account for 49% of greenhouse gas emissions. Of the annual carbon emissions associated with buildings about 80% is associated with ongoing operational carbon emissions relating to the existing building stock and the remaining 20% is related to the embodied impact of new construction.

Addressing climate change has traditionally focused on reducing carbon emissions from operational energy consumption. However, as buildings become more energy efficient, (and electricity generation has decarbonised), operational carbon of new buildings has significantly reduced. This means that embodied carbon can represent a higher proportion of whole life carbon than it used to. Thus embodied carbon has become significant and can represent 40-70% of Whole Life Carbon in a new building, see Figure 5.1 that shows the magnitude and breakdown of Whole Life Carbon.

Carbon emissions vary according to building types. This is linked to particular use and operation of each building as well as fabric specific requirements i.e. structure, volume, location and so on.

Figure 5.2 shows the breakdown of the whole life carbon stages of an office, residential development and a school. The pie charts to the left show the breakdown when the development is built to Building Regulation levels, in this case the operational energy makes up by far the largest proportion of whole life carbon. The pie charts to the right shows the breakdown of Whole Life Carbon when the development is ultra-low energy, then the product stage (A1-A3) makes up the largest proportion of whole life carbon.

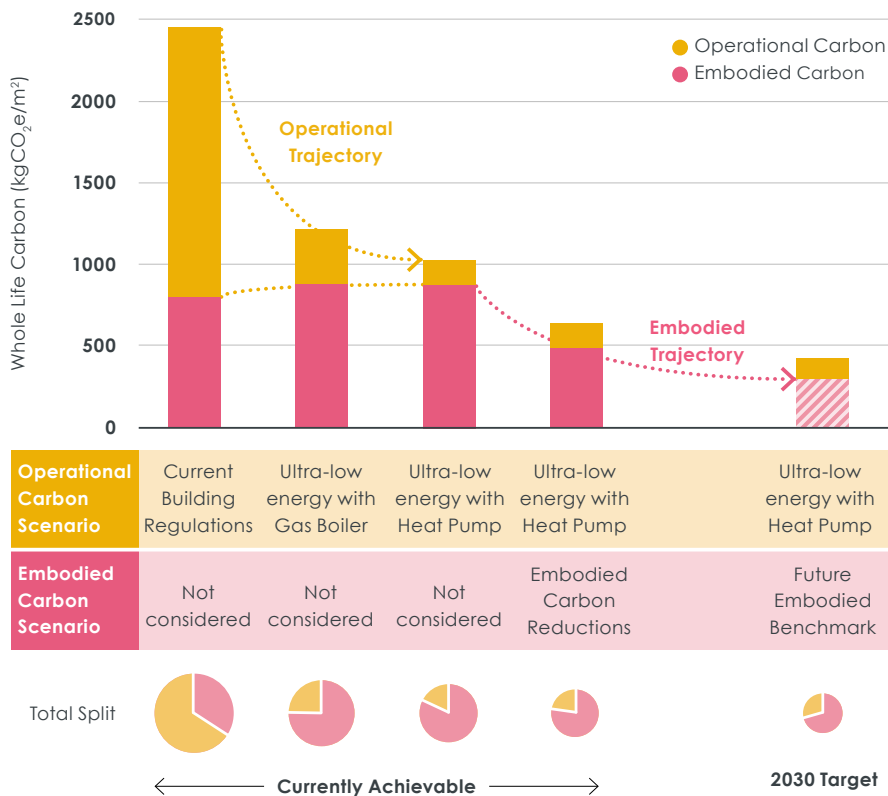


Figure 5.1 - Diagram showing operational and embodied carbon and trajectories

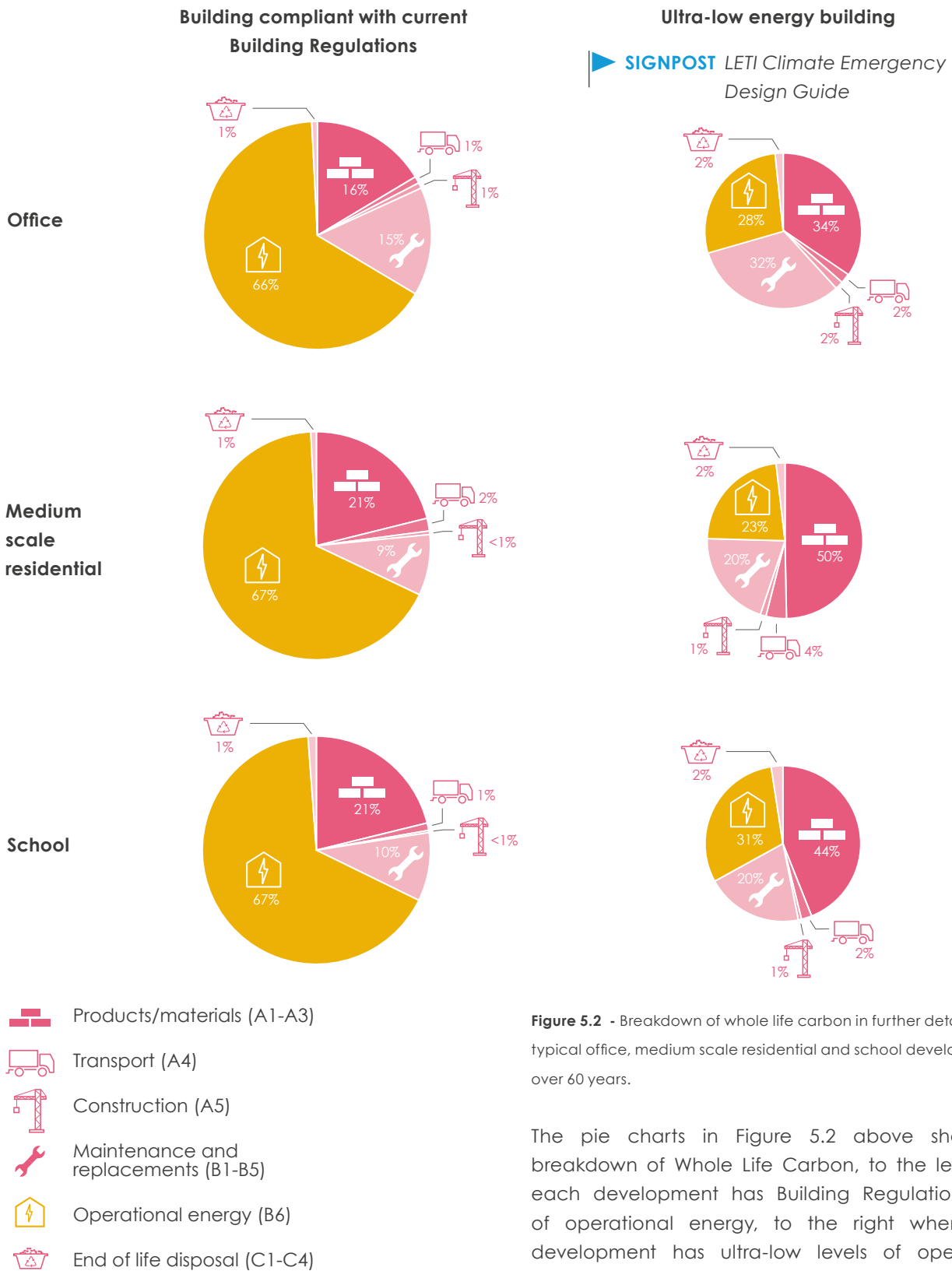


Figure 5.2 - Breakdown of whole life carbon in further detail for typical office, medium scale residential and school developments over 60 years.

The pie charts in Figure 5.2 above show the breakdown of Whole Life Carbon, to the left when each development has Building Regulation levels of operational energy, to the right when each development has ultra-low levels of operational energy with a heat pump.

6.0 Actions to drive change


The following are a set of actions that if adopted will drive significant reductions in embodied carbon and whole life carbon, and support the move towards net zero carbon development.

Client/Developer (decision making)

- Clarify the client's corporate goals for net zero carbon and circular economy developments that embrace embodied carbon reductions.
- Develop financial structures within the developer's business for allocating funds across R&D/pilot projects.
- Identify employees across the client's business who will be responsible for net zero carbon, circularity and embodied carbon performance outcomes.
- Specify in the project brief that the development will have low embodied carbon, adopting the principle of reuse and refurbish over new build and requiring a comprehensive embodied carbon reduction strategy, stipulate embodied carbon performance targets.
- Appoint a design team (consultant and contractor) with experience of conducting embodied and whole life carbon analysis and reduction strategies.
- Specify in the contract that the principal contractor will monitor and report 'as-constructed' embodied showing compliance with embodied carbon performance targets.

Policymaker (strategy)

- Adopt a policy hierarchy that advocates circular economy principles: reuse and refurbishment in preference to demolition and new construction.
- Adopt a policy that mandates embodied carbon reduction strategies based on embodied carbon and whole life carbon analysis on all projects.
- Adopt embodied carbon targets.
- Recognise a consistent methodology and data-set for embodied and whole life carbon analysis e.g. RICS Professional Statement WLC, reporting embodied carbon across the chosen life cycle stages of EN 15978, as explained in Appendix 3 - How to measure embodied carbon.
- Phasing in the mandatory requirement of EPDs for at least all building parts forming Substructure, Frame and Upper Floors.

 **SIGNPOST** Appendix 3 - How to measure embodied carbon

Designer (implementation)

- Adopt the circular economy principle of reuse and refurbish before new build ('retro first').
- Upskill the design team to develop in-house capabilities and understanding of embodied and whole life carbon reduction principles and 'big wins', to recognise where the largest reductions in embodied carbon can be made.
- Implement embodied carbon as a sustainable design metric and calculate embodied carbon emissions of all projects.
- Request Environmental Product Declarations (EPDs) from all suppliers.



Primary Actions





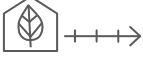

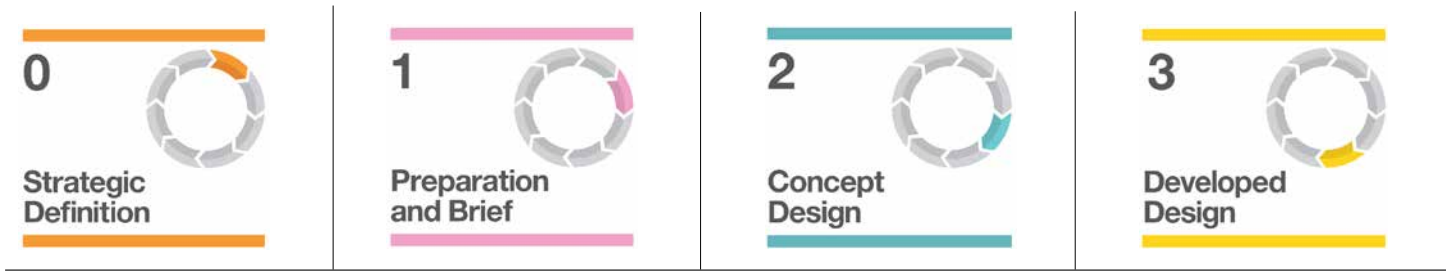
 <p>Build Less</p>	<ul style="list-style-type: none">→ Is a new building necessary to meet the brief, has retrofit been considered?→ Can existing materials on or near the site be used?→ Has the brief been interrogated against client need and represents the most efficient solution?→ Can uses be shared or spaces be multi-functional?→ Carry out a material efficiency review - are all materials proposed necessary?→ Seek to simplify the design - simple designs usually means less embodied carbon.
 <p>Build light</p>	<ul style="list-style-type: none">→ Reduce the weight of the dead loads where possible.→ What loadings are really required to meet the brief?→ Can long spans be restricted?
 <p>Build wise</p>	<ul style="list-style-type: none">→ Ensure longevity of material and systems specifications.→ Review material efficiency options like designing to standard building sizes or for a repeating module.→ Structural members should be designed for 100% utilisation rate where possible.→ Analysing a site is an important activity at the start of a project and this can be extended to the identification of ways of reducing embodied carbon. Possible opportunities include:<ul style="list-style-type: none">→ There may be existing structures or buildings that can be reused or become a source of recycled materials.→ There may be locally sourced material options, reducing transport to site while allowing architectural expression of the context.→ Designing a project around a site topography, reusing excavated soil and reducing the amount removed from site.
 <p>Build low carbon</p>	<ul style="list-style-type: none">→ Reduce the use of high embodied carbon materials.→ Identify 'Big ticket Items' and focus on the big wins first including structure and envelope.→ Consider natural and renewable materials.→ Explore Design for Manufacture and Assembly (DfMA) solutions if this reduces embodied carbon.
 <p>Build for the future</p>	<ul style="list-style-type: none">→ Ensure future uses and end of life are considered and adaptability is designed in.→ Consider soft spots in the structure.→ Consider regular structural grid and future-proofed risers and central plant space.→ Mechanically fix systems rather than adhesive fix so they can be demounted and reused or recycled, supporting a circular economy.→ Explore methods of creating longevity for materials without additional coatings, as they can reduce the recyclability of the material.
 <p>Build collaboratively</p>	<ul style="list-style-type: none">→ Solutions must involve the whole design team and the client.→ Use 'rules of thumb' data to drive decision making in meetings, especially in the early stages of design.

Figure 6.1 - Primary actions for reducing Embodied Carbon



Embodied carbon - for the designer

1. Discuss whole life carbon ambitions with client.

SIGNPOST Embodied carbon primer - Appendix 1

2. Review opportunity for retention of existing structure and building fabric and how the quantum of materials of the new build can be reduced.

1. Client brief to be developed: it should incorporate embodied carbon reduction targets.

SIGNPOST Embodied carbon primer - Appendix 3

2. Appoint a LCA specialist or design team member to be responsible for whole life carbon assessment.

1. Use rules of thumb guidance during concept to maximise opportunities for low carbon design.

SIGNPOST Embodied carbon primer - Appendices 6, 8 & 9

2. Analyse carbon reduction options for building elements using numerical analysis.

SIGNPOST Embodied carbon primer - Appendices 3 & 4

1. Include requirements and targets for whole life carbon in specifications and tender documentation at start of procurement.
 2. Have discussions with the potential contractors around whole life carbon targets. Include carbon questions on tender return forms.
 3. Continue numerical analysis and use material guides to optimise material specification.

SIGNPOST Embodied carbon primer - Appendix 5

Embodied carbon - for the Life Cycle Assessment (LCA) specialist

1. Set initial embodied carbon targets using rule of thumb guidance and benchmarks.

OUTCOMES: Early recommendations on low carbon options ahead of RIBA Stage 2.

1. As the design develops, provide more detailed analysis of the options around the key building systems: frame, floors, envelope. This is discussed with the design team through workshops.

OUTCOMES: More detailed analysis and recommendations of the agreed design options. Improved understanding of embodied and whole life carbon within design team.

SIGNPOST Embodied carbon primer - Appendix 6

1. In depth analysis of the elemental and component parts of the entire building, identifying specific materials, products and lifespans, to generate a baseline.
 2. Assess low carbon alternatives to the baseline. Agree a carbon reduction target - either percentage or absolute.

OUTCOMES: A whole life carbon budget, representing the total carbon emitted over the lifetime of the building, and an associated carbon reduction target. Initial carbon reduction option list, which will be further developed during technical design stage.

SIGNPOST Embodied carbon primer - Appendix 3

Magnitude of improvement ↑

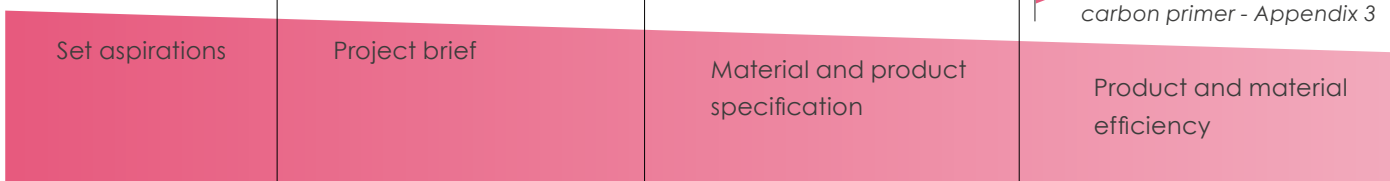






Figure 6.2 - RIBA Stages actions for the designer and LCA specialist



<div style="text-align: center;">  <p>4</p> <p>Technical Design</p> </div>	<div style="text-align: center;">  <p>5</p> <p>Construction</p> </div>	<div style="text-align: center;">  <p>6</p> <p>Handover and Close Out</p> </div>	<div style="text-align: center;">  <p>7</p> <p>In Use</p> </div>
<p>1. Finalise requirements and targets for whole life carbon in specifications and tender documentation at start of procurement.</p> <p>2. Finalise requirements with the potential contractors and subcontractors around whole life carbon targets, asking for options for improvement and including carbon questions on tender return forms.</p> <p>3. Continue numerical analysis and use material guides to optimise material specification.</p> <p>SIGNPOST Embodied carbon primer - Appendix 8</p>	<p>1. Engage with contractors to reduce waste.</p> <p>2. Review alternative products and materials selections proposed by the contractor against technical and performance standards and against the whole life carbon requirements.</p> <p>SIGNPOST Embodied carbon primer - Appendix 8</p> <p>3. Prepare for post-completion analysis by collecting numerical data through the construction phase.</p> <p>SIGNPOST Embodied carbon primer - Appendix 2</p>	<p>1. Undertake post completion analysis using as-built information to assess upfront embodied carbon.</p> <p>SIGNPOST Embodied carbon primer - Appendix 2</p>	<p>1. Recommendations regarding embodied carbon reduction strategy over the in-use stage should be followed throughout the building life cycle including at the end of life stage.</p>
<p>1. Update the whole life carbon budget to include design development and finalise the carbon reduction options list, to define the final specifications.</p> <p>2. Send pre-procurement Request for Information (RFI) forms to suppliers to collect carbon data in order to provide information for supplier selection. Review returned RFIs and analyse the environmental credentials.</p> <p>OUTCOMES: Agreed carbon reduction targets and options List. A list of recommended low-carbon suppliers. Design assessed against targets. Ensure specifications include embodied carbon of materials. A recommended a list of suitable low carbon suppliers.</p>	<p>1. Send RFIs to suppliers in order to receive construction carbon data and verify the environmental credentials.</p> <p>2. Undertake building site monitoring through monthly site logs and construction progress reporting.</p> <p>OUTCOMES: Facilitate gathering of data for the construction stage analysis and achieve the agreed carbon reduction targets.</p> <p>SIGNPOST Embodied carbon primer - Appendix 2</p>	<p>1. At the end of site works, the contractor should confirm the final carbon related data to the LCA specialist. Develop the practical completion carbon report. Align the design stage carbon targets with what was achieved at the end of construction.</p> <p>OUTCOMES: Practical completion carbon report to be issued to the client.</p> <p>SIGNPOST Embodied carbon primer - Appendix 2</p>	<p>1. Embodied carbon reduction strategy to include in-use and end of life stages.</p> <p>OUTCOMES: Client to have relevant information to continue embodied carbon reduction strategy throughout in-use and end of life stages.</p>
<p>Material and product declaration</p>	<p>Material and product verification</p>	<p>As build carbon report to client</p>	<p>In-use carbon report to client</p>

7.0 Whole life net zero carbon - best practice targets

LETI have set out a series of embodied carbon reduction targets. This includes targets for re-used materials in construction, and for building component disassembly at end of use for re-purposing. When combined with Energy Use Intensity (EUI) targets outlined in the LETI Climate Emergency design guide and 100% renewable energy supply this ultimately leads toward whole life net zero carbon design. The 'business as usual' figures give an estimate of

embodied carbon in buildings that are built without implementing embodied carbon reductions.

▶ **SIGNPOST** *Climate Emergency Design Guide Building Archetype pages*

▶ **SIGNPOST** *Climate Emergency Design Guide Chapter 1 - Operational Energy*

▶ **SIGNPOST** *Appendix 9 – Whole life carbon*

'Business as usual'

2020 target 40% reduction over baseline



Figure 7.1 - LETI Embodied Carbon Reduction Targets towards Whole Life Net Zero



'Reuse' and 'reusable' terms

Reuse: Materials, building elements and/or whole buildings previously utilised that are repurposed to construct a new or retrofitted building, in place of using virgin materials/new building elements.

Reusable: Materials or elements designed to be for disassembly and re-use in other buildings or other applications.

7.1 Further Reading

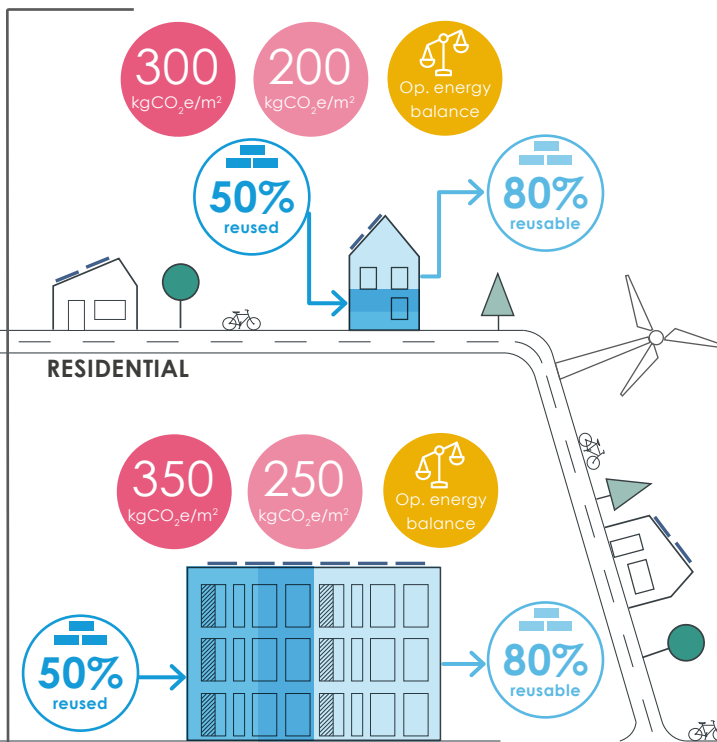
Design for a circular economy primer - Good Growth by Design, GLA.

FCRBE - Facilitating the circulation of reclaimed building elements in Northwestern Europe

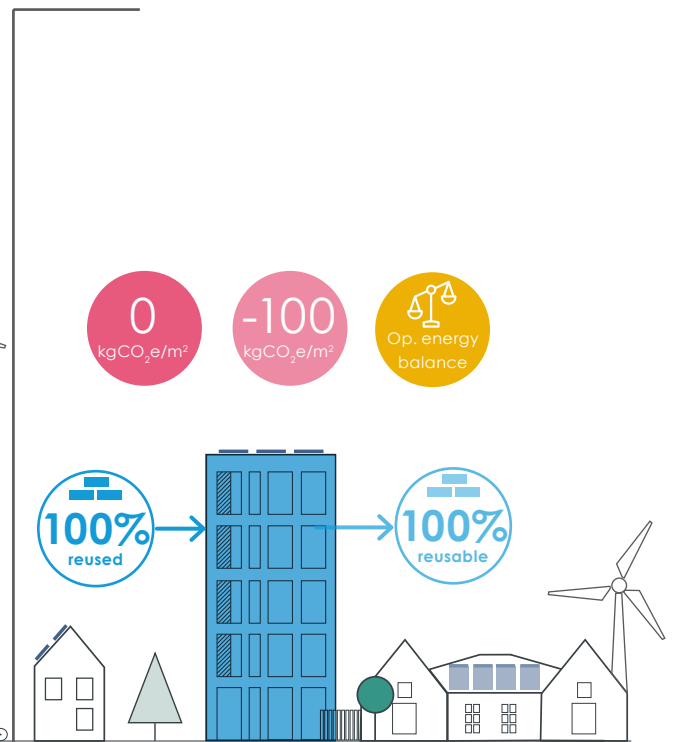
Salvo - Directory for reclaimed materials in UK

2030 target

65% reduction over baseline



Whole life net zero target



Key



Energy Use Intensity (EUI) targets outlined in the LETI Climate Emergency design guide as well as 100% renewable energy supply must be met



% target of total building construction materials & elements that are reused



% target for building materials & elements designed for reuse at the building's end of life



Embodied carbon target (Building Life Cycle Stages A1-A5). Includes Substructure, Superstructure, MEP, Facade & Internal Finishes.



Embodied carbon target, as above, also including sequestration.

8.0 Reducing embodied carbon – by building element

Proportions of embodied carbon by building element

The diagram below shows the relative proportions of embodied carbon by building element and illustrates the elements where the most savings may be made.

What is important is not just the proportion of embodied carbon per element, but the potential total embodied carbon reductions of all the elements. At RIBA Stage 3 a full building detailed whole life carbon assessment should be undertaken. As part of this a study should be undertaken that identifies the breakdown of embodied carbon by element and the carbon reductions that could be achieved for each element. This helps to identify 'big ticket items' – where the greatest embodied carbon reductions can be achieved. Figure 8.1 shows the results of this type of assessment for an example of a typical mixed used development commercial + residential. It is evident that the top five building parts (Piling, Foundation, Frame, Upper Floor and Envelope) provide the greatest embodied carbon reduction opportunities, and thus should be the focus of embodied carbon reductions.

Nevertheless, the remaining bottom items (Ceiling Finishes, Internal walls, Floor Finishes and External Works) should also be considered for establishing the project Embodied Carbon Reduction Strategy.

Rules of thumb for reducing embodied carbon per building element

Page 27 identifies the big wins by building element. For further detailed information refer to Appendix 6 - Rules of Thumb.

SIGNPOST Appendix 6 - Rules of Thumb

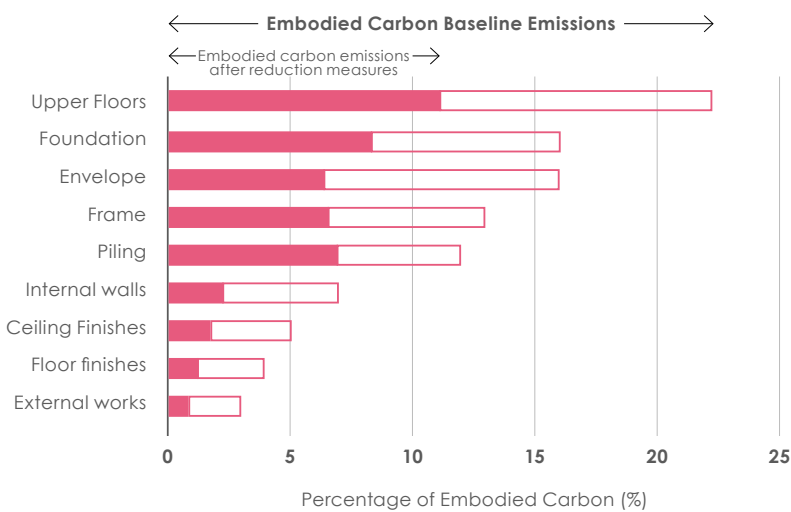


Figure 8.1 - Big ticket items study for a typical mixed use development: commercial & residential. Study by Mirko Farnetani

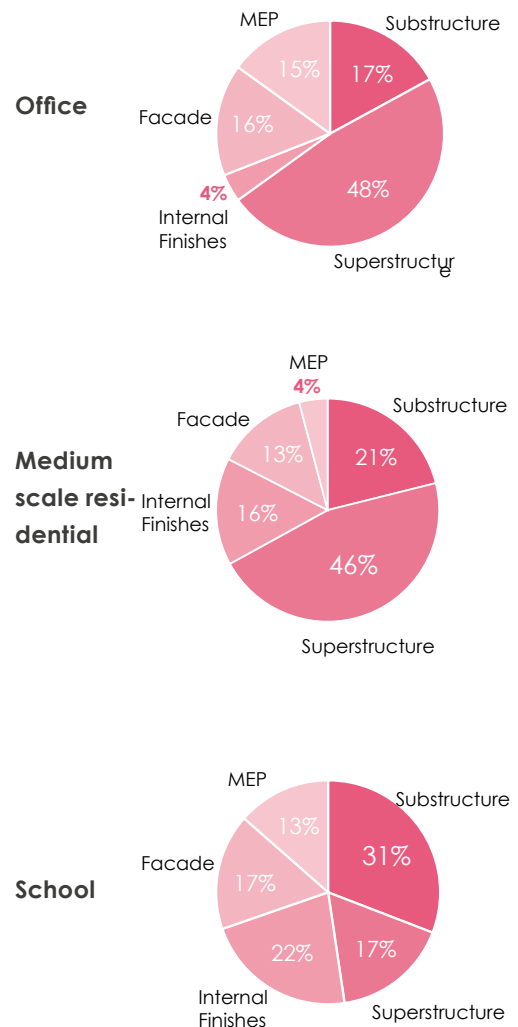


Figure 8.2 - Embodied carbon break-down per element (Cradle to Gate)



Reductions to embodied carbon by element

	Structure (Sub and super structure)	<ul style="list-style-type: none">→ Compare the embodied carbon options for sub and superstructure at an early stage to identify an optimum solution.→ Typical bay studies for the horizontal and vertical grid should be conducted at concept stage for different material arrangements to determine the impact on the total embodied carbon for each framing arrangement.→ A structural rationalisation study should be conducted to determine the impact on overall material quantity versus efficiency in construction/fabrication.→ Reduce the weight of structure where possible through voids.→ Maximum embodied carbon quantities should be specified for structural components. Targets can be achieved by cement replacement such as GGBS, low carbon concrete mix design, low carbon materials and using recycled/repurposed materials.→ Structural frame should be considered to have a dual purpose, ie the structure could serve as a shading device rather than introducing additional shading elements to control solar gain.→ Explore recycled sources of material.
	Envelope (Facade and roof)	<ul style="list-style-type: none">→ Carry out embodied carbon comparisons on typical construction bays during early design stages where decisions can be guided by benchmarks / data.→ Remember that it is the hidden parts (for example metal secondary framing) of a build up that often contain the most embodied carbon.→ Where metals are used, limit their use and ensure they can be removed and recycled at end of life.
	Mechanical, Electrical and plumbing (MEP)	<ul style="list-style-type: none">→ Avoid over-provision of plant - a detailed load assessment must be undertaken.→ Typically, fewer and simpler systems will reduce embodied carbon.→ Explore options for plant room locations which reduce duct runs.→ Design for deconstruction and recycling as MEP is typically replaced 2-3 times during the lifespan of a building.→ Specify refrigerants with low Global Warming Potential (i.e <150) and ensure refrigerant leakage is carefully considered in the whole life carbon analysis.
	Finishes and Furniture Fixtures and equipment (FF&E)	<ul style="list-style-type: none">→ Consider eliminating materials where not needed e.g. by exposing services.→ Utilise self-finishing internal surfaces like timber.→ Consider the cleaning and maintenance regime to be undertaken.→ Ensure the fit out requirement is clearly understood to avoid FF&E to be replaced when the first tenant moved in.→ Carefully compare products based on EPD data, recycled material and also avoidance of harmful chemicals like formaldehydes and VOCs.→ Consider the replacement cycle and specify for longevity.→ Choose products that do not rely on adhesives so fabrics or finishes can be replaced.→ Be wary of trends that are likely to date and require early replacement.
	Design for Manufacture and Assembly (DfMA)	<ul style="list-style-type: none">→ Compare embodied carbon of DfMA solutions with standard solutions.→ If DfMA is to be used, identify the elements by the end of RIBA Stage 2. Examples include, bathroom or WC pods, plant modules, facade elements, repeatable rooms, pre-fabricated structural elements including twin wall, columns and planks.→ Engage the supply chain early.→ Lightweight materials are preferable for transportation purpose.→ Ensure the repeatable systems are designed for deconstruction.

9.0 Undertaking Analysis

9.1 Embodied carbon and whole life carbon assessment guidance

The key standard that sets the methodology for calculating embodied and whole life carbon performance of buildings is the British Standard BS EN 15978:2011. However it is open to interpretation and leads to inconsistency and a lack of comparability between different projects.

The RICS professional Statement 'Whole life carbon assessment for the built environment' aims to provide guidance on the interpretation and practical implementation of the EN 15978 methodology, which all RICS members are required to apply when undertaking WLC assessments. The RIBA states this is the 'recommended methodology to use for undertaking carbon assessments.'

Embodied carbon and whole life carbon can be measured through a life cycle assessment, which accounts for emissions at every stage of the entire life cycle of a building's materials and products. For more details see Appendix 3.

Typically, an LCA of a proposed building consists of 4 steps:

1. Define the goal and boundaries
2. Estimate quantities of materials, products and processes in the building
3. Assess the environmental impact, meaning the carbon emissions equivalent, for each material/product and process and then sum them to obtain the overall carbon footprint
4. Interpret the results, refine and re-iterate if needed

 **SIGNPOST** Appendix 3 – How to measure embodied


9.2 How to carry out embodied carbon reduction calculations


Using the LCA method, as outlined in Section 9.1 embodied carbon reduction calculations can be carried out. The following steps are taken:

1. Creating a 'baseline model' (see Appendices 11 and 12)
2. Following the 'rules of thumb' (Section 6 and Appendix 6)
3. Considering the 'big ticket' Items (Figure 8.2).
4. Identifying the carbon reduction strategy
5. Determining an 'optimised model' and the measures needed to achieve the percentage reduction required. (see Figure 9.1)

Generally, it is possible to reduce embodied carbon of buildings by around 10-20% with simple cost neutral measures. In 2020 it is thought that reductions of around 40% represent best practice embodied carbon reductions, by 2030 it is thought that reductions of around 60% would represent best practice.

It is essential to create an initial building baseline model based on common practice assumptions adopted by the industry (see Appendices 11 and 12). This would produce a baseline model. Subsequently, the embodied carbon reduction strategy would identify the list of alternative measures in order to quantify the magnitude of carbon reduction.

 **SIGNPOST** Appendix 11 – In scope and out of scope

 **SIGNPOST** Appendix 12 – Baseline specifications



9.3 Key considerations

Key consideration when analysing embodied carbon figures are listed below:

- What RIBA stage is the project?
- What is the scope of the analysis - what life cycle stages are included?
- What is the assumed study period (lifetime of the building)?
- To enable interrogation of the data the total carbon emission figure can be broken down into categories that give a better understanding of the building such as per life cycle stage, per material and/or by building element.
- The initial breakdown can show what element or stage is the most useful to focus on for greater reduction in overall figures
- When comparing against other data, make sure there is a consistency with the method and scope of analysis
- Analyse and benchmark a project throughout the various stages of design

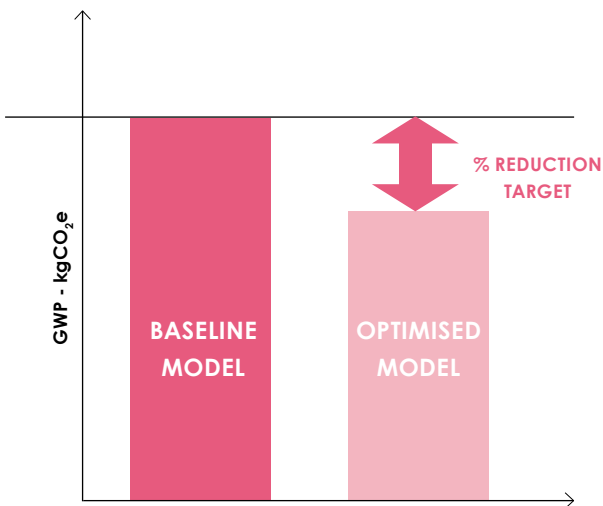


Figure 9.1 - Embodied carbon reduction models
Study by Mirko Farnetani

9.4 Getting into the details

It is useful to get a deeper understanding of the methods, processes and tools available when carrying out embodied carbon assessments.

Details are summarised here:

- ▷ **SIGNPOST** Appendix 1 - How to talk to your client
- ▷ **SIGNPOST** Appendix 2 - Scope of work of LCA
- ▷ **SIGNPOST** Appendix 3 - How to measure embodied carbon
- ▷ **SIGNPOST** Appendix 4 - Tools - BIM
- ▷ **SIGNPOST** Appendix 5 - Procurement

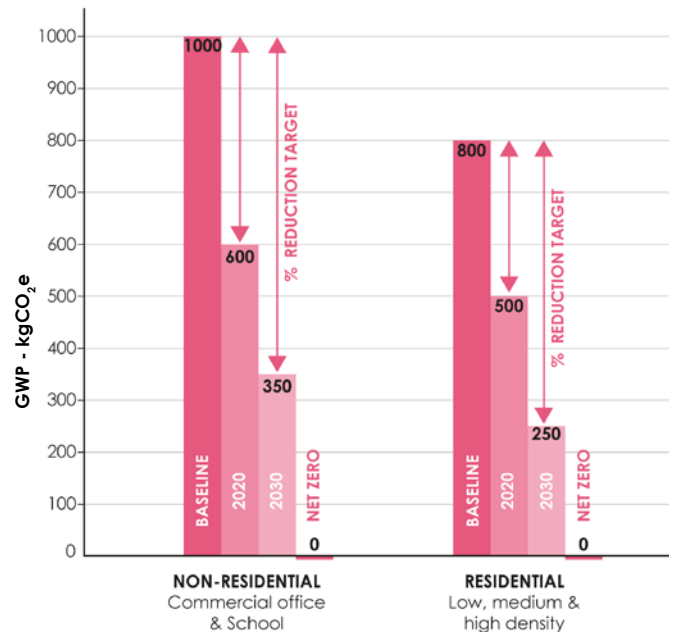


Figure 9.2 - Embodied carbon reduction targets to Net Zero

A

Appendices



Appendices

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Appendix 1

How to talk to your Client

It is important to consider when talking to any client how best to put forward your low-carbon strategies. Low embodied carbon strategies often have secondary benefits that can make them attractive to clients.

It may be that your client is a company with a strong environmental statement core to their philosophy/business objectives. They may be interested in producing housing fast and for as little cost as possible.

It is the skill of a designer to translate low-carbon strategy into a strategy that works best for their client. There are crucial times for framing the project to work in this way:

1.1. The first meeting

At the first meeting with any prospective client, you have the power to set the tone for how a project may unfold. At this point, the priorities for a project can begin to be understood. These priorities may be possible to translate directly into a low-embodied carbon strategy, for example:

- **Does your client want to keep costs low?** The principles of low-embodied carbon are of using less, and reusing material and structures wherever possible. These will also double up as strategies to reduce project costs.
- **Does your client have long-term ownership or maintenance responsibility?** Owner-occupiers or landlords? They will be concerned with the ongoing maintenance costs, and avoiding future disruption and costs to their tenants. Low-embodied carbon strategies may reduce maintenance costs, by investing in materials that will last longer and be recyclable.
- **Does your client need to build it fast?** Design For Manufacture and Assembly (DFMA) approaches to construction can reduce the embodied carbon of a project (see Appendix 7 on DFMA), as well as making on-site construction faster and safer. Reducing the use of scaffolding on site and keeping working at height to a minimum are examples of this.
- **Is your client aspirational and ambitious?** Creating a building of quality or to an award-winning standard should not mean developing high-embodied carbon for the sake of it. For example, the RIBA's Stirling Prize award has in recent years sought advice regarding Sustainability, and has considered embodied carbon as part of this. The Architect Journal is prioritising embodied carbon in their awards. Recommend to your clients that in the present climate, it is advisable to design low-carbon if they aspire to win awards. Low carbon design often results in higher quality, more interesting design. This may help them to form a public brand and or demonstrate their values.
- **Does your client have their own sustainability targets?** Different language may be used, so it may be necessary to translate low carbon strategy to meet their goals, using other buzzwords.
- **Does your client have concerns over staff well-being, reducing staff turnover, or the quality of the building users experience?** The secondary benefits that can arise from low embodied carbon strategies can improve the quality of spaces, e.g. with use of natural materials and interesting architectural design.
- **Does your client need the building to be adaptable to other uses?** The design should consider whole life carbon of the current intended use being adapted into other likely uses. This may result in a



different and more flexible design outcome from the outset, reducing embodied carbon arising later from adaptation.

- **Does your client or their shareholders have an interest in climate or social justice?** The whole life approach to design provides a greater awareness and understanding of the sourcing and circularity of materials. For clients with specific climate or social policies, whole life carbon analysis can be a beneficial process giving greater knowledge of construction supply chains. This can be of value in reducing negative social impacts of manufacturing and transport and provide numerous talking points. Where has this material come from? Who made it? Can it be recycled or repurposed locally or nationally, or will it be exported to a country where it is likely to sit on landfill, or worse?

It is also important to hold similar early meetings with the wider design team. Consultants and contractors should be made aware of the strategies in place and why design decisions have been made.

1.2. Upon appointment

This is the time when the priorities of the client can be further queried to ensure that carbon analysis is integrated as part of the scope of services and into the design programme.

The secondary benefits of reducing carbon in a project are vital and must be considered to ensure that the client appreciates the value of these approaches. You may need to translate your carbon strategy into other strategies, such as improving air quality or reducing costs, for them to be taken forward. You may feel able to undertake some or all of the analysis scope for the

project yourself. Make sure that this is included in the fee. Refer to the Building Information Modelling (BIM) section of this guidance.

You may need to advise your client to appoint a Low Carbon Assessor (LCA). It will be important to ensure that your fee reflects the time and cost of any LCA analysis required.

As a part of the new London Plan, any scheme referred to the Greater London Authority (GLA) will need to have a WLC analysis submitted. This should be considered as part of the predicted fee for most medium to large projects in London regardless.

A significant number of projects are subject to planning conditions requiring BREEAM certification, often to a high level. Both *BREEAM New Construction 2018* and *BREEAM Refurbishment & Fitout 2014* identify pathways to high value credits involving the completion of a building LCA. Clients should be encouraged to pursue these credits. In addition to their high value, the LCA will be a valuable tool to aid designers in developing low carbon solutions.

1.3. Value engineering

This is where it is important to remember the essence of your scheme, and the priorities to develop strategies that can reduce overall carbon wherever possible. More frivolous design elements may need to be omitted in order to safeguard the items which are acting most to reduce embodied carbon of your design.

Value engineering will generally see reductions in quantities of material, and thus embodied carbon. Frugality in quantity of materials is generally good.

However, if there is a reduction in the quality of the materials, this may be of concern. For clients with long term management of the building (e.g. build to rent), this will be an important consideration.

Conversely, it may be worth considering inclusion of materials that require more frequent maintenance, where the total whole life carbon remains low from regular upkeep, e.g. thatch roofs.

→ Any 'investment' or flagship items crucial for low maintenance and low lifetime carbon costs may now be under challenge. This is where having the team on board with your strategy from an early stage is important, though more effort now will be needed.

The latest technologies and systems on the market could be reviewed at this stage. It may be that new suppliers have developed similar systems or materials to those specified at earlier stages, at lower prices. Consider 'Products as Services', where the client may be able to lease elements of the building.

1.4. Upon completion

Your work is not done! Now is the time for evaluating what went well, what could have gone better, and what you can take forward for the next project you work on.

Try to encourage your client to conduct post occupancy evaluations. This should be mentioned in the first meeting and hopefully form part of your scope of services. Use the information you obtain to inform future designs.

It may be that the maintenance cycle predicted for certain systems is much longer or much shorter than expected. There may be unexpected secondary benefits from using low embodied carbon strategies that you can learn from and utilise in the future.

We are all on a journey towards net zero design, and inevitably not every project will be perfect straight away. Draw what you can from each project to ensure you are moving towards net zero.



1.5. Case studies

Duxford Paper Store, Imperial War Museum

Often a client brief can be the inspiration for a low carbon strategy. The client brief for the Paper Archive was the provision of a stable temperature and humidity for the storage of historic paper archives. However, instead of relying on a standard systems approach to provide the conditions, a Passivhaus strategy provided a low energy solution. Extremely low air changes ensure a consistent internal environment with minimal energy use compared to a standard solution.

1.6. Further Reading

Duxford Paper Store, Architype

<https://www.architype.co.uk/project/duxford-paper-store/>

Embodied carbon for Clients, NBS

<https://www.thenbs.com/knowledge/developing-an-embodied-carbon-brief-for-clients>

Developing Client Brief, UKGBC

<https://www.ukgbc.org/wp-content/uploads/2017/09/UK-GBC-EC-Developing-Client-Brief.pdf>

What is a carbon price, LSE

Carbon tax/carbon price may be introduced in future legislation. This is a further incentive to reduce embodied carbon in the building
<http://www.lse.ac.uk/GranthamInstitute/faqs/what-is-a-carbon-price-and-why-do-we-need-one/>



Duxford Paper Store, Imperial War Museum, Architype
External View



Duxford Paper Store, Imperial War Museum, Architype
Store room

Appendix 2

Scope of work for LCA

This section provides supporting information for defining a whole life carbon assessment Scope of Services, whole life carbon assessment, and related carbon reduction strategies based upon life cycle assessments, inform clients on the environmental impacts of their plans through Environmental Impact Indicators (such as Global Warming Potential). Embodied carbon is a significant contributor to these impacts.

2.1. Typical LCA consultant appointment

It is advisable that an LCA consultant should be able to demonstrate completion of at least three different building LCAs and embodied carbon Reduction Strategies for clients in the last two years. A typical fee for appointing an LCA consultant is in the range of £80-£120/hour.

2.2. Importance of client briefs

Whole life carbon Assessments and carbon reduction strategies should be included in the client brief to allow bids, proposals and tender documentation to align with clients' requirements. Consultancy firms need to be aware of the level of sustainability services to be delivered in order to ensure they have the required expertise within their sustainability teams.

2.3. How to develop client briefs

It is essential that a client brief is developed in line with the clients' ambitions and objectives. These may be to create the client's lowest embodied carbon office building, reach a specified percentage reduction that meets corporate commitments, or a target

expressed in kg CO²/m². It is good practice to ask for LCA guidance in preparing client briefs, particularly when the client is not an expert in embodied carbon strategy. For a comprehensive plan of actions in how to prepare this document it is worth reading the UKGBC embodied carbon: *Developing a Client Brief*.

2.4. Simple four-phase approach for a successful low carbon strategy

The successful implementation of an embodied carbon reduction strategy should not be the only aim of the plan of action regarding a building life cycle. Circular Economy principles should be applied in order to cover multiple building life cycles. The section 'embodied carbon Reduction Strategies overlay to RIBA Plan of Work' provides a roadmap for rewarding results.

Phase 1 – Design

The early involvement of a sustainability and LCA consultant in the design process helps define a scheme for achieving a clients' low carbon aspirations. Important aspects to consider are:

→ Iterative life cycle assessments should proceed in parallel with the design process. Wherever possible, the LCA specialist should be part of the design team and follow the design as it advances stage by stage.

 **SIGNPOST** Appendix 4 – LCA Tools

→ Operational Energy data (ref: EN 15978 Module B6) should be provided by an Mechanical and Electrical (M&E) specialist.



- The life cycle assessment results should be shared with the design team, in order to quantify the level of sustainability of design options and inform decision making.
- The output of the assessment should be a carbon reduction strategy, containing a list of low carbon alternatives. Carbon savings should be expressed in terms of kilograms saved compared to the baseline. Hence, the final outcome should be a building with a lower embodied carbon.
- Low carbon alternatives should be part of specifications in order to inform the procurement process. Consideration of Environmental Product Declarations (EPD) can better inform specifications.
- LCA third party verification (also in line with BREEAM New Construction 2018 UK – Mat 01).

Phase 2 – Procurement

Embodied carbon targets and carbon reduction strategies should be part of the tender processes. Designers should create embodied carbon standard clauses to be added to their specifications (e.g. NBS). NBS to incorporate environmental credentials of materials/products included in embodied carbon reduction strategies as per the below examples:

- **Embodied carbon XX kg CO₂e/functional unit**
- **Percentage recycled content**
- **Percentage cement substitution**
- **Environmental product declaration**

Phase 3 – Construction

The exact building components specified as a result of any carbon reduction strategies should be procured and used during the construction process to ensure consistent embodied carbon measurements. Coordination between design team and contractor is standard practice, but the overview of an LCA specialist is recommended. The adoption of construction monitoring and reporting systems can facilitate the successful achievement of carbon reduction targets.

Phase 4 – Practical Completion

The completion of an LCA service is represented by a Practical Completion Carbon Report. This report should show the carbon reduction strategy as built meets the carbon reduction strategy as designed, and therefore meets the carbon reduction targets. It is advisable to prepare a 'lessons learned' section in order to inform future projects.

2.5. Further Reading

National Building Specification – NBS.

Available from <https://www.thenbs.com/>

UKGBC Embodied Carbon: Developing a Client Brief

Available from <https://www.ukgbc.org/>

Appendix 3

How to measure embodied carbon

This Appendix provides a description on the process of carrying out embodied carbon calculations, and the steps taken. It also goes into detail on the tools used and how to consider operational energy within whole life carbon calculations.

Step 3 is illustrated below for two materials.

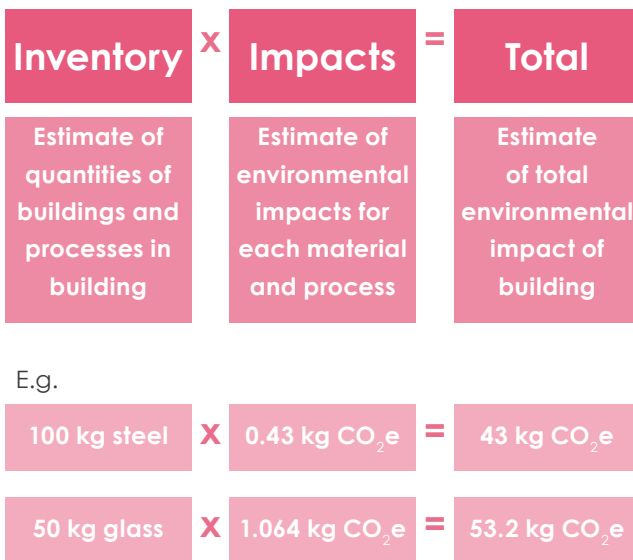


Figure A.3.1 – Simple example of LCA calculation process (Source: Carbon leadership forum practice guide 2019 p11)

3.1 Conducting a life cycle assessment (LCA)

Embodied carbon refers to the amount of greenhouse gas emissions created during the processes of material extraction, manufacturing, transport, construction, maintenance, repair, refurbishment, replacement, demolition and disposal. Whole life carbon refers to embodied carbon plus emissions related to energy and water use. The purpose of assessing WLC is to move towards a building or a product that generates lowest carbon emissions over its whole life. This can be measured through a life cycle assessment, which accounts for emissions at every stage of the entire life cycle of a building's materials and products.

Typically, a LCA of a proposed building consists of four steps:

- **Define the goal and boundaries**
- **Estimate quantities of materials, products and processes in the building**
- **Assess the environmental impact, i.e. the carbon equivalent emissions, for each material/product and process and then calculate the overall carbon footprint from all building materials/products.**
- **Interpret the results, refine and re-iterate if needed**

3.1.1 Define goal and scope

The first step is to define the goal of the LCA. Most commonly this would be to ensure the least environmental impact. To ensure consistency and understanding across the LCA it is necessary to define the boundaries for the calculation. These must be consistently used throughout all iterations of the assessment:

- **The site scope** – a clear indication of the project site and buildings included within the study.
- **The building element scope** – a clear indication of the building's components included within the study. It is important to have a consistent approach in carrying out building LCA with regard to which



building components should be considered and assessed. The *BREEAM New Construction 2018 UK – Mat 01* guide provides a reference for the industry, defining lists of in scope and out of scope building elements based upon the RICS New Rules of Measurement (NRM) classification system (N.B. this is not applicable for fit-out, Cat A, Cat B assessments).

→ **Measurement unit** – in which unit the results will be presented. For embodied carbon, it is usually kg of CO₂ equivalent (CO₂e) over 100 years.

SIGNPOST Appendix 11 – In scope and out of scope

→ **The (reference) study period** – period of time considered for the LCA study. This will affect the results related to the in-use stage due to replacement of building parts and systems. The study period should be defined in order to

establish the building's whole expected life and the related service life of building components and systems. 60 years is most commonly used as the study period.

→ **The system boundary/life cycle stages** – which life cycle stages (as defined by EN 15978) are considered in the LCA study. The life cycle stages assessed must be comparable for each iteration of the assessment. Figure A.3.2 shows the activities within each stage (A-C) and supplementary Module D as laid out in EN 15978:

- Cradle to gate: Stage A1-A3.
- Cradle to practical completion of works: Stages A1-A3 and A4-A5.
- Use: B1-7.
- End of life: C1-4.
- Cradle to grave: Stages A-B-C.
- Cradle to cradle: Stages A-B-C and Module D.

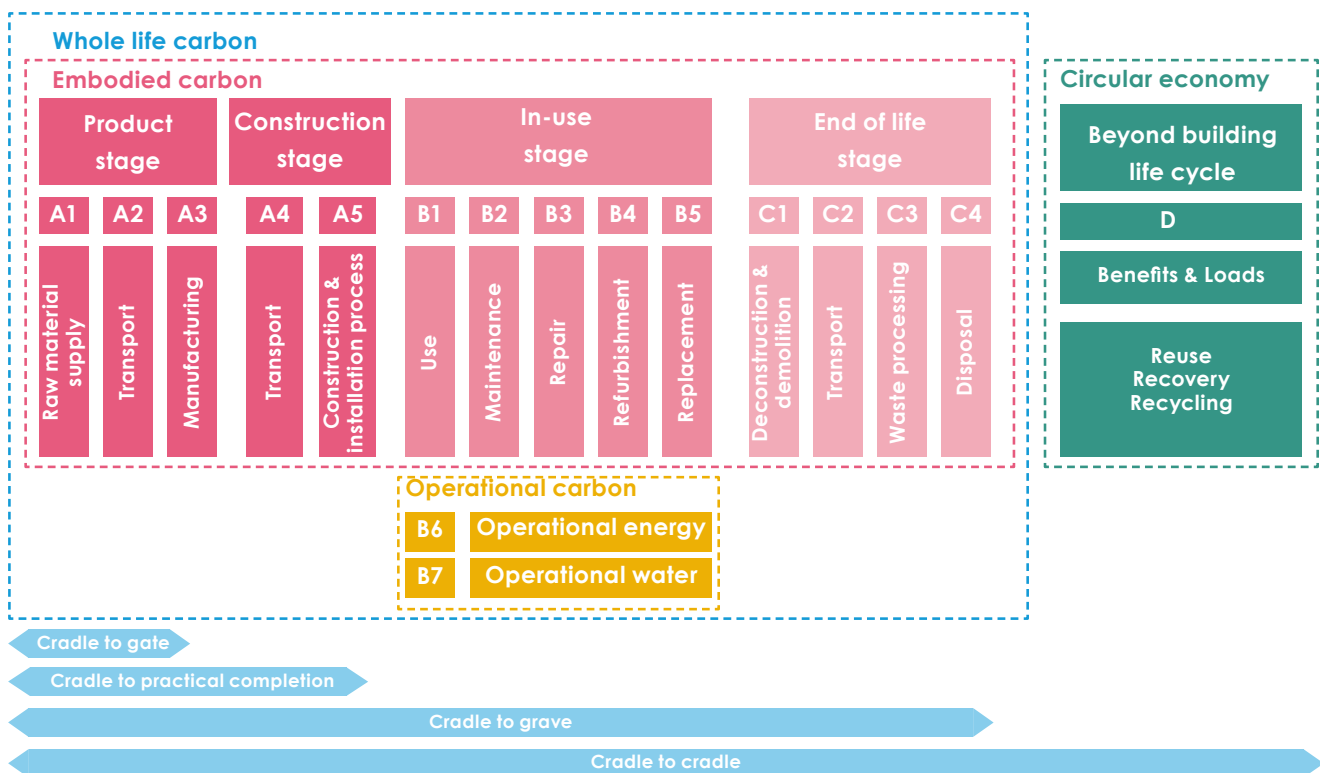


Figure A.3.2 - System Boundary: EN 15978:2011 Display of modular information for the different stages of the building assessment

3.1.2 Estimate quantities of materials, products and processes in the building

Embodied carbon

Building quantities should be calculated at two different scales: overall building level, material product level. This list of quantities is called the 'Inventory'.

At the overall building level material quantities can be calculated manually by listing all materials, products and systems within the building, however it is recommended to use BIM models to identify the different quantities. This is less time consuming than a manual take-off.

At the material product level, all materials should be identified within the building, including all material layers for the assessed components and the processes involved in the production, in-use and end-of-life stages. This is a time-consuming process; therefore, design teams should refer to Environmental Product Declarations from manufacturers or other generic information from the industry which calculates the environmental impacts throughout life cycle stages.


Operational carbon

It is important to realistically estimate the operational energy and water use of the building. Use in-use verified data on energy consumption if available. For design stage calculations use predictive modelling allowing for a performance gap to estimate energy consumption. If this is not available use benchmark figures relevant to the building type and location. Do not use SAP/SBEM (calculations carried out for Building Regulations) for calculating operational energy as these calculations are for compliance only and do not predict energy consumption.

3.1.3 Assess the environmental impact

Embodied carbon

At the building level the environmental impact can be calculated by multiplying the quantity of each material product with its respective environmental impact coefficient for each life cycle stage of the building. It would be recommended to use specific tools which gather all the information in the same place with an inbuilt database. BIM based LCA tools have the ability to link the BIM model material quantity data for each building element with environmental impact coefficients to give an overall quantitative assessment.

 **SIGNPOST** Appendix 3 – How to measure embodied carbon

Different life cycle impact assessment methods currently exist: the method used by the tool at building level should be consistent with the methods used at the product level (from EPDs, for instance).

Operational carbon

It is important to realistically estimate operational carbon emissions. It is recommended to use annual lifetime carbon emissions factors, at present this is 0.07 kg CO₂/kwh for the average content of the UK grid over the next 30 years (BEIS. Updated energy and emissions projections. London: BEIS; 2018).

3.1.4 Interpret the results, refine and re-iterate

Conducting life cycle assessments is an iterative process by nature. As the design teams are exploring different



design options, it is a tool to inform on the environmental impacts to help the decision making process on what is the best solution from an environmental point of view.

In essence, the following step sequence lists how to model embodied carbon reductions:

Create a 'baseline model'.

- Understand the big-ticket items – the building elements that have the most impact.
- Identify the carbon reduction strategy.
- Determine an 'optimised model' and percent carbon reduction.

 **SIGNPOST** Appendix 6 – Rules of thumb

The baseline model

The baseline must be defined using the first design iteration before any carbon saving measures are introduced. It is imperative to build a consistent and solid baseline model in order to calculate the reductions brought about by any carbon reduction measures. The baseline will highlight which building elements generate the most carbon emissions, allowing the designer to focus attention on areas where greater carbon mitigation interventions are possible.

 **SIGNPOST** Appendix 12 – Baseline specifications

Embodied carbon reduction strategy

Subsequently, an embodied carbon reduction strategy would identify a list of alternative measures and quantify the magnitude of carbon abatement that each would provide.

3.2 Timber biogenic carbon

In terms of impact assessment of wood-based products and related biogenic carbon (also defined as timber carbon sequestration) – designers should take into consideration the following:

- In general, the biogenic carbon balance over the life cycle of the wood product equates to 'zero'.
- The amount of biogenic carbon stored shall be calculated and reported in Module D and not deducted from the total within the system (modules A-C). This is because the benefits of the carbon storage may continue after the building life cycle is complete, if the timber elements are used in another building for example, or as a fuel offsetting the need for fossil fuels elsewhere.
- When biogenic carbon is reported in life cycle assessments, the end-of-life (EN 15978 Stage C1-C4) processes of wood and wood-based products should be reported in parallel.

3.3 Further Reading

EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings calculation method

EN 15804:2012 + A1:2017 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products

ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework

ISO 14041:1998 Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis

ISO 14042:2000 Environmental management – Life cycle assessment – Life cycle impact assessment

ISO 14043:2000 Environmental management – Life cycle assessment – Life cycle interpretation

ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.

Appendix 4 LCA tools

A number of tools to conduct life cycle assessment for buildings exist today. Apart from different user process or interfaces, they can differ by their Life Cycle Impact Assessment (LCIA) methodologies, data sources, standards followed and the certifications with which they comply.

To illustrate this diversity, some tools are presented below:

- **Tally is an American tool which uses generic data adapted for the North American market from the GaBi database.** It uses TRACI as the LCIA methodology, compliant for LEED and the Living Building Challenge.
- **One Click LCA is a Finnish tool.** It uses generic data and EPDs (Environmental Product Declarations produced by manufacturers) and TRACI or CML LCIA methodology depending on the project location and certification required (BREEAM, LEED, HQE etc). The tool also provides Life Cycle Cost analysis.
- **eTool LCD was originally developed in Australia.** BRE recognises this tool as compliant to produce building LCAs towards MAT 01 credits in the current suite of BREEAM certification tools. The tool is BIM-enabled and provides a simple user interface that can also link LCAs with Life Cycle Costing.
- **H\B:ERT is a free to use British tool based on generic data from the ICE database at the University of Bath.**



This list is non exhaustive, and LETI does not recommend the use of any particular tool over any other available. However, the use of BIM based LCA tools like Tally, One Click LCA, H\B:ERT and eTool LCD offers the possibility of full integration of LCA within the design process. BIM based LCA tools are plug-in tools embedded into BIM software such as Revit and ARCHICAD. The basic concept is to automate LCA by extracting dimensional data from the 3D model, such as material identification and volume and augment it with environmental data held in an external database. When correctly modelled, the process is likely to provide quicker results, with reduced risk of data losses or errors than if the LCA was done manually. LETI makes the following recommendations concerning LCA tools:

- The data from the tool used should be third party verified and reflect the geographical location of the project. Manufacturing processes, types of products used, transport and energy grid mixes all vary between countries and continents.
 - The tool used should account for all life cycle stages A to C, and optionally D, as this is referenced by the EN standard and means at least cradle-to-grave.
 - Generic data (average across the industry) is usually more relevant earlier on in the design process. EPDs are suitable at later stages when the construction materials have been selected. There should be at least two full LCA iterations, one at stage 2 and one at stage 4.
 - Detailed studies for the facade, roof, floor and structure should be undertaken early in the design process. They can be beneficial to inform early design decisions with more accuracy than the whole building LCA straight away.
- The process should focus on iterations and comparison of design options during the whole design process. The global warming potential tends to increase as the project develops and more elements are defined.
 - When using BIM based LCA tools, it is important to keep the data from the final BIM model in order to compare the reality to the proposed design. The BIM model can also be used to aid maintenance and replacement, as well as compare to the assumed replacement cycles established in the LCA. The tool should also be able to recognise most elements of the 3D model to make sure nothing is left behind ('takeup methodology'). Great care and precision must be given to the elaboration of the 3D model as it will directly impact on the LCA.

Appendix 5 Procurement

LETI believe that public procurement teams, responsible for 25% of all UK construction procurement annually, should lead the way for best practice nationally. The Public Contracts Regulations 2015 already make it clear that the most economically advantageous tenderer (MEAT) is one who offers best value, defined as cost and quality.

The regulations specifically note that quality includes the consideration of life cycle costing, and that it should be included within the review process. The costing can cover environmental externalities such as pollution from material manufacture, i.e. embodied within the materials used. However, feedback from designers and other industry experts suggest that a life cycle approach is rarely undertaken.

LETI urges a review of procurement framework awarding criteria for public buildings and infrastructure. All tender scores must incorporate carbon targets and wider social and economic responsibility in terms of life cycle costs.

Encouraging collaboration through procurement can be used to foster a culture in projects where sustainability is the primary focus. Collaborative procurement forms can also enable working with suppliers and contractors to develop strategies for supply of low carbon materials and reducing carbon in construction methods. Procurement types that encourage collaboration from an early stage enable innovations and a fuller integration of the whole life approach to a building.

The agency of the designer, client or policy maker is to ensure that carbon becomes a measurable aspect of the specification. However the building is constructed, the strategy for carbon should form part of the contractual obligation of those building it. Likewise, the requirement for all materials to provide an EPD as part of the specification could form part of this.

The form of procurement impacts the agency of the designer in maintaining low carbon strategies. Different forms of procurement will prioritise different aspects, e.g. cost, time, and quality. Some forms of procurement are better suited to whole life carbon approaches to design than others. It will be important regardless of what method is chosen that the contractor(s) bidding for work are given full access to carbon strategies for the scheme. The specification must be written in enough detail for them to price the works accordingly. Your task as the designer is to adapt and make relevant the carbon reduction strategies as required depending on the form of procurement to ensure that the scheme meets the targets you have set out. Here are some suggestions for how different procurement priorities may align with carbon reduction strategies:



5.1 Low carbon strategy and procurement priorities

Quality

- Materials that are made to last, with minimal maintenance. Natural materials.
- Carbon strategy in line with RIBA or other awarding body targets to enable scheme to be eligible for winning awards.
- Continued professional development by designers in low carbon materials and techniques.
- Designed with the beauty of the structure on display, rather than additional, superfluous finishes.

Time

- Considering carbon at an early stage in the project. Supporting a client to include carbon requirements in tenders, contracts and performance specifications.
- Wherever possible, earlier engagement between designer and main contractor.
- Design for manufacture and assembly (DFMA) – designed with prefabrication in mind, reducing construction waste and generally speeding up construction.

Cost

- Less is more. Reducing overall building size and material quantities and complexity in form will generally reduce the overall embodied carbon.
- Making use of the site and retrofitting existing buildings rather than building anew.
- Cost of construction is one consideration; cost of maintenance is another. Designing with whole life carbon and life cycle maintenance in mind. Conduct whole life cost analysis.
- Products as services.

Risk

- Risk of future costs arising from carbon embodiment of building maintenance can be avoided by designing low carbon now.
- Risk of future tenants and prospective buyers not wanting to purchase or lease a building that is problematic environmentally.
- Many planning authorities have declared a climate and biodiversity emergency. Schemes that demonstrate an effort to reduce carbon may be preferable to those where this has not been considered. In Scotland and Manchester more specific zero carbon requirements have been set out. It is likely that this practice will spread throughout the UK. For a long-term slow project, the risk of a planning condition with regards to embodied carbon can be avoided.
- Safety in construction – designing in MMC/DfMA methods may reduce WLC carbon, and has a secondary benefit of limiting works at height on site, and can potentially eliminate the need for scaffolding.

Finance

- The Bank of England and other financial institutions, including lenders, are increasingly concerned by climate change and the impact it will have on their investments. For large scale schemes, or public schemes, it is likely that lenders and financial providers will take a more active interest in the measurable aspects of 'sustainability' of proposals, to meet their shareholders' interests and obligations. Major international investors are already aligning to campaigns such as Climate Action 100+.

5.2 Further Reading

Bloomberg news

<https://www.bloomberg.com/news/articles/2019-10-02/major-investors-to-ask-companies-to-be-carbon-neutral-by-2050>

Climate Action 100+

<http://www.climateaction100.org/>

ONS: 2019, Construction statistics, Great Britain: 2018

<https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/articles/constructionstatistics/latest>

Crown Commercial Service: guidance on awarding contracts, 2016

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/560263/Guidance_on_Awarding_Contracts_-_Oct_16.pdf

ISO 20400:2017 gives guidance for integrating sustainability and procurement

<https://www.iso.org/standard/63026.html>

CIRIA guide to sustainable procurement in construction

<https://www.ihsti.com/CIS/document/296922>



Appendix 6 Rules of thumb

6.1 Substructure

Substructures range from strip foundations through to large underground basements and are usually made from concrete. The substructure of a building is generally the element where structural performance aspects are the largest design driver.

6.1.1 How to use fewer materials

- Reuse existing substructures wherever possible.
- Remove the need for basements, reduced services, avoid underground parking.
- Use geotechnical surveys to optimise design.
- Reduce the building weight where possible, taking into account the whole life carbon impacts of any thermal mass benefits.
- Review live-load requirements with the client and seek to optimise these.
- Reduce the amount of reinforcement in the design.
- Reduce the amount of retaining required in basement designs by landscaping surrounding ground levels rather than creating retaining structures.

6.1.2 Use low carbon materials

- Use as high a cement replacement mix as possible below ground. This could be possible if the need for early strength gain is managed.

SIGNPOST Appendix 8 – Material guides – concrete

- Use 100% recycled reinforcing steel. This should be standard practice.
- Design to use reusable formwork to reduce waste. This can be done by repeating modules in the design and accepting different finishes.

- For retaining walls consider pre-cast units, which may allow higher cement replacement, or using geotextile reinforced earth walls.
- Use concrete alternatives such as Limecrete or Hempcrete where performance requirements allow, such as in ground floor slabs.
- Investigate screw-pile foundations if the project is likely to have a short lifespan.
- Investigate low-carbon options such as timber piles (used in maritime applications), rubble trenches or dry-stack masonry. Often suitable for smaller scale projects where materials are available locally.
- Use low-carbon below-ground insulation such as foamed glass.

6.1.3 How to reduce waste

- Use recycled aggregate where possible for ground work. This may sometimes be available on-site.
- On site waste can be effectively reduced by moving more of the construction activities off site, so that on site work becomes mainly assembling components rather than cutting and shaping materials.

6.1.4 Adaptability

Ensuring the building can be adapted for future changes in use.

- Consider loadings in terms of potential future uses of the building and in terms of climate resilience. In the future there may be larger swings between wet and dry, or hot and cold weather.

6.1.5 Disassembly

- If the building is likely to have a short lifespan, consider screw piles, which can be reused/recycled at end-of-life.

6.1.6 Products as services/leasing

- Relevant to modular short-life buildings only.

6.1.7 Further Reading

The Concrete Centre (Aggregate)

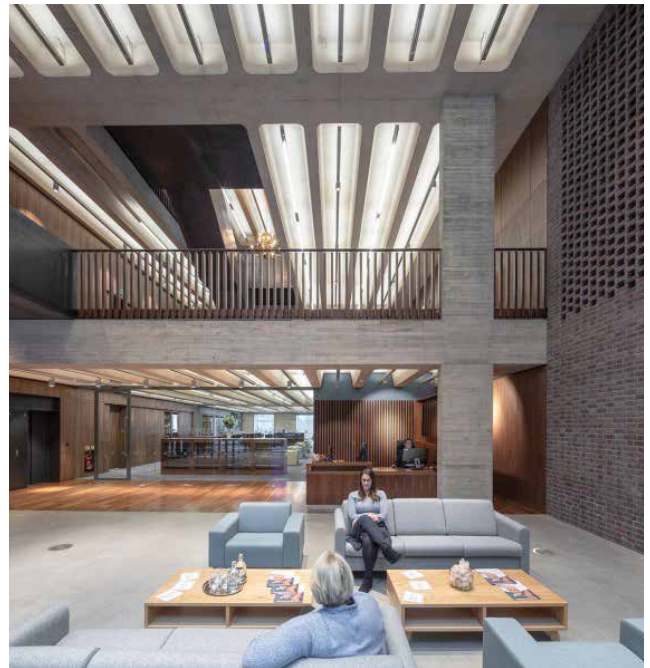
[https://www.concretecentre.com/Performance-Sustainability-\(1\)/Circular-economy/Material-Efficiency/End-of-life-recycling.aspx](https://www.concretecentre.com/Performance-Sustainability-(1)/Circular-economy/Material-Efficiency/End-of-life-recycling.aspx)

David Cheshire. Building Revolutions. RIBA Publishing. 2016.

6.1.8 Case studies

Royal College of Pathologists

The new London headquarters for the Royal College of Pathologists is a flexible, environmentally efficient building. Located in the rapidly-changing area of Aldgate on the city's eastern fringes, the seven-storey building replaces an existing office block. The existing concrete foundations were re-used as part of the low carbon strategy. Internally, the spaces are unified by the use of exposed coffered concrete slabs throughout, which gives a strong visual character and forms a key part of the building's passive cooling strategy.



Royal College of Pathologists

Internal view

<https://www.bennettsassociates.com/projects/royal-college-of-pathologists-hq/>



Water Polo Arena, David Morley Architects

The London 2012 Olympic and Paralympic Games Water Polo Arena was designed from a kit of parts that come from and were returned to the supply chain of temporary structures, including removable screw pile foundations and sheet pile retaining walls.

A system of screw anchors was used for the foundations. The main advantages to this pile type are the ease of installation and the ease of removal. The piles can be installed with limited arisings of contaminated material and can be taken out to leave the site clean, the pile can then be reused or recycled.



Water Polo Arena
External view

<http://davidmorleyarchitects.co.uk/projects/london-2012-water-polo-arena>

6.2 Superstructure

The Superstructure is the frame of the building required to support the suspended slabs, roof and internal finishes and provide stability. Typically, a superstructure is made up of columns, slabs, shear walls and bracing members.

6.2.1 How to use fewer materials

- Preserve and re-use existing structures wherever possible; this can include extending if appropriate.
- Review and reduce loading requirements with client wherever possible: Could high loading points be allocated closer to cores rather than in the middle of floors?
- Reduce spans taking into account the impact on long-term flexibility.
- Design lighter facades that allow larger deflections at slab edges.
- Consider the carbon impact of the cladding elements.

 **SIGNPOST** Appendix 6 – Facade


If using concrete:

- Post-tensioning to reduce concrete volumes. Consider the impact on long-term flexibility and possibly design in soft spots for later adaptation.
- Forms that minimise material use, such as coffered slabs. Consider the impact on long-term flexibility in terms of partition grids and servicing.
- Using re-usable formwork to reduce the amount of waste generated
- Using concrete as a surface finish to minimise use of other internal finishes.

- If using steel, use castellated beams or trusses to reduce material volume and weight and allow services to run through.

6.2.2 Use low carbon materials

- Sustainably sourced cross laminated timber (CLT) usually has lower embodied carbon than steel or concrete. Consult with a life cycle assessment (LCA) specialist and service engineer about other life cycle trade-offs. (N.B. concrete has thermal mass benefits).
- Consider materials such as rammed earth and modular cassettes such as sealed straw bale panels, particularly on smaller scale projects.
- If using steel, prioritise high recycled content and shorter transport distances to site.

 **SIGNPOST** Appendix 8 – Material guides – Steel

- Consider hybrid structures that optimise the performance of each material.


→ If using concrete:

- Prioritise highest possible cement substitution with industrial by-products (PFA, GGBS) for each element. Replacement in vertical structures is likely to be greater than in slabs. Review alternatives with a LCA consultant or manufacturer.
- Use recycled aggregates if they are available on or near the site.



6.2.3 How to reduce waste

- Adopt Design for Manufacture and Assembly (DfMA) principles.

 **SIGNPOST** *Appendix 7 – Designing for manufacture and assembly*

6.2.4 Adaptability

Ensuring the building can be adapted for future changes in use.

- Modular design – consider separating structural elements from functions that could be changed or moved as part of future adaptation, for example not enclosing lifts, stairs and toilets within shear walls, restricting where these could move in future fit-outs.
- Consider where it may be possible to incorporate soft-spots or easily demountable structure for future alterations.
- Consider spans, loads and structural grids that allow for changes and alternative uses, particularly if designing for typologies that may become obsolete in the near future such as car parking.

6.2.5 Disassembly and recyclability

- Avoid composite materials (e.g. concrete on metal deck), which may be hard to deconstruct in future.
- DfMA strategies are most likely to allow for deconstruction and re-use.
- Design connections to be visible and reversible.

6.2.6 Pitfalls (unintended consequences, or things people normally forget)

- High cement replacement concrete mixes are often resisted due to perceived risks with early strength gain, and increase in striking time. This can be mitigated by temperature monitoring during curing and allowing switches to higher cement mixes during particularly cold weather.
- High cement replacement content can cause changes in the colour of concrete: GGBS is lighter, PFA is darker.
- Timber frames may require encapsulation, sprinklers or other fire-protection measures to overcome surface spread of flame and combustibility issues.

6.2.7 Further Reading

The Concrete Centre download guide on Specifying Sustainable Concrete

<https://www.concretecentre.com/Publications-Software/Publications/Specifying-Sustainable-Concrete.aspx>.

6.2.8 Case studies

Anna Freud Centre, Penoyre and Prasad

The new Kantor Centre of Excellence is a 3,200m² new build and refurbishment project located on a restricted site near London's Kings Cross. It will be the first centre of excellence for children and young people's mental health in England. The super-structure has been designed as low embodied carbon utilising a hybrid timber and concrete structure alongside a refurbishment.



Anna Freud Centre

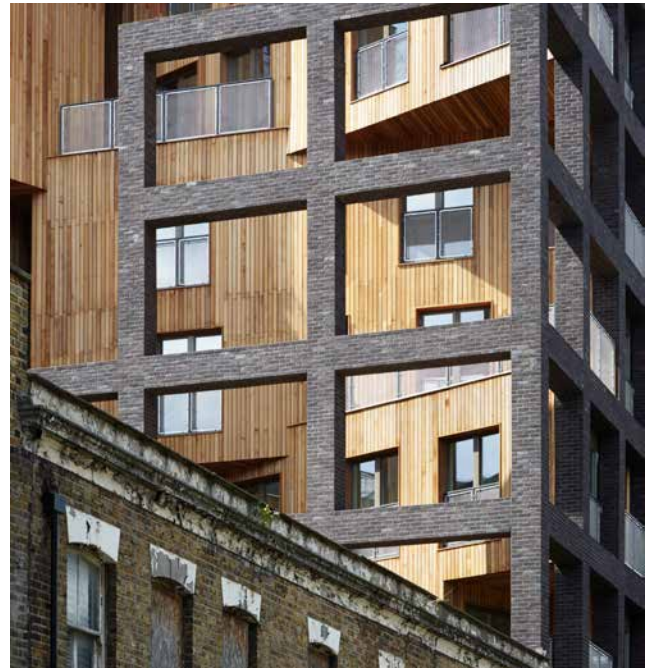
Internal view

<https://www.penoyreprasad.com/project/kantor-centre-of-excellence-anna-freud-centre-campus/>

Wenlock Cross, Hawkins\Brown

The client brief was to maximise value by creating something a little bit different. A unique building of 50 apartments with good daylight, great views and generous terraces.

The building is a solid cross-laminated timber structure, manufactured off-site, it uses steel reinforcement where necessary, and is one of the tallest of its kind in Europe. The innovative CLT hybrid structural strategy, developed by timber and steel specialist B+K Structures, proved the most efficient and sustainable way to achieve the unique 10-storey building.



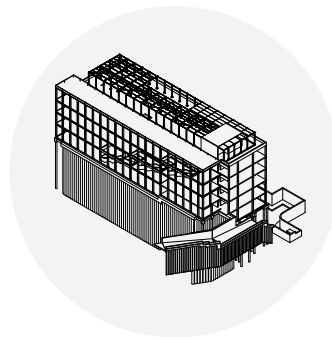
Wenlock Cross

External view

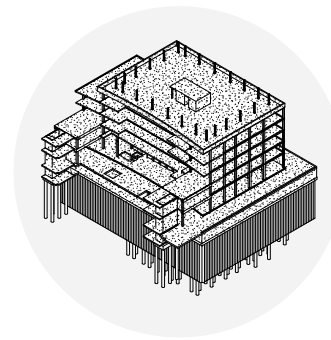
<https://www.hawkinsbrown.com/projects/17-21-wenlock>



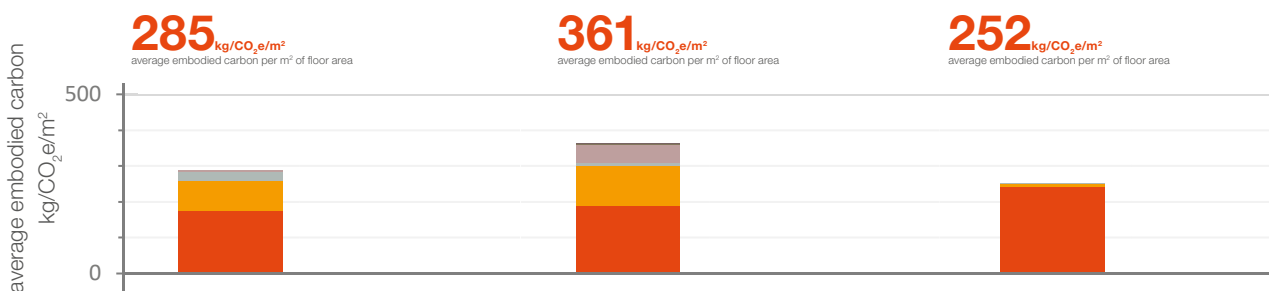
Urban Sciences Building



Biomedical Research Building



Neurological Research Centre



Structural frame:

Main structural frame cast in-situ concrete frame with hybrid timber and steel for roof

Architect: Hawkins\Brown

Location: Newcastle, UK

Sector: Education

Size: 12,800 sq m

Sustainability: BREEAM Excellent, Bespoke Framework, Blueprint Award 2018 for Best Sustainable Project (shortlisted), Lord Mayor's Design Award 2018 for Sustainability

Status: Complete

Structural frame:

Main structural frame hybrid timber and concrete

Architect: Hawkins\Brown

Location: Warwickshire, UK

Sector: Education

Size: 6,800 sq m

Sustainability: BREEAM Excellent target

Status: Construction

Structural frame:

Main structural frame cast in-situ concrete frame

Architect: Hawkins\Brown

Location: London, UK

Sector: Education, workplace

Size: 17,200 sq m

Sustainability: BREEAM Excellent target

Status: Concept

Figure A.6.2.1 – Structural frame comparison case study, data and images courtesy of Hawkins\Brown Architects LLP, not to be copied or reproduced without consent. Results assessed by H\B:ERT tool covering stages A1-A5, B4 and C1-C4 according to BS EN 15978:2011.

6.3 Facade

Focus on the facade at early design stages can be highly beneficial to a project. Offering less-carbon intensive material solutions in design development stages can lead to exciting design decisions and help reflect a client's values. A reinforced rammed earth façade instead of reinforced concrete façade can make a statement about a client's values. It is important to consider the assumed lifespan at the beginning of the project in order to inform material choices.

6.3.1 How to use fewer materials

- Design in material savings to reduce total material use and weight of facade panels. For example:
 - Perforated metal cladding – reuse of the waste from the perforating should be considered in the decision-making and carbon calculations.
 - Precast concrete façade panels can be profiled to maximise structural efficiency and can add aesthetic detail to the facade
 - Use of non-load bearing materials such as metal, can raise embodied carbon.
- Work closely with the whole design team to ensure the structural system is the most appropriate for the facade system.
- Consider the thermal performance of the façade as a whole life cycle exercise.
- Consider the construction method in the early stages to design in efficiency, for example accurate wall build-ups and thicknesses.
- Consider what will happen to the facade materials at the end of the building's life as part of the design decision process.
- See the life cycle impact of various cladding materials in the 'references' section.

6.3.2 Use low carbon materials

- The carbon intensity of facade materials should not be considered in isolation, but as part of a whole facade system.
- Lime render or mineral wool can have a big impact in achieving lower embodied carbon.
- Traditional brick build-up can be a low carbon solution and further enhanced by using recycled bricks and lime mortar. Use of lime mortar enables bricks to be reused at the end-of-life.
- Timber framing can often be used instead of metal framing, subject to fire regulations.
- Aluminium clad timber windows can have lower embodied carbon than aluminium framed windows.
- All timber should be from regulated and responsible sources.
- Specify aluminium from a source that uses less carbon-intensive production methods – Polyester Powder Coating (PPC) aluminium is easier to recycle at the end-of-life than anodized aluminium, but needs more maintenance.
- Ceramic or terracotta may be suitable in place of metal as rainscreen cladding. Self-supporting brick and concrete facades can reduce the need for sub structure.
- Choose facade systems and materials that match the whole building life cycle impact and lifespan. Consideration should include maintenance and likely replacement rates.
- The window-to-wall ratio is a good metric to assist design but it can be limiting. Consider the facade as a combined average of windows and walls, not separate entities to inform better embodied carbon decisions.
- Insulation choices should be assessed as part of a whole life carbon study alongside the operational



carbon – how quickly is the embodied carbon cost of additional insulation thicknesses offset by the benefit of operational carbon savings, taking in to account the additional lengths of brackets and supports?

- Insulation comparison study:
 - 1m² of PIR at 160mm thick will achieve a U-value of 0.18, at a carbon cost of 14.4 kgCO₂e. ¹
 - 1m² of Rockwool stone wall at 200mm thick will also achieve a U-value of 0.18, at a carbon cost of 8.3 kgCO₂e. ²
 - 1m² Knauf mineral wool at 190mm thick. will achieve a U-value of 0.18 at a carbon cost of 3 kgCO₂e. ³
- This demonstrates that PIR insulation has superior insulative performance at a given thickness but at the cost of higher embodied carbon.
- Lower embodied insulation options include plant based products such as hemp or wood fibre board, products under development such as Fungalogic and Glimps and sheep's wool (see reference section).

6.3.2 How to reduce waste

- Consider how to coordinate design development to avoid over design, especially in structural elements.
- Where appropriate, design for repetition and off-site manufacture. Use standard sized components and materials to minimise bespoke pieces and offcut waste.
- Consider shuttering and the transport structures for prefabrication; try to reduce the waste that arises in construction process.

6.3.3 Adaptability

Ensuring the building can be adapted for future changes in use.

- Heating and cooling – design in shading and openable windows for cooling where possible. Additional materials used should offset the embodied carbon by reducing the need for cooling.
- Aim to achieve better u-values and thermal performance and consider appropriate air tightness to reduce operational carbon emissions. Note that there is a balance to be achieved as improving thermal performance can lead to higher embodied carbon figures.
- Consider adaptability options when setting up facade grids and modular panelling.
- Design fixings that can easily be disassembled for adaptation, maintenance or replacement.

6.3.4 Disassembly

- Consider panelised construction for easier disassembly.
- Ensure that if one glazing unit fails, and needs to be replaced, this single unit can be replaced, rather than a whole section of a facade.
- For brick facades, using lime mortar enables the bricks to be reclaimed and reused following disassembly.

6.3.5 Products as services/leasing

- It is uncommon for facades to be leased or produced as a service; the industry is underdeveloped in this area.
- Facade or window systems such as Wicona are a step towards development in this field.

6.3.6 Pitfalls

- Concealed metal support framing in façades has the most impact on the embodied carbon content, especially in rainscreen cladding. The heavier the cladding panel the greater the embodied carbon. If available, recycled metal can be specified. Accurate modelling of façade systems should be undertaken at early stages.
- When comparing façade options, the U-value should be consistent for each option build up to allow like-for-like comparison.
- Facade design tends to increase in detail and proportionally in embodied carbon values as the project progresses. Some tolerance should be factored in at the early stages to allow for this.
- The choice of façade system can be 'locked in' very early on in a project. Once planning consent is granted, the facade design is less likely to change. Early stage evaluation of whole life carbon impacts is recommended.
- Value engineering can also lead to less well considered material choices, for example, a precast concrete panel being replaced by a less durable and cheaper material such as GRC.
- Facade articulation can be carbon intensive. For example, for a brick facade, if a lightweight brick slip system is chosen over a traditional method this can increase the embodied carbon figure drastically. A precast system may have higher in embodied carbon than a traditional system due to the use of metal framing but have lower embodied carbon than a lightweight system (fig. A.6.3.1). Life expectancy of the building and alternative framing systems (such as a timber system – where appropriate, due to combustibility) should be considered alongside the embodied carbon value.

6.3.7 Further Reading

Wicona Systems

<https://www.wicona.com/en/uk/Range-of-systems/Facades/>

E-tool study on cladding materials life cycle impact

<https://etoolglobal.com/eblog/what-cladding/>

Study on facades whole life carbon

<https://www.building.co.uk/whole-life-carbon/whole-life-carbon-facades/5078620.article>

Plant based insulation links

<https://woodfiber.dk/traefiberisolering/>
<http://www.fungalogic.nl/wordpress/design/>
<https://glimps.bio/portfolio>

Report on the embodied carbon of different insulation alternatives

<http://www.greenspec.co.uk/building-design/embodied-carbon-of-insulation/>

6.3.8 References

1. **PIR EPD** http://highperformanceinsulation.eu/wp-content/uploads/2016/08/Factsheet_13-1_Environmental_product_declaration__EPD__for_PU__PUR-PIR__thermal_insulation_boards_and_energy_saving_potential__updated_12-12-14_.pdf
2. **Rockwool EPD** <https://static.rockwool.com/globalassets/rockwool-fi/tyokalut/dokumentit-ja-sertifikaatit/hyvaksynnat/environmental-product-declaration.pdf>
3. **Knauf EPD** https://heraklith.co.uk/application/files/1515/3415/5572/epd_heraklith_houtwolpanelen.pdf



6.3.9 Case studies

The Enterprise Centre, University of East Anglia, Architype

The Enterprise Centre at UEA has minimised the emissions associated with construction through the use of natural and recycled materials for every part of the building. This includes the use of recycled aggregates and reinforcement, a timber structural frame, external thatched panelling. Reclaimed timber was also used from the original lab benches and a local fallen tree.



The Enterprise Centre at UEA, Architype
External view

<https://www.uea.ac.uk/adapt/the-enterprise-centre>

The Wales Institute for Sustainable Education, Centre for Alternative Technology, David Lea and Pat Borer

The WISE building is designed to have a very low environmental impact in construction and in use, through the use of natural materials with a low embodied energy – including timber, earth and hemp. An internal rammed earth wall is fundamental to the sustainability strategy.



The WISE building
Internal view

<https://www.cat.org.uk/info-resources/free-information-service/building/wise-building/>

Architect: Hawkins\Brown
Location: Cambridge, UK
Sector: Workplace

Methodology

Initial scoping studies carried out at concept stage to assess the comparative embodied carbon of a wide range of facade types which were considered for a wellbeing-focused project. Each typology has been modelled in detail in Autodesk Revit to generate a value per square metre of facade based on an 8m² test panel. The analysis has been carried out using the H\B:ERT plugin.

Assumptions

The same volume of concrete frame has been assumed on each of the options.

The structural design of the frame and subframe shown is indicative and will depend on further study by a facade specialist.

All options have a similar steel or aluminium sub-frame, more detailed modelling is required with the help of a specialist facade consultant to determine the exact amount of structure needed to support each facade type (ceramic will be heavier than aluminium for example).

All have the same assumed U-value.

Material contributors:

- Steel
- Aluminium
- Precast Concrete
- Ceramic
- Reinforced Concrete
- Mineral Wool
- Zinc
- Sheathing



Figure A.6.3.1 – Embodied carbon study of facade design options at stage 2. Data and images courtesy of Hawkins\Brown Architects LLP, not to be copied or reproduced without consent. Results assessed by H\B:ERT tool covering stages A1-A5, B4 and C1-C4 according to BS EN 15978:2011.

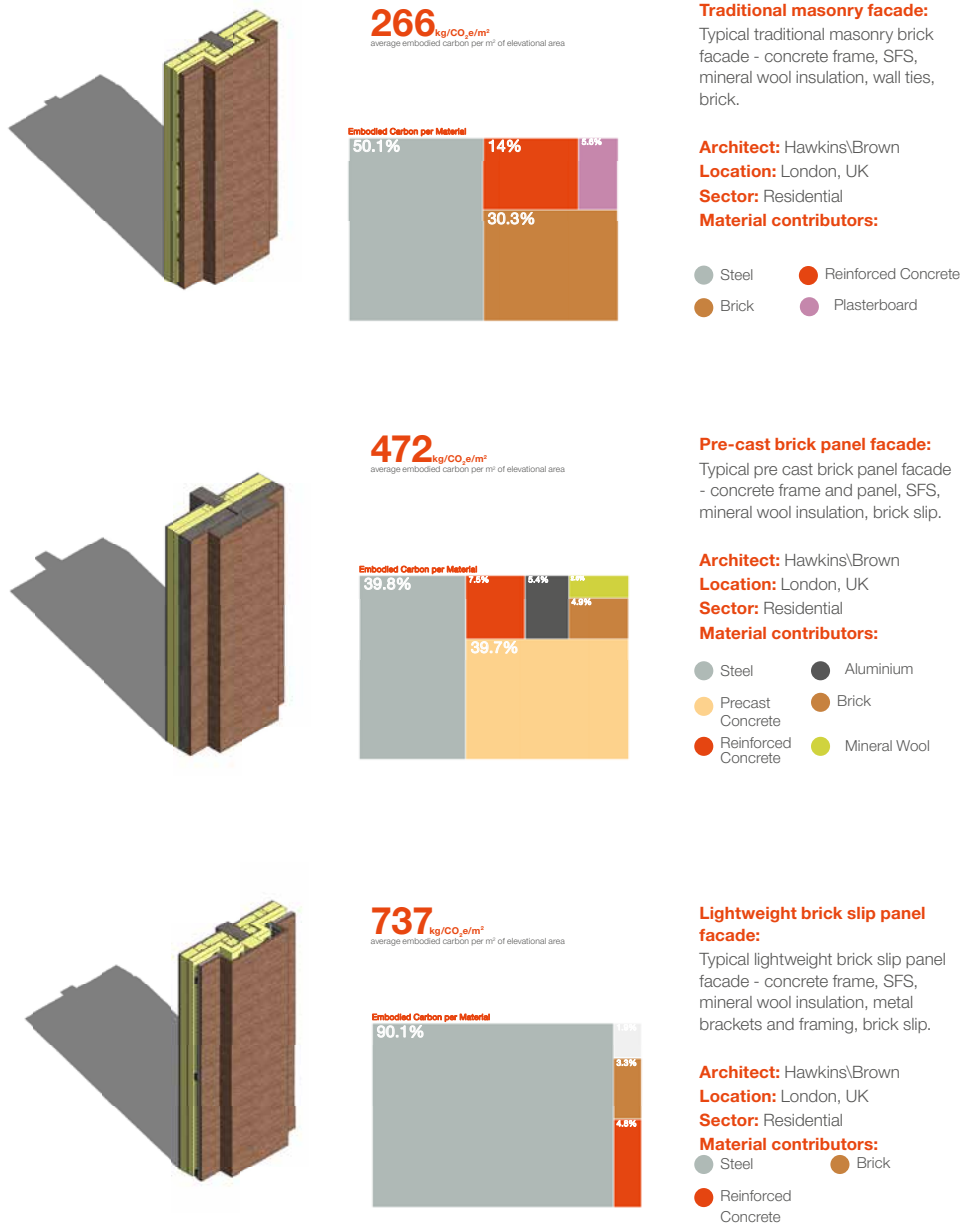


Figure A.6.3.2 – Brick facade construction method comparison case study. Data and images courtesy of Hawkins\Brown Architects LLP. Not to be copied or reproduced without consent. Results assessed by H\B:ERT tool covering stages A1-A5, B4 and C1-C4 according to BS EN 15978:2011.

6.4 Building services

Building services comprise the lighting, heating, cooling, ventilation and air conditioning plant. Studies have shown that building services account for 2%-27% of embodied carbon (11% on average). In retrofit schemes, the proportion of embodied carbon related to building services can be considerably higher.

Many building services have a much shorter life span than the building itself, particularly the fit-out elements such as lighting and terminal units in commercial buildings. Others, such as distribution systems and communal heating, typically have a long life and may in some cases outlast the building itself.

6.4.1 Key recommendations

Consider embodied carbon alongside the other functional implications of building services, including operational carbon, comfort, and health and safety. There are many opportunities for design strategies that reduce both embodied and operational carbon. If it is possible to meet functional requirements without plant, then this is the best solution.

If plant is needed, optimise its provision and size by adopting load reduction measures, carrying out detailed load assessments, and carefully considering the requirements for flexibility and back-up.

Specify equipment with:

- Low refrigerant GWP and leakage.
- High thermal efficiency.
- Long lifetime.
- Light weight.
- Materials with low embodied carbon.
- Materials that can be demounted, disassembled and reused.

The servicing strategy will often not be fully detailed at the planning stage, so any assessment at this stage is likely to be subject to a high number of assumptions. It is important to re-visit the assessment at Stage 4 design and at final completion. In cases such as speculative shell and core offices, it may be necessary to differentiate what is within the applicants control, from what will be the responsibility of future occupiers, in a similar way as for operational carbon. There are nevertheless a number of key early stage design decisions that will influence the embodied carbon of building services.

There is currently little data available on building services embodied carbon when compared to other building elements. In order to build a better understanding on projects and on the industry as a whole, designers should ask for Environmental Product Declarations (EPDs) from suppliers and compare the GWP data that should be available therein. This should help to make informed choices when specifying plant.

6.4.1 Overview

The embodied carbon of building services needs to be considered at several levels, broadly corresponding to increasing levels of detail:

- At the whole building level, when strategic design decisions are being made e.g. whether to have mechanical or natural ventilation.
- At the system level, when a strategy has been selected and systems are being designed – drawing ventilation routes, determining the amount of back-up plant, considering the level of insulation on distribution pipework.
- At the product level: this will typically be left until post-planning.

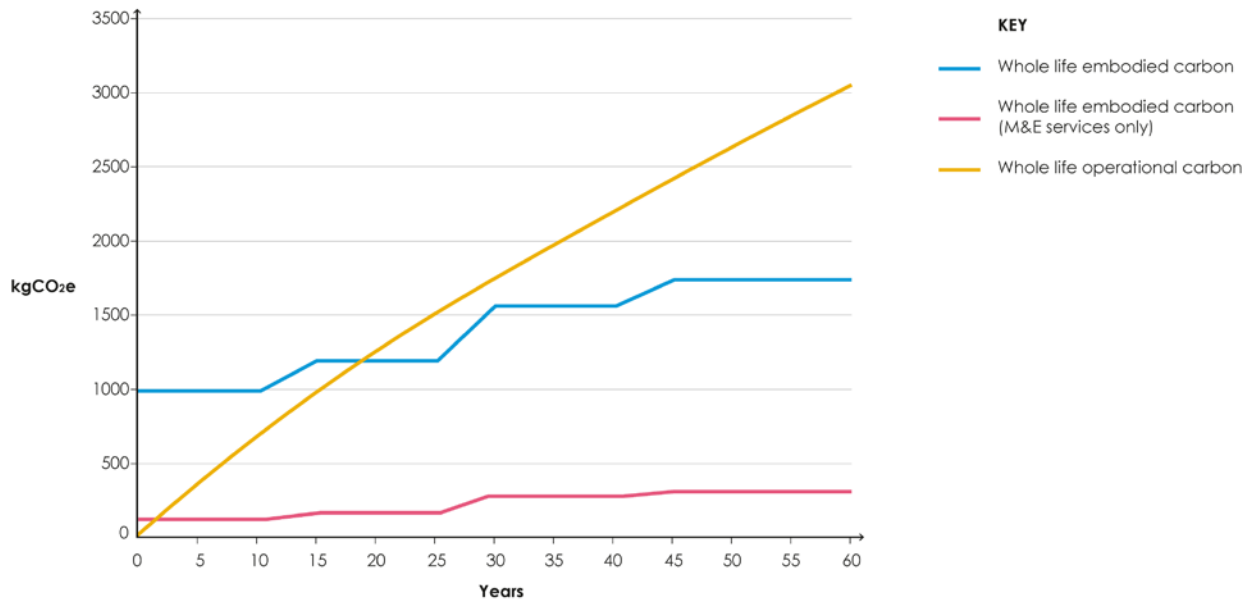


Figure A.6.4.1 Embodied carbon of building services should be considered alongside potential impacts on operational carbon emissions from energy use. Trade-offs may be needed in some areas, and decisions will often be project-specific, depending on building use, expected building lifetime, fit-out cycle etc. Illustration shows one air-conditioned office over 60 years (source: AECOM analysis, for CIBSE TM56).

When considering the initial embodied carbon cost of passive design and efficiency measures, designers should review whether, by going further in reducing the load, a step change can be obtained that reduces the need for plant, which would result in significant savings in both operational and embodied carbon, as well as operational and capital costs.

6.4.2 How to use fewer materials

Fewer, simpler systems will usually mean lower initial embodied carbon, and often also help improve operational efficiency. There are many examples of new complex or innovative systems which were switched off or replaced in the early years of a building's use phase because they were too complex for the occupant to operate. The system must be understandable if it is to be used correctly.

Question the brief and the amount of flexibility and back-up incorporated in the scheme, to avoid over-provision of plant and oversized plant. This should include:

- Early discussions with the client on what are reasonable provisions.
- A review of possible alternatives to plant provision on day 1. For example, resilience may be provided by a second grid supply rather than an on-site generator, or instead of providing plant for peak loads during occasional events, leasing arrangements may be more appropriate and cost effective.
- Rather than applying a 'safe' rule of thumb, detailed load modelling will provide better predictions of energy use and help size plant requirements more accurately, saving unnecessary materials and costs.

Ensure that energy, water and carbon saving systems operate as efficiently as possible, so that carbon savings over their lifetime compensate for the initial embodied carbon cost. This should include best practice design, installation and commissioning, and ensuring that maintenance procedures are understood and followed by appropriate FM resources. Make enquiries from suppliers about embodied carbon (ideally, through EPDs) and end-of-life implications.

Heating and cooling plant

Passive design and energy efficiency measures will reduce peak as well as annual loads. This should be taken into account to reduce the amount and size of plant. Exemplar low-energy design could even omit the need for heating and cooling plant, leaving only a very small occasional load that can be met with minimal alternative systems like small direct electric heaters or heating coils.

Distribution systems have relatively long lifespans and can determine future options for heating and cooling plant. They should be designed to allow as much flexibility as possible in the future, in particular to accommodate heating and cooling from low-carbon sources. Typically, the carbon savings made during the operational phase of services are greater than the extra embodied carbon incurred during installation, so is worth greater consideration.

Thermal storage and distribution systems should be well insulated as the benefits in operation will typically outweigh the initial embodied carbon costs.



Ventilation

Natural ventilation will save significant amounts of plant compared to mechanical systems. However, this should be considered carefully in balance with the benefits that mechanical ventilation can provide. Many of the best-performing buildings in terms of energy consumption, carbon emissions and user comfort include both mechanical ventilation with heat recovery, and openings for summer comfort.

As a general rule, in large buildings with differing spaces and highly variable occupancy patterns, dedicated AHUs serving key spaces will be more efficient in operation than a single AHU. This is likely to be more significant than the initial embodied carbon implications.

Ductwork is a large component of the embodied carbon of ventilation systems. Larger ducts may increase the amount of materials needed, but this will usually be offset by operational efficiencies, and so is recommended.

Savings in materials used for ductwork can be obtained by carefully considering ducting routes. This can also improve operational efficiency, for example minimising the length of insulated ducts can reduce fan power needs.

Ductwork is typically made of galvanised steel; lighter components may sometimes be used, such as fabric or plastic, but they need careful consideration regarding fire, hygiene, acoustics etc. The end-of-life should also be considered as this may have other impacts. Some plastics cannot be recycled. Removable insulation rather than composite materials makes recycling easier. Ductwork that can be flat-packed reduces the environmental impact of transportation and packaging.

Lighting

In lighting systems, the largest amount of material is associated with luminaires (ref: CIBSE TM56). Therefore, it is best to specify luminaires that use materials with a high recycled and recyclable content wherever possible.

6.4.3 Use low carbon materials, systems and products

Building services components are in the main made of metals and therefore have a large initial embodied carbon content, but also have high recycling rates. The crucial aspect is to ensure the products and equipment are easily accessible for inspection, maintenance and replacement. They should also be demountable and easy to disassemble in order to operate well for a longer period, and be recycled or reused at their end-of-life.

There is much less data available on building services' embodied carbon than on other materials used in building construction. To help address this and to promote knowledge in the industry, designers should ask for Environmental Product Declarations from suppliers.

Think holistically when selecting cooling plant and refrigerants: Consider the impacts of refrigerant leakage. Refrigerants (e.g. R410A, R407C) often have a high Global Warming Potential (GWP), which means that even at low leakage rates, they can still be damaging to the environment. CO₂ and ammonia have substantially lower GWPs, but have other health and safety implications that must be taken into account. Other low GWP refrigerants are available.

6.4.4 How to reduce waste

Off-site construction is increasingly common, for example off-site ductwork fabrication, pre-assembled and pre-wired pump sets, bathroom pods, pre-assembled and pre-wired fan coil cooling units and complete boiler rooms. It can reduce waste arising on site as well as improving workmanship quality and providing faster construction times. A high level of planning and coordination ahead of construction is required in order to avoid mistakes that result in increased waste and delays.

A key consideration to reduce waste and increase the lifespan of plant is to provide easy access for regular inspections and maintenance. This will also benefit operational efficiency.

When a product or system has reached the end of its life consider whether some of its components may be re-used in-situ, or elsewhere.

6.4.5 Adaptability

Ensuring the building can be adapted for future changes in use.

As well as questioning the brief mentioned above, consider the potential impacts of future climate change and how best to avoid the need for extensive retrofit. This may not mean that extra plant is provided from day one, but that there is space allowed for it in the future.

6.4.5 Disassembly

This is a crucial consideration for building services,

which typically have shorter life spans than many other building elements. Components are often high in value and embodied carbon, and are often highly recyclable if they can be disassembled correctly.

6.4.6 Products as services (leasing)

Where peak loads are infrequent and planned in advance, leasing arrangements to serve temporary peak loads may be more cost effective than redundant hardware.

6.4.7 Pitfalls (Unintended consequences, or things people normally forget)

Where looking at materials substitution to reduce embodied carbon, consider all functional requirements, including health and safety.

6.4.8 Further Reading

CIBSE Guide L, due 2019/20, Chapter 12 – Materials and Resource Use

CIBSE TM56, Resource Efficiency in Building Services, 2014

CIBSE & ARUP research project

<https://www.cibsejournal.com/uncategorized/servicing-the-circular-economy/>

CIBSE article on office retrofit case study based on the whole-life carbon impact of building services

<https://www.cibsejournal.com/general/getting-to-grips-with-whole-life-carbon/>



6.4.7 Case Studies

Research on the whole life carbon of heat generation equipment

This study investigates WLC of four types of heat-generation equipment: gas boiler, gas fired combined heat and power (CHP), air source heat pump (ASHP), and variable refrigerant flow systems (VRF). For ASHP and VRF, carbon equivalent emissions from refrigerant leakage make up a large proportion of the CO₂e because the

global warming potential of refrigerants currently most commonly used is higher than that of CO₂. In some situations, refrigerant leakage has a higher impact than operational carbon emissions, and the WLC impact of ASHP can become similar to gas boilers. However, when refrigerants with a global warming potential of 150 are used, ASHP emits approximately 80% less WLC than gas boilers and 85% less WLC than CHP.

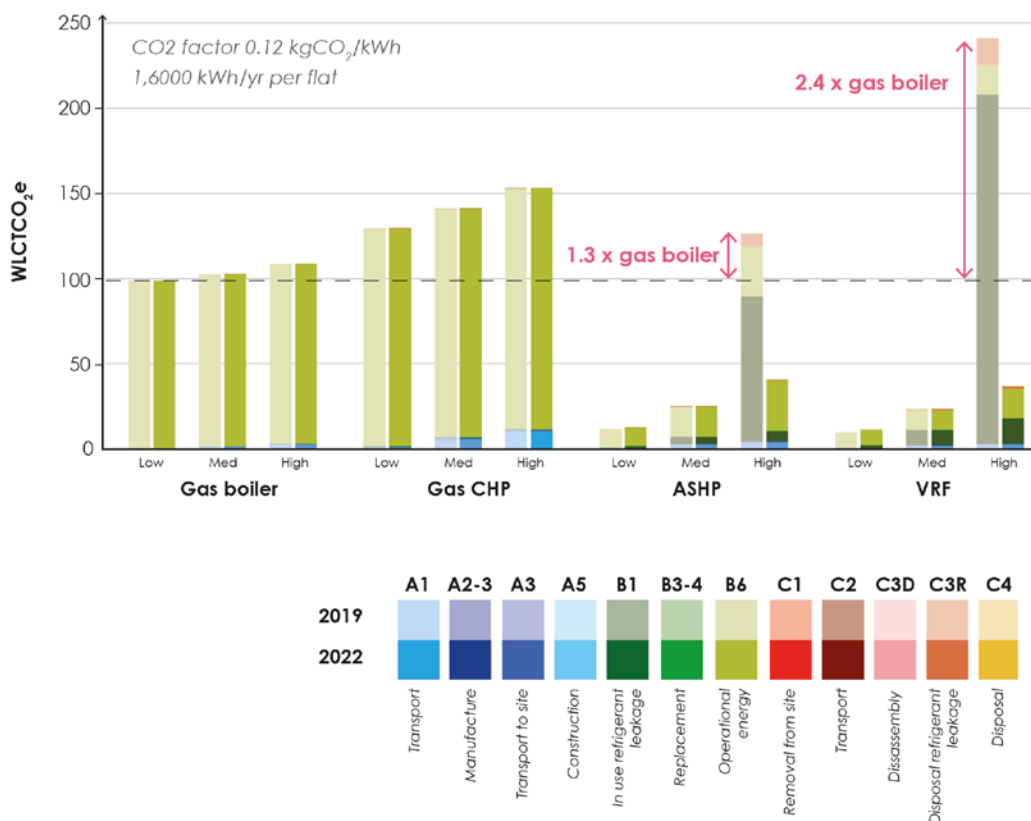


Figure A.6.4.2 – Study results for the whole life carbon of heat generation equipment by Elementa consulting

Breakdown of embodied carbon of an office retrofit

The aim of the study was to start to understand the whole life carbon emissions associated with MEP systems compared to the whole building emissions and the variance of embodied carbon of MEP products. The study was based on an office refurbishment in San Francisco. Operational carbon emissions were calculated based on in-use consumption. All building services elements were included, from cables, light switches to VRF. The material quantities were taken from a detailed BIM model using a dynamo script and cross referenced with schematics and plans.

- Key findings from the whole life carbon case study
- Building services would account for 40% of the full building whole life carbon emissions over 30 years (retrofit – without PV – medium impact scenario)
- Building services (including PV) accounts in the case of this retrofit for 40-75% of Embodied carbon (depending on scenario tested) - Refer to figure A.6.4.3
- Refrigerant leakage of VRF can have a large impact on whole life carbon emissions
- HVAC, Electrical and Plumbing have similar embodied carbon emissions across the impact scenarios



Embodied carbon of building services compared to the whole building

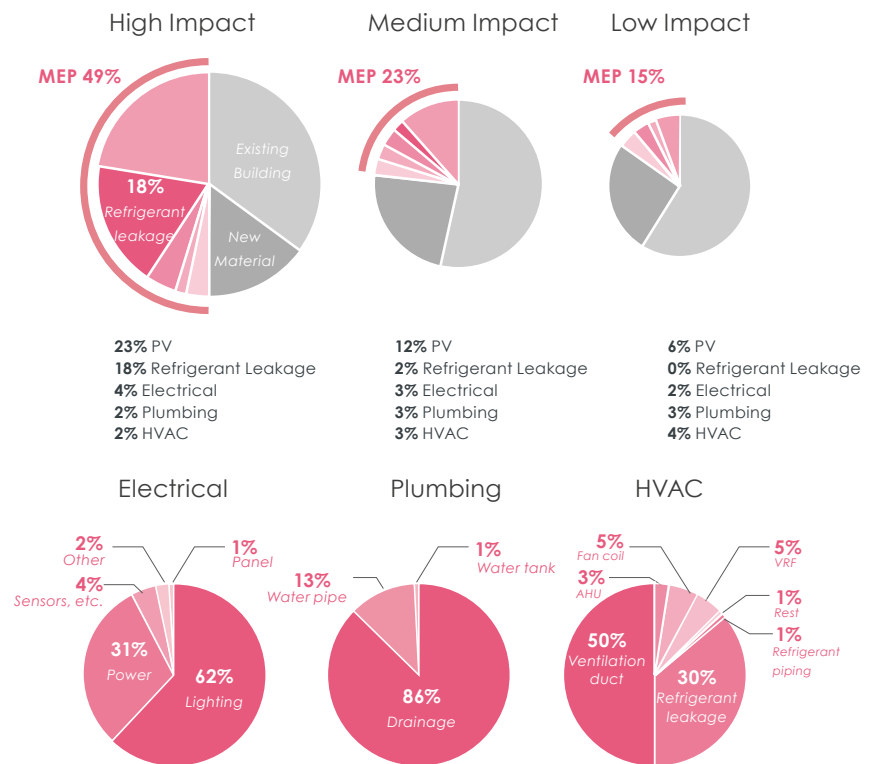


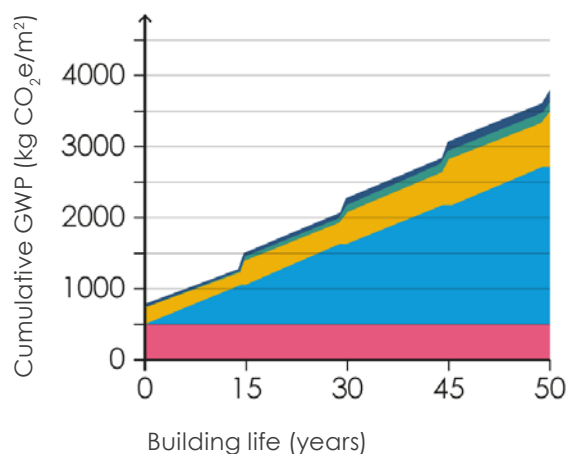
Figure A.6.4.3 – Whole life carbon study on Office Retrofit by Elementa consulting



Research on embodied carbon of HVAC+R systems in office buildings of the Pacific Northwest (US)

This dissertation provides a new simplified method to assess the embodied carbon (EC) across the life cycle of heating, ventilation, air conditioning and refrigerant systems that can assist design teams to assess the overall EC impact of HVAC systems in early stages of design. A method such as this would contribute to reduce four important barriers in LCA practice that prevent a better understanding of embodied carbon in buildings: (1) the time consuming process behind most LCA methods; (2) limited availability of building LCA data; (3) limited availability of material quantity data, and (4) a focus on structural, foundation and enclosure systems in the building scope of most WBLCA studies. Figure A.6.4.4 summarises the embodied carbon estimates for each HVAC system type.

In line with these findings, this study exemplifies that while HVAC system represent a relatively small share compared to other systems (i.e structural), with recurring instalments and lack of refrigerant management across the typical 60 year lifespan of the building, this initial impact can add up overtime and surpass the embodied carbon of other systems



Building Type	System Type	Equipment	Distribution	Total (kgCO ₂ e/m ²)
Standard	Packaged rooftop AC + Furnace	9.8	25.6	35.4
	Packaged rooftop heat pump	18.0	39.2	57.3
	VAV AHU w/ PFP terminals	66.8	61.0	127.8
	WSHP	40.1	44.8	85.0
High Performance	DOAS + Chilled Beam	38.7	21.3	60.0
	DOAS + VRF	22.2	17.6	39.8
	DOAS + WSHP	64.7	51.2	115.9
	DOAS ERV + packaged rooftop heat pump	30.2	52.0	82.3
	DOAS ERV + VRF	48.2	39.3	87.5

Figure A.6.4.5 – Embodied Carbon (EC) vs Operational Carbon in HVAC+R Systems a high impact worst-case scenario (no refrigerant management)

- Distribution
- Equipment
- Refrigerants
- Operations
- Initial construction

Figure A.6.4.4 – Embodied Carbon (EC) estimates for each HVAC system type

Case study information provided by Barbara Rodriguez Droguett, Ph.D, EMPA, LEED AP

BAM and Whitecroft Lighting **Circular thinking at Cheshire Police Headquarters**

BAM developed the 23,000m² headquarters and Force training centre for the Cheshire Police Authority (CPA), and has since provided a full range of FM services.

In 2018, they recognised a need to update the building's 15 year-old internal lighting system as a significant number of the old light fittings started to need replacing, and the lighting control system could only be maintained by rewiring each fitting. Maintaining the current lighting system would cause ongoing and significant disruption to the CPA so to upgrade their lighting BAM proposed, instead a solution that reused many of the existing fittings and also enabled increased functionality, efficiency and a healthier work environment.

In line with developing a circular economy approach, Whitecroft Lighting agreed to take three of the original fittings from CPA back to their manufacturing warehouse and explore the opportunities for reuse. BAM's installation partner, Gibson and Ryan, also took time to carry out on-site investigations into possible installation options. The partners worked collaboratively and came up with a variety of solutions:

→ Retrofitting lights: 120 'Cirrus' light fittings were changed from fluorescent tubes to LED, these were removed from the main building and refitted in the outbuildings. This reduced disruption to the

CPA's main areas, and provided an upgrade to the lighting in the outbuildings.

- 75 stairwell fittings were changed from fluorescent tubes to LED. A fitting procedure was developed to allow this to be done on-site, so that the stairwells could remain in operation. This was a success and BAM now plan to use the same technique in other BAM FM buildings.
- The installation of 1,300 bespoke bezel units throughout the corridors in the main building provides more efficient downlights without the need to replace the existing ceiling tiles.
- A total of 82 control modules were modified and reused in the corridors to upgrade the corridor lighting functionality.
- A new wireless control system was installed, which drastically reduced the need for new cabling and increased functionality.
- Whitecroft Lighting used Ecopack reusable packaging, to both take the old light fittings back to their factory and to deliver the new fittings to CPA. This saved the use of one and a half tonnes of cardboard (400g per luminaire) and one tonne of wooden pallets, and also eliminated waste disposal costs as the cartons were stacked on-site before being returned to Whitecroft Lighting for reuse. Once an Ecopack can no longer be reused the materials are recycled.



Benefits of retrofitted light fittings:



Saved 2,000kg of material (8kg per fitting) compared to using new lights



Retrofitted lights use 23w less energy than the old lights



Retrofitted lights were £30 cheaper (per unit) to manufacture compared to new lights



Whitecroft offer the same warranty on both the new and retrofitted lights

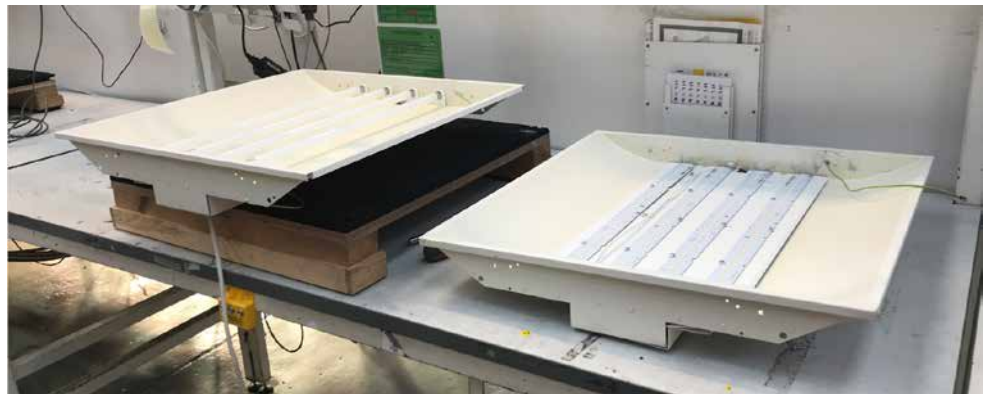


Figure A.6.4.6 – Retrofit lighting strategy by BAM and Whitecroft Lighting

6.5 Internal finishes

Internal finishes are frequently replaced over the lifetime of a building and can require considerable maintenance and upkeep. While the overall quantity of this component is smaller compared to superstructure/substructure, the embodied carbon of maintenance and upkeep can be considerable across the whole life cycle, particularly in large buildings with significant wall/floor/ceiling area. Finishes are also the area of the building that people have most contact with, and so considering how low embodied carbon approaches can improve the human experience of a space is important.

6.5.1 How to use fewer materials

Use the exposed surface of superstructure and exposed MEP systems as the final finish rather than concealing these under layers of materials such as dry lining. This can add architectural interest, though this requires collaboration at an early stage with engineers and other designers to ensure viability, and impacts on other carbon strategies. Avoiding suspended ceilings and using soffits for thermal mass can reduce operational carbon too.

Internal finishes are often required to meeting Building Regulations, particularly for their fire resistance, thermal and acoustic properties. Consider how these requirements can be met using as little material as possible. If this has not been adequately considered early on, internal finishes may contribute disproportionately to the design's embodied carbon.

Consider importance of lining that allow for fixing of fixtures and fittings – include necessary pattringing.

Specify products with a high recycled content and consider 'cradle-to-cradle' certified products.

6.5.2 Use low carbon materials

- **Linoleum** is a natural alternative to vinyl. When produced correctly it can help to sequester carbon and will decompose naturally at the end of its useful life. Vinyl is plastic based so will not decompose and will often end up in landfill.
- **Water based eco paints** are readily available as alternatives to oil or water based paints. Limewash is breathable, helping to manage indoor moisture levels, offers lower embodied carbon and, as it is alkaline in nature, has antifungal properties that reduce the likelihood of mould.
- **Cork** can be harvested without felling trees and is a carbon store. As an internal finish, it offers a sense of warmth and acts as acoustic and thermal insulation, avoiding the need for additional finishes.
- **Bamboo** is a fast-growing wood, and offers a rapid form of carbon sequestration. It can be made into a range of products, including flooring. Consider though that bamboo usually needs to be laminated, and the impacts this may have on its future reuse.
- **Timber** can be used internally in a range of ways. It is important to ensure the right timber is used for the job, to ensure that there is not irresponsible felling of the most carbon absorptive mature trees for products where a younger, more quickly grown tree would have been sufficient. Trees generally reach their maturity for carbon sequestration around halfway into their lifespan, and after this their absorption reduces. Refer to the timber/wood material sheet for more information.
- **Recycled** products use no raw materials and are increasingly available. Plasterboard, kitchen tops and floor panels for example can all be specified as almost 100% recycled content.



6.5.3 How to reduce waste

Design to use the full dimensions of off-the-shelf materials. This avoids wasted embodied carbon by reducing offcuts and saves money.

Over specifying is in itself wasteful. Consider carefully what you need and design economically.

End-of-life use should be considered when designing residential homes for unknown end users where the finishes specified may ultimately be changed and disposed of within years, or even months of the homes being sold. Shell-and-core residential design may be one solution, whereby the project is designed to provide a basic level of finish, and the buyers of properties can then adapt the space to their own needs.

End-of-life waste of flooring products in particular can be mitigated against, by specifying materials that reuse or contain recycled material, or are recyclable.

Durable materials will last longer, and require fewer replacement cycles over a building's lifespan. Sometimes this enduring quality may come at a higher upfront embodied carbon cost but this may be a price worth paying to avoid later replacements. Designers should consider the expected lifespan of the building and likelihood for changes to interior finishes when specifying materials that are long-lasting and high embodied carbon. This should include the potential for flexibility and adaptability.

6.5.4 Adaptability

If designing for a typology where change is required over a building's lifespan, consider designing interior finishes to allow spaces to be reconfigurable and not too specific for the current anticipated use. More timeless and consistent finishes throughout the building may help with this.

A useful exercise to undertake with your client is to imagine the alternative uses of the building during its lifespan and to design with this in mind. This applies to all aspects of the building design, but particularly to finishes, and may significantly impact the final design solution.

While engaging with your client to define budgets for internal finishes, ensure that they understand the long-term maintenance costs and embodied carbon of their approach. They may be inclined to invest more money or time at an early stage to develop an approach to reduce future costs.

6.5.5 Disassembly

Internal finishes are often in their nature difficult to disassemble for reuse – for example plaster and paint, or glued flooring. Wet trades are particularly problematic, as products that are otherwise 'good' in terms of embodied carbon or recyclability may be rendered impossible to reuse/recycle by the nature of their fixing detail.

Try to use standard size products wherever possible rather than bespoke finishes. As standard sized products may be useful for a wider range of purposes.

It is likely that composite materials will be harder to reuse and recycle. If possible, avoid the use of glues and adhesives that will be absorbed into materials and instead opt for fixings that will not affect the integrity of the material in the future, for example screws rather than nails. Where adhesives are required, opt for non-toxic and solvent free products. There are natural adhesives available that can make reuse more straightforward. There are issues with toxicity of glues with regards to disposal/reuse/recycling that will impact WLC.

Interlocking floor systems exist that require no adhesives, as well as some roll linoleums that stay put under their own weight. Wherever possible, use materials that have an EPD (refer to section on EPDs) or other green certification.

6.5.6 Pitfalls

Shell and core specification may result in the use of materials, that then get stripped out at Fitout stage. This can be mitigated by sharing information about the shell and core clearly with prospective buyers, and developing a catalogue of potential finishes.

Consider the systems required to support finishes, particularly for elements such as raised floors. There may be substantial embodied carbon in the system required.

Cleaning requirements for different systems can increase their lifetime embodied carbon, as well as contributing chemicals to water systems, which then need to be eliminated through energy (and thus carbon) intensive processes.

Ensure that all internal finishes are compliant with fire requirements. It may be that you need to develop a strategy for main escape routes, and another for

general spaces to limit overall embodied carbon while staying compliant.

6.5.7 Further Reading

Greenguard

<http://greenguard.org/en/CertificationPrograms.aspx>

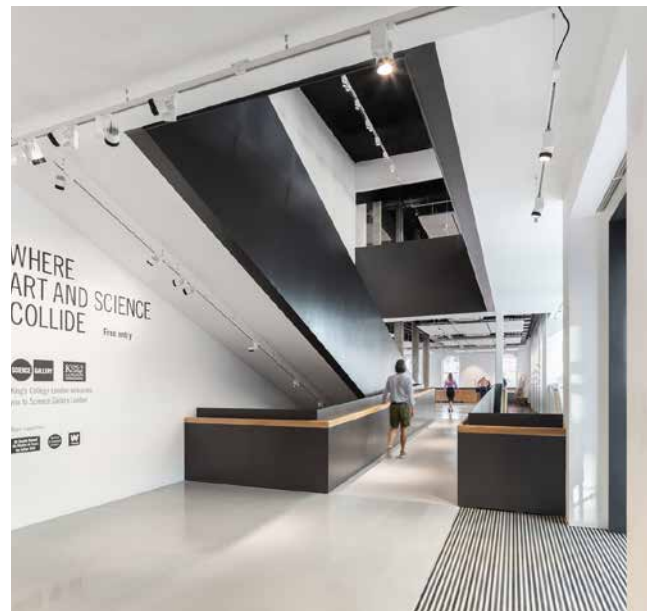
Recycled raised flooring

https://www.rmfi-services.co.uk/recycled_raised_flooring/default.aspx

6.5.8 Case studies

Science Gallery London, LTS Architects

This refurbishment of the old Guy's Hospital uses numerous materials with high recycled content including Fermacell partitions, made from almost 100% recycled content.'



Science Gallery London

Internal view

<https://www.fermacell.co.uk/>



Cork House, Matthew Barnett Howland with Dido Milne and Oliver Wilton

'An entirely cork construction, with solid structural cork walls and roof, the building has exceptionally low whole life carbon. The biogenic construction of prefabricated cork blocks and engineered timber is has remarkably low whole life carbon. All the components can be reused or recycled, and the expanded cork blocks have been made using by-products and waste from cork forestry and the cork stopper industry.'



Cork House, Matthew Barnett Howland with Dido Milne and Oliver Wilton

Internal view

<https://www.architecture.com/awards-and-competitions-landing-page/awards/riba-regional-awards/riba-south-award-winners/2019/cork-house>

Maggie's Centre, Oldham dRMM

Constructed from tulipwood, Maggie's Oldham is the UK's first permanent hardwood cross-laminated timber (CLT) building. Tulipwood's growth annually exceeds the harvest of this prolific timber in America, an example of regenerative forestry practice. Use of timber not only reduced embodied carbon, wood also has co-benefits for wellbeing. Hardwood offcuts from CLT manufacture create the ceiling finish, reducing waste from construction. For the flooring, a low-maintenance natural rubber solution was used.



Maggie's Centre, Oldham, dRMM

Internal view

<http://drmm.co.uk/projects/view.php?p=maggies-oldham>

6.6 Fixtures and fittings

Fixtures are items which are attached to the property (e.g. kitchens, fixed furniture such as reception desks, in-build wardrobes, electric sockets, light fixtures and radiators). Fittings are not attached (e.g. mirrors, carpets, blinds, fridges, beds/sofas, lamps). The way spaces are configured and used can change many times within a building. By the time a building is demolished its carbon footprint will have increased through their cumulative changes and it is therefore important to integrate flexibility in the design from the outset. Because of their short life cycles, there are potential easy wins for a whole life carbon count if material can be reused, recycled and maintenance is kept to a minimum.

6.6.1 How to use fewer materials

Avoid over specifying lighting by creating different lighting zones (e.g. back of house / transitional spaces without feature lighting, high priority spaces), design each zone with the appropriate amount of lighting fittings.

When designing shell and core, it is important to allow for the right amount and types of sockets, for example, to avoid the need for re-work (refer to internal finishes section).

For refurbishments: assess if existing items can be transformed or reused (e.g. carpet cleaning, painting of cupboards).

Design with flexibility and simplicity in mind. Avoid being over-prescriptive about the way things are used (e.g. light fittings that also have a USB plug).

Early coordination (e.g. grids) can prevent over-cluttering of walls and ceilings with electrical and other services at a later stage.

Specify products with a high recycled content and consider 'cradle-to-cradle' certified products.

6.6.2 Use low carbon materials

- Opt for FSC chain of custody certified timber and locally sourced natural materials.
- Use materials with a high percentage of recycled content, (e.g. carpets).
- Compare material options by assessing maintenance requirements and embodied carbon. The ICE database at Bath University offers a large UK specific dataset for cradle-to-factory gate carbon costs and free software like HBERT can help with calculations.
- Choose refurbished white goods where possible white goods that have a good energy rating (A+++ European standard) with energy saving options).
- Provide sockets with on/off switch for appliances so that users can avoid leaving electrical goods in standby mode. Despite technological improvements, products that connect to the internet such as televisions and printers show an increase in energy consumption when left in standby mode.
- Use energy saving light fittings with the appropriate lumen/brightness.
- Choose products and materials with a long life cycle.
- Use carpets with high recycled yarn content (floor finishes, predominantly carpet, account for 12% of a building's environmental footprint).



6.6.3 How to reduce waste

- Aim for timeless design and avoid gimmicks that could become unfashionable very soon.
- Choose good quality materials that do not need frequent replacement.
- Donate what can be re-used elsewhere.
- Unwanted electrical equipment is a fast-growing type of waste in the UK. Make utility managers aware that retailers are obliged to provide a way for their customers to dispose of their old household electrical and electronic equipment when they sell them a new version of the same item.
- Use natural materials that decompose or can be recycled, such as timber or natural stone. Nanocellulose fibreboards can replace MDF and cork fabrics can replace leather. Metal fasteners in joinery can make recycling difficult – consider alternatives (e.g. dovetail).
- When designing metal assemblies, make sure you avoid the contact of dissimilar metals – use a non absorbent insulate between them to prevent corrosion.
- Upholstery has a shorter durability than its framing elements. Only select furniture designed for ease of repair, maintenance and disassembly with screws and bolts rather than glue to avoid premature discarding. Fabrics should be detachable and machine washable, not dry clean.
- Use on-line reuse marketplaces for sourcing recycled goods.

6.6.4 Adaptability

Make sure that the building can be adapted for future change of use.

- Where possible, design or specify highly adaptable systems from the start and to industry unit sizes where appropriate.
- The use of robust good quality materials means that they can be re-used in the future.
- Compare prices and life cycle carefully when considering increased warranties on products.
- Choose non-toxic finishes and material treatments that can be altered (e.g. colour) and select products that are free of dangerous components (See the 'references' section for links to Human Scale and the Declare Label project).
- Consider joinery methods that use no metal fasteners at all.

6.6.5 Disassembly

- Design with flexibility in mind, especially when out of sight (e.g. exposed high-level cables & ductwork).
- Choose systems that can be reconfigured.
- Allow for easy disassembly in fixings (e.g. screws over nails).

6.6.6 Products as services (leasing)

- Consider leasing schemes for fittings, furniture and artwork (see link below).
- Many furniture and carpet companies now offer take-back schemes.

6.6.7 Further Reading

ICE database

<http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html>

H\B:ERT

<https://www.hawkinsbrown.com/services/hbert>

Online reuse marketplaces

<http://www.freecycle.org>

<https://www.globechain.com/>

Electronic equipment

<https://www.gov.uk/electricalwaste-producer-supplier-responsibilities>.

Natural materials

<https://www.dezeen.com/2015/07/02/nanocellulose-fibreboard-all-natural-replacement-mdf-moulded-plastic-rca-yunting-lin>

<https://www.cortizza.com/cork-fabric-yardage/>

Declare - ingredients label for building products, paired with an online database.

<https://living-future.org/declare/declare-about/>

Energy Consumption in the UK (ECUK) 1970 to 2018, National statistics.

<https://www.gov.uk/government/collections/energy-consumption-in-the-uk>

Statistics floor finishes/carpet

<http://www.wrap.org.uk/carpetguide>

Leasing scheme case study

<https://www.ellenmacarthurfoundation.org/case-studies/selling-light-as-a-service>

Lights fittings retrofit case study

<http://sustainability.bam.co.uk/case-studies/2019-02-05-circular-thinking-at-cheshire-police-headquarters>

Human Scale

<https://www.humanscale.com>



6.6.8 Case studies

The Westworks, Refurbishment, Allies and Morrison

Allies and Morrison were commissioned by developers Stanhope with Mitsui Fudosan and Amico to refurbish and extend the Westworks building, which was designed by Scott Brownrigg Turner for the BBC in the late 1980s. The buildings generous floor to floor heights and daylight access enabled a complete fit-out that exposes fixtures and fittings and minimises finishes materials through exposure of structural elements.



Westworks refurbishment, Allies and Morrison

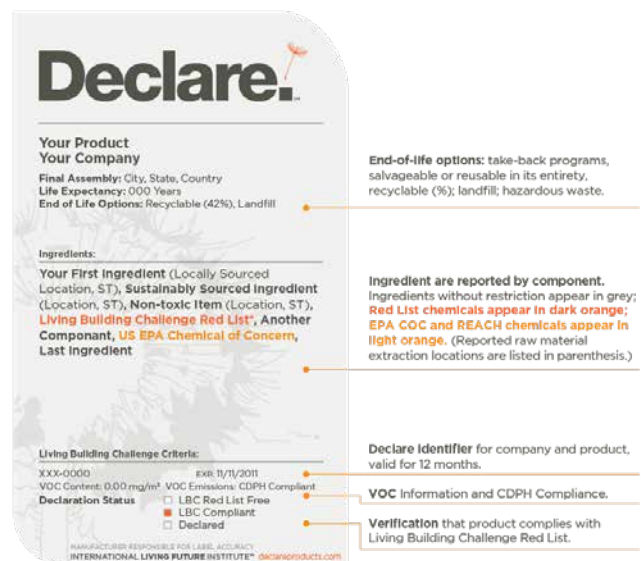
Internal view

<https://www.alliesandmorrison.com/project/the-westworks/>

The Declare Label, Living Futures

Declare is an ingredients label for building products, paired with an online database. It allows manufacturers to demonstrate their leadership in the marketplace and it provides consumers with honest information for product selection.

All products are eligible for inclusion, regardless of their composition; the key to Declare is honest information sharing.



Declare Label

The Declare Label, Living Future

<https://living-future.org/declare/declare-about/>

6.7 The site

Analysing a site is a standard procedure for designers to best assess what is viable to construct. Designers carry out studies analysing a site in terms of its neighbourhood context, planning restrictions, physical features and microclimate to name but a few but embodied carbon, until now, has rarely been a specific consideration.

The following is a selection of criteria often identified during site analysis which could offer alternative, low embodied carbon approaches compared with conventional solutions.

6.7.1 Site selection

When presented with a site, it is important to consider the existing ecosystem which may already be acting to absorb and store carbon. From a policy perspective this is important to consider when deciding on whether the site is appropriate for redevelopment or not.

Wherever possible, minimise disruption to existing natural features acting as a carbon sink e.g mature trees, grasslands, wetlands.

6.7.2 Reducing impact on the site

Exploring opportunities where existing buildings and foundations can be retained is possibly the greatest saving of embodied carbon a project site can offer. Consider:

- Recladding an existing structural frame – this can give the appearance of a completely new building.
- Opportunities to add additional storeys to an existing frame to increase financial viability of the development.
- If the frame is deemed unusable/unsuitable for the purpose of the proposed (re)development then look to the foundations for potential re-use. Particularly if there are opportunities to use a less carbon intensive superstructure than was deployed in the original building.

6.7.3 Use low carbon materials

Guidance on specific low carbon materials can be found in the rest of Appendix 6 however, as designers of any building project, it is standard practice to look at the immediate surroundings for inspiration and the local vernacular may be heavily influenced by particular design features and materials.

Using locally sourced materials to reduce transport emissions, particularly for high mass materials, should be considered.

Use materials with a high recycled content, such as crushed concrete as base or reclaimed materials



6.7.4 How to reduce waste

Working with the existing 'lay of the land' will minimise the amount of cutting required and subsequently the embodied energy associated with the plant and machinery required for the groundworks as well as carting away the spoil from the site.

There may be opportunities to re-use man-made materials in some way. Steel can be recycled but it can also be re-used on or off site. Recycled steel still needs to be melted down at high temperatures and manufactured into a new product which has much higher impacts than simply re-using the same piece of steel in a new application.

Depending on the quality and mix of any unwanted concrete on site, there may also be some scope to either re-use it, or crush it so that it can be added to new concrete as a recycled aggregate or used elsewhere in construction.

6.7.5 Pitfalls

As identified under site selection; allowing existing natural features to be retained may be challenging for clients looking to maximise returns for their investors.

6.7.8 Case studies

100 Liverpool Street, Hopkins Architects, AKT II

The project involves the refurbishment and extension of 100 Liverpool Street for British Land in Broadgate, London. The project will reinvigorate the existing outdated building, stripping it back to its structural frame and providing it with a dynamic new identity thanks to a new curving façade and revamped public realm.



100 Liverpool Street, Hopkins Architects, AKT II

External view

<https://www.akt-uk.com/projects/100%20liverpool%20street>

6.8 External works

External works can cover hard and soft landscaping on ground floor level, terraces, roofs and can include below ground items, such as irrigation tanks. Key factors are where materials such as paving slabs have been sourced and what maintenance is required. Open areas can accommodate PV panels and plants to improve the overall carbon footprint of a development.

6.8.1 How to use fewer materials

- Many natural stone paving slabs on the market are thinner than equivalent concrete products due to their strength.
- Specify different thicknesses according to the loadings of different areas (pedestrian / traffic). Some maintenance, such as glass replacement, might need a method statement to avoid damage through point loadings (temporary boarding to transfer loads evenly).
- Design external paving for minimum waste.
- If there is a basement, consider the allowed loading of the slab first to avoid over-specifying surface material.

6.8.2 Use low carbon materials

- Integrate PV panels on roofs if appropriate.
- Careful material selection has a big carbon impact. Use recycled materials (e.g. sleepers, timber, waste stone, glass). There are some landscape architects who specialise in this.
- Use natural stone instead of concrete slabs. Consider quarry location for transport, durability and specific maintenance requirements to be sure there is a carbon benefit.
- For timber decking make sure the wood is certified and sustainably sourced. Consider surface

treatment for slip resistance and check if it must be treated to comply with fire regulations.

- Use solar lighting where possible
- Maximize the amount of plant-life in amenity spaces (e.g. green walls) and unused areas such as roofs, balconies, façade set-backs and vertical walls, for additional insulation and carbon capture.
- Ensure as many areas are used for planting as possible with the many benefits of carbon capture, enhanced biodiversity and wellbeing.
- Choose plants for pollinators to encourage self-seeding and integrate bug hotels, nesting places for birds and bats to support biodiversity (credits – BREEAM & LEED).

6.8.3 How to reduce waste

- External lighting should be carefully considered to be efficient, i.e. avoid light pollution, such as uplighters below non-evergreen trees, and reduce overall lux levels on the floor by lighting object such as walls. This reduces the number of light fittings.
- Use permeable mortar joints to enable the reuse of paving slabs.
- Consider reducing waste from site by crushing materials on site for use as aggregate or a subbase for the new development.

6.8.4 Adaptability

Make sure that the building can be adapted for future change of use.

The use of an open area above a basement should not only be designed with the intended use in mind,



but an analysis of possible future uses should be considered, i.e. temporary boarding to allow for a concert.

6.8.5 Disassembly

- Infrastructure objects such as bridges can be designed for disassembly
- Wherever possible, use materials that have an EPD or other green certification.
- Use mortar beds that are permeable so that slabs can be removed without damage.

6.8.6 Pitfalls

- Natural stone will not always have a low carbon footprint. It could be sourced from far abroad with significant emissions and product wastage across the supply chain. There could also be limited data related to responsible and ethical sourcing.
- Many stone traders do not want to disclose the stone origin at an early stage which can be a problem because the embodied carbon through transport is not known and the amount of energy and water used for extraction are difficult to assess. Communicate these concerns and restrict the search area to a maximum distance from the site
- Some natural stone samples have been treated to enhance colour. A stone expert can be engaged for a second opinion to find out if chemicals or varnishes have been used.
- Natural stone finishes can have an effect on maintenance requirements (e.g. crystals can be split in a certain way).
- Some natural stones are water absorbent, requiring frequent maintenance cycles and can cause staining through chemical reaction with

certain mortar beds.

- Polystyrene void formers can not be recycled
- Only plants with the necessary resilience to cope with local pollution conditions found in dense urban areas as a result of high traffic volumes should be considered.
- It is important that the maintenance regime for green walls and trees above concrete slabs is considered at the early design stage, without maintenance they will not survive.

6.8.7 Further Reading

CEEQUAL, infrastructure sustainability rating scheme
<http://www.ceequal.com/>

6.8.8 Case studies

Study of PV vs. Green Roof, eTool Global UK

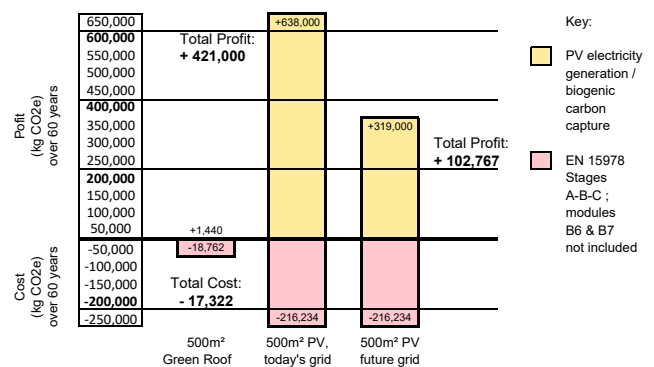


Figure 6.8.1 - Analysis of the carbon footprint over 60 years of Photovoltaic Array versus Extensive Green Roof System (sedum) by eTool.
<https://etoolglobal.com/>

Newcastle Urban Sciences Building, Hawkins\Brown and B|D Landscape

The project is a Living Lab and provides 12,500sqm of new University teaching and research space on a new site called the Helix. It is the new home of the Department of Computing and Institute of Sustainability. The landscape was an integral part of the scheme and includes a wildflower rooftop garden, rain gardens and a swale that is designed to protect the masterplan and surrounding city centre from flooding.



Newcastle Urban Sciences Building

Rooftop view

<https://www.hawkinsbrown.com/projects/urban-sciences-building-newcastle-university/>

London 2012 Olympic Park Temporary Bridges, Allies and Morrison

Temporary bridges were designed for the London 2012 Olympic Games alongside permanent bridges intended for the legacy (post-games) condition, which only required 1/4 of the initial crowd capacity. The bridges were designed for a ten year design life, disassembly and re-use using the following components to reduce embodied carbon:

- Softwood decking fixed with clips
- Bolted guardings
- Standard plate girders with limited design life protection treatment



Temporary bridges

Aerial view

<https://www.alliesandmorrison.com/project/bridges-london-2012/>



Appendix 7 Designing for manufacture and assembly

Large quantities of building materials are wasted in construction processes, through offcuts or because wrong quantities have been ordered. One way to avoid this waste is through DfMA, where components are prefabricated and pre-assembled off-site as much as possible, reducing the amount of unnecessary material that reaches site in the first place.

On-site work becomes more focused on final installation. This method has been employed in the past where high volumes of repetition occur. Other scenarios where DfMA may be preferable are sites with limited space or access challenges or where speed and high quality are both important factors (e.g. commercial or residential façades). Volumetric DfMA where whole suites are assembled off-site has been used successfully in high-end hotel bathrooms and rooms in large scale housing, pocket living, student accommodation and budget hotels.

7.1 How to use fewer materials

- Explore DfMA elements, such as facade modules, bathrooms and M&E units for material savings on site.
- Explore volumetric DfMA for rooms to be craned into position on site.
- For residential developments, consider the MMC framework that defines five pre-manufacturing categories (3D & 2D primary structural systems, non systemised structural components, additive manufacturing and non-structural assemblies), traditional building product and site process led labour reduction.
- Ideally the entire design team would be able to use the same platform (e.g. Revit) to develop and inform the design from different angles. BIM (Building Information Modeling) can be used to visualise, perform stress, deflection and other simulations in-house to avoid material-intensive methods.
- Digital prototyping ensures that product development is based on data from the outset, rather than untested assumptions. Design solutions can be tested, optimised and validated before releasing them to manufacturing.
- BIM is useful throughout the building life cycle to determine the best material choices, check manufacturability of part and mould designs to help avoid production delays, manufacturing defects or costly mistakes.
- There are some advantages in using lightweight material for DfMA in terms of transportation costs, provided the distances and mode of transportation are also taken into account
- Quality control is an advantage of DfMA and is a useful tool to reduce the need for frequent repairs and maintenance which can otherwise increase the whole life carbon (e.g cumulative frequency of transport for visits, use of equipment and replacement materials).

7.2 Use low carbon materials

- Architects and subcontractors working together from an early stage gives the opportunity to optimise the design in order to reduce embodied carbon through material selection.
- Controlled factory conditions widen the choice of materials, their finishes and how they are assembled.
- DfMA is not a safeguard against material substitution (e.g. for cost savings) but it makes it more difficult as procedures are required.
- Factory testing is in place to guarantee that the final product matches the specification.
- Steel, precast and timber construction suit DfMA because they offer speedy installation on site.
- Wherever possible, choose materials that have a high recycled content and are low in embodied carbon – this will often be symbiotic.
- Use locally sourced material i.e. from a local forest or quarry, especially when heavy material or thermal mass is required

7.1.3 How to reduce waste

- An early partnership of architect and subcontractor can lead to innovative new solutions and is an opportunity to develop take-back schemes. Ideally the subcontractor would guarantee that all materials can be reused, recycled or redirected.
- Elements arrive on site already tested and ready for installation with minimum waste..
- The design and workmanship has in principle been signed-off through factory visits.
- The production line can be tailored to minimise offcuts.
- Offcuts that never left the factory stand a better chance of being reused or recycled.

7.3 Adaptability

- Where the early partnership is established, innovative solutions that are designed for adaptability can be found.
- Standardisation through DfMA produces systems that are repeated – making adaptation more likely.
- Developed systems can be varied for reuse on other buildings, leading to a portfolio of possible future adaptations.

7.4 Disassembly

- DfMA should be designed for disassembly and easy repair/maintenance. Standardisation across large scale schemes can help with this, but can also be a pitfall if the whole system is based on things which later become obsolete (e.g. USB ports).
- Choose materials that have non-toxic finishes and integrate them in a way that does not reduce their potential to be reused.
- Permanent fixings should be designed out, replaced with solutions such as interlocking parts. In less visible areas screw-fixings should be used to avoid glue or nails.

7.5 Pitfalls

- Where the procurement process allows, early collaboration between the design team and the contractor should be prioritised.
- Attention to detail is important – take care how elements are joined. Little things like whether screws are used instead of glue or nails can be the deciding factor if a material is considered reusable in the deconstruction phase.



- Shipping may require extra strengthening that could be avoided with traditional methods. As a result elements that don't have to hold themselves up or withstand weather conditions could end up more carbon intense (e.g large ceiling panels).
- Lightweight material might be chosen for transport reasons over material that would perform better (e.g. acoustics and thermal mass).
- Structural stiffness that is required for transport should be designed so that these elements also serve a purpose in the installed location (e.g. concrete where thermal mass is needed).
- Restrictive transport sizes can limit the potential of volumetric DfMA and might require further breaking down into modular panelised systems.
- Standardisation across large scale schemes can be a problem if the whole system is based on things which later become obsolete.

7.6 Further Reading

NLA Exhibition Catalogue (2018/2019) – Factory made housing – A solution for London?

<https://www.newlondonarchitecture.org/whats-on/publications/all-nla-publications/factory-made-housing-a-solution-for-london>

The Modern Methods of Construction (MMC) definition framework, an independent report published March 2019 by the Ministry of Housing, Communities and Local Government

<https://www.newlondonarchitecture.org/whats-on/publications/all-nla-publications/factory-made-housing-a-solution-for-london>

Modern methods of construction (MMC), the Concrete Centre

<https://www.concretecentre.com/Building-Elements/Frames/Modern-Methods-of-construction-%28MMC%29.aspx>

MMC Hub, NHBC

<http://www.nhbc.co.uk/builders/productsand-services/TechZone/MMCHub/>

7.7 Case Studies

Sumner Street

Landsec's Sumner Street project comprises two nine storey office buildings in Southwark. Two separate designs for the scheme were undertaken to RIBA Stage 3, using independent design teams, one using traditional construction techniques and the other using Bryden Wood's Platforms approach to DfMA. An independent comparison of the embodied carbon between the two designs has identified a

19.4% reduction in embodied carbon intensity in the P-DfMA design. The major contributors to this carbon reduction are:

- Reduced material quantities.
- Reduced basement size due to rationalisation of building services plant from the DfMA process.
- Unitising the cladding improves efficiency without compromising the high quality of the design.
- DfMA approach enables a wider choice of materials to be used for the facade without compromising the visual appearance.
- Potential additional reduction in wastage on site due to DfMA methods.

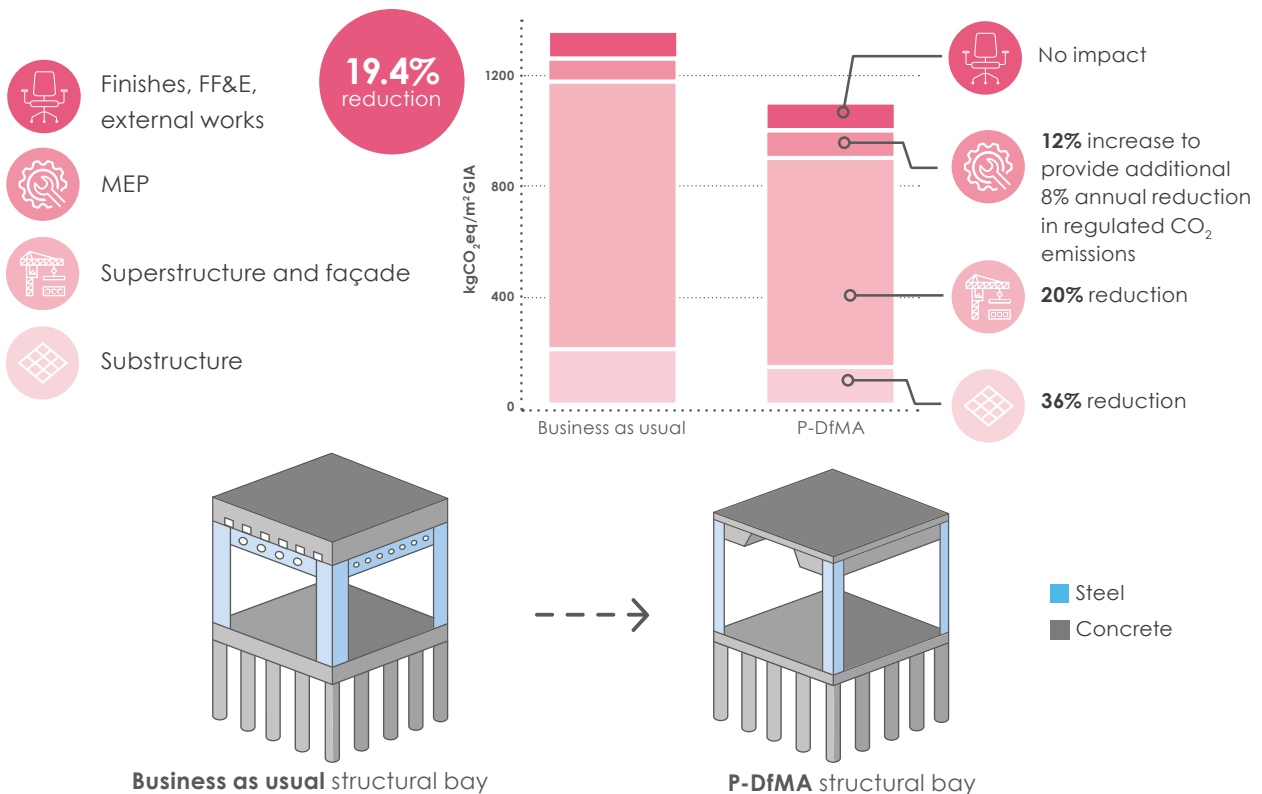


Figure A.7.1 - Comparison study of the difference in embodied carbon between traditional construction design and DfMA design for Sumner Street, Landsec. EN 15978 Product and Construction stage, modules A1-A5.



Appendix 8 Materials guide

In this appendix, a range of materials are appraised, analysing each of them for both benefits and pitfalls. When it comes to materials choices, there is no single solution that suits all low embodied carbon buildings. Each material should be chosen only when it has the best performance compared to other materials and has the lowest whole life carbon impact. Materials with a higher embodied carbon could be considered only if a reduction of the operational carbon over a building's lifetime can be achieved.

Wherever possible, local reclaimed materials should be used to minimise delivery distances and packaging. The environmental product declaration (EPD), obtained via thorough life cycle analysis (LCA), details the environmental impact of a material or component. The recyclability of the material at the end of the building's life expectancy should also be considered.

For any material specified in a building, designers should consider if the product:

- Has an EPD.
- Can be recycled or reused.
- Has a high embodied carbon, and what can be done to reduce this.

Unless otherwise stated, all embodied carbon figures come from the *Inventory of Carbon & Energy (ICE) database 2019 update* (Hammond & Jones) and refer to the embodied carbon from 'cradle-to-factory gate', that is to say all carbon emissions incurred before the product is ready for transportation to site (Product stages A1-A3). The database is available at <http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html>.

8.1 Concrete

This is the most used material in the building sector. It is used for infrastructure, foundations, floors, walls and framing.

8.1.1 Embodied carbon

Given the multivariate compositions of concretes, it is impossible to state a definitive embodied carbon value for the product. Due to the large quantities of relatively untreated aggregate used in concrete, the embodied carbon is relatively low if considered on a weight basis, but its impact becomes significant as it is used in such large quantities.

- Low example – general (GEN 0) (6/8 MPa), 70% ground granulated blast-furnace slag substitute for cement (GGBS) **0.034 kg CO₂/kg**.
- High example – reinforced concrete (RC 40/50) (40/50 MPa), with no cement substitution (CEM1) **0.172 kg CO₂/kg**.

8.1.2 Background

The typical composition is a mixture of a cement binder, usually Ordinary Portland (OPC) and aggregate. Concrete can be produced to different compressive and tensile strengths with variations in aggregates and binders. If concrete of higher compressive strength is required, this means using more cement and therefore a higher embodied carbon cost.

OPC, the binder in concrete, is produced from clinker (from heated limestone and minerals) and gypsum. The abundance of these raw materials, all over the world, is one of the reasons for its popularity.

8.1.3 Benefits

- Thermal mass: the ability to absorb and store heat before releasing it later. Concrete acts as a heat sink during the daytime and as a heat source during the night. Applying thermal mass materials such as concrete is a useful strategy to reduce the energy consumption of buildings (Shafiqh, P., Asadi, I., & Mahyuddin, N. B., 2018).
- Endurance
- Strength

8.1.4 Considerations

- Concrete's environmental impact can be reduced by replacing some of the OPC and sand content with fly ash or ground granulated blast furnace slag (GGBS). The substitution of OPC with other materials can however reduce the strength of the concrete obtained; the designer should therefore assess the suitability of the product for the application considered.
- Another alternative is recycled Construction and Demolition (C&D) waste and waste glass, which can be used in aggregates to reduce the use of virgin materials and provide a second useful life for high volume of waste otherwise destined for landfill.
- The designer should be aware of the cement content in concrete components and exercise prudence in the selection process, minimising the use of cement and virgin materials while maintaining strength and integrity.
- Concrete structures designed for thermal mass are based on current climate information. When pursuing a thermal mass strategy, the possibility of future increasing daytime and nighttime temperatures should be taken into account.
- A significant reduction of embodied carbon could be achieved by slimming off the excess: a decrease of the slab thickness from 200 mm to 190 mm could be structurally minimal but could save a considerable amount of material.
- Adopting standardised detailing would enable formwork to be re-used multiple times and would allow for repetition of reinforcement.
- Reusable plastic formwork should be considered.



- Design for Manufacture and Assembly (DfMA)
 - Pre-cast planks can be used elsewhere at the end-of-life if the screed is broken, allowing future change of use.
- DfMA – In situ can have soft spots designed into them so they can be broken out and the building re-purposed.
- DfMA – Over-designing for future change of use. Consider a structural grid suitable for different use types.

8.1.5 Further reading

Eco-efficient cements: Potential economically viable solutions for a low CO₂ cement-based materials industry

<https://doi.org/10.1016/j.cemconres.2018.03.015>

Solidia

<https://solidiatech.com/>

Hoffman Green Cement Technologies

<https://www.ciments-hoffmann.com/>

Shafigh, P., Asadi, I., & Mahyuddin, N. B. (2018). Concrete as a thermal mass material for building applications –

A review. Journal of Building Engineering, 19, 14–25. doi:10.1016/j.jobbe.2018.04.021

8.1.6 Case studies

Park Hill, Hawkins\Brown

The challenge for Sheffield Council was how to regenerate a notoriously neglected estate on the outskirts of the city into a place people wanted to live in. An identity overhaul was desperately needed in a climate of declining public investment.

Reusing the existing concrete frame within the regeneration program meant that the need for a new frame was avoided, saving a potential 3,219 tonnes of CO₂e in further construction.



Park Hill

External view

<https://www.hawkinsbrown.com/projects/park-hill-sheffield>

8.2 Timber/wood

In order to ensure the harvested wood used for any timber products is replaced by a new sapling wood and timber products should always be sourced from sustainably managed forests.


Carbon sequestration rates in forests are dependent on many variables, i.e. maturity, forest type, local climate, soil and forest management. The optimum sequestration rate is reached by felling trees as they reach maturity, as the carbon sequestration rate then reduces considerably, starting the process again by planting new trees. Using the fell timber in long life harvested wood products (HWP) such as construction products provides the additional benefit of delaying any re-emissions. At the end of its useful life, timber retains a Calorific Value (CV) and can be used as a fuel, displacing the need for further fossil fuel use.

8.2.1 Embodied carbon

- **0.493kg CO₂e/kg** average
excluding carbon sequestration
- **-1.03kg CO₂e/kg** average
including carbon sequestration

Carbon sequestration can only be claimed for sustainably sourced timber, this is to ensure that trees felled are replaced with at least the same number of trees planted and are therefore not contributing to deforestation and the subsequent depletion of the overall carbon absorbing capacity of woodlands. Carbon sequestration can only be applied to timber that ends up in a product, not to excess timber that will become waste material as this may be used as a biofuel and therefore the sequestered carbon returned to the atmosphere.

See Appendix 3 for more information on Carbon Sequestration. It is important to remember that the biogenic carbon balance over the life cycle of the timber product equates to 'Zero' as it will release carbon when it is burnt or composted. When biogenic carbon is reported in life cycle assessments, it must be reported separately. For example the embodied carbon figure excluding carbon sequestration should be given as well as the embodied carbon figure including carbon sequestration.

 **SIGNPOST** Appendix 3 – How to measure embodied carbon

8.2.2 Key terms

- **Wood** – the hard fibrous material that forms the main substance of the trunk of a tree.
- **Timber** – wood that has been felled, dried and treated, ready for use.
- **Engineered timber:** a range of highly manufactured timber products, which generally see the binding/lamination of wood elements. Come in standard product sizes, or can be bespoke, and curving is possible.

8.2.3 Benefits

- Timber can be lighter than other structural materials, reducing the amount of substructure materials required.
- Some types of timber, such as pine and certain firs have been shown to improve air quality and be of benefit to human health, although further consideration of glues and laminates should be given when using engineered timber.



- The thermal benefits of timber are important in healthcare applications – timber's thermal resistivity makes it a neutral temperature to touch, a benefit for many patients.
 - Humans respond favourably to the perceived warmth and natural aspect of the material.
 - Wood is breathable and has a positive impact on indoor humidity regulation.
 - As timber can be a carbon negative material, its use is to be encouraged wherever possible, provided it is harvested from responsibly managed woodlands. This means that fell timber is replaced by a new planting to ensure sequestration in the product and ongoing capture in the new sapling.
- mechanical fixings (screws) or interlocking strategies rather than permanent fixings that make components difficult to disassemble and reuse (nails, adhesives).
 - Where viable, timber using polyurethane as the adhesive agent should be specified instead of formaldehyde; polyurethane is required in smaller quantities, reducing the environmental impact.
 - Wood is susceptible to certain pests, wood boring insects in particular, and may require treatment for this. As local temperatures in the UK increase due to climate change, pests usually found in warmer climates may pose a problem.

8.2.4 Considerations

- Products such as Oriented Strand Board (OSB) are made using glues and resins which can emit volatile organic compounds (VOCs), affecting local air quality.
- Most engineered timbers are currently shipped in to the UK; consideration should therefore be given to the carbon cost of transportation when compared with locally available materials.
- Sustainable sourcing is vital and deforestation is a serious issue. The designer should consider the impact on EC of transportation of hardwoods over long distances such as from distant rainforests, and select a closer certified alternative, if available.
- Engineered timbers that use glues/adhesives in the lamination process may be more difficult to reuse.
- Treatment of timber may affect end-of-life reusability; fixings can make dismantling more or less labour intensive. Consider reversible

8.2.5 Further readings

London is a Forest, Paul Wood

https://books.google.co.uk/books/about/London_is_a_Forest.html

Deforestation

<https://www.theguardian.com/environment/2019/sep/12/deforestation-world-losing-area-forest-size-of-uk-each-year-report-finds>

8.2.6 Case studies

Sky Health and Fitness Centre, dRMM

As a demonstration of their commitment to the health and wellbeing of their staff, Sky commissioned dRMM to design a staff building to rehouse their employee gym and provide other wellness uses.

With sustainability an imperative for both client and architect, engineered timber was chosen as the predominant building material, significantly reducing the embodied carbon compared to more traditional methods. The building frame is a carefully composed as a unique structural arrangement of glue laminated

bifurcated timber columns and beams and cross-laminated timber (CLT) perimeter walls. Internally the timber structure is left exposed to add richness of texture to the sculptural form.

The building has an efficient, rectilinear form that is clad in lightweight materials, predominantly a stratified composite timber cladding was selected for its natural characteristics and minimal embodied carbon. To the west, a 'saw-tooth' facade limits overheating from the afternoon sun.



Sky Health and Fitness Centre
Internal view

<http://drmm.co.uk/projects/view.php?p=sky-health-fitness-centre#extended>



Sky Health and Fitness Centre
External view

<http://drmm.co.uk/projects/view.php?p=sky-health-fitness-centre#extended>



8.3 Bricks

Brick is a popular choice for walls, façades and paving, as well as some foundations. In the UK, red brick is probably the most trusted building material and therefore always attractive to the homebuying market. Its production is the largest sector in the UK clay construction products market. Brick is produced by cutting a piece of clay into units which are fired at around 2,000 degrees. Emissions come from both the fossil fuels used in the heating and from the processes related to the clay manufacturing.

On larger scale buildings, brick slips are usually used to save time and costs. Brick slips are mounted on steel fixings and used as a rainscreen. This increases embodied carbon on a weight basis and also sacrifices the thermal mass benefits.

8.3.1 Embodied carbon

→ **0.213kg CO₂e/kg** or **0.454 kg CO₂e** per standard brick weighing 2.13kg.

8.3.2 Benefits

- Thermal mass
- Durable and hard wearing. A brick typically has a useful life of 150 years or more.
- Trusted by the market

8.3.3 Considerations

- Local reclaimed brick should be sourced wherever possible. An unfired brick system with much lower embodied carbon may be suitable for internal non load bearing walls and can also help with humidity regulation.
- For a circular approach, it is advised to use a mortar which is softer than the brick. Hard concrete mortars cannot be removed easily from brickwork, resulting in damaged and broken bricks. Soft mortars (lime) are easier to remove and the brick can therefore be reused. Damaged bricks can be ground up and used in aggregates.
- Similar to concrete, consideration should be given to mortar use as well as brick. The designer should opt for a mix that is low in EC but strong enough for purpose, while allowing the brick to be easily reclaimed.

8.3.4 Further readings

The Brick Development Association

<https://www.brick.org.uk>

UK Clay Brick EPD

<https://brick.org.uk/admin/resources/brick-epd.pdf>

BRE Information Paper on unfired clay masonry

https://www.bre.co.uk/filelibrary/pdf/projects/low_impact_materials/IP16_11.pdf

8.3.5 Case studies

The unfired brick used in the WISE Building at the Centre for Alternative Technology, Machynleth, Wales:
https://www.bre.co.uk/filelibrary/pdf/casestudies/Case_study_UCB.pdf

WISE Building at the Centre for Alternative Technology David Lea and Pat Borer

The WISE building was designed to have a very low environmental impact in construction and in use.

The plinth walls that support the timber frame were constructed using sand lime (calcium silicate) bricks. These are autoclaved (cured in pressurised steam), which uses much less energy than firing standard bricks. They are affected by moisture and will expand and contract very slightly, to give the necessary flexibility.



WISE Building
External view

Resource Rows, Lendager Group

The Resource Rows housing project, built largely from recycled construction materials, is part of the Ørestad Syd development area on the outskirts of Copenhagen. The scheme is arranged around a shared courtyard and roofscape, which includes a number of greenhouses made from recycled windows.

The facades are created from upcycling old buildings using 3m² cut-out segments of old brick walls complete with their mortar, from three different buildings.



Resource Rows
External view

<https://lendager.com/en/architecture/resource-rows/>



8.4 Steel

51% of global steel is used for construction (World Steel Association). Steel is used in a wide range of construction projects, ranging from single dwellings to large scale infrastructure.

8.4.1 Embodied carbon

Table A.8.4.1 shows the embodied carbon of various components made from steel in a 'cradle-to-gate' scenario. The second column shows the amount which can be saved if 85% of the steel used is recycled. In a standard EN15978 assessment, this amount would be allocated to 'Module D', which deals with effects outside the lifecycle of the building as the steel existed before the building lifecycle began.

	A1-A3 (kg CO₂e/kg)	Module D (kg CO₂e/kg)
Section Steel	1.55	-0.34
Rebar	1.99	-0.79
Plate Steel	2.46	-1.16

Table A.8.4.1 - Embodied carbon in steel
(data from ICE database V3, Aug 19).

8.4.2 Considerations

- To facilitate the re-use of materials, bolted connections and clamped fittings should be preferred to welded joints.
- If practicable, the designer should specify standard connection details, including bolt sizes and the spacing of holes.
- Easy and permanent access to connections should be guaranteed.
- Where feasible, steel should be free from coatings or coverings that would prevent visual assessment.
- The origin and properties of the component

should be identified by bar-coding, e-tagging or stamping, and an inventory of products (material passport) shall be kept.

- Long-span beams should be adopted to maintain flexibility of re-use in the future, allowing further cutting at a later stage.
- The designer should rationalise and simplify the design, eliminating unnecessary variations and taking advantage of any opportunities provided by manufacturing off site, potentially using prefabricated solutions.

8.4.3 Further readings

World Steel

<https://worldsteel.org>

Steel life cycle thinking

<https://www.worldsteel.org/steel-by-topic/life-cycle-thinking.html>

Steel Construction

<http://steelconstruction.info>

Eco-reinforcement/BES 6001 certification to ensure highest possible current standards

<http://www.eco-reinforcement.org/requirements-of-ecoreinforcement/>

Eco-reinforcement steel for Crossrail

<https://www.bregroup.com/case-studies/eco-reinforcement-steel-for-crossrail/>

EN15978:2010 Steel static storage systems. Terms and definitions

8.5 Aluminium

The production of primary aluminium requires a very high consumption of electricity, almost 10 times that of steel. Due to the energy intensive process, the EC is very high, especially if aluminium is used in large volumes. In order to reduce the embodied carbon as much as possible, electricity from renewable sources shall be used; therefore, if the use of aluminium is unavoidable, it should be specified from a country with largely renewable energy infrastructure (i.e. Norway, Iceland).

By contrast, aluminium is highly recyclable, with properties that do not deteriorate as the material is re-used. Worldwide, around 75% of all aluminium produced is still in use. Recycling uses only around 5% of the energy needed to produce primary aluminium. The recycled material supply chain is however not enough to cover the current demand; it is therefore imperative to reclaim as much aluminium as possible at the end-of-life of each product. Inventories of all aluminium components should be kept to ensure the material is tracked and can be recycled.

8.5.1 Embodied carbon

The embodied carbon of aluminium depends on where it was produced and the proportion of recycled material used. For example:

- Produced in Europe and assuming a recycle rate of 83% based on worldwide flow model of the construction sector = **5.58kg CO₂e/kg**
- General mix in Europe, including imports and assuming a recycle rate of 95% = **6.67kg CO₂e/kg**

8.5.2 Benefits

- High durability
- Strong and light
- Low maintenance

8.5.3 Considerations

- Aluminium is one of the most energy-intensive materials to produce, the largest consumer of energy on a per-weight basis and, because it is produced on such a large scale, one of the largest contributors to carbon dioxide emissions of all industries (Robinson, 2004).
- As it is produced in countries around the equator (i.e. Australia, China, Brazil, India, Guinea, Indonesia, Jamaica, Russia and Suriname), the EC increases due to the long transportation routes between extraction, processing and fabrication.
- In addition to being very energy intensive, the most common method of refining aluminium from bauxite – the Bayer process – consumes large amounts of water.
- The unwanted residue of the process is in the order of 120 million tonnes per year. Most of it is stored in holding ponds, as there are virtually no further suitable applications. As this is a toxic material that could cause harm to animals and plant life, its impact should be taken into consideration in a life cycle analysis approach.
- As a result of its high environmental impact, aluminium should be treated as a high-value material and used sparingly, with re-use in mind.
- Coatings should be avoided when unnecessary; environmental product declaration (EPD) coatings should be used wherever possible.



8.5.4 Further readings

Many case studies can be found in the Aluminium Recyclability and Recycling Report published by the International Aluminium Institute available at

http://www.world-aluminium.org/media/filer_public/2016/10/03/tsc_report2_arr_72dpi_release_locked_1016.pdf

International Aluminium Institute publications including Sustainable Mining and LCA information

<http://www.world-aluminium.org/publications/>

Aluminium and sustainability

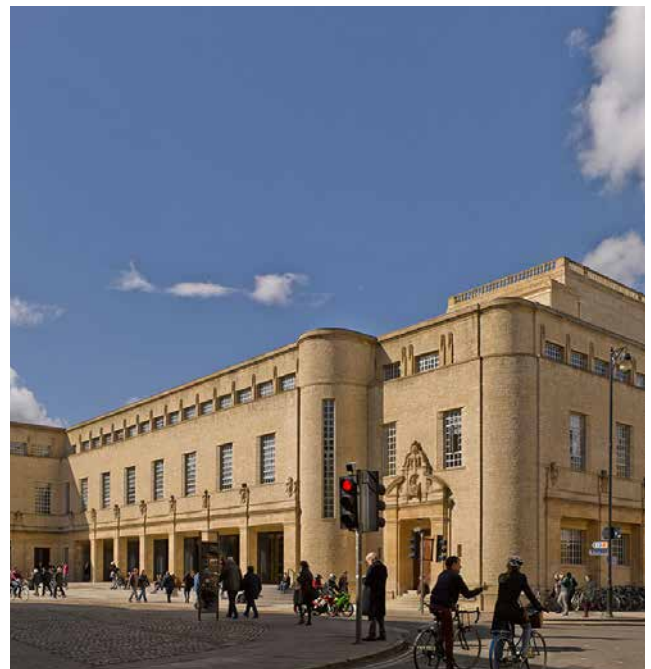
<http://recycling.world-aluminium.org/review/sustainability/>

Robinson, T. Lowering energy intensity and emissions in the aluminum industry with government/ industry/ academia partnership. In Light Metals; TMS: Warrendale, PA, USA, 2004; pp. 277–281.

8.5.5 Case studies

Weston Library, University of Oxford, Wilkinson Eyre

The refurbishment of the New Bodleian Library, a Grade II listed building extends over 11 floors. All of the major features of Gilbert Scott's original architecture were retained during refurbishment, including the 77 year old anodised aluminium windows.



Weston Library

External view

<https://www.wilkinsoneyre.com/projects/weston-library>

8.6 Glass

Soda-lime glass accounts for 90% of all the manufactured glass. It is made up of 70-74% silica, along with sodium carbonate, lime, magnesium oxide and aluminium oxide to enhance its performance.

With its unique translucent properties, glass is used for curtain walls, façades, windows, skylights, partitions, bulbs and tubes. Recycled glass can have a second use as insulation or aggregate.

8.6.1 Embodied carbon

- Glass, general (2.5kg glass per mm thickness, per m² averaged from 109 datapoints) :
1.44kg CO₂e/kg
- Sky light including frame (averaged from five EPDs) : **3.10kg CO₂e/kg**

8.6.2 Benefits

- Glass is translucent, capable of reflecting and refracting light
- Although brittle, silicate glass is extremely durable.
- Moldable to any shape.
- Double and triple glazed units with gas infill provide good u-values and permit solar gain.

8.6.3 Considerations

- Glass requires the use of sand and minerals, which are non-renewable natural raw materials.
- Consideration should be given to coatings, as some processes produce solid waste and emit VOCs.
- The whole life carbon (WLC) of any project should be considered: low embodied carbon is a false economy if heat is easily lost in the operational phase.
- Conversely, in some cases double glazing can be more carbon efficient than triple glazing, as the carbon footprint derived from using a triple glazing system can be higher than the operational carbon saving over the anticipated lifetime of the building. Detailed modelling may be necessary to compare the two systems.
- Where framing is required, timber is usually the best (although not cheapest) option. Timber has a longer life span than polyvinyl chloride (PVC) and a better thermal performance than steel or aluminium. Currently, a very small percentage of PVC is recycled, whilst the vast majority breaks down very slowly in landfill. Aluminium cladding of timber frames can reduce maintenance and increase the expected life span of the product, however a balance must be struck between durability and carbon cost.
- Glazing is durable but recycling, particularly of laminated glass, can be problematic; adopting standard sizes can therefore ease the re-use of the product at the end of expected life stage.
- Glass furnaces run permanently during their lifetime (15-18 years), making the introduction of new technologies difficult. These can only be integrated during furnace replacement or upgrade.



8.6.4 Further readings

The EPBD and glazing

https://glassforeurope.com/wp-content/uploads/2019/04/EPBD_guidance_webversion.pdf

LCA of float glass

<https://glassforeurope.com/report-life-cycle-assessment-of-float-glass/>

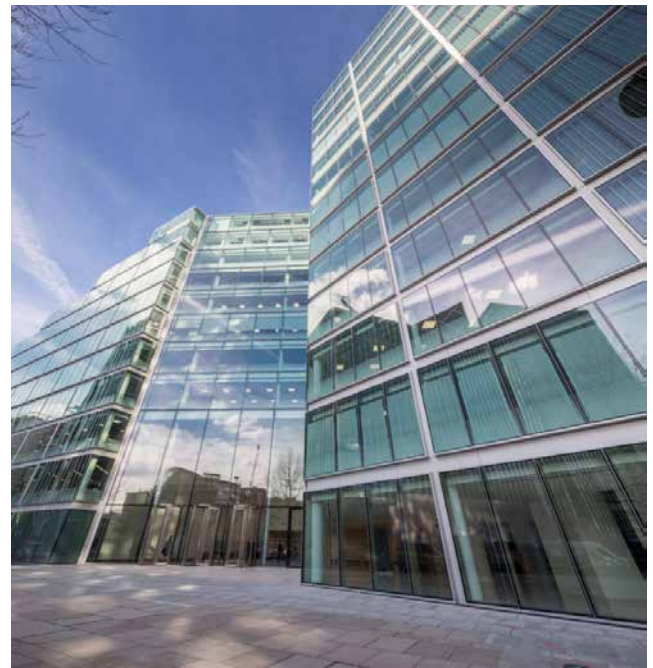
8.6.5 Case studies

Verde SW1

The Verde SW1 is an office building adjacent to the regeneration area of Victoria station in London. The project aimed to revitalise the appearance of the Eland House building, which was originally completed in 1998.

The refurbishment works focused mainly on volume remodelling including the addition of 9,000m² floor area, alongside full re-cladding with new glazing units. The glass waste from removal of the existing fully-glazed facade was sent to a recycling facility rather than landfill, saving approximately 100 tonne of CO₂e.

For more information see Verde SW1 (client: Tishman Speyer) in the article 'Mirko Farnetani & Juan Jose Lafuente. Whole-life carbon Fabric Retention. 18/04/2017. Available from: building.co.uk



Verde SW1 (London, UK) - Tishman Speyer (Developer); Aukett Swanke (Architect); WSP (Structure); Arup (Facade); Sturgis Carbon Profiling (Carbon Consultant); Mace (Cost); Multiplex (Contractor).

External view

<https://www.multiplex.global/projects/verde-sw1-london-sustainability/>

Appendix 9

Whole life carbon

This report has focused mainly on the reduction and calculations surrounding embodied carbon. Whole life carbon (WLC) includes embodied carbon and operational carbon-carbon emissions associated with daily energy use. The purpose of using WLC is to move towards a building or a product that generates lowest carbon emissions over its whole life stages (sometimes referred as 'cradle-to-grave').

9.1 Operation carbon

Operational carbon relates to carbon dioxide and other greenhouse gases associated with the in-use operation of the building. This usually includes carbon emissions associated with heating, hot water, cooling, ventilation and lighting systems as well as energy used in cooking, equipment and lifts.

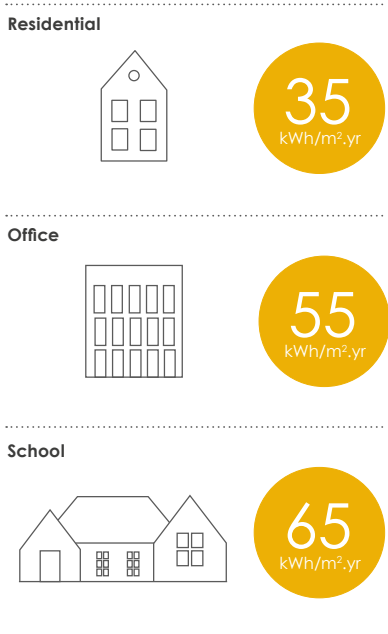


Figure A.9.1 - LETI Energy Use Intensity (EUI) targets
EUI targets above are based on GIA areas and exclude renewable energy contribution.

Clear targets for operational energy for various building types, and advice on how to achieve them are found in Chapter 1 of the Climate Emergency Design Guide.

This report focusses on actions to reduce embodied carbon. Below is a list of strategies to reduce the operational carbon of buildings. For more information see the LETI Climate Emergency Design Guide.

9.1.1 Actions to reduce operational carbon

- **Fabric:** High performance fabric and airtightness
 - Space heating should be no more than 10 W/m² in peak design conditions (- 4 degrees celsius).
- **Form:** Compact form factor
- **Glazing:** Sensible glazing ratios with appropriate orientation and external shading.
- **Heating and hot water:** A fossil fuel-free efficient heating and hot water system.

SIGNPOST *Climate Emergency Design Guide*
Chapter 3: Future of heat

- **Ventilation and cooling:** Mechanical ventilation with heat recovery providing fresh air in Winter with natural ventilation in summer. Design out cooling where possible.
- **Lighting:** Efficient lighting with appropriate controls.

SIGNPOST *Climate Emergency Design Guide*
Introduction - Building archetypes

SIGNPOST *Climate Emergency Design Guide*
Chapter 1 - Operational Energy



Operational energy

Implement the following indicative design measures:

Fabric U-values (W/m².K)

Walls	0.13 - 0.15
Floor	0.08 - 0.10
Roof	0.10 - 0.12
Exposed ceilings/floors	0.13 - 0.18
Windows	0.80 (triple glazing)
Doors	1.00

Efficiency measures

Air tightness	<1 (m ³ /h. m ² @50Pa)
Thermal bridging	0.04 (y-value)
G-value of glass	0.6 - 0.5
MVHR	90% (efficiency) ≤2m (duct length from unit to external wall)

Window areas guide (% of wall area)

North	10-15%
East	10-15%
South	20-25%
West	10-15%



Balance daylight and overheating



Include external shading



Include openable windows and cross ventilation

Reduce energy consumption to:

35
kWh/m².yr

Energy Use Intensity (EUI) in GIA, excluding renewable energy contribution

Reduce space heating demand to:

15
kWh/m².yr



Maximise renewables so that 100% of annual energy requirement is generated on-site



Form factor of 1.7 - 2.5

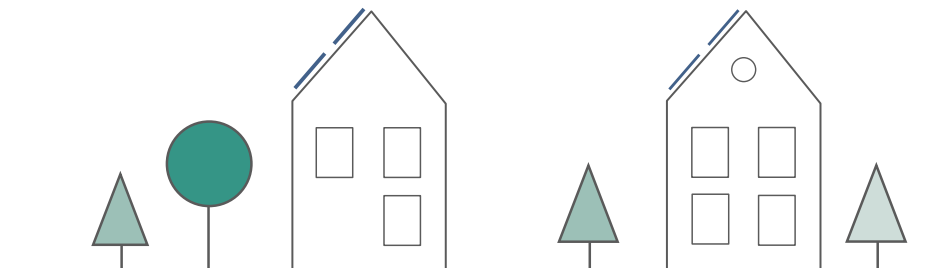


Figure A.9.2 – Extract from LETI Climate Emergency Design Guide showing indicative design measures to achieve operational energy consumption target.

9.2 Interaction between embodied carbon and operational carbon

It is important to consider whole life carbon, this includes carbon emissions associated with all in-use energy and embodied carbon associated with production and transport of materials for use in constructing, maintaining and deconstructing the building. Figure A.9.3 shows how operational and embodied carbon interact throughout the lifetime of the building:

Built environment professionals should be aware of the proportion of embodied carbon and operational carbon. It is important to note that operational carbon can be measured in-use. It is the energy measured at the meter multiplied by the carbon intensity of the fuels used (i.e. gas or electricity). Embodied carbon will always be more of an estimation even if calculated post construction.

It is a legal requirement to limit the operational emissions of almost all planned new buildings in the UK under Part L of the Building Regulations (England and Wales), Part F (Northern Ireland), or Section 6 of the Building Standards (Scotland).

The graph in Figure A.9.4 shows how the relationship between operational carbon and embodied carbon is changing and the impacts we can have on whole life carbon.

The graph shows that:

- It is not the proportion of embodied and operational carbon that is important, it is the magnitude of change that can be achieved.
- The biggest impact (with the highest level of certainty) on whole life carbon is moving from a Building Regulations compliant building that has a gas boiler to a high performing low energy building that uses an air source heat pump for heating and hot water.
- Efforts to reduce embodied carbon are vital.

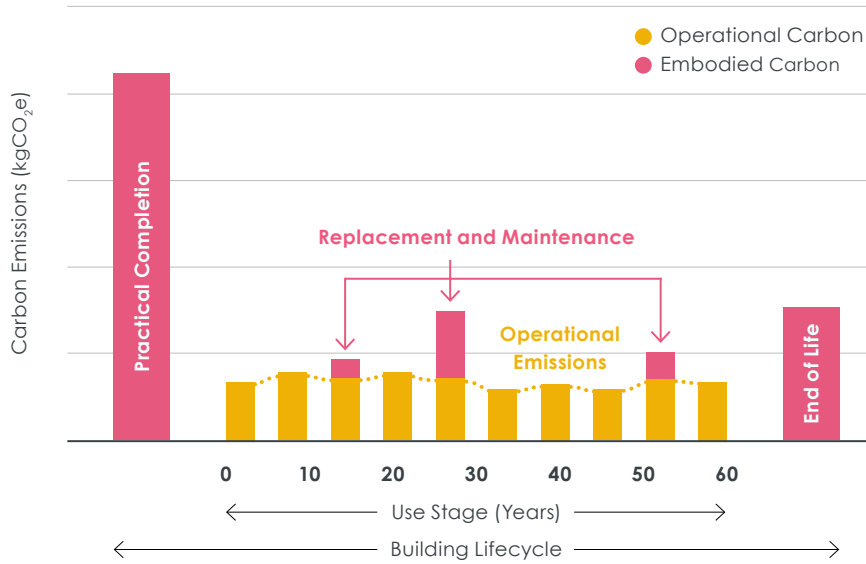


Figure A.9.3 – Graph showing interaction between operation and embodied carbon throughout the lifetime of a building

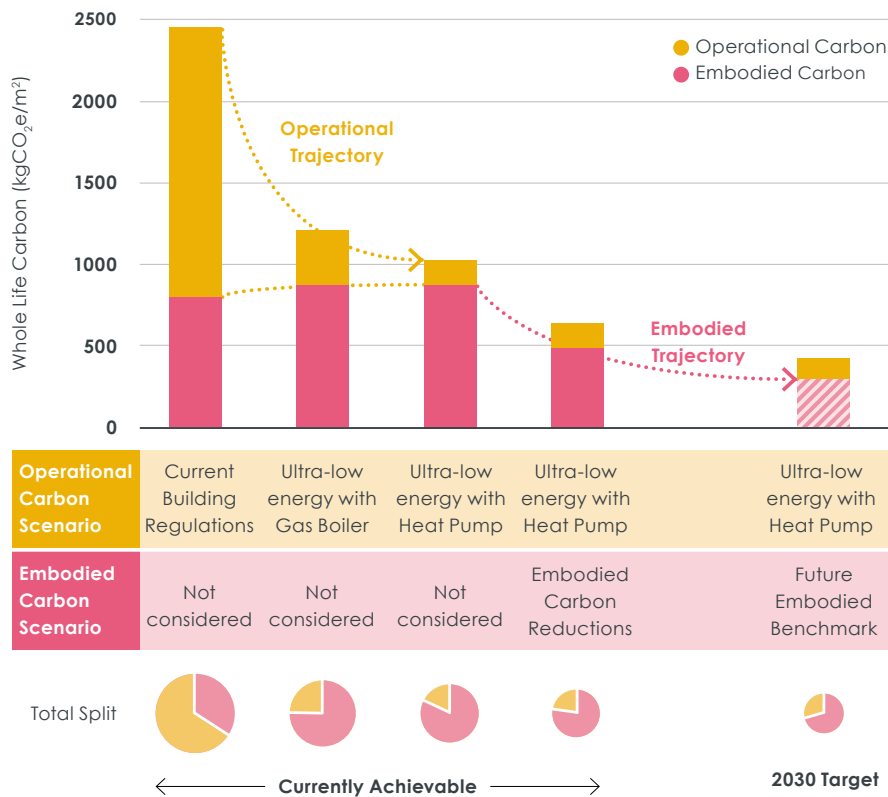


Figure A.9.4 – Diagram showing operational and embodied carbon and trajectories

9.3 How to include operational energy in whole life carbon calculations


When calculating whole life carbon it is important to realistically estimate operational carbon emissions. LETI recommends that:


- Annual lifetime carbon emissions factors are used. At present this is 0.07kg CO₂/kwh for the average of the next 30 years for electricity (30 year average calculated from BEIS. Updated energy and emissions projections. London: BEIS; 2018).
- Use in-use verified data on energy consumption if available.
- Do not use results from modelling that was done to prove compliance with Building Regulations or planning policy for calculating operational emissions. These SAP/SBEM models were never intended to be used to predict energy consumption and should not be used for this purpose. SAP/SBEM modelling use the National Calculation Methodology (NCM) that relies on standardised occupancy and usage data. Instead use predictive modelling (PHPP or TM54) to estimate operational energy or Dynamic Simulation Modelling (DSM).
- Allow for performance gap.

9.4 Relationship between embodied carbon and operational carbon

Various design decisions have an impact on embodied carbon and operational carbon These are outlined below.

- **Building Form.** An efficient building form means less materials used, and reduced surface area for heat loss.
- **Insulation and building fabric:** The building archetype pages recommend the U-Values needed to achieve the operational energy targets. A high performing façade in terms of operational performance should be prioritised. A higher performing fabric can mean thicker walls and a larger volume of insulation. Low carbon insulation materials are available and should be fully considered.

 **SIGNPOST** *Climate Emergency Design Guide Building Archetype pages*

 **SIGNPOST** *Appendix 6 – Facade rules of thumb*

- MEP: Larger MEP plant such as air handling units, have higher operational efficiencies yet will have more embodied carbon. It is likely that the benefit in operational saving will outweigh an increase in embodied carbon.

 **SIGNPOST** *Appendix 6 – MEP rules of thumb*

- Thermal Mass: Exposing the inside of a room to thermal mass reduces the risk of overheating in summer, reducing the need for cooling. Thermal mass is often associated with higher embodied carbon material such as concrete. A detailed study should be undertaken to understand the optimal volume of thermal mass.



9.5 What do we mean by 'Net Zero Carbon'?

It is important to note the distinction between 'Net Zero' and 'Whole Life Zero Carbon' when talking about carbon targets.

The UK Government has committed to Net Zero emissions by 2050 by law, defining this term as,

'Net zero means any emissions would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere, such as planting trees or using technology like carbon capture and storage'

<https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law>

Therefore, Net Zero means that the UK will still be emitting GHGs in 2050. Mechanisms will be required, to balance the UK's emissions with offsets, carbon capture and sequestration (see Appendix 10 for more on offsetting), while also it is important to note that off-shoring (carbon arising from products we import, or international supply chains) and some industries have been excluded from the calculation.

In developing this guidance, LETI have proposed targets for Net Zero Embodied Carbon for 2020 and 2030, 20 years ahead of the UK Government's target. In doing so, it became clear that these targets could not be developed without considering the circular economy. To truly achieve a zero carbon national economy, we need to move away from considering the design and construction of buildings independently from one another, and move the whole construction industry towards a circular economy.

While by 2020, LETI see it to be fully possible to achieve net zero operational carbon, without the use of offsets, through a zero carbon balance, it is apparent that for embodied carbon, there will still be some way to go before this can be achieved.

▶ **SIGNPOST** *LETI Climate Emergency Design Guide*

As such, when this document refers to net zero carbon it refers to a new building that achieves the operational net zero requirements in-use, outlined on the previous page (e.g. 35 kWh/m² for residential + renewables/ investment in renewables), as well as assessing and reducing the impacts of Upfront embodied carbon emissions (Product, transport and construction stage (A1-A7) in line with current best practice targets for upfront embodied carbon emissions. (e.g. 500 kgCO₂e/m² . Best practice targets for Upfront emissions (Product, transport and construction stage (A1-A7))

The Intergovernmental Panel on Climate Change (IPCC) have stated however that we have 10 years to make the level of carbon emission reductions needed in order to limit global warming to 1.5°C. Emerging from this is a 'carbon budget', to stay within the 1.5°C level of global warming. As such, it is important to note that while LETI have defined kgCO₂e/m² for key building archetypes for 2020 and 2030, these targets need be considered on a national scale, in terms of how many m² of buildings and infrastructure we are able to build at this level of embodied carbon while staying within this global carbon budget. The UK's carbon budget will need to be regularly reviewed against true global carbon emissions. Additionally, when global climate events, such as the devastating Australian fires of 2019/2020, emit substantial emissions, the amount of carbon released into the atmosphere will need to be taken into account in future carbon budgeting.

9.5 What do we mean by ‘Whole Life Zero Carbon’?

LETI have taken a view that circularity is more relevant than offsets for the design team and for policy makers, and advocate a circular economy approach within this guide.

As such, LETI have defined true Whole Life Zero Carbon to be where the embodied carbon associated with all typologies is 0kgCO₂/m² over its lifetime, where a 100% circular economy exists, and where no offsets, sequestration or carbon capture are needed. This means that 100% of its materials and products are made up of re-used materials and the building is designed for disassembly such that

100% of its materials and products can be re-used in future buildings. When construction, transport and disassembly is carried out with renewable energy there will be zero carbon emissions associated with the embodied carbon.

Some believe that if you are not achieving 0kgCO₂/m² then offsets should be required, Figure A.9.4 shows how this would work in practice, using the LETI 2020 targets with the different life cycle stages that would require offset. Others believe offsets are not relevant to building design, as offsets typically fall outside the remit of designers, architects and engineers.



	Stage	Reduction target	Verification	Whole life zero carbon balance
Embodied carbon	Upfront emissions - Product, transport and construction stage (A1-A5)	→ Residential - 500kgCO ₂ /m ² → Non-residential - 600kgCO ₂ /m ²	Post completion	Carbon offset
Operational carbon	Operational emissions (B6)	→ Residential - 35kWh/m ² /yr (GIA) → School - 65kWh/m ² /yr (GIA) → Office - 55kWh/m ² /yr (GIA)	Annually	Renewable energy procurement (additional renewables not Green Tariff)
Embodied carbon	Maintenance and operational water and refrigerant leakage (B1-B5, B7)	<i>to be defined</i>	Annually	Carbon offset
Embodied carbon	End of life (C1-C4)	<i>to be defined</i>	After demolition	Carbon offset

Figure A.9.4 – Table showing different life cycle stages, with 2020 targets and offsets.



Appendix 10 Offsetting

10.1 Introduction

All buildings emit CO₂ while they are being occupied, in the materials used to construct them (their embodied energy), during the construction process onsite, and at the end of their life when they are taken down. Design and construction practices have improved so it is now technically possible to create buildings that are virtually carbon neutral while in use. As the report clearly demonstrates, this has to be done now. However, residual emissions from the building materials and the construction process have not benefited from the same degree of attention and development. For building materials that consume a lot of energy in their production (e.g. concrete, steel, bricks) and those that are transported long distances, this embodied CO₂ can be significant. It is these emissions from the embodied carbon in the construction process that this section is considering.

Offsetting is defined as the use of carbon negative activities to remove greenhouse gases from the air and store them for long periods of time. For example, when a tree grows it takes carbon out of the air and locks it into the wood for long periods. These offsetting methods should last long enough (about 100 years) for us to develop new technologies or ways of doing things to replace the activities that still emit CO₂ and other greenhouse gases.¹

Some argue offsetting could also include reducing energy demands elsewhere by adding insulation and more efficient heating and cooling systems to existing buildings. It could also include additional renewable energy capacity to speed up the decarbonisation of the electricity supply. Offsetting is controversial, particularly when it seems to displace the problem

to other locations and sectors. This section attempts to give a dispassionate review of offsetting, looking at the advantages, disadvantages and technical and societal challenges to its effective implementation.

10.2 Where did offsetting come from?

The idea that we can compensate for greenhouse gas emissions from an individual development or sector by paying for projects that reduce greenhouse gas emissions elsewhere came from the business sector's response to the Kyoto climate summit in 1997. It mirrors measures that had been in the US Clean Air Act since the 1970s, when new emissions were allowed if they were offset by emissions reductions in other facilities. For climate change, it does not matter where on the globe the CO₂ is emitted or where it is stored, but there can be significant local and regional social and environmental consequences to offsetting schemes – both positive and negative.

Another related feature of the Kyoto Summit was the clean development mechanism, which stated that developed countries had a responsibility to assist developing countries move straight to low carbon technologies, rather than following the high carbon development path taken so far by developed countries. Offsetting schemes in developing countries are in part driven by not-for-profit organisations, following a climate justice agenda. People in developing countries can meet their basic energy needs without unnecessary CO₂ emissions and local deforestation by leap-frogging and jumping straight to green energy technologies. For commercially motivated organisations, offsetting in developing countries can be seen as an opportunity to offset at a lower cost per tonne and the argument in favour is that you can

get much more impact for each pound invested. Offsetting firms are also attracted to countries and regions where land and labour costs are lower and there are fewer domestic regulations to comply with. One city council in England, Liverpool, are meeting their carbon neutral ambitions by partnering with a private sector organization, the Poseidon Foundation, to offset their own organisational emissions.²

There is an argument that, in the UK, we should be helping developing countries make a low carbon transition. There is however, a clear message from the Committee on Climate Change that we should deal with our own residual emissions here rather than 'exporting' them.³ Public perception of offsetting can be negative, viewing it as another tax. Public and business concerns have been managed successfully with the congestion charge in London, and the business community, through London First, supported it when it could see the funds generated going directly into new public transport.⁴ This is a wider principal for environmental taxes, that they gain greater trust and acceptance if the funds raised are spent directly on addressing that issue in that area.

So far in England, the adoption of carbon offsetting schemes in relation to new buildings has been limited. Outside London, only Southampton and Milton Keynes charge carbon offsetting payments and Bristol and South Gloucestershire have used offsetting in individual projects. These are all part of the 'allowable solutions' approach where a developer can, through a S106 agreement, pay into a fund for carbon abatement offsite.⁵

10.3 Main methods of offsetting

- **Forestation:** growing trees and improving the management of existing woodlands. As trees grow they take CO₂ out of the atmosphere and store it in the living tree and in the soil.
- **Bioenergy with Carbon Capture and Storage:** As the plants grow they take CO₂ out of the atmosphere. This can be captured and put into long-term storage when the plants are burned to generate electricity. Crops can be grown specifically - fast growing plants like the grass Miscanthus, or waste materials used from forestry and farming (e.g. straw, sugar cane stems). Bioenergy and carbon capture and storage technologies have been deployed separately in several countries but not yet combined at scale.
- **Building with Biomass:** Using forest materials in buildings extends the time that carbon is stored and enables the land to be used for new forestry growth, thus increasing the absorption of CO₂. This is limited by the rate at which buildings are constructed and the percentage of homes and other buildings that are timber frame (currently only 30% of homes and flats).³
- **Restoring habitats:** Improving peatland and coastal wetlands so they can store more carbon and help ensure the carbon they already store does not degrade.
- **Farming:** changing agricultural practices including crop rotations and how land is tilled to increase the carbon in the soil. Using Biochar in farming, a charcoal like substance created when organic matter is burned without oxygen, stabilizing organic matter in soil.
- **Direct:** air capture and carbon storage (DACCS)



Using engineering technologies to capture CO₂ directly from the atmosphere and putting it into geological storage. A variation of this involves using the CO₂ to make products of economic value such as plastics, concrete and biofuel.

- **Installing new renewable energy generation onsite:** Renewables now make up 30% of the energy generated in the electricity grid. In the short to medium term there is a case for adding to the renewables generating capacity in the UK. ⁶
- **Completing energy efficiency measures to existing buildings:** this could be to improve energy efficiency in publically owned buildings such as affordable homes, community buildings and schools. It could also be used to improve the incentives for private building owners – more free advice and discounts for small business efficiency schemes.
- **Removing sources of greenhouse gas emissions:** buying and retiring carbon intensive infrastructure or paying for the safe disposal of potent greenhouse gases.

10.4 What are the key requirements of a carbon offset?

- **An accurate measure of the emissions to be offset.**

This can have high levels of uncertainty. Aviation offsetting is one of the most developed parts of the offsetting sector, but measuring emissions from flights has been fraught with problems as factors including the height of the flight, cargo load and weather

conditions have an impact, giving for example, variations between 1.43 tonnes to 4.14 tonnes for flight from Boston to Frankfurt. ⁷

- **An accurate measure of the carbon that is being saved elsewhere.**

If the offsetting scheme involves planting trees then calculations need to be made to see how much carbon is being absorbed. Schemes that involve retrofitting including new insulation and heating systems will depend on that activity taking place (not just funds being set aside for it) and behaviour engagement by the building occupiers. In-depth monitoring of the carbon savings could take up a large proportion of the funds generated, and one way to address this is to require the measurement and reporting of emissions from larger projects, whilst using a set of standard assumptions for smaller projects.

- **Additionality**

Is the funding supporting something new or something that would have happened anyway? For example, Climate Care offset emissions from the Guardian Newspaper group by distributing 10,000 low energy lightbulbs in South African townships only to find that the local energy company had already distributed the same kind of lightbulbs to its customers and the reductions would have happened anyway. ⁷ The same can also apply to a domestic insulation project or a small business buying more energy efficient equipment – is it something that would have happened anyway without the offsetting funding?

10.5 More renewables capacity?

We are currently part way through a rapid transition in the power sector where the price of renewables is being driven down. Lower carbon electricity from the grid is helping to reduce emissions in other sectors including buildings. As the Committee on Climate Change notes, contracts being signed for new wind and solar projects, due to be completed in the early 2020s, are price competitive with high carbon generation sources of power. ³ Given the mature state of the market, the funds generated from a built environment offsetting scheme from a city the size of London would have limited impact on delivery and raise questions about additionality – the likelihood that the renewables schemes will happen anyway. There is currently a need to add more renewable capacity to the grid to replace existing fossil fuel sources and to accommodate the extra demand to come from electric vehicles and heat pumps. Adding more renewable capacity should not continue indefinitely, and adding more capacity from wind turbines and solar panels eventually just adds to the over supply of renewable energy during peak periods without helping when the grid supply comes under pressure - when weather conditions are cold, cloudy and not windy. Other solutions including demand response and storage are needed, rather than just adding more and more renewables. ⁸

10.6 Managing carbon offsetting schemes

From an unregulated sector 20 years ago, offsetting is no longer a 'wild west' but self-regulated through an industry standard – the Gold Standard. This places increasing emphasis on technology including remote sensing and blockchain to manage and monitor off setting projects whilst avoiding high administration costs. ⁹ The costs of collecting green taxes can be very high and this needs to be kept in mind as any new offsetting system is introduced in London. For example, the costs of implementing the congestion charge in London were 76% of total income in the early stages, which later fell to 35%. This contrasts with the congestion charge introduced in Stockholm at a similar time but with an eye to national standardisation. When Gothenburg introduced its own congestion charge in 2013 it was able to use the same back office procedures, which has kept costs down for Gothenburg and reduced costs for Stockholm. ¹⁰

Could carbon offsetting be administratively combined with funds from biodiversity net gain policies – to increase funds available and reduce administrative costs? Is there the potential to develop a scheme that can be readily adopted by other cities, again to reduce administration costs? It would not be advisable to combine the administration with the Community Infrastructure levy as this is an area based fund and does not take the embodied carbon in the new building into account. Figures from the current GLA allowable solutions offset fund involve allocating 10% of the funds generated to support the administration. Many voluntary offsetting schemes exceed this, where around 20% of the funds generated are commonly used in the administration. ¹¹



The most appropriate mechanism to administer the fund will depend on the range and type of projects that are eligible and the size of the fund. For example, if lots of applications are expected from the community for small scale retrofitting projects, outsourcing the day-to-day management to a community organisation could be well aligned. As with other certification schemes, there are barriers to assessing the impact of multiple small scale interventions. Blockchain technology, which is already being deployed to manage some offsetting programmes, may also be appropriate to support low administration costs and transparency for smaller intervention. ²

10.7 Demands on land

One of the main challenges is the finite amount of land available on which to undertake offsetting activities. All of the options apart from 10.6, 10.8 and 10.9 require significant land and there will be other demands for this space. Other sectors will also be looking for land to offset their emissions, in particular aviation and shipping where low and zero carbon technologies appear decades away from being market ready, and the solutions, if they do reach the market place, could require significant land use.

Even more problematic are the investments we need make urgently to move towards a low carbon future. The steps we need to take to improve public transport infrastructure in cities and insulate our existing building stock will use building materials that have embodied energy, and will need to be offset. These measures urgently need to take place, but in the short to medium term will lead to a significant rise in emissions from the sector.

The Centre for Alternative Technology (CAT) in its Zero Carbon Britain report has looked at competing demands for land in detail. Its research shows that it would be possible to capture 47.8 MtCO₂e per year from land-based solutions by

- doubling forest cover
- harvesting more timber to use in buildings
- restoring 50% of peatlands
- converting waste wood into Biochar

This level of land-based offsetting would offset all residual emissions assuming a 91% reduction from 2017 levels. While it is possible to plant more trees or restore more peatland, significant competition with other land uses, including growing food emerge. ¹

10.8 Reinventing London's Greenbelt

Growing crops for biomass with carbon capture and storage is carbon positive. This is helped by not then transporting the harvested fuel crops long distances and we should grow our own in the UK rather than importing it. Yields of energy crops are higher if good quality land currently used for intensive grassland is converted to Miscanthus grass and short rotation coppice (willows and poplars). The CAT Zero Carbon Britain scenario 2019 involves turning 2.5 Mha of intensive grassland in the UK over to energy crops without having a negative impact on food production. ¹ Currently 59% of the Greenbelt within London is agricultural land use for horse grazing and arable crops while only 22% has public access and/

or ecological designations. ¹² And that is before we look at the 7% of London's greenbelt that is golf courses! These energy crops require very little fertilizer inputs and provide good habitat for wildlife when compared to current agricultural uses. As part of a low carbon future, could London repurpose the Greenbelt for the 21st century and offset some of its own emissions with carbon negative technology - growing energy crops on farmland for electricity generation? Although it is important to note that the Committee on Climate Change looked at this in some detail and concluded that sequestration in the built environment was substantially better than burning for energy and that uses of land / biomass for energy without sequestration were inferior to other sources of low carbon energy unless combined with Carbon Capture Storage (CCS). ¹³



A section of London's green belt



10.9 Seeing the wood for the trees

The first large scale environmental campaign to take place in modern times was a public tree planting initiative. A few readers will remember “Plant a tree in ‘73” and “Plant some more in ‘74”. They may also remember watching them die in ‘75 and picking up sticks in ‘76. A salutary reminder of the importance of thinking about maintenance as well as planting trees, and the impact of extreme weather events on tree planting – in that case the exceptionally hot summer drought.

Woodland and forests absorb carbon as they grow. This is not an even process and they store relatively small amounts of carbon immediately after planting and then depending on the species, peak years later. A mature, well-managed forest will store less new carbon – eventually these stores become ‘full’. There are many wider benefits of tree planting including reducing overheating in cities; mitigating flood risk; improved air quality; physical health benefits from the recreational space; and improvements to mental health and wellbeing. ^{14 15} However a systematic review of 160 articles about new woodland planting in the UK found few scientific studies look at these multiple benefits in the round. Similarly, the Natural Capital Committee notes the 25 Year Environment plan does not connect woodland’s role in carbon sequestration with other public goods such as cultural and recreational services. This is especially important in and around London where each piece of open land will be needed to deliver multiple benefits. The high value that the people place on woodland was visible when the Government was forced to drop plans to sell off publicly owned woodland. New mapping initiatives like Maplango show the potential for existing tree planning within greater London

with ambitious projections showing the potential to increase the tree cover in London by 10% by 2050. ¹⁶. Some of the landscape scale benefits can be more readily achieved and planting costs reduced per new tree in the metropolitan greenbelt in the counties surrounding London rather than the built up centre.

As well as mitigating the impacts of climate change, tree planting is also affected by climate change. New trees planted now should be selected to thrive in the climate we are likely to see in the second half of the century. These considerations are in many instances not taking place and trees could be ill suited to future average temperatures. UK Climate models also predict extreme drought and heating events in the summer being more common. It could be these extreme events, and not average temperatures, that result in tree deaths. While maintenance of new planting is essential, regimes that require longer term watering of mature trees are more problematic. If our cities run short of water, it will be used for people and not for trees. The extreme weather events in France in 2018 resulted in many dead trees in urban areas. Areas of dead trees and extremely hot conditions represent a future fire risk in cities. Tree planting schemes also need to be planned and scaled so that UK tree nurseries can grow stock. Mass importing of trees can spread tree diseases, a situation also made worse by climate change. Tree planting should not be seen as a cheap and easy option compared to other measures to address climate change. Taking all these factors into account is important for political pledges on tree planting to be turned into a positive legacy.

10.10 Retrofit

There is an urgent need to retrofit the UK's 30 million buildings, most of which are domestic homes. The Committee on Climate change has called for this to be a national infrastructure priority. Offset payments that fund the retrofit of existing buildings can accelerate the transition to low carbon energy by both funding a transition away from fossil fuel based heating to electric heating and investing in efficiency measures to ensure that this energy is affordable. In this way, offset payments can form a valuable component of the transitional process by increasing the speed and number of buildings able to achieve zero carbon status. This is not something that the market is currently doing without additional public funding; the Green Deal, a scheme introduced to help fund the scaling up of domestic retrofit was cancelled by the government in June 2015 and is still without a replacement.

A combination of cavity or solid wall insulation; floor and loft insulation; improved glazing and draught-proofing can reduce heat loss from homes by 50%. One of the challenges for programmes now is that the easiest to treat homes (those with cavity walls) and the easiest residents to engage with have already had basic energy efficiency retrofit measures installed. Measures that involve significant disruption and homeowners taking time off work to manage builders are more difficult to implement, particularly when the cost savings appear modest for middle-income home-owners. Split incentives with private rental properties – where the renter is the main beneficiary of the warmer more comfortable home, but the owner has the costs and additional workload managing the building works also act as a barrier.

Across all housing types and tenures there is some rebound as residents enjoy a warmer home, this averages at a 15% reduction in the expected performance. For retrofits on affordable housing, this often results in little or no carbon savings.^{17 18} When researchers have returned to see why the carbon savings have not been achieved they found that residents were living in acute fuel poverty and only heating part of their home. After the retrofit they were able to afford to heat their whole house. Retrofits to address fuel poverty bring significant health benefits to the individual, wider benefits in reduced NHS spending (between £1.4-£2.0bn pa)³, as well as less easy to quantify benefits including children doing better at school, not embarrassed to have friends to their home and people feeling happy about where they live and taking pride in it.^{19 20} Retrofitting homes where residents are in fuel poverty is important for climate justice and an essential step in a just transition, but will not however guarantee carbon savings because these households were using so little energy beforehand.

Previous publicly funded retrofit programmes have almost all been piecemeal and installed individual measures rather than taking a whole house approach. Some improvements have been so modest it will require returning to add further insulation in the near future if 2030 and 2050 reduction targets are to be achieved. Cost estimates vary greatly between studies from £17,000 per house²¹ to give an 80% reduction, to £40-47K for a 67% reduction²², and £75K per house to meet 90% reductions, with a potential to drive this down through scaling up retrofit programmes to £35K.²²



Upfront costs are certainly one important barrier, but lack of knowledge of the right solution for your house, lack of time to research options and manage different trades people, and lack of trust are also important factors. The failure of the Green Deal in reaching only 14,000 homes or 0.05% of the target, illustrates the challenges that are ahead. ²² This lack of trust by the public has only heightened since the Grenfell fire, and particularly affects new insulation products and external cladding. A successful retrofit scheme funded through a levy on existing construction should address the finance barrier by providing interest free loans to carry out the work. This could work as a revolving loan fund so as one building owner pays off the loan this money is circulated to the next retrofit project. Any scheme should also address other barriers including getting trusted advice on what is right for your home. To drive the costs of whole house retrofit down and to get change and scale as has successfully happened in the renewables sector, far more funding will be needed than that levered from a carbon tax on existing construction. To refurbish the 762,200 affordable homes in London with a deep retrofit approach (assuming a cost of £35,000 per home) giving 90% energy savings would cost £26.7 billion if substantial cost reductions through scale were achieved.

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Appendix 11 In scope and out of scope

The BREEAM New Construction 2018 UK – Mat 01 defines a list of In-Scope and Out of Scope building elements based upon the RICS New Rules of

Measurement (NRM) classification system up to level 3 sub elements (see Tables 1,2,3 & 4).

11.1 In-Scope

Level 1 Group element	Level 2 element	Level 3 Sub Element
1.Substructure	1. Substructure	1.Standard Foundations
		2.Specialist foundation systems
		3. Lowest floor construction
		4. Basement excavation
		5. Basement retaining walls
2.Superstructure	1. Superstructure	1. Steel frames
		2. Space decks
		3. Concrete casings to steel frame
		4. Concrete frames
		5. Timber frames
		6. Other frames
	2. Upper Floors	1. Floors
	3. Roof Coverings	1. Roof structure
		2. Roof coverings
		3. Specialist roof systems
		4.Rooflights, skylights and openings
	4. Stairs and ramps	1. Stairs and ramps structures
	5. External walls	1. External enclosing walls above ground floor level.
2. External enclosing walls below ground level.		
3. Solar or rain screening.		
6. Windows and external doors	1. External windows	
7. Internal Wall and Partitions	1. Wall and partitions (Education only)	

Figure A.11.1 - In-scope building elements (extract from RICS NRM)

Level 1 Group element	Level 2 element	Level 3 Sub Element
5. Services	5. Heat source	1. Heat source
	6. Space heating and air conditioning	1. Central heating 2. Local heating 3. Central heating 4. Local cooling 5. Central heating and cooling 6. Local heating and cooling 7. Central heating and cooling 8. Local air conditioning
	6. Ventilation	1. Central ventilation 2. Local ventilation 3. Smoke extract or control
	9. Fuel Installations and systems	1. Fuel storage 2. Fuel distribution systems
8. External works	2. Roads, paths and paving	1. Roads, paths and paving 2. Special surfacing and paving

cont: **Figure A.11.1** - In-scope building elements (extract from RICS NRM)



11.2 Out of Scope

Level 1 Group element	Level 2 element	Level 3 Sub Element
2. Superstructure	2. Upper floors	2. Balconies
	3. Roof	6. Roof features
	4. Stairs and ramps	2. Stair or ramp finishes 3. Stair or ramp balustrades and handrails 4. Ladder, chutes, slides
	5. External walls	4. External soffits 5. Subsidiary wall, balustrades, handrails, railings and proprietary balconies 6. Facade access or cleaning systems
	6. Windows and external doors	2. External doors
	Internal walls and partitions	2. External doors 3. Moveable room dividers 4. Cubicles
	8. Internal doors	1. Internal doors
	7. Internal finished	1. Wall finishes
2. Floor finishes		1. Floor finishes 2. Raised access floors
3. Ceiling finishes		1. Finishes to ceilings 2. False ceilings 3. Demountable suspended ceilings
4. Fittings, furnishings and equipment	1. Fittings, furnishings and equipment	1. General fittings, furnishing and equipment 2. Domestic kitchen fittings, furnishings and equipment 3. Special purpose fittings, furnishings and equipment 4. Signs and notices 5. Works of art 6. Equipment 7. Internal planting 8. Bird vermin control

Figure A.11.2- Superstructure - Out of Scope (extract from BREEAM UK NC 2018)

Level 1 Group element	Level 2 element	Level 3 Sub Element
8. External works	1. Site preparation works	1. Site clearance 2. Preparatory groundworks
	3. Soft landscaping, planting and irrigation systems	1. Seeding and turfing 2. External planting 3. Irrigation systems
	4. Fencing, railings and walls	1. Fencing and railings 2. Walls and screens 3. Retaining wall 4. Barriers and guardrails
	5. External fixtures	1. Site or street furniture and equipment 2. Ornament features
	8. Minor building works and ancillary buildings	1. Minor building works 2. Ancillary buildings and structures 3. Underpinning to external site boundary walls.

Figure A.11.3- Substructure and hard landscaping - Out of Scope (extract from BREEAM UK NC 2018)



Level 1 Group element	Level 2 element	Level 3 Sub Element
2. Superstructure	1. Upper Floors	3. Drainage to balconies
	3. Roof	4. Roof drainage
5. Services	1. Sanitary installations	1. Sanitary appliances 2. Sanitary ancillaries 3. Pads
	2. Services equipment	1. Services Equipment
	3. Disposal installations	1. Foul drainage above ground 2. Chemical, toxic and industrial liquid waste drainage 3. Refuse disposal
	4. Water installations	1. Mains water supply 2. Cold water distribution 3. Hot water distribution. 4. Local hot water 5. Steam and condensate distribution
	7. Ventilation	2. Special ventilation
	8. Electrical installations	1. Electrical mains and sub-mains 2. Power installations 3. Lighting installations 4. Special lighting installations 5. Local electricity generation systems 6. Earthing and bonding systems
	10. Lift and conveyor installations or systems	1. Lift and enclosed hoists 2. Escalators 3. Moving pavements 4. Powered stairlifts 5. Conveyors 6. Dock levellers and scissor lift 7. Cranes and unenclosed hoists 8. Car lift, car stacking systems, turntables and like. 9. Document handling systems

Figure A.11.4- Core building Services - Out of Scope (extract from BREEAM UK NC 2018) cont. on next page

Level 1 Group element	Level 2 element	Level 3 Sub Element
5. Services cont.	11. Fire and lighting protection	1. Firefighting systems 2. Fire suppression systems 3. Lightning protection
	12. Communication, security and control systems	1. Communication systems 2. Security systems 3. Central control or building management systems
	13. Special installations or systems	1. Specialist piped supply installations 2. Specialist refrigeration systems 3. Other specialist electrical or electronic installations systems 4. Water features
	14. Builder's works in connection with services	1. General builder's work
8. External works	6. External drainage	1. Surface water and foul water drainage 2. Ancillary drainage systems 3. External chemical, toxic and industrial liquid waste drainage 4. Land drainage
	7. External services	1. Water mains supply 2. Electrical mains supply 3. External transformation devices 4. Electrical transformation devices 5. Electricity distribution to external plant and equipment 6. Telecommunications and other communication system connections 7. External fuel storage and piped distribution systems 8. External security systems 9. Site or street lighting systems 10. Local or district heating installations 11. Builder's work in connection with external services.



Appendix 12 Baseline specifications

Extract from RiCS professional statement 'whole life carbon assessment for the built environment' Table 6: Default specifications for main building materials.

	Material	Details	Specifications
1	Concrete	Piling	C32/40 - 20% cement replacement Baseline: 0.12 kg CO₂e/kg Ref: ICE V3 - RC 32/40 (32/40 MPa) 20% GGBS
		Substructure	
		Superstructure	
		Generic concrete	C16/20 - 0% cement replacement Baseline: 0.113 kg CO₂e/kg Ref: ICE V3 - GEN 3 (16/20 MPa) with CEM
2	Steel	Reinforcement bars	97% Recycled content Baseline: 1.00 kg CO₂e/kg Ref: ICE V3 - Steel rebar 97% Recycled content
		Structural steel sections	20% Recycled content Baseline: 2.29 kg CO₂e/kg Ref: ICE V3 - Steel section 20% Recycled content
		Studwork/Support frame	Galvanised Steel - 15% Recycled content Baseline: 2.79 kg CO₂e/kg Ref: ICE V3 - Steel, electro-galvanised steel 15% Recycled content
3	Blockwork	Precast concrete blocks	Lightweight blocks for building envelope Baseline: 0.280 kg CO₂e/kg Ref: ICE V3 - Autoclaved aerated concrete (AAC) Concrete block
			Dense blocks for other uses Baseline: 0.093 kg CO₂e/kg Ref: ICE V3 - Concrete block, high density solid, average strength

Figure A.12.1- Baseline Specifications (extract from RiCS professional statement 'Whole life carbon assessment for the built environment')

	Material	Details	Specifications
4	Timber	Manufactured structural timber CLT, glulam, etc.	100% FSC/PEFC Baseline: 0.437 kg CO2e/kg Ref: ICE V3 - Timber CLT, No Carbon Storage Baseline: 0.512 kg CO2e/kg Ref: ICE V3 - Timber Glulam, No Carbon Storage
		Formwork	Plywood Baseline: 0.681 kg CO2e/kg Ref: ICE V3 - Timber Plywood, No Carbon Storage
		Studwork/ framing/ flooring	Softwood Baseline: 0.263 kg CO2e/kg Ref: ICE V3 - Timber Softwood, No Carbon Storage
5	Aluminium	Cladding panels	Aluminium sheet - 35% Recycled content Baseline: 13.00 kg CO2e/kg Ref: ICE V3 - Aluminium Sheet, Worldwide
		Glazing frames	Aluminium extrusions - 35% Recycled content Baseline: 13.20 kg CO2e/kg Ref: ICE V3 - Aluminium extruded profile, Worldwide
6	Plasterboard	Partitioning/ceiling	Min. 60% recycled content Baseline: 0.390 kg CO2e/kg Ref: ICE V3 - Plasterboard
7	Insulation	To floor, roof & external walls	PIR Baseline: 5.293 kg CO2e/kg Ref: BREG EN EPD 000226 Issue 01

cont: **Figure A.12.1-** Baseline Specifications (extract from RiCS professional statement 'Whole life carbon assessment for the built environment')



Appendix 13 Survey and workshop results

13.1 Online Survey

Methodology

The survey was developed by a LETI working group in July 2019 and distributed online via member networks and specialist groups e.g. University of Cambridge BaseCamp MEICON or LinkedIn groups e.g. World Green Building Council. The survey deadline for completion was extended from the 16th July until the middle of August. Many responses were quantitative and the data has been presented unamended. Qualitative responses to questions on building elements and RIBA stages were classified into broadgroups by the researcher to provide greater clarity on key actions. Level of expertise was also highlighted in many of the responses provided to the working group.

The initial survey questions, providing personal details, level of expertise and experience, were completed by 119 people. Over 76% of the respondents were from the UK, 17% from the USA/Canada and the remainder from Spain, Denmark, Egypt and Australia. However, only 63 of these respondents provided answers to the main survey questions. Of these 26 classified themselves as experts, 24 with Intermediate knowledge and 13 as beginners. Numbers responding to questions within Part 1 varied, with those on building stages answered by 38-47 people; the questions on RIBA stages had between 36-45 respondents. For some categories this has resulted in only very minimal number of comments for some stage categories i.e. envelope and internal walls. Part 2 questions were addressed by 37-48 participants.

13.2 Part 1 - Guidance on reducing embodied carbon

Building Element and RIBA Stages

The respondents agreed that structuring the guidance by building element and RIBA stage would be a useful way of approaching embodied carbon (85.7%). Survey participants provided ideas and thoughts about how to reduce embodied carbon at each building element and RIBA stage. Responses were clustered and analysed by level of expertise. The findings are incorporated into the 'rule of thumb' guidance. The two tables below (table 1 and table 2) highlight the top three rules identified by respondents for each building element and RIBA stage.

This information formed the basis of further evaluation and validation at LETI workshop of LCA experts in London on the 10th October 2019. Respondents were also asked if they could suggest viable alternatives to concrete foundations in medium and large sized buildings, suggested treated wood, threaded screw foundations, masonry and geopiles. However, many did not feel there were viable alternatives and that cement replacement and lighter structures were equally important.

Benchmarks

Participants answering the survey, provided information on several benchmark datasets and datasets available to support the development of LCA based benchmarks. Experts and intermediate respondents identified issues which were around the quality of data, standardisation of methodology, database availability (especially if paid for), limited amounts of data available and opposition from material manufacturers. Several commented that it is 'better than nothing' and 'you have to start somewhere'.

The respondents were asked to identify, in their opinion what should be included in an embodied carbon benchmark. As highlighted in Figure A.13.3 the overall response would suggest all elements should be included. However, the experts appear to be more pragmatic at this stage, primarily suggesting the substructure, superstructure and envelope.

The participants were then asked to consider benchmarks in conjunction with RIBA stages: there is strong consensus between expert and intermediate respondents. RIBA stage 6 is identified as most important for benchmarking. However, the comments highlighted that it would be ideal to have benchmarks at all stages, or if not, then at Stages 2, 4, and 6. One of the respondents asked for benchmarks to be set at Stage 6 but to be in a form that can influence Stage 2.

It should be noted that several respondents identified early in the design stage as important in setting embodied carbon. They appear to have approached the question, not on the basis of where 'should the data come' from, but at which stage would the benchmark have the greatest impact.

Carbon offset strategies for whole life net zero carbon buildings

Whilst it was clear from the responses that offsetting was not a first option, and indeed 7 of the respondents opposed the idea, with several mentioning hierarchies to support reduction, there were several interesting suggestions for carbon offsetting. The most suggested offsets were the planting of trees (11) or other plant-based solutions (3) and the development of renewable energy (7).

Carbon capture and sequestration were mentioned by several participants, as well as supporting improved 'green transport' infrastructure. Thought provoking ideas such as using offset funds to support the development of low carbon materials, including supporting SMEs to pay for EPDs or to pay for retrofit were also put forward. Respondents additionally recommended work by other bodies such as the UKGBC and the International Living Future Institute's Living Building Challenge offset requirements.



Building Element	Most Highly Rated	Second Most Highly Rated	Third Most Highly Rated		
Substructure	cement replacement	minimise volume of materials	use of other materials		
Superstructure - Frame	sustainable wood and mass timber (FSC)	design	best practise for each material - compare products inc. end of life		
Superstructure - Upper Floors	sustainable wood and mass timber (FSC)	cement replacement	design		
Envelope	natural cladding - inc recycled brick façade	use of timber - esp CLT	design life/ DfD		
Internal Walls	use natural materials - inc timber	use exposed structure	use less materials	recycled content materials	timber stud walls
Building Services	eliminate need for mechanical temp control/ vent etc - natural	refrigerants - low GWP refrigerants/ leak management/ knowledge of gasses	use passive house guidance/ strategies/ approach		

Figure A.13.1- Top three 'rules of thumb' by building element

RIBA Stage	Most Highly Rated			Second Most Highly Rated	Third Most Highly Rated	
RIBA 0-1	set project goals/ targets			challenge fundamentals, brief early	reuse of materials & structure	
RIBA 2-3	look at key elements - i.e. foundations, structure, facade			work with carbon data to support design/ baseline	test alt. materials, low carbon concrete	
RIBA 4	sustainable/ carbon specification guidance	update carbon budget, footprint and/ or LCA	design optimisation	inc. low carbon materials as part of tender docs	review service and MEP (inc ease of use)	local materials
RIBA 5	low to 0 waste strategies			transport to site	monitoring materials and carbon (benchmark)	
RIBA 6-7	commissioning and education of users			O&M to include maintenance info	manual for refurb and end of life	

Figure A.13.2 - Top three 'rules of thumb' by RIBA stage

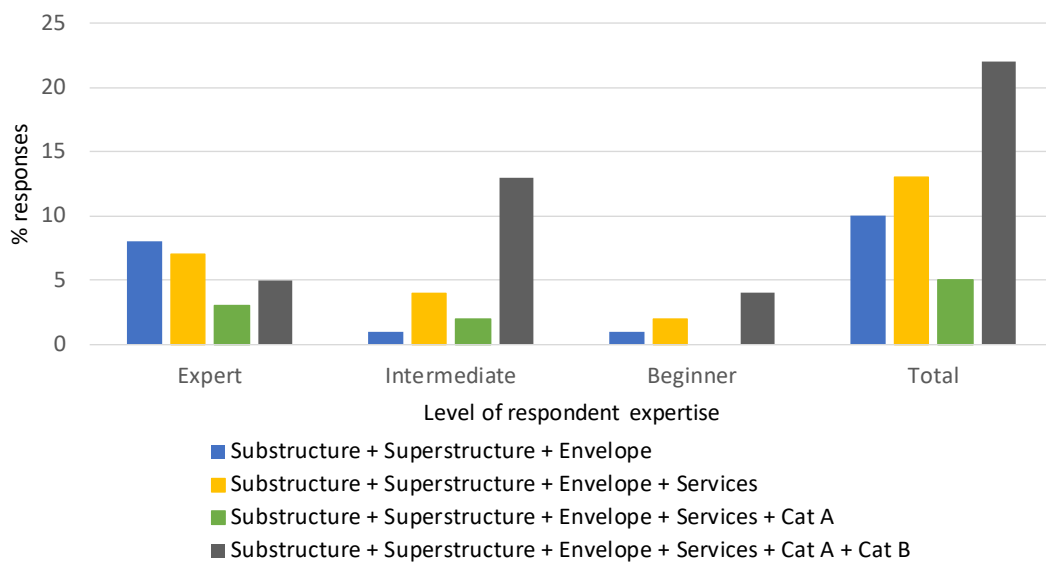


Figure A.13.3 -What should be included in embodied carbon assessment/benchmark?

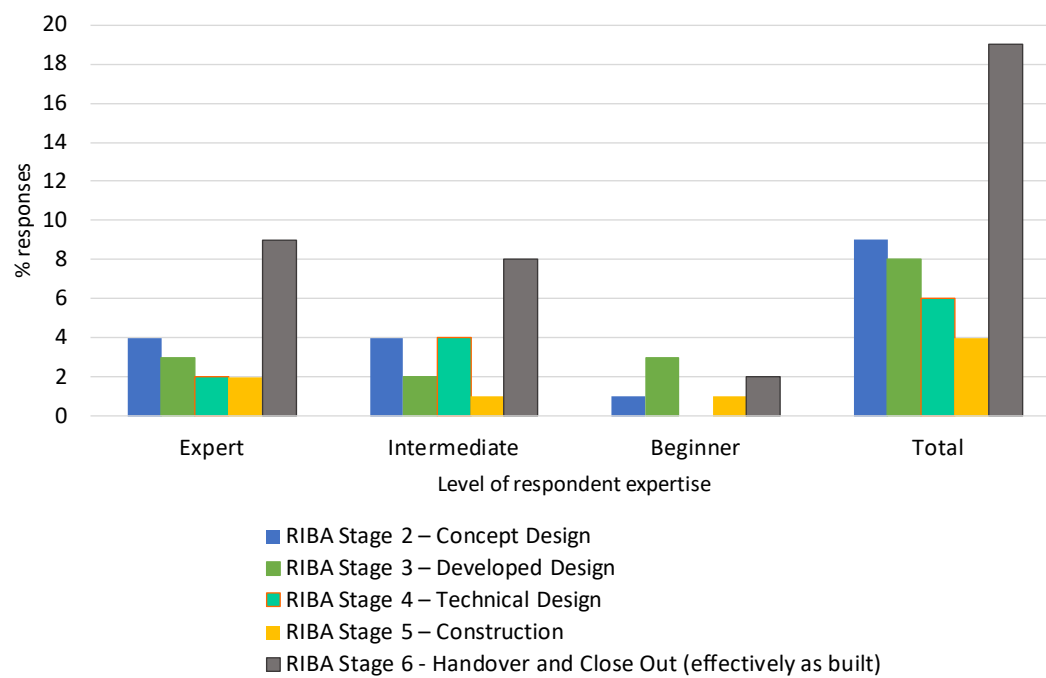


Figure A.13.4 -When creating benchmarks, which RIBA stage should the benchmarks be based on?

13.2 Part 2 - Guidance for the London Plan

System Boundary Setting

A cradle to grave approach i.e. Stage A + B + C + D, with D to be reported separately, is the most preferred option for system boundaries. However, it should be noted that there is not a clear consensus amongst those identifying as experts with this position. Experts select a range of stages, with some noting current data limitations. Several suggest an A1-A3 position, with A4-A5 initially on a voluntary basis, then becoming mandatory over time. Nearly 90% of the respondents (34) believed that the EN 15978:2011 Module B6 Operational Energy should be considered for reporting whole life carbon in the London Plan. Respondents were less adamant on including EN 15978:2011 Module B7 Operational Water as part of Embodied Carbon calculations, with only 54% agreeing; 46% of experts.

Data

60% of respondents when asked about a UK National database (28) agreed that one is required for carrying out whole life-cycle carbon studies for the London Plan. They agreed that this would ensure results would be consistent for comparison.

Methodology

84.2% of respondents (32) agreed that they identified whole life carbon assessments with the creation of a project baseline following EN15978 from which carbon emission reductions are shown. Over 65% of experts agreed with this statement (17) with 19% disagreeing. Those who disagreed felt that targets would be more effective, or they felt that EN15978 was too vague and RICS WLC assessment offered more consistency. One expert suggested that USGBC LCA could be another

approach. There was strong consensus that to support embodied carbon calculations it would be beneficial to have a common UK methodology on the end of life (EOL) of construction materials. This was agreed by 69% of the respondents (29), with 23% feeling it would be useful but not essential. Three experts disagreed, two feeling that EOL is already represented in Stage D, and that the UK may not be necessary. One expert felt the focus should be on inputted material carbon. When the respondents were asked whether carbon emission reduction through circular economy principles in Module C (As per EN 15978:2011) should be included in the assessment 50% agreed, whilst the remaining respondents either were unsure or disagreed. There appear to be concerns about allocating future 'deconstruction' when it is impossible to foresee future technology advances or to ensure commitments at build are undertaken at end of life. The responses suggest that some considerable work is still needed in this area. It was noted that ISO TC 323 is also working on this issue. Respondents felt that Biogenic Carbon should be reported separately (60%) with 32% believing it should be subtracted from the carbon budget. 70% (31) of respondents agreed that Grid Decarbonisation should be taken into consideration for manufacturing of materials and/or building products. Those who disagreed were concerned about the complexity that this would generate, a potential requirement for grid data to be based on local databases and others commented that this information should already be included in EPD data.

Environmental Product Declarations (EPD)

Whilst 26% of respondents felt that EPD's must be required for all building parts forming Substructure, Frame and Upper Floors, 42.8% only stated that it would be ideal to have them. 31% did not agree stating it was best to use generic data at planning a



were some concerns about the accuracy of EPDs, there was a strong feeling that at the planning and early stages of design generic carbon factors could be used (although there is also concern about the age/viability of some of this data too). It is noted by one respondent that EPDs would not be possible at Planning stage but RICS methodology supports initially generic and then EPD substitution as the design evolves. Several believe that, unless a specialist product is specified, EPDs could be used by tender stage, when the supply chain is identified. This is also the point when it is envisaged that the client and legal contracting constraints will be defined/overcome.

Targets

78.3% of respondents (36) agreed that embodied carbon reduction targets (i.e. a % reduction over the baseline) should be part of the requirements to be submitted for planning under the London Plan.

Concerns arose over the current ability to set targets based on realistic baselines, the ability to 'game' targets if set by designers, a lack of knowledge in the sector about embodied carbon and one respondent made it clear that targets should be set for whole life carbon, not embodied carbon.

Verification

Nearly 70% of respondents felt that there should be a third-party verification process before submitting design results for planning under the London Plan. Issues that were raised by respondents to negate this position were issues of delay and cost. It was also suggested that this should be done by the design team. When asked if RIBA Stage 5 construction monitoring activities should be carried out in order to verify design requirements and targets to match as built status 88.4% agreed.

13.3 Expert workshop

To review, validate and expand the findings of the online survey, a workshop of LCA, embodied carbon and construction carbon experts was held in London on the 10th October 2019, 15.00 -18.00. All participants were sent draft copies of the LETI guidance and any information provided by each breakout session lead. Selection of participants was based on LETI member knowledge of experts in this field and included individuals from academia, commercial organisations and public sector bodies. Around 80 people were contacted by personal email and of those that confirmed attendance, 36 were present on the day.

All participants were provided with an overview of the project and the aims of the workshop sessions and then through self selection attended 3 group workshops working in parallel (3 x 45 minute sessions per workshop).

Each session was supported by a note taker and participants were additionally encouraged to comment using post-it notes. All sessions were managed by a LETI work group facilitator. All notes and post-its were written up and added to a standard response template that had been developed by one of the work group members. These comments and observations were then incorporated into the LETI guidance by work group section leads.

13.3.1 Session on 'What does good look like'

These ideas are the product of a workshop held with industry experts in October 2019 allowing this guidance document to also act as a platform for some broader thinking;

The Design Process

Although this guidance is focussed on embodied carbon it is important to understand the consequences of decisions made on material and assembly choices in terms of the WLC impacts of a project. Remember the iterative nature of the design process and that each iteration should be tested for its impact over 60 years and include all modules determined by the system boundary as stipulated in the brief, in order to give the full WLC picture. More detailed information on this can be found in Appendices 2 and 3.

Challenges of the Methodology

▷ **SIGNPOST** *Appendix 2 – Scope of work for LCA*

▷ **SIGNPOST** *Appendix 3 – How to measure embodied carbon*

Although there is a consistent methodology (BS EN 15978) for defining what can be included when accounting for carbon in a project the boundary conditions are not clearly set. The RICS professional Statement 'whole life carbon assessment for the built environment' aims to provide guidance on the interpretation and practical implementation of the EN 15978 methodology, which all RICS members are required to apply when undertaking WLC assessments. The RIBA Climate Challenge proposes a current benchmark with further, more challenging targets for 2020, 2025 and 2030, using the RICS whole

life Carbon23 assessment for the built environment guidance (A - C). The UKGBC Net Zero Carbon Buildings framework definition only requires stage A and module B6 to be considered but are planning to increase the scope over time. The industry needs to be fully aligned on matters such as this. There are a number of databases that hold carbon factors for various materials and construction processes. Ideally there needs to be a single comprehensive database to achieve a reasonable degree of accuracy and comparability. This builds on the need for an overarching body to represent and support LCA practitioners, so that appropriately qualified professionals can be represented and promoted in this emerging field. Tools and databases are only effective if the end-user has a knowledge of how to use them.

Building Efficiently

One futuristic idea that was presented was taking DfMA to the next level. Automating building sites using robots instead of construction workers on site. This idea may be far fetched but it could be something we see in the future, offering opportunities to save time, reduce errors and subsequently create cost and carbon savings.

Building and Materials Longevity

Should buildings be demolished leading up to 2030 and beyond? There are clear arguments that favour retrofitting over demolition so it makes sense that a building owner should provide evidence (from an embodied carbon perspective) to support the demolition of a building. Any building demolished after 2030 should be completely dismantled and all materials reused. A license for demolition (meaning dismantlement) should be needed and evidence on where/ what the materials would be reused for should be provided.



13.3.2 Benchmarks

The RIBA Climate Challenge sets embodied carbon benchmarks for domestic and non-domestic (office and school) buildings types. At the workshop, experts were asked to put a sticker where they thought the benchmark should be, in comparison to the RIBA Climate Challenge benchmarks. The data collected at the workshop is shown in the Figure aside.



Figure A.13.5 -RIBA 2030 Climate Challenge Target Benchmarks Review

This data is taken from the results of the LETI embodied carbon Expert workshop held on 10th October 2019. This data is an estimation of WLC stages A-C.



Appendix 14 Further reading

Signposting to useful resources, assessment methods, guidance.

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Appendix 15 Definitions

Biogenic carbon: Carbon derived from/contained in biomass. ¹

Biomass: Material of biological origin excluding material embedded in geological formations and material transformed to fossilised material. ¹

Biogenic carbon neutrality: Balance of biogenic carbon uptake during growth of biomass and release during natural decay or incineration. ¹

Carbon storage: Biogenic carbon stored over a specific period of time. ¹

Carbon emissions/CO₂e emissions/CO₂ equivalent/Greenhouse gas emissions: shorthand for emissions of any of the basket of greenhouse gases (GHG) that affect climate change. Carbon emissions are usually expressed as CO₂e (i.e. CO₂ equivalent), which is a unit of measurement based on the relative impact of a given gas on global warming (the so called global warming potential). For example, if methane has a global warming potential of 25, it means that 1 kg of methane has the same impact on climate change as 25 kg of carbon dioxide. Thus, 1 kg of methane would count as 25 kg of CO₂e. ²

Circular Economy: An economic model in which resources are kept in use at the highest level possible for as long as possible in order to maximise value and reduce waste, moving away from the traditional linear economic model of 'make, use, dispose'. ³

Cradle-to-cradle: 'the process of making a component or product and then, at the end of its life, converting it into a new component of either the same quality (e.g. recycling of aluminium cans) or

an inferior quality (e.g. downcycling of a computer plastic case into a plastic container, which is then turned into a building insulation board, eventually becoming waste).' ²

Cradle to grave: 'carbon emissions associated with all building life cycle stages: product, construction, use, end of life.' ²

Embodied carbon: 'carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products. Embodied carbon can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO₂e per kilogram of product or material.' ⁴

Engineered timber: a range of highly manufactured timber products, which generally see the binding/lamination of wood elements. Come in standard product sizes, or can be bespoke, and curving is possible.

Life cycle assessment: methodology used to measure the environmental impact of a product (or a system) over a life cycle. It measures the environmental impacts from extraction of raw materials, through processing, manufacture, refurbishment to eventual end of life and disposal. Typically, this includes five basic phases as follows.

→ Extraction phase (known as the cradle): The raw material(s) of the product are identified along

with the means of extracting and transporting that material to a manufacturing site.

- Material formation and manufacturing phase: The processes to turn ore into raw materials, such as steel correspond to cradle to gate data. However, in addition, there are usually a number of manufacturing phases, such as forming, anodizing or galvanizing, fabrication, etc. Some phases are concurrent, while others are consecutive.
- Construction phase: The products are transported from a factory to the site and installed as part of the normal construction process.
- Use phase: The product begins its useful service life as part of the building to the benefit of the building owner and users.
- End of life phase (known as the grave): At the end of the useful life in the building, the product needs to be removed and either reclaimed, repurposed, recycled, reused, or disposed. ⁵

Operational energy use: EN 15978 Module B6 - The energy performance of a building is determined on the basis of the calculated or the actual annual energy required for heating, domestic hot water supply, air conditioning (cooling and humidification/de-humidification), ventilation, lighting, auxiliary energy used for pumps, control and automation. ⁶ The energy use of other building-integrated technical systems (e.g. lifts, escalators, safety and security installation and communication systems) necessary for the technical and functional performance of the building shall be included in B6 and reported and communicated separately.

Timber: wood that has been felled, dried and treated, ready for use.

Whole life carbon is 'both the embodied carbon and the carbon associated with operation (heating, cooling, powering, providing water etc). Understanding the relationships between 'embodied' carbon and 'operational' carbon can assist in determining the overall optimum carbon reductions' ⁷.

15.1 References

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Appendix 16 Abbreviations

BIM – Building Information Modelling

BREEAM – Building Research Establishment Environmental Assessment

CIBSE - Chartered Institution of Building Services Engineers

CO₂ - Carbon Dioxide

CLT – Cross Laminated Timber

DFMA - Design for Manufacture and Assembly

DSM - Dynamic Simulation Modelling

End of Life

EUI - Energy Use Intensity

FSC - Forest Stewardship Council

GGBS - Ground Granulated Blast-furnace Slag

GHG - Greenhouse Gases

GIA – Gross Internal Area

GLA – Greater London Authority

GRC - Glass Reinforced Concrete

GWP - Global Warming Potential

IEA - International Energy Agency

LCA – Life Cycle Assessment

LETI – London Energy Transformation Initiative

NBS - National Building Specification

NRM - New Rules of Measurements

PFA - Pulverised Fuel Ash

RIBA – Royal Institute of British Architects

RICS – Royal Institute of Chartered Surveyors

UKGBC - United Kingdom Green Building Council

WGBC - World Green Building Council

WLC – Whole life carbon

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Embodied Carbon Primer

This Embodied Carbon Primer offers supplementary guidance to those interested in exploring embodied carbon in more detail. There is lack of knowledge in the built environment industry surrounding embodied carbon reduction strategies and calculations. Therefore the London Energy Transformation Initiative has produced this document to support project teams to design buildings that deliver ambitious embodied carbon reductions.

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