WEST OF ENGLAND
Combined Authority

Evidence Base for West of England Net Zero Building Policy: Embodied Carbon

West of England
Spatial Development Strategy
December 2021

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Spatial Development Strategy Evidence summary sheet

Why is this document required?

National planning legislation requires Local Plans to contribute to climate change mitigation and adaptation. This evidence will be used to inform policy in the Spatial Development Strategy and local authorities' Local Plans regarding climate change mitigation.

What is the purpose of the document?

This report provides evidence and guidance to support the Spatial Development Strategy and Local Plans to deliver a net zero target for new buildings. This supports the authorities to show they are meeting the requirements of climate change legislation. This document reviews a series of energy and carbon targets across different building types and considers the cost uplift of different scenarios. This supports policy makers to explore options for setting embodied carbon targets.

Embodied Carbon is the term used to describe the carbon emissions used in the development of a building and the manufacturing of its materials and fabric. The assessment looks at the lifecycle of a building, from obtaining raw building materials, all the way to disposal of the building at the end of its life (defined as 'Whole Life Carbon'). The assessment then moves on to look at costs involved relating to the building's fabric (embodied carbon). It does not consider costs of direct heating, cooling and electrical services (operational energy) which is covered in an accompanying report.

How will it be used?

This evidence demonstrates that achieving net zero embodied carbon across building typologies is achievable in practice, however its viability ranges across building typologies and the approaches to fully demonstrate whole life carbon are still under development nationally. The report includes tools and recommendations for policy to measure and assess embodied carbon and reduce emissions. This evidence will be used to inform policy in the Spatial Development Strategy and subsequent Local Plans.

Who was this document produced by?

This document was commissioned by the four local authorities (Bath and North East Somerset Council, Bristol City Council, North Somerset Council and South Gloucestershire Council) in the West of England, and the Combined Authority. It was produced by WSP and Gardiner & Theobald LLP.

Engagement and consultation

Active and ongoing engagement and consultation with planning and sustainability teams within the Combined Authority and local authorities.

West of England

EVIDENCE BASE FOR WEST OF ENGLAND NET ZERO BUILDING POLICY

Embodied Carbon

DECEMBER 2021

West of England

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PROJECT NO. 70077079

DATE: DECEMBER 2021

West of England

EVIDENCE BASE FOR WEST OF ENGLAND NET ZERO BUILDING POLICY

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QUALITY CONTROL

Issue/revision	First issue	Revision 1
Remarks	Draft	Final
Date	25/06/2021	05/082021
Prepared by	Danae Petrou	Danae Petrou
Checked by	Snigdha Jain	Snigdha Jain
Authorised by	Snigdha Jain	Snigdha Jain
Project number	70077079	70077079
Report number	00	01
File reference		

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APPENDICES

1 INTRODUCTION

We have been jointly commissioned by the four local authorities (LAs) in the West of England (WoE): Bath and North East Somerset Council (B&NES); Bristol City Council (BCC); North Somerset Council (NSC) and South Gloucestershire Council (SGC), and in collaboration with the West of England Combined Authority (WECA), to provide part of the evidence base for revised Local Plan climate policies for the West of England Authorities and potentially the WoE Spatial Development Strategy (SDS). The findings in this report are however not geographically specific, with the intention that the results can inform policy elsewhere in the UK.

This study will specifically focus on the embodied carbon of domestic and non-domestic buildings (Section B of the brief) and the cost uplifts anticipated.

2 METHODOLOGY

This section will describe the methodology followed for the deliverability analysis in terms of carbon and cost calculations. The reasoning behind this scope is to produce results as reliable as possible, through assessing lifecycle stages and building elements for which good sources of data exist. This way the correlation between the carbon and cost uplift can be accurate.

However, the scope of the current study serves a different purpose from the scope for the embodied carbon assessment that will be instructed by the NZB policy for new developments. Therefore, it is likely that the methodology instructed by the NZB policy will not follow the current study but instead will align with guidance such as RICS or the latest ‘Embodied Carbon Target Alignment’ work by LETI, RIBA etc.

2.1 CARBON ASSESSMENT METHODOLOGY

Building Typologies

Four building typologies were explored for this exercise, two for non-domestic developments and two for domestic, which were selected as four very common building typologies for the region:

Non-Domestic:

- Office: 4 storeys, Gross Internal Floor Area (GIFA) of 1,600 m^2
- School: 3 storeys, Gross Internal Floor Area (GIFA) of 2,355 m^2

Domestic:

- Apartment block: 5 storeys, Gross Internal Floor Area (GIFA) of 3,360 m^2
- Semi-detached house: 2 storeys, Gross Internal Floor Area (GIFA) of 92 m^2

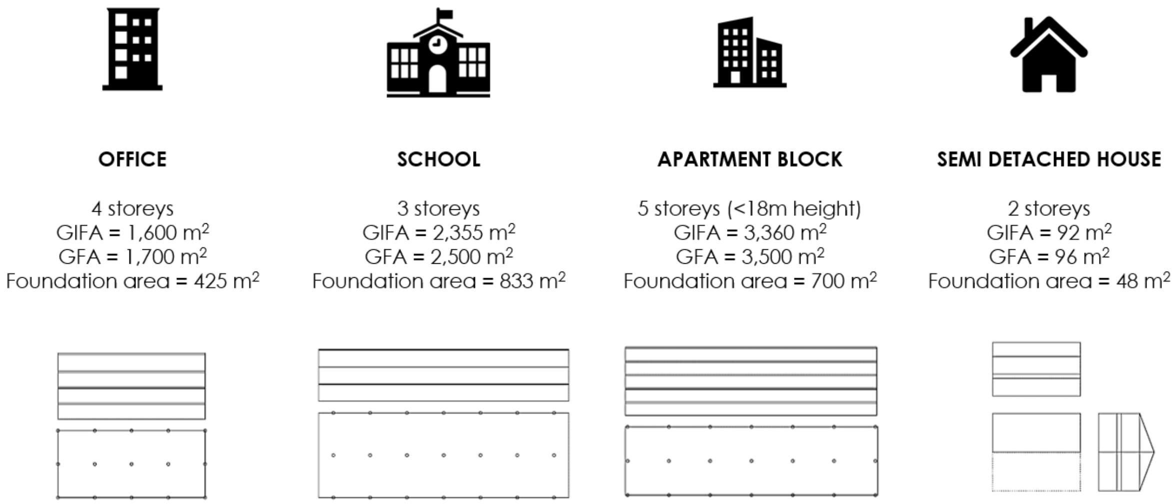


***Figure 2-1** - Building Typologies*

All the building typologies have a height of less than 18 meters, to ensure compliance with fire regulations in terms of material combustibility. The Table 3-1 below summarises some key dimensions and areas for each typology.

Table 2-1 – Key dimensions and areas for the four building typologies

	Office	Primary School	Semi - detached house	Low Rise Apartment Block
Number of storeys	4	3	2	5
Foundation area (m^2)	425	833	48	700
GIFA (m^2)	1,600	2,355	92	3,360
GFA (m^2)	1,700	2,500	96	3,500
Height (m)	14.4	11.0	5.6	15.0
Width (m)	32.1	51.0	12.0	55.0
Depth (m)	14.6	18.0	5.5	14.0
Int. Floor height (m)	3.3	3.5	2.5	2.7
Max Column spacing distance (m)	9	9	9	9

Building Elements

To assess which building elements should be in-scope or out-of-scope, the guidelines from the Whole life carbon assessment for the built environment (2017) by RICS[1] have been reviewed and followed. According to these guidelines, the minimum requirements for a whole life carbon assessment in terms of building elements are the Substructure (RICS 1) and Superstructure (RICS 2) elements.

For the purpose of this study, the scope for the detailed analysis includes the Substructure (RICS 1), Superstructure (RICS 2) and Finishes (RICS 3) elements, because:

- They are expected to have a high share of embodied carbon emissions
- They are commonly considered during early design stages
- There are satisfactory databases available today for their accurate assessment

However, in order to safely compare the results against the selected embodied carbon targets (such as RIBA) more elements should be accounted for, so that the scopes are aligned. For this reason, after the modelling the substructure, superstructure and finish elements (as per detailed analysis scope) for the baseline, a percentage increase was added on the results to account for the building services (RICS 5) and the external works (RICS 8). The factors used for this percentage increase are based on LETI's work 'Climate Emergency Design Guide' and 'Embodied Carbon Primer' and

[1] RICS, 2017. Whole life carbon assessment for the build environment. Online Available at: https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf

are summarised in the table below. These figures refer to the initial installation of MEP and External works and they don't account for later replacements. This is a limitation of the current study to be highlighted.

Table 2-2 – Percentage increase per building typology for the Building Services/MEP and the External works (extended scope)

	Building services/MEP Share (%)	External Works Share (%)
Office	15%	3%
School	12%	3%
Apartment Block	4%	3%
Semi Detached House	5%	3%

Finally, there are some categories of building elements which were left out of both scopes (detailed and extended) because to date there no databases which would allow these elements to be considered as part of Lifecycle Carbon Assessments. These categories include the Facilitating works (RICS 0), the Fittings, Furnishings and Equipment (RICS 4), the Prefabricated buildings and building units (RICS 6) and the Works to existing building (RICS 7).

The *Figure 2-2* below summarises the in-scope and out-of-scope elements for this study.

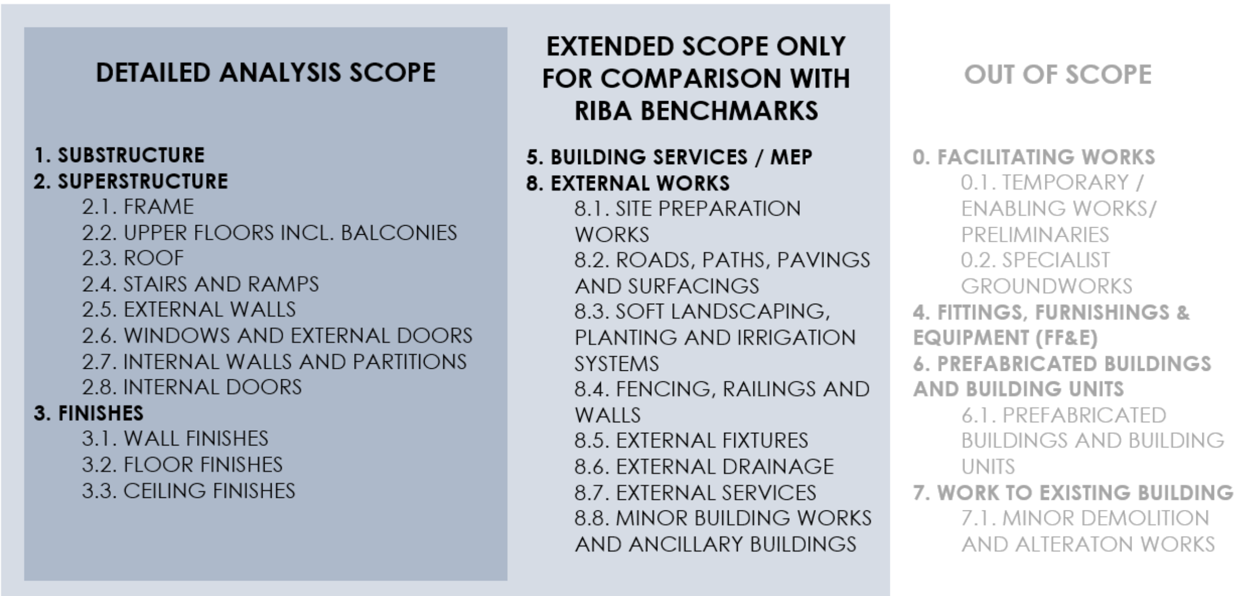
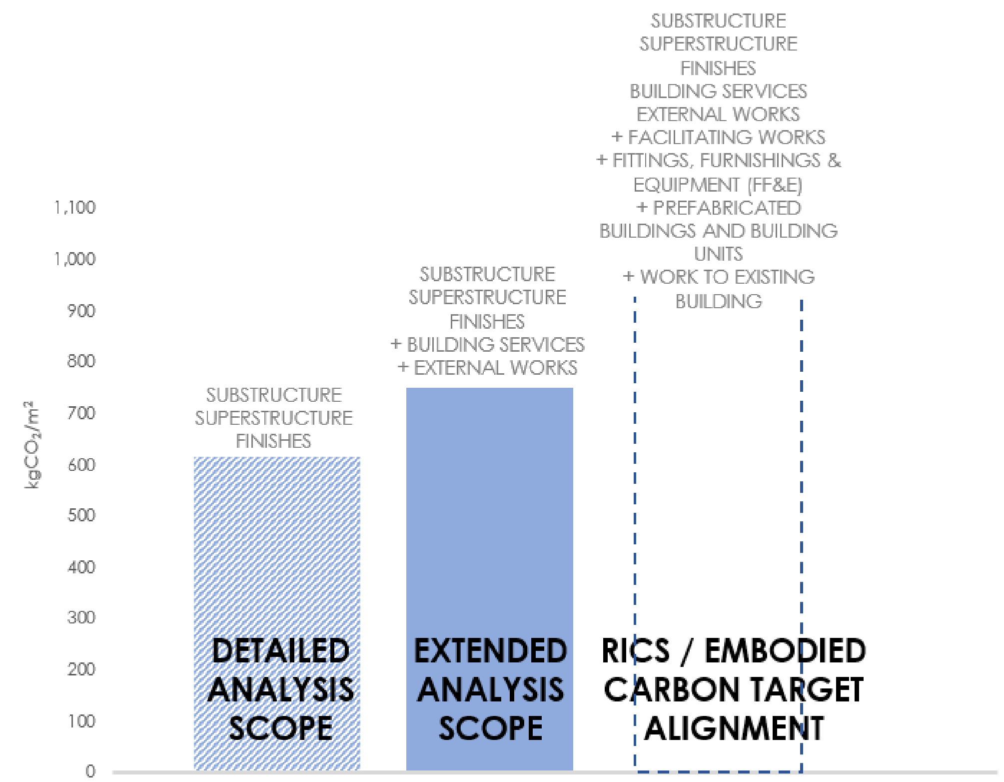


***Figure 2-2 –** In scope and Out-of-Scope Building Elements*

Both these building element scopes are more limited than the RICS scope for building elements (*Figure 2-4*). Therefore, the findings of this assessment should be considered under this limitation.



Embodied Carbon per Module per Element ($kgCO_2e/m^2$, GIA)

		A1-3	A1-3 (Sequestered)	A4	A5	B1-3	B4&5	C1-4	D
Demolition	Toxic Material Treatment								
	Major Demolition Works								
Facilitating Works	Temporary/ Enabling Works								
	Specialist Ground works								
Substructure	Substructure	X		X	X		X	X	
Superstructure	Frame	X		X	X		X	X	
	Upper Floors	X		X	X		X	X	
	Roof	X		X	X		X	X	
	Stairs and Ramp	X		X	X		X	X	
	External Walls	X		X	X		X	X	
	Windows and External Doors	X		X	X		X	X	
	Internal Walls and Partitions	X		X	X		X	X	
	Internal Doors	X		X	X		X	X	
Finishes	Wall Finishes	X		X	X		X	X	
	Floor Finishes	X		X	X		X	X	
	Ceiling Finishes	X		X	X		X	X	
FF&E	FF&E (Fixed)								
	FF&E (non-fixed)								
Building Services	Building Services	X		X	X		X	X	
	Refrigerant Leakage								
	Renewable Electricity Generation								
Prefabricated Buildings	Pre-fab Building Units								
Work to Existing Building	Minor Demolition and Alterations								
External Works	External Works	X		X	X		X	X	

Whole table = RICS scope

X Detailed scope

X Extended scope (added as %)

Figure 2-3 – *Comparisons of detailed and extended scope of building elements with RICS scope*

Lifecycle stages

To determine the lifecycle stages to be included in the scope of this study, new LETI guidance ‘Embodied Carbon Target Alignment’ (2021) and the guidelines from the “Whole life carbon assessment for the built environment" (2017) by RICS[2] have been reviewed. As a result, two lifecycle stages scopes were followed.

The guidance from RICS, focuses on the whole life carbon scope, and specifies as a minimum requirements for this to include the Product Stages (A1-A3), the Construction Process Stages (A4-A5), the Replacement Stage (B4) and the Operational Energy (B6)[3].

According to the 'Embodied Carbon Target Alignment' publication by LETI, there suggest two available scopes of lifecycle stages (see *Figure 2-4*).

- "Upfront Carbon" scope includes stages A1-A5. When following this scope, carbon sequestration is reported separately
- "Embodied carbon" scope includes stages A1-A5, B1-B5 and C1-C4. When following this scope, carbon sequestration shall be included since the end-of-life emissions (C1-C4) when carbon may be emitted back to the atmosphere (i.e. if timber is burned) are also part of the assessment

Module D should only be reported separately for both scopes.

[2] RICS, 2017. Whole life carbon assessment for the build environment. Online Available at: https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf
[3] RICS doesn't include in its minimum requirements the stages B1-Use, B2-Maintenance, B3- Repair or B5-Refurbishment. These stages are not likely to have a major impact when compared to stages A1-A5 and B4, and the databases for them are still very limited. Short explanations of stages B1, B2, B3 and B5 are following:

- B1-Use: It includes carbon emitted from building components (i.e. GHG emissions from HFC blown insulation, paints, refrigerants) + carbon absorbed (i.e. carbonation process from exposed concrete and lime, carbon sequestration by green roofs/facades)
- B2-Maintenance: Any cleaning/maintenance activities for the elements of roof, external walls, windows, external doors, finishes and MEP
- B3-Repair: Allowance for repairing any unpredictable damage over and above the maintenance schedule of B2 (for the same building elements as B2). If no data available, then B3=25% of B2.
- B5-Refurbishment: Similar to replacement (B4), but in this case one building material is replaced by a different one (change of aesthetics, function etc.). On the other hand, B4 assumed replacement with the same product.

It should be noted that the exclusion of stages B1, B2, B3, B5 is only for the purpose of this assessment, while the new NZB policy is advised to include them to stimulate relevant thinking and decision making

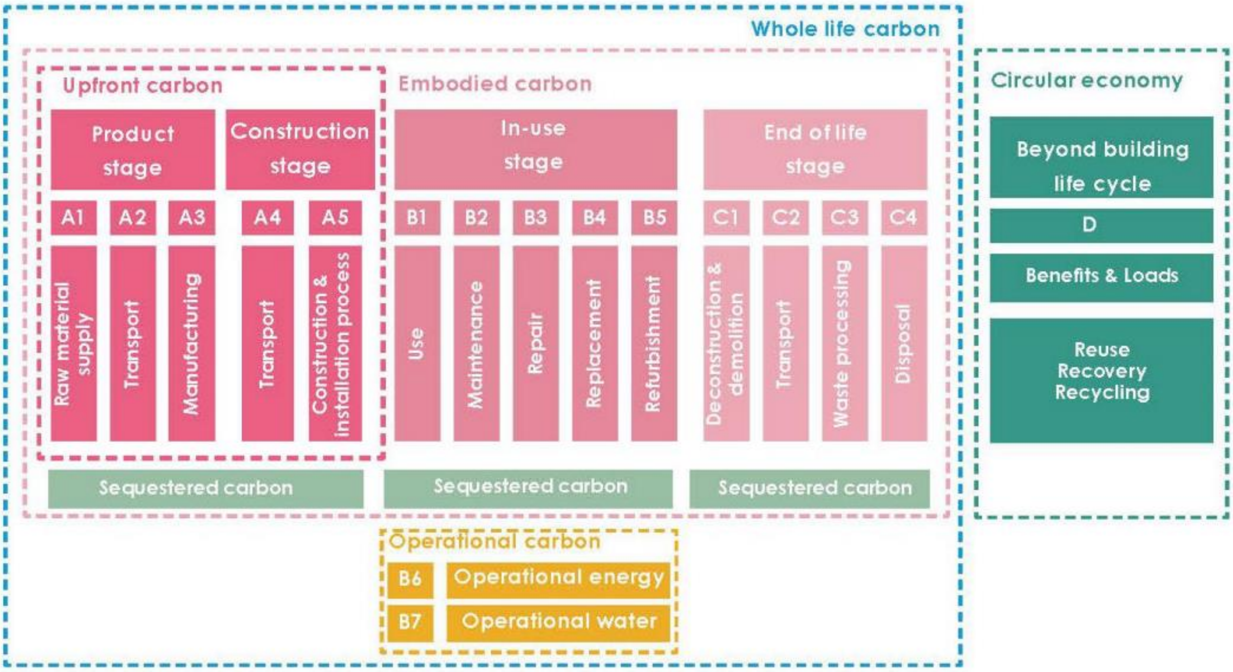


Figure 2-4 – *Life cycle stages as defined by BS EN 15978:2011, Diagram by LETI.*

For the purpose of this study, we have shaped two lifecycle stages scopes.

- **Scope A – Upfront Embodied Carbon**: This scope focuses only on the upfront carbon (A1-A5)
- **Scope B – Whole Life Embodied Carbon**: This scope focuses on the upfront carbon (A1-A5), the carbon from future replacements with the same material (B4) and the end-of-life carbon (C1-C4). It should be highlighted that the stages B1-Use, B2-Maintenance and B3- Repair have been excluded from the scope due to limited data and their relatively small impact in comparison with the rest of the lifecycle stages. Moreover, the stage B5-Refurbishment, which focuses on replacements with different materials, hasn't been considered as it depends on highly unpredictable parameters such as change of function, aesthetic preferences, technological outdate etc.

Module D and carbon sequestration have been excluded from both scopes for the purpose of this assessment, but it is recommended that these carbon 'benefits' are asked to be reported separately by the new policy.

The *Figure 2-5* below summarises the in-scope and out-of-scope lifecycle stages for this study.

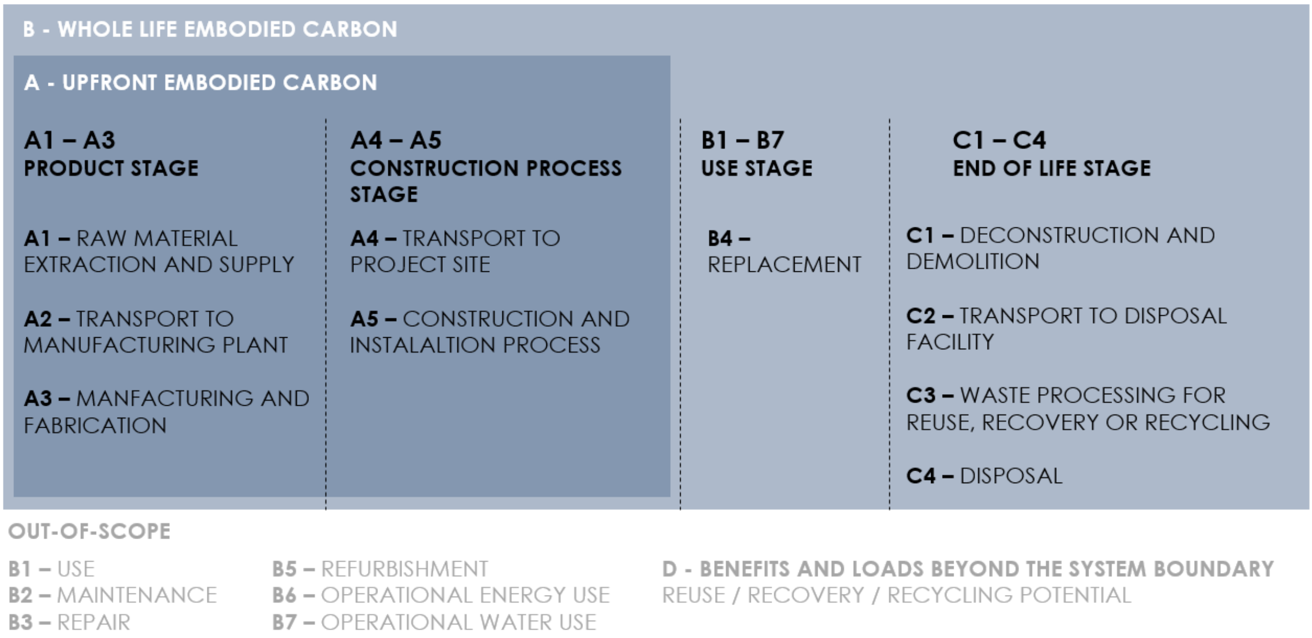


Figure 2-5 – *In scope and Out-of-Scope Lifecycle stages*

Replacement Rates

The expected service life of materials has been based on 'Whole Life Carbon for the Built Environment' (November 2017) by RICS professional standards and guidance (Table 9) for the office, school and apartment block typologies. Structural elements have been assumed to have a service life equal with the building's life.

Table 2-3 – Default expected lifespan for UK projects (RICS Whole Life Carbon for the built environment 2017)

Building Part	Building elements/components	Expected lifespan (years) – Office, School, Apartment Block
Roof	Roof coverings	30
Superstructure	Internal partitioning	30
Finishes	Wall finishes: render/paint	30/10
	Floor finishes: Raised Access Floor (RAF)/finish layers	30/10
	Ceiling finishes: Substrate/paint	20/10
Façade	Opaque modular cladding, e.g. rain screens, timber panels	30
	Glazed curtain walling	35
	Windows and doors	30

However, in reality some building typologies are associated with a higher replacement rate in their components than others. For example, a commercial space can go through refurbishment as often as every three years, while a house can be refurbished less frequently than 30 years. This is an important limitation for this study that should be considered when reviewing the results.

Furthermore it should be noted that these component lifespans have been used here for the purpose of this assessment, but it is recommended that the new policy should encourage the use of specific EPD data and the use of as long component lifespans as possible.

Baseline and Alternative Scenarios

Three different superstructure baselines were created. These are:

- Load-bearing masonry walls, sawn timber floors and sawn timber roof (semi-detached house)
- Concrete structural frame and hollowcore concrete slabs for floors and roof (apartment block)
- Steel structural frame and composite concrete-steel deck slabs for floors and roof (office and school)

Then, five alternative material scenarios were developed as summarised in the *Figure 2-6* below and further explained in Tables A.1 to A.3 of the Appendix.

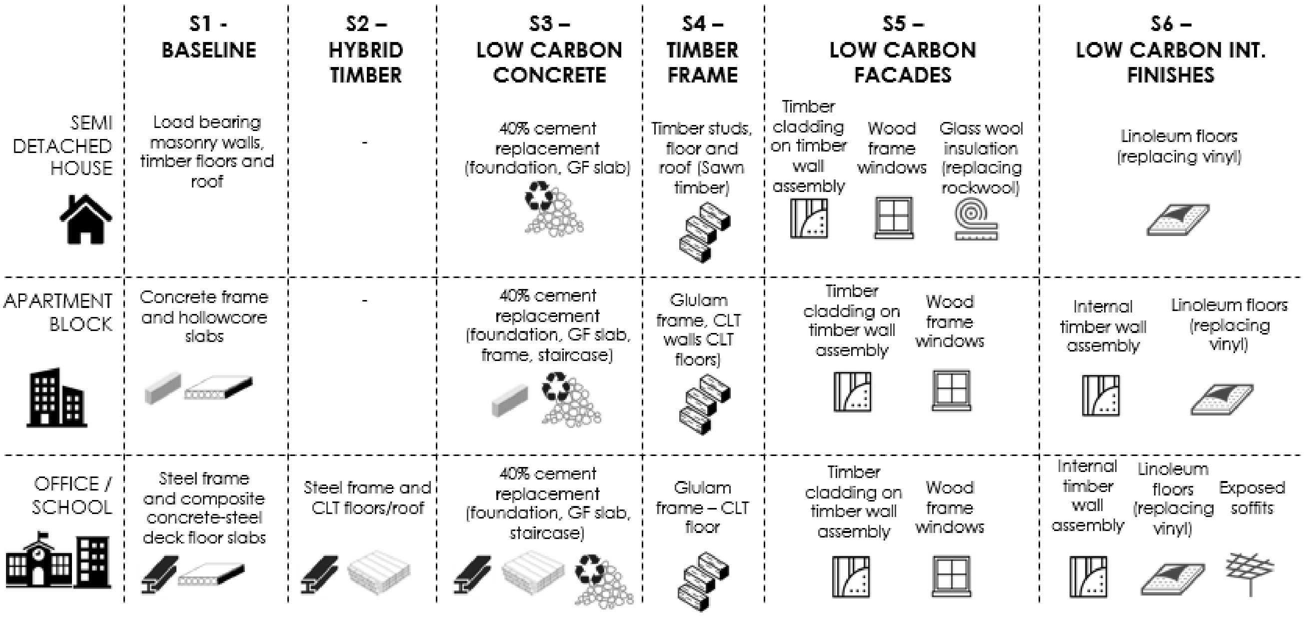


Figure 2-6 – *Baselines and alternative scenarios*

Firstly, the baseline scenarios were applied separately to allow the absolute and percentage carbon reductions attributable to each measure to be examined. Secondly, the scenarios described above were applied cumulatively to the baseline, in order, so that the combined impact could be examined. This assessment allowed to explore how low each typology can compare against the RIBA 2030 Climate Challenge targets when all measures are considered. This could help inform any embodied carbon targets set by the policy.

2.2 COST ASSESSMENT METHODOLOGY

Gardiner & Theobald LLP has undertaken an independent cost analysis of the scenarios presented within this report. The study analyses the capital cost for each building type and embodied carbon scenario and is intended to inform policy.

This cost study relates to the specified building fabric elements as outlined within the report and does not include any analysis or pricing of the building elements which are not specifically outlined within the alternative scenarios. The excluded elements are mechanical and electrical services, fit out and external works. To ensure a comprehensive cost picture can be presented we have developed a weighting system to ensure that the cost differences for reduction of embodied carbon in the elements studied are expressed as a proportion of the total expected project costs.

The analysis is split into the four building types and six embodied carbon scenarios outlined within this report, please refer to the Analysis section for detail.

The building elements and quantities for each scenario have been produced by WSP in consultation with their internal design team. G&T reviewed the material and quantity outputs and advised on their relevance in reference to current practice based on our construction experience. Examples include the adopted foundation solution for the semi-detached house and the integration of a concrete frame and CLT hybrid. However, these scenarios are indicative only, and they would benefit from a further design assurance, design validity or buildability assessment as part of the next steps.

Once the final schedule of quantities was agreed, G&T developed this into a cost plan format in order to accurately assess the cost of each scenario. The original set of quantities were broken down into individual materials, these items were grouped together in order to price composite rates with our assumptions being made and stated clearly within the comments section of the detailed pricing documents.

The building fabric elements were priced in detail based on benchmark rates and in consultation with the industry supply chain for key building elements such as structural steel, timber, reinforced concrete and masonry.

The cost analysis results are shown within the section 3.2.2 below as a percentage variance from the baseline for each alternative scenario, this is not cumulative and should be read with reference to the change from the baseline.

The building elements included within the cost exercise only make up a proportion of the overall construction costs, therefore a weighting system has been developed to show them as a portion of the total construction cost.

The studied building fabric elements make up approximately 50% of the Office, School and Apartment costs and 65% of the semi-detached house and the percentages below have been adjusted accordingly to show the change between each scenario for the total construction cost including the building fabric, M&E systems, fit out and external works.

3 RESULTS AND DISCUSSION

3.1 POLICY THRESHOLDS

LEGISLATORY FRAMEWORK

On the 20th of April 2021, UK government announced a new law-binding target to reduce emissions by 78% compared to the 1990 levels by 2035[4]. This target comes as an interim target to the target of reducing emissions by 68% by 2030 and the net zero carbon target by 2050.

STANDARDS AND GUIDANCE REVIEW

The standards and guidance for embodied carbon were reviewed in order to understand what embodied carbon targets are recommended for domestic and non-domestic developments on their pathway towards net zero carbon, along the lifecycle stage scopes of these targets. Such targets are set in the documents below:

- RIBA 2030 Climate Challenge: The scope of these targets covers the whole life of a building (A-B-C), as defined by RICS[5]. In reality, not enough data exists today to address all these stages in a reliable way.
- LETI (London Energy Transformation Initiative) Climate Emergency Design Guide (the LETI targets are also followed by the work of UKGBC in their 'Building the Case for Net Zero' report).

Table 3-1 below summarises the RIBA and LETI targets.

Table 3-1 – Embodied Carbon Targets according to the RIBA 2030 Climate Challenge and LETI (London Energy Transformation Initiative) Climate Emergency Design Guide

	RIBA 2030 Climate Challenge (A, B, C life stages)			
Embodied Carbon ($kgCO_2/m^2$)	**Current Benchmarks**	**2020 Target**	**2025 Target**	**2030 Target**
Domestic	<1000	<600	<450	<300
Non-Domestic	<1100	<800	<650	<500

	LETI Climate Emergency Design Guide / UKGBC ("A" life stage-upfront only)			
Embodied Carbon ($kgCO_2/m^2$)	**Current Benchmarks**	**2020 Best Practice**	**2025**	**2030 Best Practice**

[4] https://www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035
[5] A limitation on this comparison is that the current scope only doesn't include stages B1, B2, B3 and B5, while the RIBA 2030 Climate Challenge target includes them. This would be likely to have a very minor effect on the results.

Domestic	<800	<500	-	<300
Non-Domestic	<1000	<600	-	<350

At the end of May 2021, RIBA and LETI published their 'Embodied Carbon Target Alignment' work[6], which aims to produce a standardised performance and reporting scope for embodied carbon assessments. This document therefore provides an alignment of embodied carbon measurement and benchmarking among RIBA, GLA, Institution of Structural Engineers and UKGBC. This publication introduces a rating system which allowed quick comparison of ambition across various typologies and portfolios and brings together the previous RIBA and LETI targets (mentioned above). Some highlights on this work (see also Figure 3-1):

- Two scopes for the included lifecycle stage are provided as explained earlier (A-Upfront only, B-Whole life)
- The embodied carbon targets are shaped in letter bandings, rather than a single value target. The industry is already familiar with the letter rating system, as it has been used in the context of Display Energy Certificates.
- Targets are set for four typologies: Residential, Office, School and Retail

Upfront Carbon, A1-5 (exc. sequestration)

	Band	Office	Residential	Education	Retail
	A++	<100	<100	<100	<100
	A+	<225	<200	<200	<200
LETI 2030 Design Target	A	<350	<300	<300	<300
	B	<475	<400	<400	<425
LETI 2020 Design Target	C	<600	<500	<500	<550
	D	<775	<675	<625	<700
	E	<950	<850	<750	<850
	F	<1100	<1000	<875	<1000
	G	<1300	<1200	<1100	<1200

Embodied Carbon, A1-5, B1-5, C1-4 (inc. sequestration)

	Band	Office	Residential	Education	Retail
	A++	<150	<150	<125	<125
	A+	<345	<300	<260	<250
	A	<530	<450	<400	<380
RIBA 2030 Built Target	B	<750	<625	<540	<535
	C	<970	<800	<675	<690
	D	<1180	<1000	<835	<870
	E	<1400	<1200	<1000	<1050
	F	<1625	<1400	<1175	<1250
	G	<1900	<1600	<1350	<1450

All values in $kgCO_2e/m^2$ (GIA)

***Figure 3-1 –** 'Embodied Carbon Target Alignment' - Letter bandings*

[6] 'Embodied Carbon Target Alignment' report. Online Available at: https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_89cf50315c884fa796fdf07d1428b2e6.pdf

As part of this work, LETI and RIBA have aligned the new letter banding system with their previous targets. More specifically, the LETI position is that for buildings that are currently in the **design** stage:

- Average design achieves an E
- Good design achieves a C (LETI 2020 target)
- LETI 2030 design target achieves an A

The RIBA 2030 Climate Challenge **built** performance is equivalent of a B rating (note that this assumes practical completion in 2030, so designed earlier).

The bandings do not currently differentiate between new build or refurbishment. Part of the rationale for this is that refurbishment projects will find it easier to achieve good performances and this provides an incentive for retrofit. It is expected that as more data is collected for ranges of retrofit, the bandings could be adapted if necessary.

SHORT TERM AND LONG TERM POLICY THRESHOLDS

According to the their 'Embodied Carbon Target Alignment' work, the current average practice in terms of embodied carbon performance is considered to be E, while the current best-practice performance is considered to be a C rating. Ratings from B and above are considered robust stretch targets.

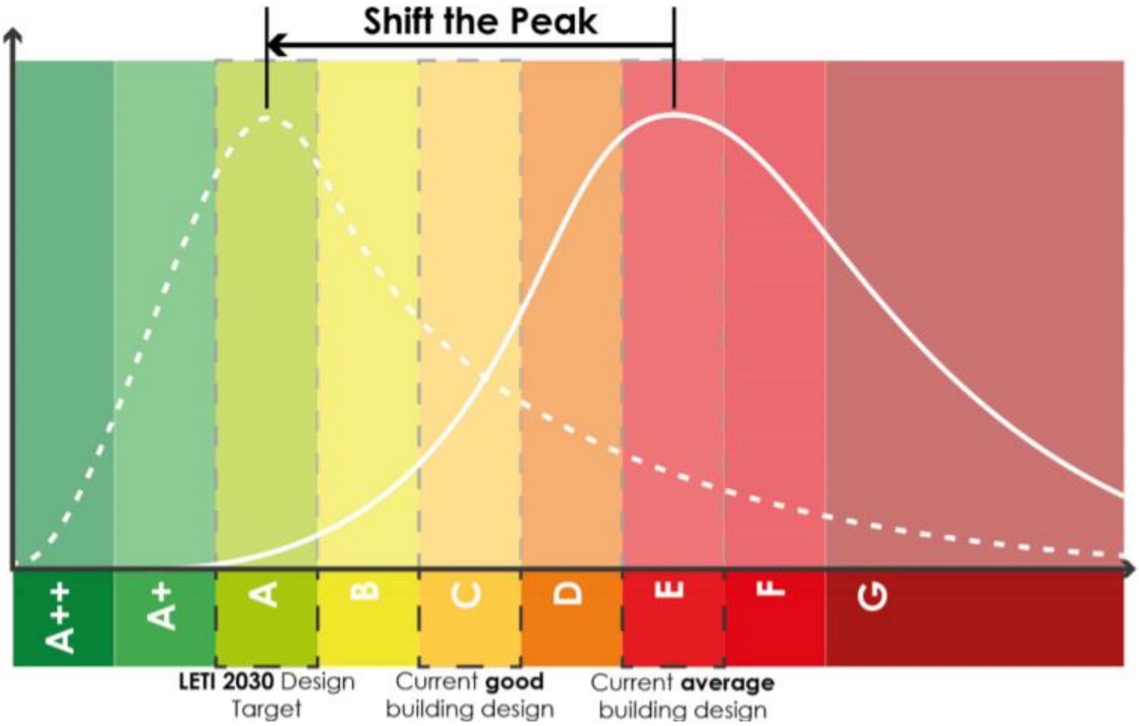


Figure 3-2 – *'Embodied Carbon Target Alignment' - Letter bandings with current average practice (E) and good practice (C)*

3.2 ANALYSIS OF DELIVERABILITY

EMBODIED CARBON RESULTS

An initial analysis of the baseline embodied carbon scenario was undertaken to identify "carbon hotspots" - the building elements containing the most embodied carbon in buildings delivered through current industry practice. *Figure 3-3* shows the carbon share for the main building elements for the four building typologies (Life cycle stages A to C). In the office and school which start with a baseline of a steel frame structure, the superstructure has the largest carbon share (office: 36%, school: 40%), followed by the façade (office: 18%, school: 17%) and the substructure (office: 8%, school: 12%). Internal partitions have a relatively small share in these two typologies (office: 8%, school: 5%). Finally, building services have been assumed to have an important share of carbon emissions, as per LETI % reference explained in the methodology section (office: 15%, school: 13%).

For the apartment block which starts (as shown in the pie charts below) with a baseline of a concrete frame structure, the superstructure and façade elements have similar carbon shares (superstructure: 30%, façade: 22%). This is because the concrete frame is a lower carbon option than a steel frame. The third largest carbon share is the internal partitions (18%), as this typology has more internal wall elements and the fourth is the substructure (10%). Building services have a smaller share of carbon emissions, as per LETI reference (4%).

Finally, the semi-detached house has the lowest carbon baseline structure option, which is load-bearing masonry walls and timber upper floor and roof. The carbon share of the superstructure is only 10%. The largest carbon share for the semi-detached house is the facades (51%), followed by substructure (18%) and the internal partitions (14%). Similarly with the apartment block, building services again have a relatively small share of carbon emissions, as per LETI reference (5%).

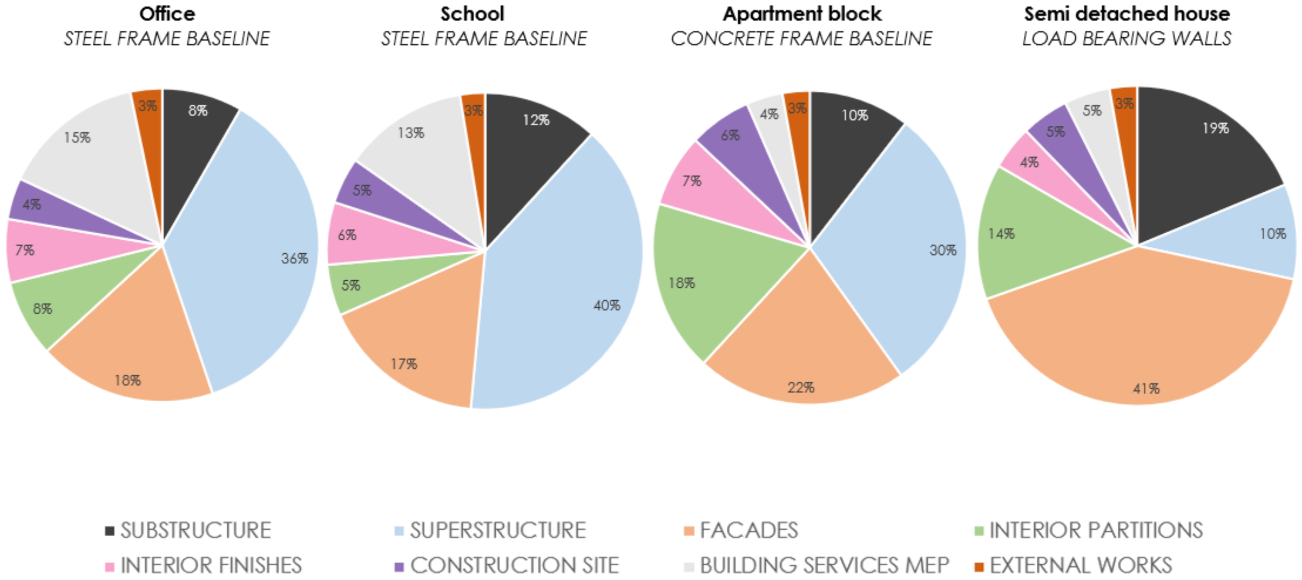


Figure 3-3 – *Carbon Hotspots per typology*

Then the baseline carbon results for the four typologies were compared against the RIBA Climate Challenge targets. As explained in the methodology section, the modelling results as per the Detailed Analysis scope were given a percentage increase to account for building services and external works, which is the extended scope of this assessment (both scopes are shown in Figure 3-7 below). The extended scope is used for a more accurate comparison with the RIBA targets. As shown in *Figure 3-4*, the office, school and apartment block baselines are broadly aligned with RIBA 2020 targets for non-domestic and domestic respectively. The baseline for the semi-detached house lies in between the domestic RIBA 2020 target and the Current Benchmark, and not far from the RIBA 2020 target. This difference lies in the large deviation of this typology in terms on GIFA.

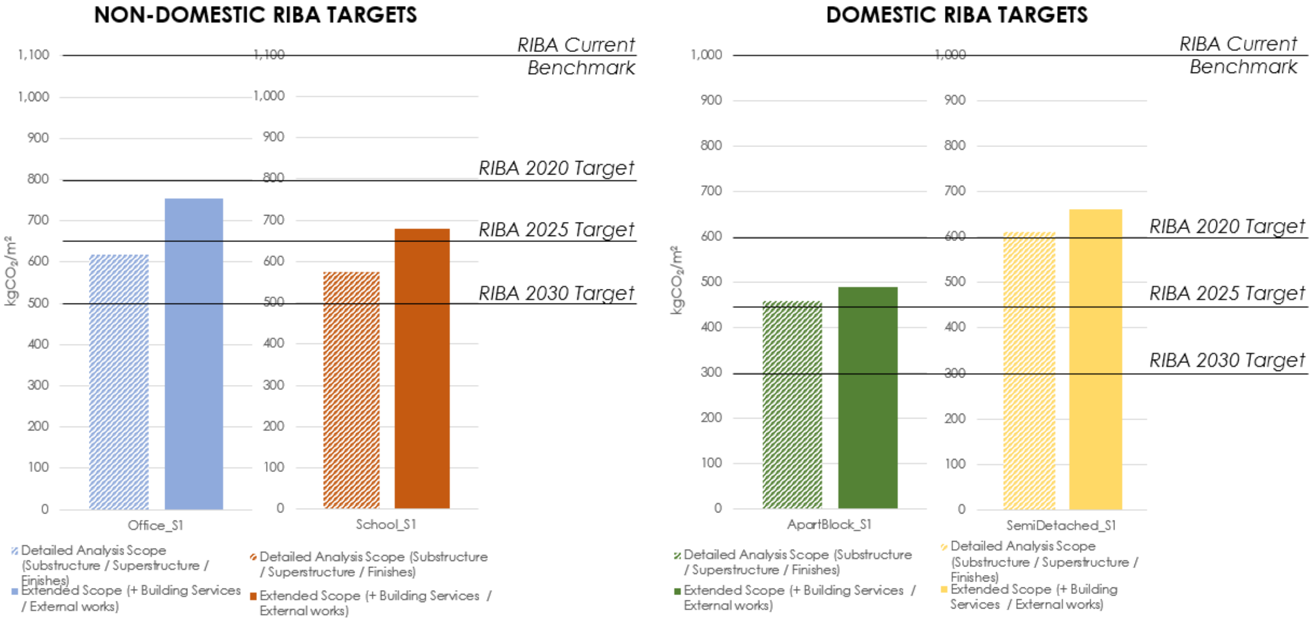
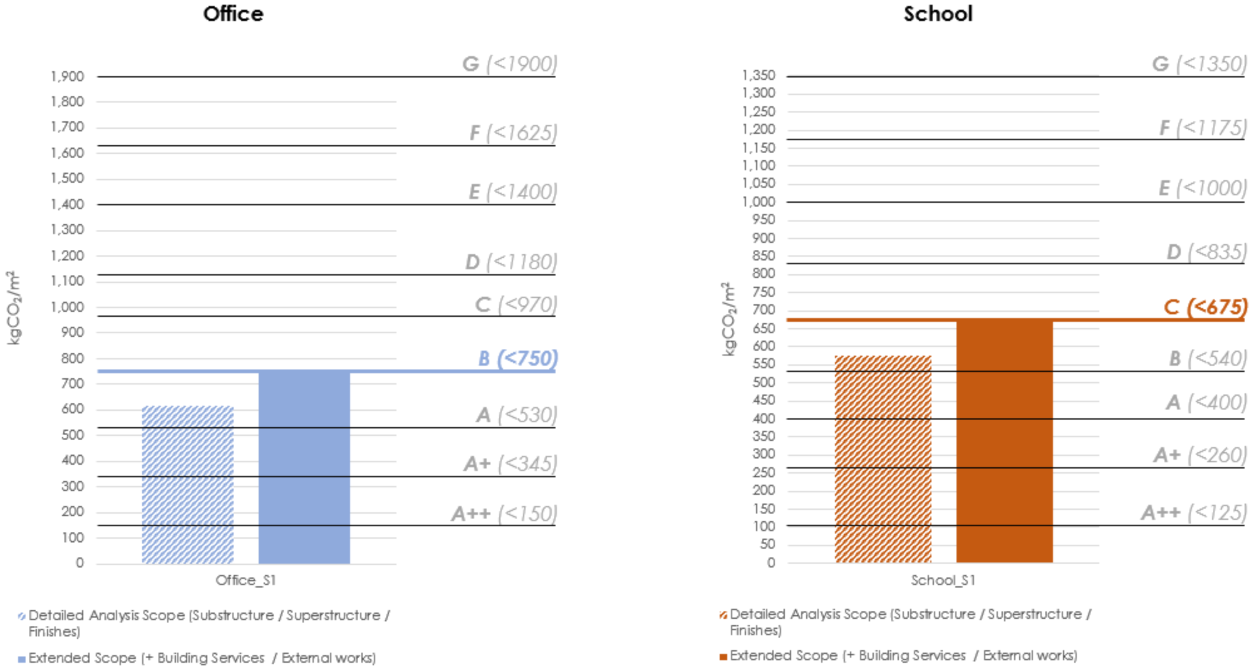


Figure 3-4 – *Current industry practice / Baseline and Comparison with RIBA 2030 Climate Challenge targets*

A similar comparison of the baseline scenarios was then drawn with the Embodied Carbon Target Alignment letter bandings (*Figure 3-5*).



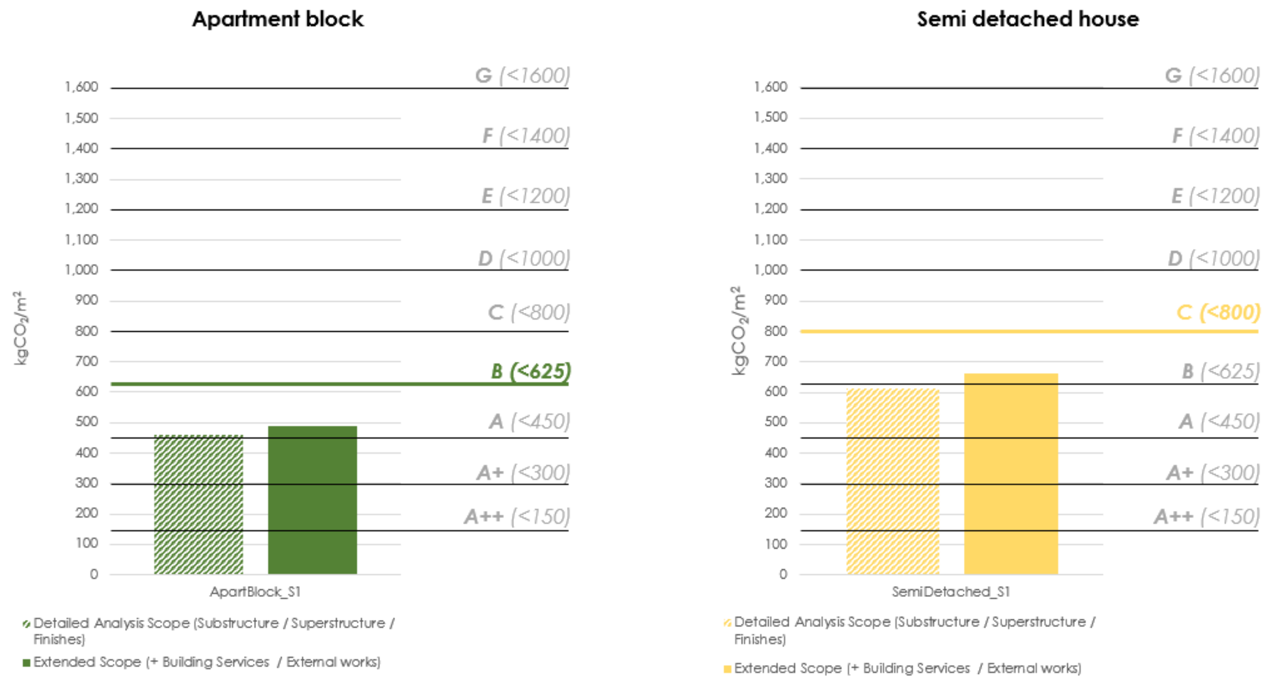


Figure 3-5 – *Current industry practice / Baseline and Comparison with Embodied Carbon Target Alignment*

To understand the impact of each scenario in terms of embodied carbon reduction, the detailed results for each typology are presented and explained in the following paragraphs. These include:

- the application of each measure separately, which helps compare their individual impacts, and
- the cumulative application of the same measures in an indicative order, which helps understanding the combined potential all these measures
- the comparison of the results against the RIBA Climate Challenge targets (Extended scope[7], Life stages A-C)
- the comparison of the results against the LETI targets (Extended scope[7], Upfront carbon only-Life stage A)

All results follow the extended scope, which includes Substructure, Superstructure, Finishes, Building Services and External Works.

- Starting from the office typology (*Figure 3-6*), a steel structure with CLT floors and roof can result in a reduction of 12% compared with the composite steel/deck slabs baseline.
- When the steel structural frame is additionally changed to mass timber frame (i.e. glulam), the carbon reduction increases to 24%.
- Low carbon facades and low carbon interior can bring 10% and 6% carbon reductions respectively compared to the baseline.
- The use of low carbon concrete (with 40% cement replacement) can bring a small carbon reduction of 2% from the baseline (20% cement replacement). This measure is expected to

[7] Substructure, Superstructure, Finishes, Building Services and External Works

have a larger percentage impact when the baseline has zero carbon? cement replacement, and it should still be considered by new office developments.

- When all the measures above are combined (All Combined scenario), the total carbon reduction from the baseline is 41%, and the embodied carbon results are meet the RIBA 2030 Climate Challenge target.

To compare the results against the RIBA targets, all life stages A-C are included in the scope. The baseline office scenario (Office_S1) complies with the RIBA 2020 target, while the most challenging office scenario (Office_S6) complies with the RIBA 2030 target.

When comparing all the results against the LETI targets, only the upfront embodied carbon of life stage A is included in the scope. The baseline office scenario (Office_S1) almost complies with the LETI 2020 target, while the most challenging office scenario (Office_S6) complies with the LETI 2030 target. The results of the current study have also been compared with the results of a similar study undertaken by UKGBC and presented in their report 'Building the case for Net Zero', which focused on reducing the embodied carbon emissions of an office tower. These results are marked on the same graphs, to enable transparency and comparison. From this comparison we understand that the reduction rate from the measures applied is similar. However, UKGBC has included more building element types (i.e. fit out) in the scope of the assessment, and therefore the absolute result figure is higher than the current study. On top of that, the comparison with a tower building (>18m) is complicated due to the stricter fire regulations it needs to comply with.

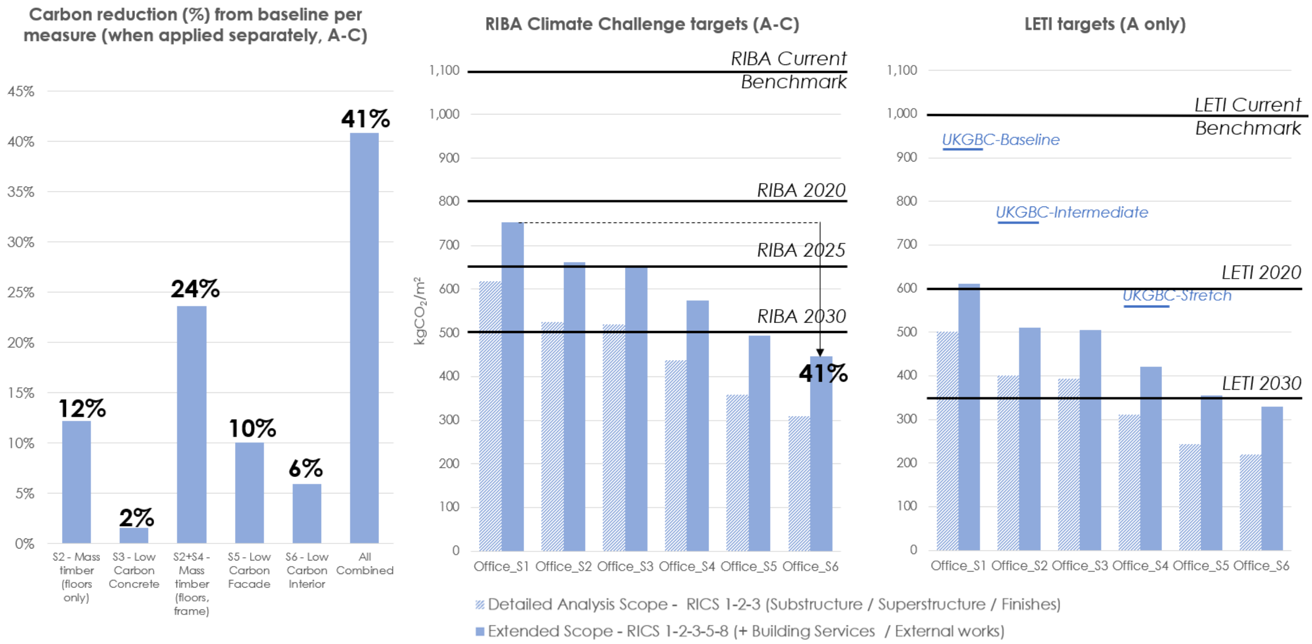


***Figure 3-6 –** Office results. **Left:** Carbon reduction (%) from baseline per measure (when measures applied separately, scope including RICS 1-2-3-5-8). **Middle:** Carbon reduction (kgCO$_2$/m^2) per scenario and comparison with RIBA Climate Challenge targets (measures applied cumulatively, Detailed and Extended scopes, Life stages A-C). **Right:** Carbon reduction (kgCO$_2$/m^2) per scenario and comparison with LETI targets (measures applied cumulatively, Extended scope, Upfront carbon only-Life stage A).*

For the school typology (*Figure 3-7*), the results are similar to the office typology, given that these two typologies share the same baseline.

- The steel structure with CLT floors and roof can result in a reduction of 14% compared with the composite steel/deck slabs baseline.
- When the steel structural frame is additionally changed to mass timber frame (i.e. glulam), the carbon reduction increases to 25%.
- Low carbon facades and low carbon interior can bring 9% and 5% carbon reductions respectively compared to the baseline.
- The use of low carbon concrete (with 40% cement replacement) can bring a small carbon reduction of 2% from the baseline (which only uses 20% cement replacement). This measure is expected to have a larger percentage impact when the baseline has zero carbon cement replacement, and it should still be considered by new school developments.
- When all the measures above are combined (All Combined scenario), the total carbon reduction from the baseline is 40%, and the embodied carbon results are aligned with the RIBA 2030 Climate Challenge targets.

As with the office, to compare the results against the RIBA targets, all life stages A-C are included in the scope. The baseline school scenario (School_S1) complies with the RIBA 2020 target, while the last school scenario (School_S6) complies with the RIBA 2030 target. When comparing all the results against the LETI targets, only the upfront embodied carbon of life stage A is included in the scope. The baseline school scenario (School _S1) complies with the LETI 2020 target, while the last school scenario (School _S6) complies with the LETI 2030 target.

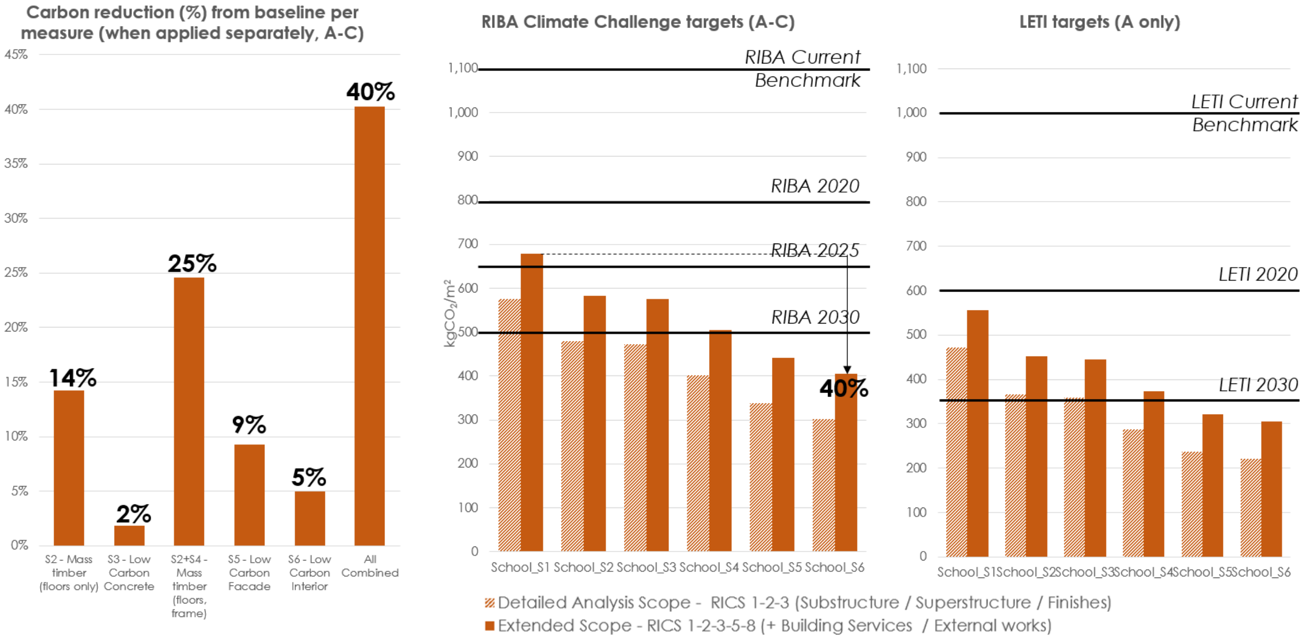


Figure 3-7 – *School results.* ***Left:*** *Carbon reduction (%) from baseline per measure (when measures applied separately, scope including RICS 1-2-3-5-8).* ***Middle:*** *Carbon reduction (kgCO$_2$/m^2) per scenario and comparison with RIBA Climate Challenge targets (measures applied cumulatively, Detailed and Extended scopes, Life stages A-C).* ***Right:*** *Carbon reduction (kgCO$_2$/m^2) per scenario and comparison with LETI targets (measures applied cumulatively, Extended scope, Upfront carbon only-Life stage A).*

The apartment block starts from a different baseline than the office and the school, with a concrete structure frame and hollowcore concrete slabs with 20% cement replacement. The results for this typology are shown in *Figure 3-8*.

- The use of low carbon concrete (with 40% cement replacement) can bring a small carbon reduction of 2% from the baseline (20% cement replacement). As explained before, this measure is expected to have a larger percentage impact when the baseline has zero carbon cement replacement, so it should still be considered by new apartment block developments.
- The option with a mass timber structure with CLT walls, floors and roof can bring a reduction of 14% compared with the baseline.
- Low carbon facades and low carbon interior can bring 11% and 4% carbon reductions respectively compared to the baseline.
- When all the measures above are combined (All Combined scenario), the total carbon reduction from the baseline is 27%, and the embodied carbon results are aligned with the RIBA 2025 Climate Challenge targets.

To compare the results against the RIBA targets, all life stages A-C are included in the scope. The baseline apartment block scenario (ApartBlock_S1) complies with the RIBA 2020 target, while the last apartment block scenario (ApartBlock_S6) complies with the RIBA 2025 target. When comparing all the results against the LETI targets, only the upfront embodied carbon of life stage A is included in the scope. The baseline apartment block scenario (ApartBlock_S1) complies with the LETI 2020 target, while the last apartment block scenario (ApartBlock_S6) complies with the LETI 2030 target. The results of the current study have also been compared with the results of a similar study undertaken by UKGBC and presented in their report 'Building the case for Net Zero', which focused on reducing the embodied carbon emissions of a residential tower. These results are marked on the same graphs, to enable transparency and comparison. From this comparison we understand that the reduction rate from the measures applied is similar. However, it is again obvious that the building typologies modelled as part of this study include less building elements (i.e. fit out) than the building modelled by UKGBC.

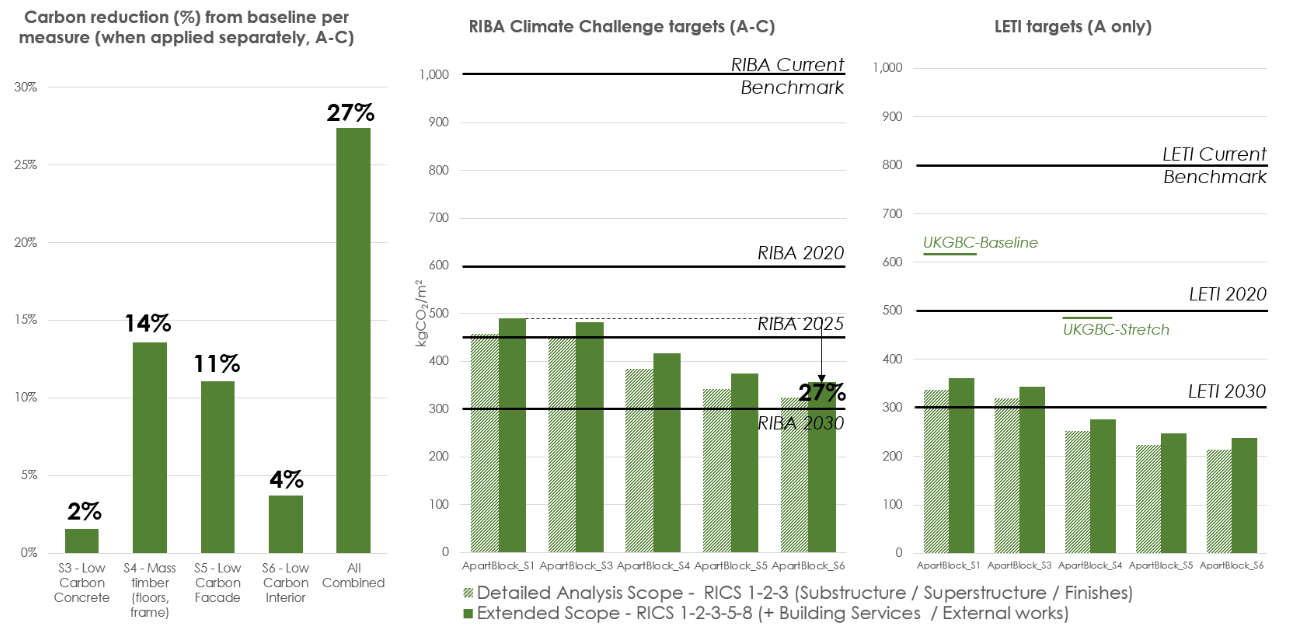


Figure 3-8 – *Apartment Block results.* ***Left:*** *Carbon reduction (%) from baseline per measure (when measures applied separately, scope including RICS 1-2-3-5-8).* ***Middle:*** *Carbon reduction (kgCO_2/m^2) per scenario and comparison with RIBA Climate Challenge targets (measures applied cumulatively, Detailed and Extended scopes, Life stages A-C).* ***Right:*** *Carbon reduction (kgCO_2/m^2) per scenario and comparison with LETI targets (measures applied cumulatively, Extended scope, Upfront carbon only-Life stage A).*

Finally, *Figure 3-9* presents the results for the semi-detached house which starts from a lower carbon baseline in comparison with the other three typologies, since it consists of load-bearing masonry walls and timber floors and roof.

- The use of low carbon concrete (with 40% cement replacement) can bring a small carbon reduction of 1% from the baseline (20% cement replacement). The smaller impact can be explained from the fact that the concrete quantities on the baseline are already limited. As explained before, this measure could have a larger percentage impact when the baseline has zero carbon cement replacement, so it should still be considered by new apartment block developments.
- The option with a mass timber structure with sawn timber stud walls, can bring a reduction of 6% compared with the baseline.
- Low carbon facades can lead to a 26% carbon reduction compared to the baseline. The large impact of this measure derives from the fact that facades consist 41% of total embodied carbon emissions in the baseline for this typology.
- Low carbon interiors have a very small impact of 1% carbon reduction, as here the change from block to timber studs is included instead in S4.
- When all the measures above are combined (All Combined scenario), the total carbon reduction from the baseline is 34%, and the embodied carbon results comply with the RIBA 2025 Climate Challenge targets.

Similarly with the previous typologies, to compare the results against the RIBA targets, all life stages A-C are included in the scope. The baseline house scenario (SemiDetached_S1) is very close but doesn't comply with the RIBA 2020 target, while the last house scenario (SemiDetached_S6) complies with the RIBA 2025 target. When comparing all the results against the LETI targets, only the upfront embodied carbon of life stage A is included in the scope. The baseline house scenario (SemiDetached_S1) almost complies with the LETI 2020 target, while the last house scenario (SemiDetached_S6) almost complies with the LETI 2030 target.

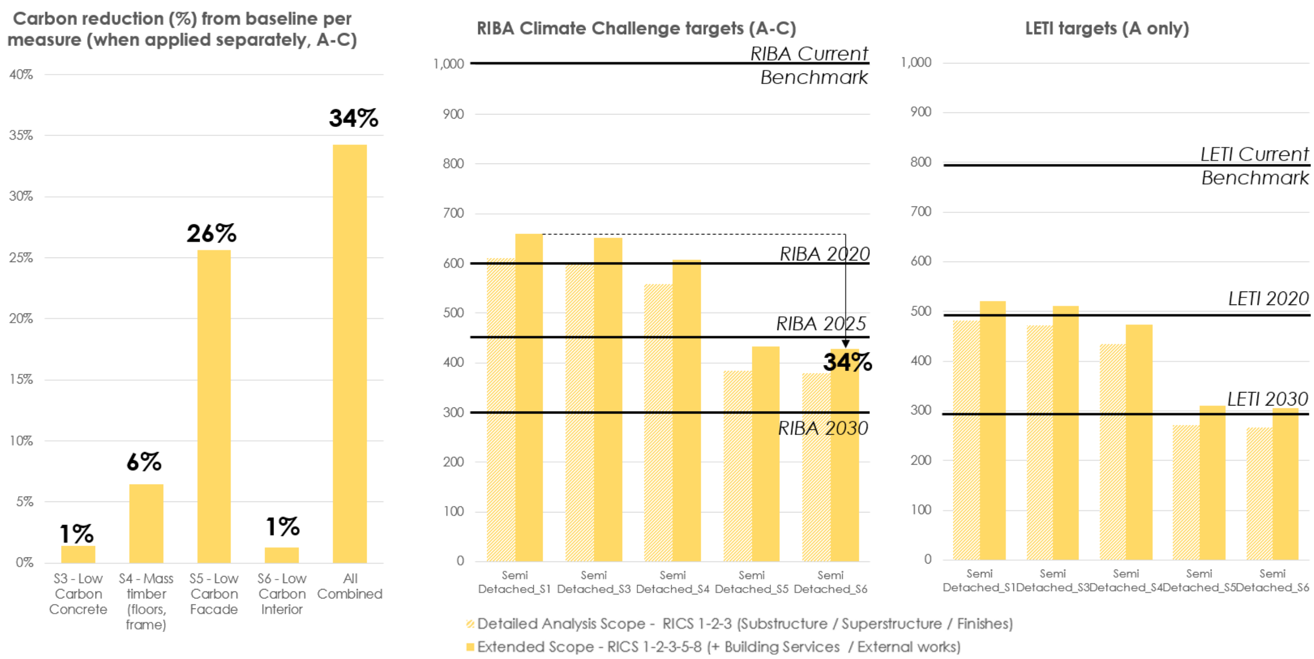


Figure 3-9 – *Semi Detached House results.* ***Left:*** *Carbon reduction (%) from baseline per measure (when measures applied separately, scope including RICS 1-2-3-5-8).* ***Middle:*** *Carbon reduction (kgCO_2/m^2) per scenario and comparison with RIBA Climate Challenge targets (measures applied cumulatively, Detailed and Extended scopes, Life stages A-C).* ***Right:*** *Carbon reduction (kgCO_2/m^2) per scenario and comparison with LETI targets (measures applied cumulatively, Extended scope, Upfront carbon only-Life stage A).*

COST UPLIFT RESULTS

This section will focus on presenting and analysing the results from the cost uplift assessment. Table 3-2 below provides a summary of the percentage (%) cost uplift and is followed by some considerations in the paragraphs below. It should be noted that the cost uplift identified is based cost data at the time of reporting. It would be reasonable to suggest that premiums would decrease as new technologies and construction methodologies are normalised into the construction industry.

Table 3-2 – Embodied Carbon Targets according to RIBA 2030 Climate Challenge targets and LETI (London Energy Transformation Initiative) Climate Emergency Design Guide

Cost Uplift from Baseline Scenario				
Scenarios	**Office**	**School**	**Apartment**	**Semi Detached**
Baseline	**n/a**	**n/a**	**n/a**	**n/a**
Scenario 2 - Timber Hybrid (Cost Uplift from Baseline)	**6%**	**7%**	**n/a**	**n/a**
Scenario 3 - Low Carbon Structure (Cost Uplift from Baseline)	**6%**	**7%**	**0%**	**0%**
Scenario 4 - Timber Frame (Cost Uplift from Baseline)	**9%**	**9%**	**9%**	**3%**
Scenario 5 - Low Carbon Façade (Cost Uplift from Baseline)	**16%**	**14%**	**14%**	**15%**
Scenario 6 - Low Carbon Finishes (Cost Uplift from Baseline)	**16%**	**15%**	**15%**	**15%**

Baseline

The baseline scenario reflects the current industry standard for each building type and is shown as an n/a within this table as the costs are presented as a change from this baseline.

The traditional build is typically a steel or concrete framed construction solution, please refer to the preceding pages for detail on the materiality of each building type. The images below identify the typical frame construction cost and methodology for the baseline scenarios.

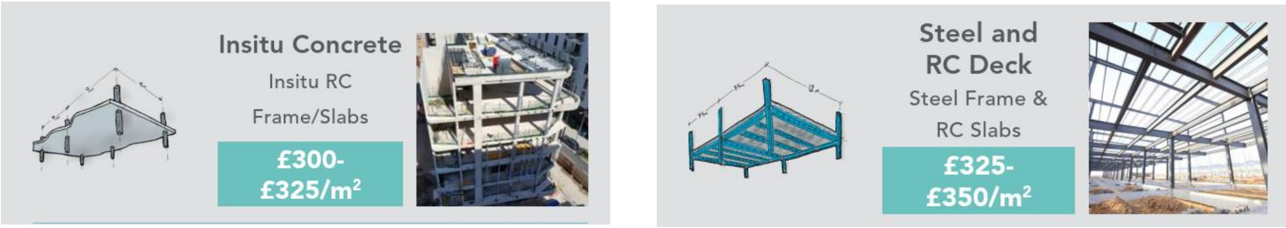


Figure 3-10 – *Typical frame construction cost for insitu concrete frame and slabs (left) and steel frame with reinforced concrete slabs (right)*

Scenario 2 – Timber Hybrid

Scenario 2 is a timber hybrid solution with cross laminated timber (CLT) slabs replacing composite floor slabs and a reduction in the pile sizes by circa 25% to reflect lighter weight construction.

Cost Impact

The total cost uplift of circa 7% for the Office and School reflects the inclusion of CLT slabs within a hybrid CLT and Steel solution. The introduction of CLT slabs to a steel frame can incur a cost premium of 25% on the frame costs which make up a significant proportion of the overall construction cost. This uplift has been accounted for within the 7% overall construction total uplift when adjusted for the weighting. The images below identify the typical cost for the frame of a hybrid steel and CLT frame.

Figure 3-11 – *Typical frame construction cost steel frame with CLT panel slabs*

Other Considerations

Hybrid timber solutions are becoming increasingly popular within the commercial market as it allows developers to retain the design benefits of a traditional steel solution whilst also reducing the embodied carbon impact of the development. However they tend to be less efficient from a design perspective as CLT slabs tend to be thicker than composite decks, resulting in an impact on either the overall building height, the internal floor to ceiling heights or the internal areas.

Scenario 3 – Low Carbon Structure

Scenario 3 reflects a Low Carbon Structure, utilising 40% recycled elements within the concrete frame construction.

Cost Impact

There is no cost impact over and above the introduction of CLT slabs as outlined within Scenario 2, the use of GGBS within the cement mix is cost neutral but there are material resourcing concerns when procuring in large quantity.

Other Considerations

The introduction of Ground Granulated Blast Furnace Slag (GGBS) as a replacement for cement within a concrete mix acts as a recycled element and is commonly used. GGBS is a by-product of the production of iron and its utility within concrete mix is better from an embodied carbon perspective than traditional Portland cement.

Scenario 4 – Mass Timber Solution

Scenario 4 reflects a 100% Mass Timber Framed Structure, as outlined within the 'Glulam and CLT Deck' option.

Cost Impact

There is a circa 9-10% increase for the inclusion of a mass timber glulam frame and CLT deck to the Office, School and Apartment Block Scenarios. This would increase to 11-12% uplift when incorporating a LVL (laminated veneer lumber) and CLT frame. This is a stronger timber product allowing for a design solution with a more similar grid layout to a traditional steel frame which is typically utilised within offices to accommodate better floor to ceiling heights and longer internal spans. The uplift is more minimal for the Semi Detached house as the baseline includes a considerable amount of timber elements already. The typical frame costs for the two mass timber construction types are outlined below, these apply to Scenario 4, 5 and 6.

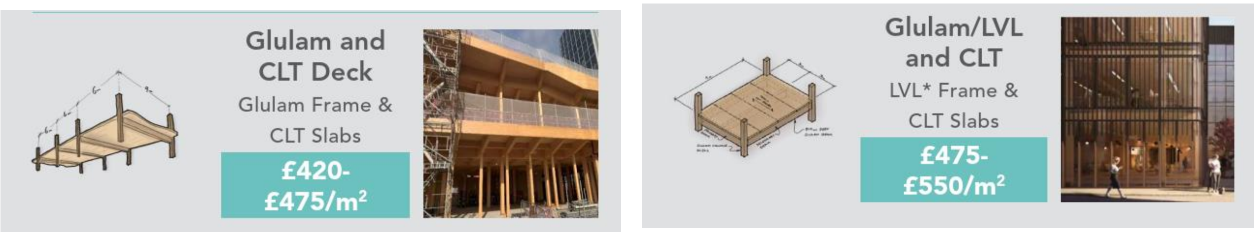


Figure 3-12 – *Typical frame construction cost for glulam frame with CLT deck (left) and glulam/LVL frame and CLT deck (right)*

Other Considerations

There is a significant lack of experience within the UK construction industry utilising mass timber construction and timber facades resulting in a number of project risks when considering its use in proposed development.

1. Fire - In the wake of Grenfell interest in mass timber residential buildings has substantially decreased and there are challenges around securing the required insurance for mass timber construction in other building types. Until these concerns and challenges are overcome conclusively it is unlikely that mass timber would be utilised within construction of apartment blocks.

2. Insurance - There are many risk factors insurers have to consider when underwriting a mass timber construction. Whilst some of these risks are similar to other types of construction risk, others stem from the lack of technical knowledge when using timber as a building material. They do not fit easily into long-established construction classes and comparatively little statistical data exists to help insurers when underwriting mass timber buildings.

3. Construction Experience – Although this is not common practice within the construction industry at present there has been a significant increase in the utilisation of mass timber

construction within the UK, especially within offices and schools. That being said the UK has some way to go before integrating this as standard industry practice and should look to examples from the Netherlands and the US for inspiration on how to incorporate greater use of mass timber within construction developments.

Scenario 5 – Low Carbon Facade

Scenario 5 reflects a mass timber framed structure as outlined within Scenario 4 with the addition of timber wall panels and a timber façade.

Cost Impact

There is circa 15% increase from baseline for the inclusion of a timber façade and mass timber frame to the four building types. The significant uplift for the facade cost reflects the challenge and cost involved with installing a timber solution over a traditional masonry cavity wall which has been included within the previous scenarios. The cost uplift is driven by the price of material and the relative lack of industry experience utilising this facade system.

Other Considerations

The same risks identified within Scenario 4 around fire, insurance and construction experience apply and are increased in Scenario 5 as the use of mass timber facades is not a technique that is used within the UK construction industry. There will be significant challenges procuring this solution with the current supply chains and specialist input will be required, the cost could far exceed the 12-18% depending on the location, local supply chain, design, construction methodology etc.

Scenario 6 – Low Carbon Finishes

Scenario 6 reflects a mass timber framed structure and façade as outlined within Scenario 5 with the addition of low carbon internal finishes

Cost Impact

There is a slight uplift from Scenario 5 and a total uplift of circa 16% from the baseline across the four building types following the inclusion of timber stud internal walls and linoleum flooring.

Other Considerations

The same comments surrounding fire, insurance and construction experience risks apply.

CARBON REDUCTION / COST UPLIFT COMPARISON

After analysing the carbon reduction and the cost uplift for each scenario separately, the data were combined to calculate the cost uplift (£) per carbon saved (tCO_2). *Figure 3-13* presents the results of this assessment.

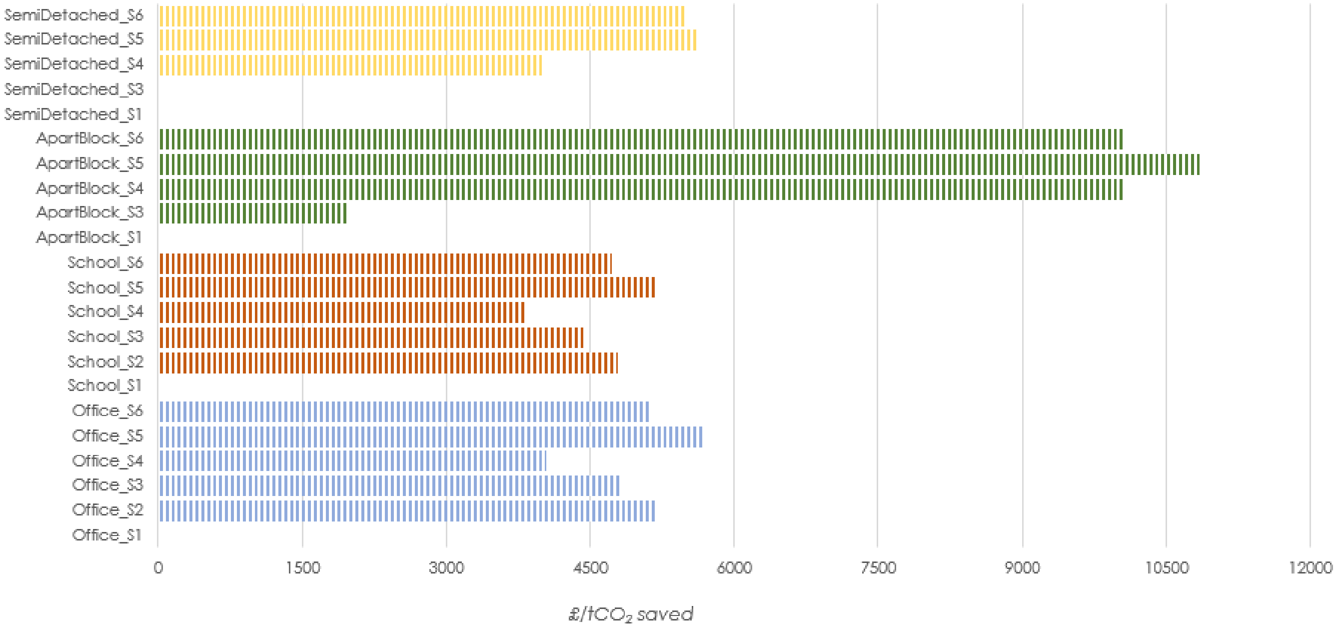


Figure 3-13 *– Cost uplift (£) from baseline per tCO_2 carbon saved for each scenario*

The apartment block with the concrete frame baseline are the typology/baseline structure with the higher cost uplift. This derives from the fact that the baseline of a concrete frame structure is a lower carbon option than the steel structure baseline (of the office and school). Therefore the percentage carbon reduction from similar measures is also lower[8].

For the office and school, the combined structural option of a glulam frame with CLT floors and low carbon concrete (S4) is more cost effective per carbon saved than the previous scenarios S2 and S3. This is partly explained from the reduced foundation quantities required for this lighter structural option.

Moreover, for all the typologies, considering low carbon interiors on top of the low carbon façade (S6) is more cost-effective per tonne of carbon saved than when considering low carbon facades only (S5). Finally, low carbon concrete (S3) is a cost-effective measure for all typologies because it is a zero cost measure, and it should always be considered.

COST UPLIFT COMPARISON WITH RIBA AND LETI TARGETS

Figure 3-14 below shows the associated cost uplift pe carbon saved for each scenario, along with how its performance compares against the RIBA 2030 Climate Challenge targets. *Figure 3-15* does

[8] For example, the Scenario 6 for the apartment block leads to a carbon reduction of 27%, while the Scenario 6 for the office leads to a carbon reduction of 41%.

the same comparison against the LETI targets. It should be considered that the compliance with the targets can vary depending on the building materials and complexity of the assessment, but the relative carbon reduction for each measure is likely to stay similar.

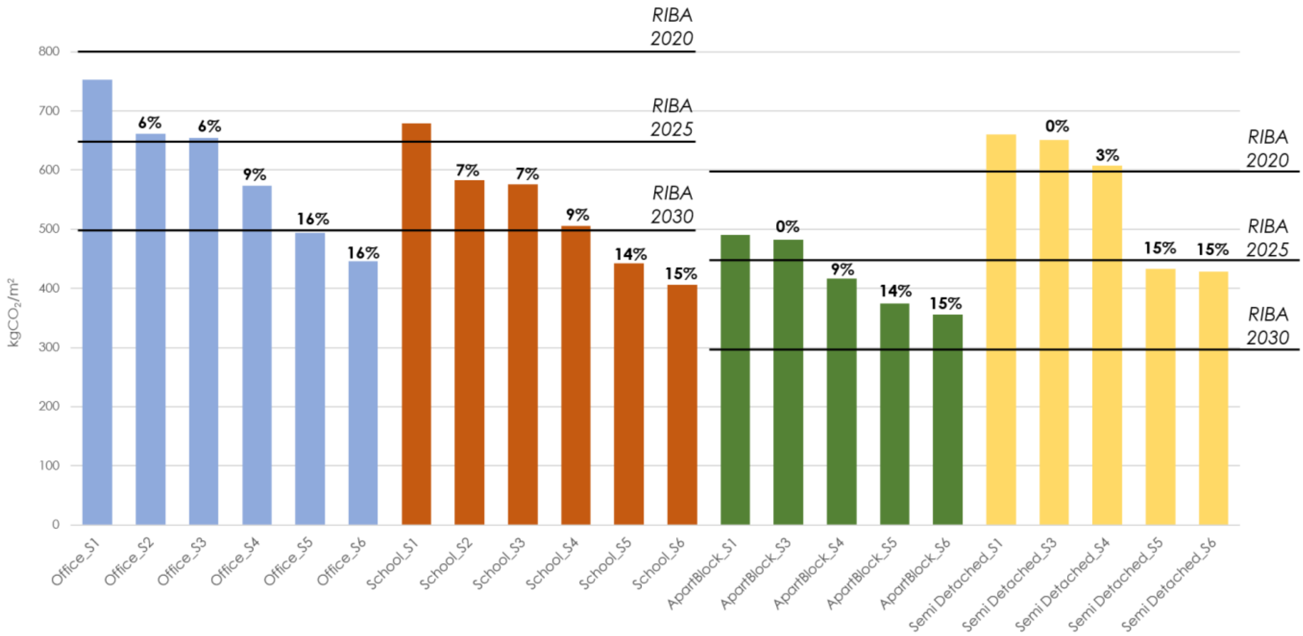


Figure 3-14 *– Cost uplift (%) from baseline for each scenario and comparison with RIBA targets*

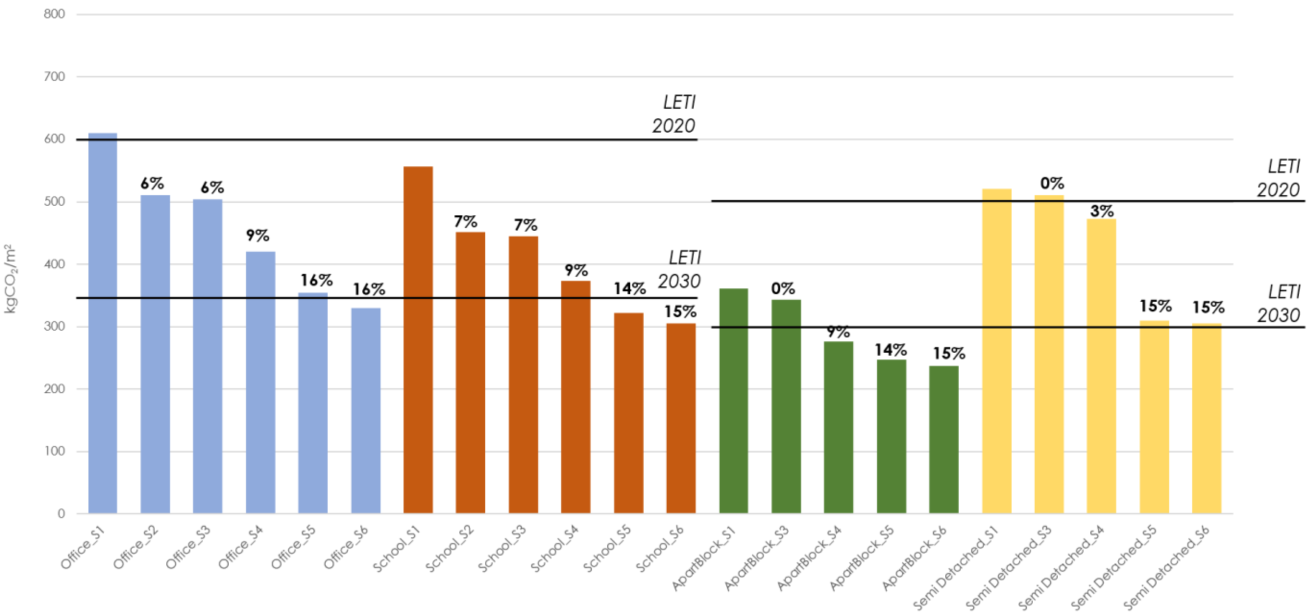


Figure 3-15 *– Cost uplift (%) from baseline for each scenario and comparison with LETI targets*

The cost uplift to comply with each RIBA and LETI target per building typology is summarised in the Table 3-3.

Table 3-3 – Cost uplift per typology to comply with the RIBA (top) and LETI (bottom) targets

Building Typology	2020	2025	2030
RIBA			
Office	0%	9%	16%
School	0%	7%	14%
Apartment Block	0%	9%	*No compliance*
Semi-detached house	(3%)	15%	*No compliance*
LETI			
Office	6%	-	16%
School	0%	-	14%
Apartment Block	0%	-	9%
Semi-detached house	3%	-	(15%)

The results indicate that:

- The office complies with the RIBA 2020 typology with a 0% cost uplift (weighted). The cost uplifts to comply with the RIBA 2025 and RIBA 2030 targets are 9% and 16% respectively. To comply with the LETI 2030 target, the cost uplift is also 16%.
- The school complies with the RIBA 2020 typology with a 0% cost uplift (weighted). The cost uplifts to comply with the RIBA 2025 and RIBA 2030 targets are 7% and 14% respectively. To comply with the LETI 2030 target, the cost uplift is also 14%.
- The apartment block complies with the RIBA 2020 typology with a 0% cost uplift (weighted). The cost uplift to comply with the RIBA 2025 is 9%, while no compliance was indicated with the RIBA 2030 target from the current assessment. To comply with the LETI 2030 target, the cost uplift is 9%.
- The semi-detached house almost complies with the RIBA 2020 typology with a 3% cost uplift (weighted). The cost uplift to comply with the RIBA 2025 is 15%, while no compliance was indicated with the RIBA 2030 target from the current assessment. To almost comply with the LETI 2030 target, the cost uplift is 15%.

COST UPLIFT COMPARISON WITH LETTER BANDING TARGETS

B-WHOLE LIFE EMBODIED CARBON (A-C)

Figure 3-16 below shows the associated cost uplift pe carbon saved for each scenario, along with how its performance compares against the letter banding targets for Whole Life Embodied Carbon (Stages A-C). It should be considered that the compliance with the targets can vary depending on the in scope building elements of the assessment, but the relative carbon reduction for each measure is likely to stay similar.

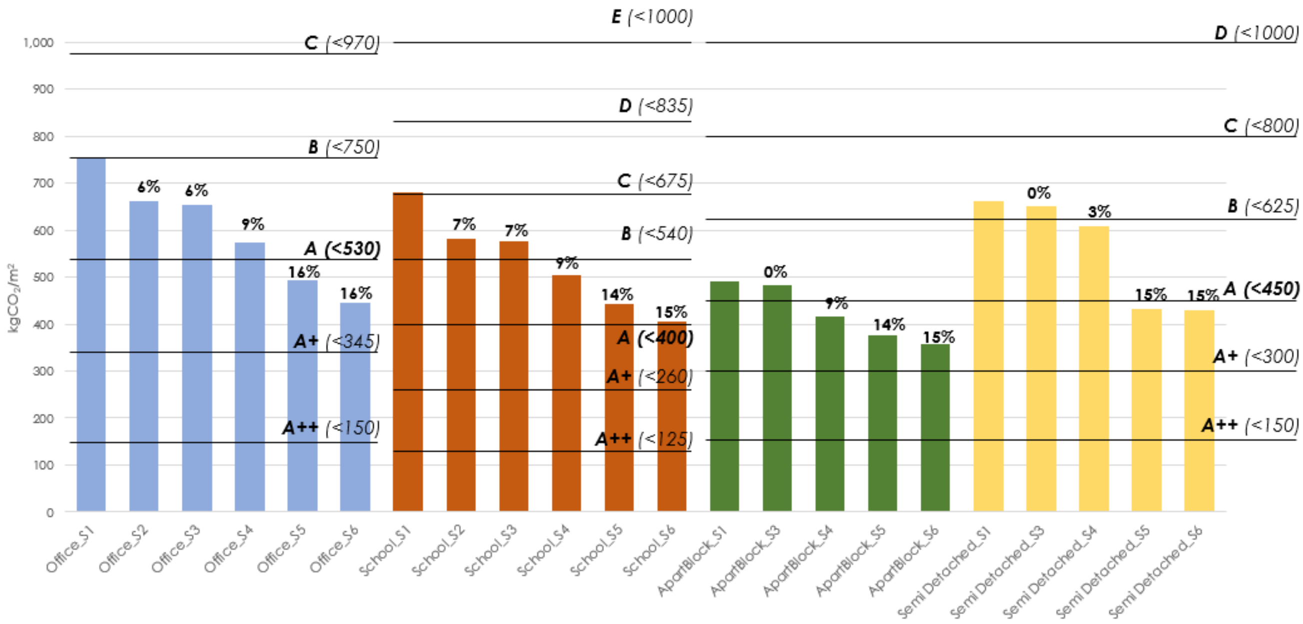


Figure 3-16 *– Cost uplift (%) from baseline for each scenario and comparison with letter banding targets (Whole life embodied carbon-stages A-C)*

ONLY UPFRONT EMBODIED CARBON (A)

Figure 3-17 below shows the associated cost uplift pe carbon saved for each scenario, along with how its performance compares against the letter banding targets for Upfront Embodied Carbon (Stage A only). It should be considered that the compliance with the targets can vary depending on the in scope building elements of the assessment, but the relative carbon reduction for each measure is likely to stay similar.

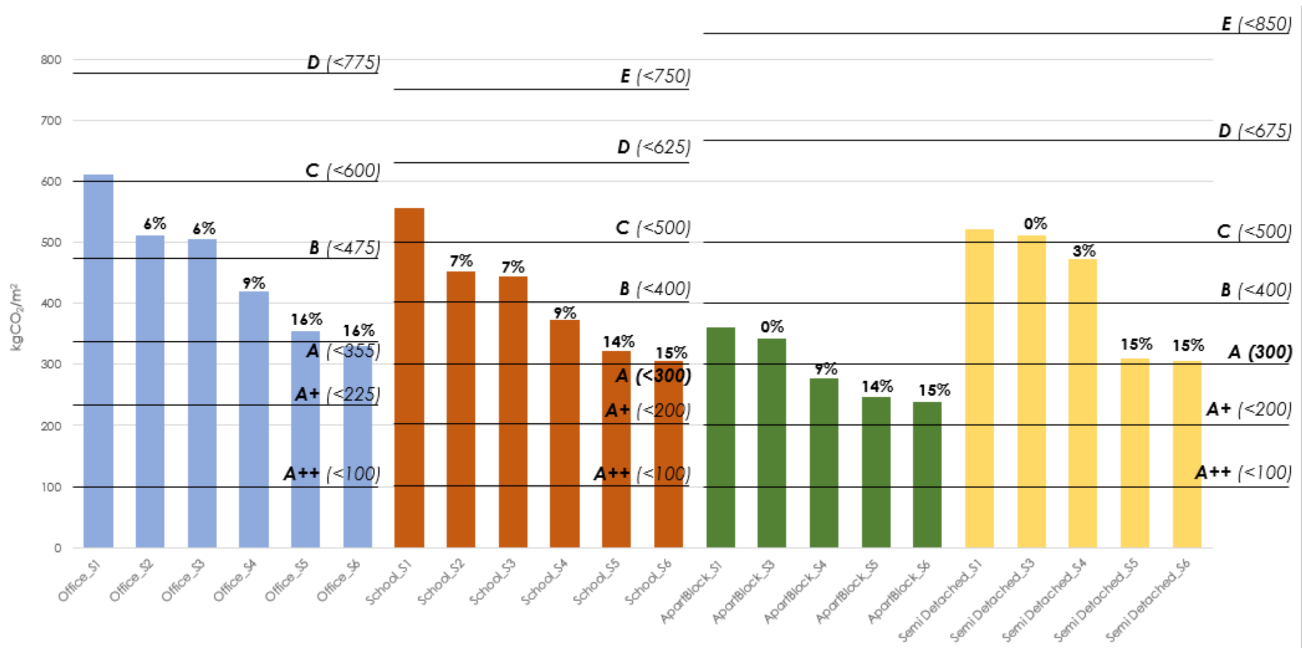


Figure 3-17 *– Cost uplift (%) from baseline for each scenario and comparison with letter banding targets (Upfront embodied carbon-stage A only)*

The cost uplift to comply with each RIBA and LETI target per building typology is summarised in the Table 3-4.

Table 3-4 – Cost uplift per typology to comply with the letter banding targets

Building Typology	D, E, F, G	C	B	A	A+, A++
Whole Life Embodied Carbon (A-C)					
Office	0%	0%	0%	16%	*No compliance*
School	0%	0%	9%	15%	*No compliance*
Apartment Block	0%	0%	0%	9%	*No compliance*
Semi-detached house	0%	0%	3%	15%	*No compliance*
Upfront Embodied Carbon (A)					
Office	0%	6%	9%	16%	*No compliance*
School	0%	7%	9%	15%	*No compliance*
Apartment Block	0%	0%	0%	9%	*No compliance*
Semi-detached house	0%	3%	15%	15%	*No compliance*

The results indicate that:

- Office:
  - Whole Life Embodied Carbon: The office complies with the letter banding B with a 0% cost uplift (weighted). The cost uplift to comply with the A rating is 16%.
  - Upfront Embodied Carbon: The office complies with the letter banding D with a 0% cost uplift (weighted). The cost uplifts to comply with the C and B ratings are 6% and 9% respectively. The cost uplift to comply with the A rating is 16%.
- School:
  - Whole Life Embodied Carbon: The school complies with the letter banding C with a 0% cost uplift (weighted). The cost uplift to comply with the B rating is 7%. The cost uplift to comply with the A rating is 15%.
  - Upfront Embodied Carbon: The school complies with the letter banding D with a 0% cost uplift (weighted). The cost uplifts to comply with the C and B ratings are 7% and 9% respectively. The cost uplift to comply with the A rating is 15%.
- Apartment Block:
  - Whole Life Embodied Carbon: The Apartment Block complies with the letter banding B with a 0% cost uplift (weighted). The cost uplift to comply with the A rating is 9%.
  - Upfront Embodied Carbon: The Apartment Block complies with the letter banding B with a 0% cost uplift (weighted). The cost uplift to comply with the A rating is again 9%.

- Semi-detached house:
    - Whole Life Embodied Carbon: The semi-detached house complies with the letter banding C with a 0% cost uplift (weighted). The cost uplift to comply with the B rating is 3%. The cost uplift to comply with the A rating is 15%.
    - Upfront Embodied Carbon: The semi-detached house c complies with the letter banding D with a 0% cost uplift (weighted). The cost uplifts to comply with the C and B ratings are 3% and 15% respectively. The cost uplift to comply with the A rating is also 15%.

OFFSETTING

Overall, the embodied carbon emissions of a new developments today are expected to be higher than its operational carbon emissions. Especially in the case of new all-electric developments which can achieve even lower operational carbon emissions as the electricity grid is decarbonising, the relative significance of embodied carbon emissions is expected to be even higher.

The cost of offsetting at 95 £/tCO_2 is calculated with the aim to encourage the use of on-site renewables, over the offset payment, when trying to reduce the operational carbon emissions of a new development. Therefore, it is not known if this would be an appropriate price for offsetting the embodied carbon emissions of a new development. Careful investigation of an appropriate carbon offsetting price specific for providing advantage to low carbon alternatives is recommended, as part of a separate piece of work.

3.3 IMPLEMENTATION

IMPLEMENTATION CONSIDERATIONS

SCOPE

It is recommended for the scope of the lifecycle carbon assessment instructed by the new NZB policy to be aligned with the 'Embodied Carbon Target Alignment' work. This new framework aims to provide a rationalised common way to measure and report embodied carbon emissions from new developments and aligning with it is the most forward-thinking approach. According to this document, the proposed scope includes all lifecycle stages and building elements (Whole Life Carbon scope, incl. sequestration), but also reports separately the Upfront embodied carbon (stage A only, excl. sequestration). Any benefit from future reuse/recycling of the building components is reported also separately as Module D. This is the most complete scope and it fuels innovative thinking encouraging developers to think about the lifespan of the components and materials used, and therefore prioritise durability and responsible end-of-life. It should be noted that the current assessment follows a more limited scope.

TARGETS

The findings of this study showed that an embodied carbon rating C can be achieved with zero cost uplift for all four building typologies. It should be highlighted again that this finding follows the scope of this study, and not the RICS scope followed to the 'Embodied Carbon Target Alignment'. Therefore, if all building elements where accounted for, then the embodied carbon rating achieved is likely to be lower (D-E). The rating C is also marked by guidance as the current *good* building design standard, while rating E is also marked as the current *average* building design standard. A recommendation for the new NZB policy would be to encourage all developments to reach rating C, while allowing the opportunity to explain why any variations from it if they exist. Moreover, an aspirational target of A rating could be proposed to inspire innovation, accompanied by the cost uplifts found by this study (Table 3-4), as per the described scope.

HOW TO DEMONSTRATE COMPLIANCE

The assessment process should be aligned with the "RICS professional standards and guidance - Whole life carbon assessment for the built environment" (1st edition, November 2017), as this is currently the most complete and widely recognised guidance on embodied and lifecycle carbon assessments in the UK market.

To demonstrate compliance, there is a wide variety of software and tools that are currently used by industry to assess the lifecycle embodied carbon emissions of new developments, such as One Click LCA, eTool etc. One Click LCA software is especially gaining popularity in the industry[9]. Specifically within One Click LCA, there are a series of tools each of which is used for a different purpose. The most commonly used of them are:

- **One Click LCA – LCA for BREEAM UK tool**: This is an official BRE-approved LCA in compliance with ALL BREEAM UK versions, including BREEAM UK NC 2018, BREEAM UK NC 2011, BREEAM UK NC 2014, BREEAM UK RFO 2014 for Mat 01 Life cycle impacts. It allows achieving the full available credits in every BREEAM version, including in the UK RFO the full 100 % of potential score in the Mat 01 calculator (including exemplary credit) in all the above schemas.
- **One Click LCA – LCA for BREEAM UK IMPACT-compliant tool:** This is an IMPACT-compliant LCA application according to IMPACT v5, intended for use for with BREEAM UK New Construction 2011, 2014 and 2018 for the Mat 01 credits. This database includes a limited amount of materials to allow for comparison between the projects.
- **One Click LCA – Whole life carbon assessment, RICS tool:** This tool meets the RICS professional standards and guidance, whole life carbon assessment for the built environment 1st edition, November 2017 and RIBA Embodied and whole life carbon assessment for architects.
- **One Click LCA – Whole life carbon assessment, Greater London Authority tool:** This tool meets the RICS professional statement and guidance, whole life carbon assessment for the built environment 1st edition, November 2017 and RIBA Embodied and whole life carbon assessment for architects.

The 'Whole life carbon assessment, RICS' tool within One Click LCA is recommended for the purpose of the new policy, as it is aligned with the RICS guidance and its database has a considerable amount of options from the UK market.

Regarding retrofitting developments, there are currently no specific benchmarks for this category. Instead, they are usually benchmarked against the embodied carbon targets for the new

[9] A drawback of the One Click LCA software, as highlighted by Simon Sturgis, is that it provides generally low estimates for modules B1-B5.

developments. This way, they are given a significant advantage in terms of compliance. Following a similar approach in the new embodied carbon policy could encourage developers to consider the option of retaining and retrofitting existing structures over demolishing.

During the early stages of the design, a free tool to be considered is the FCBS Embodied Carbon Tool. This tool:

- Reports both operational and embodied carbon emissions (whole life carbon scope)
- Assesses carbon emissions in a simple way - and is therefore more appropriate for very early stages because:
  - It calculates automatically the material quantities depending on some very basic dimensions/area/floor inputs
  - It has a small variety of available materials per building element
  - It doesn't offer the option of inserting your specific EPD product if needed (as far as I know), which becomes increasingly important in the final design stages
  - It focuses only on two typologies: Housing (flat, single family house, multi-family with >6 storeys, 6-15 storeys or >15 storeys) and Offices
- Reports carbon sequestration from timber products
- Calculates the hectares of British woodland required to offset the residual carbon. This may seem unrelated if the upcoming offsetting study ends up indicating different or additional uses for the offset fund

Therefore, the FCBS Embodied Carbon Tool could be considered for an early stage assessment (i.e. outline planning application stage) when there are not always enough detailed information for the design.

REPORTING TOOL

Along with the 'Embodied Carbon Target Alignment' document, an excel file for reporting was created. This is free for everyone to use to encourage common reporting standards across the industry. Therefore, it is advised for this tool to be recommended by the new NZB policy.

BREEAM CONSIDERATIONS

The BREEAM Mat 01 assessment on the 'Environmental impacts from construction products - Building life cycle assessment (LCA)' consists of three parts:

- **Comparison with BREEAM LCA benchmark:** This benchmarking is done in ecopoints units, instead of $kgCO_2/m^2$ that is used from RIBA and LETI. This benchmarking exercise is applicable only for the typologies of the office, industrial and retail buildings. For the other building types it is excluded, and the same numbers of credits is available for the Option Appraisal alone. For this assessment is it required to use an IMPACT-compliant tool (i.e. One Click LCA - LCA for BREEAM UK IMPACT-compliant tool). For comparison with the BREEAM LCA benchmark, the number of credits awarded depends on the environmental impacts of the building compared with the BREEAM LCA benchmark.
- **Option Appraisal:** This is obligatory for Superstructure and optional for Substructure and Hard Landscaping categories. A short series of alternative options (2 to 4 for Concept design and 2 to 3 for Technical design stage) is developed and explained why it has been included or excluded from the final design. For this assessment is it not required to use an IMPACT-compliant tool, so

for example the One Click LCA - LCA for BREEAM UK tool could be used which offers a larger variety of materials in its material database. For option appraisal, the number of credits depends on the number of design options included in the options appraisal.

- **Other exemplary level criteria:** This category includes additional credits that could be pursued for a higher credit score. These are applicable for all building typologies and are:
    - Options Appraisal for Core Building Services during Concept design stage (1 credit)
    - LCA and LCC alignment (1 credit)
    - Third party verification (1 credit)

The scope for BREEAM Mat 01 is a limited version of the RICS Whole Life Carbon scope. It is similar with the Extended scope of this assessment with the difference lying in the further exclusion of balconies, internal doors and internal finishes.

The system with the ecopoints that BREEAM uses for the comparison with BREEAM LCA benchmark is more difficult to understand when compared with the $kgCO_2/m^2$ targets that are used from RIBA and LETI. Additionally, the methodology allows for a project to fail the comparison with BREEAM LCA benchmark but still earn some credits for undertaking the options appraisal. Therefore, it is not the most straightforward methodology to lead the pursue of 'Embodied Carbon Target Alignment' targets for net zero developments.

A recommendation would be for the NZB policy to instruct a Whole Life Carbon (WLC) assessment (i.e. as per Embodied Carbon Target Alignment), to promote carbon literacy and wholistic thinking on reducing emissions. Then this WLC assessment could feed into any BREEAM credits targeted by each design team (i.e. Mat 01, Mat 02, Mat 03, Mat 05 etc.). BREEAM could therefore be considered as a complementary assessment to the requirements for the net zero carbon policy, which aims to ensure that developments consider sustainability in a holistic way.

CONCLUSIONS

Some key conclusions to be considered on how the embodied carbon of new developments could be reduced are:

- For the buildings which start with a steel frame structure baseline (office and school in this study), the solutions of hybrid timber structure or mass timber structure will have the larger carbon reductions when applied separately to the baseline. These will be 12-14% carbon reduction for hybrid timber structure and 24-25% for the mass timber structure. Low carbon facades will have the third larger carbon reduction (9-10%).

- For the buildings which start with a concrete frame structure baseline (apartment block in this study), the solution of mass timber structure will have the larger carbon reduction (14%) when applied separately to the baseline. Low carbon facades will have the second larger carbon reduction (11%).

- For the buildings which start with a load bearing masonry walls structure baseline (semi-detached house in this study), the solution of Low carbon facades will have the larger carbon reduction (26%) when applied separately to the baseline. Timber stud bearing walls will have the second larger carbon reduction (6%).

- Low carbon concrete (with as high cement replacement as possible) should always be examined by the design team, as it can be a zero cost uplift measure. Cement replacement in concrete components is the most obvious measure as this study showed that it is associated with zero cost uplift. The results indicate that 40% cement replacement can lead to a carbon reduction between 1-2%, when compared to a baseline of 20% cement replacement. However, depending on the concrete quantities and the cement replacement of the baseline this carbon reduction percentage could be higher. Therefore, the option of cement replacement in concrete elements should always be examined in the early design stages in close collaboration with the structural engineers, so that related opportunities can be embedded in the design process.

- For the structural elements of a building, the combined option of a glulam frame with CLT floors and low carbon concrete (S4) has a lower cost uplift per tonne of carbon saved than the hybrid timber option (steel structure with CLT-S2) and the hybrid timber option with low carbon concrete (S3). Therefore, there is a relative cost benefit in the option of mass timber structure over the hybrid timber structure.

- For the non-structural elements of a building, there is a relative cost benefit per carbon saved when considering both low carbon interiors and low carbon facades, in comparison with considering only low carbon facades. The second lowest cost measure is the low carbon interiors, which is associated with a 0-1% cost uplift (cost change from Scenario 5 to Scenario 6). For the domestic typologies this option includes timber stud walls (instead of standard steel stud or brick walls) and could lead to a 1-4% carbon reduction from baseline. For the non-domestic typologies, low carbon interiors additionally include omitting ceiling systems and finishes. This naturally cost reducing solution is advised to be explored by new non-domestic developments, as it can bring a 5-6% carbon reduction from the baseline.

- Regarding the cost uplift per target achieved, when following the latest Embodied Carbon Target Alignment work (recommended benchmark scheme):
    - Office - Whole Life Embodied Carbon: The office complies with the letter bandings C and B with a 0% cost uplift (weighted). The cost uplift to comply with the A rating is 16%.
    - School - Whole Life Embodied Carbon: The school complies with the letter banding C with a 0% cost uplift (weighted). The cost uplift to comply with the B rating is 7%. The cost uplift to comply with the A rating is 15%.
    - Apartment Block - Whole Life Embodied Carbon: The Apartment Block complies with the letter bandings C and B with a 0% cost uplift (weighted). The cost uplift to comply with the A rating is 9%.
    - Semi-detached house - Whole Life Embodied Carbon: The semi-detached house complies with the letter banding C with a 0% cost uplift (weighted). The cost uplift to comply with the B rating is 3%. The cost uplift to comply with the A rating is 15%.
    - It should be noted that the in-scope building elements from our assessments are more limited than the in-scope building elements from the benchmarks of Embodied Carbon Target Alignment work.

Table 4-1 – Cost uplift per typology to comply with the letter banding targets of Embodied Carbon Target Alignment work

Building Typology	D, E, F, G	C	B	A	A+, A++
Whole Life Embodied Carbon (A-C)					
Office	0%	0%	0%	16%	*No compliance*
School	0%	0%	9%	15%	*No compliance*
Apartment Block	0%	0%	0%	9%	*No compliance*
Semi-detached house	0%	0%	3%	15%	*No compliance*

- The modelling conducted for the office and the apartment block shows similar reduction rates with the measures applied with the UKGBC's work on 'Building the case for Net Zero'. However, the absolute embodied carbon per floor area in our modelling is lower than the UKGBC's results. This comparison highlights the fact that each building has unique complexities and therefore a unique pathway is required to comply with embodied carbon targets.

Finally, we have attempted to shape some policy considerations:

- Scope of the assessment: It is recommended for the scope of the lifecycle carbon assessment instructed by the new NZB policy to be aligned with the 'Embodied Carbon Target Alignment' work. This new framework aims to provide a rationalised common way to measure and report embodied carbon emissions from new developments and aligning with it is the most forward-thinking approach. According to this document, the proposed scope includes all lifecycle stages and building elements (Whole Life Carbon scope, incl. sequestration), but also reports separately the Upfront embodied carbon (stage A only, excl. sequestration). Any benefit from future reuse/recycling of the building components is reported also separately as Module D. This is the most complete scope and it fuels innovative thinking encouraging developers to think about the lifespan of the components and materials used, and therefore prioritise durability and responsible end-of-life. It should be noted that the current assessment follows a more limited scope

- Reporting tool: Along with the 'Embodied Carbon Target Alignment' document, an excel file for reporting was created. This is free for everyone to use to encourage common reporting standards across the industry. Therefore, it is advised for this tool to be recommended by the new NZB policy.

- Targets: The findings of this study showed that an embodied carbon rating C can be achieved with zero cost uplift for all four building typologies. It should be highlighted again that this finding follows the scope of this study, and not the RICS scope followed to the 'Embodied Carbon Target Alignment'. Therefore, if all building elements where accounted for, then the embodied carbon rating achieved is likely to be lower (D-E). The rating C is also marked by guidance as the current *good* building design standard, while rating E is also marked as the current *average* building design standard. A recommendation for the new NZB policy would be to encourage all developments to reach rating C, while allowing the opportunity to explain why any variations from it if they exist. Moreover, an aspirational target of A rating could be proposed to inspire innovation, accompanied by the cost uplifts found by this study (Table 4-1), as per the described scope.

- BREEAM: A recommendation would be for the NZB policy to instruct a Whole Life Carbon (WLC) assessment (i.e. as per Embodied Carbon Target Alignment), to promote carbon literacy and wholistic thinking on reducing emissions. Then, this WLC assessment could feed into any BREEAM credits targeted by each design team (i.e. Mat 01, Mat 02, Mat 03, Mat 05 etc.). BREEAM could therefore be considered as a complementary assessment to the requirements for the net zero carbon policy, which aims to ensure that developments consider sustainability in a holistic way.

Appendix A

MODELLING DETAILS

Table A1 – Office and School – Modelling Details for baseline and alternative scenarios (Steel frame baseline)

Office/School						
CATEGORY	**S1 - Baseline - Steel Structure**	**S2 - Hybrid Timber**	**S3 - Low Carbon Structure**	**S4 - Timber frame (mass timber)**	**S5 - Low Carbon Facades**	**S6 - Low Carbon Int. Finishes**
STRUCTURE						
Frame (Columns/Beams)	Steel	Steel	Concrete precast - Low carbon	Glulam	Glulam	Glulam
Foundation	Concrete in-situ piles	Concrete in-situ piles - 25% less volume than S1	Concrete in-situ piles - Low carbon - 25% less volume than S1	Concrete in-situ piles - Low carbon - 35% less volume than S2	Concrete in-situ piles - Low carbon - 35% less volume than S2	Concrete in-situ piles - Low carbon - 35% less volume than S2
GF slab	Concrete In-situ	Concrete In-situ	Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon
Upper floor slabs	Composite deck floor slab	CLT	CLT	CLT	CLT	CLT
Roof slab	Composite deck floor slab	CLT	CLT	CLT	CLT	CLT
Staircase	Concrete precast	Concrete precast	Concrete precast - Low carbon	Concrete precast - Low carbon	Concrete precast - Low carbon	Concrete precast - Low carbon
SKIN (External walls, Finishes)						
GF-Insulation	EPS	EPS	EPS	EPS	EPS	EPS
Wall - External layer	Bricks / Mortar	Bricks / Mortar	Bricks / Mortar	Bricks / Mortar	Treated wood cladding	Treated wood cladding
Wall - Insulation	Rockwool	Rockwool	Rockwool	Rockwool	Rockwool	Rockwool

Wall - Internal layer	Concrete blocks - lightweight	Concrete blocks - lightweight	Concrete blocks - lightweight	Concrete blocks - lightweight	Timber studs	Timber studs
Wall - Internal layer	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster
Roof - Covering	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof
Roof - Insulation	EPS 100%	Glasswool 75% + EPS 100%	Glasswool 75% + EPS 100%	Glasswool 75% + EPS 100%	Glasswool 75% + EPS 100%	Glasswool 75% + EPS 100%
Ext. Windows	Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Timber frame	Triple Glazed - Timber frame
Ext. Door	Aluminium framed glazed	Aluminium framed glazed	Aluminium framed glazed	Aluminium framed glazed	Aluminium framed glazed	Aluminium framed glazed
SPACE (Internal walls, ceilings, floors, doors)						
Internal wall	Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on timber studs / Paint
Internal wall - Insulation	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm
Floor finish	Vinyl flooring - 25%	Vinyl flooring - 25%	Vinyl flooring - 25%	Vinyl flooring - 25%	Vinyl flooring - 25%	Vinyl flooring - 25%
Floor finish	Carpet tiles - 70%	Carpet tiles - 70%	Carpet tiles - 70%	Carpet tiles - 70%	Carpet tiles - 70%	Linoleum
Floor finish	Ceramic tiles - 5%	Ceramic tiles - 5%	Ceramic tiles - 5%	Ceramic tiles - 5%	Ceramic tiles - 5%	Ceramic tiles - 5%
Ceiling finish	Plasterboard	Plasterboard	Plasterboard	Plasterboard	Plasterboard	-
Internal doors	Wood	Wood	Wood	Wood	Wood	Wood

Table A2 – Mid Rise Apartment block – Modelling Details for baseline and alternative scenarios (Concrete frame baseline)

Mid-rise Apartment Block					
CATEGORY	**S1 - Baseline - Concrete Structure and Floor**	**S3 - Low Carbon Structure**	**S4 - Timber frame (mass timber)**	**S5 - Low Carbon Facades**	**S6 - Low Carbon Int. Finishes**
STRUCTURE					
Frame (Columns/Beams)	Concrete precast	Concrete precast - Low carbon	Glulam	Glulam	Glulam
Foundation	Concrete in-situ piles	Concrete in-situ piles - Low carbon - 15% less volume than S1	Concrete in-situ piles - Low carbon - 20% less volume than S2	Concrete in-situ piles - Low carbon - 20% less volume than S2	Concrete in-situ piles - Low carbon - 20% less volume than S2
GF slab	Concrete In-situ	Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon
Upper floor slabs	Concrete Hollowcore	Concrete Hollowcore	CLT	CLT	CLT
Roof slab	Concrete Hollowcore	Concrete Hollowcore	CLT	CLT	CLT
Staircase	Concrete precast	Concrete precast - Low carbon	Concrete precast - Low carbon	Concrete precast - Low carbon	Concrete precast - Low carbon
SKIN (External walls, Finishes)					
GF-Insulation	EPS	EPS	EPS	EPS	EPS
Wall - External layer	Bricks / Mortar	Bricks / Mortar	Bricks / Mortar	Treated wood cladding	Treated wood cladding
Wall - Insulation	Rockwool	Rockwool	Rockwool	Rockwool	Rockwool
Wall - Internal layer	Concrete blocks - lightweight	Concrete blocks - lightweight	CLT	CLT	CLT
Wall - Internal layer	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster
Roof - Covering	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof	Aluminium standing seam roof

Roof - Insulation	EPS 100%		EPS 100%	Glasswool 75% + thin layer of EPS 100%	Glasswool 75% + thin layer of EPS 100%	Glasswool 75% + thin layer of EPS 100%
Ext. Windows	Triple Glazed - Aluminum frame		Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Timber frame	Triple Glazed - Timber frame
Ext. Door	Aluminium framed glazed doors		Aluminium framed glazed doors	Aluminium framed glazed doors	Aluminium framed glazed doors	Aluminium framed glazed doors
SPACE (Internal walls, ceilings, floors, doors)						
Internal wall	Plasterboard on steel studs / Paint		Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on steel studs / Paint	Plasterboard on timber studs / Paint
Internal wall - Insulation	Glasswool 100mm		Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm
Floor finish	Vinyl flooring		Vinyl flooring	Vinyl flooring	Vinyl flooring	Linoleum
Floor finish	Carpet tiles		Carpet tiles	Carpet tiles	Carpet tiles	Carpet tiles
Floor finish	Ceramic tiles		Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles
Ceiling finish	Plasterboard		Plasterboard	Plasterboard	Plasterboard	Plasterboard
Internal doors	Wood		Wood	Wood	Wood	Wood

Table A3 – Semi-detached house – Modelling Details for baseline and alternative scenarios (Load bearing walls baseline)

Semi-detached house						
CATEGORY	**S1 - Baseline**	**S2 - Hybrid Timber**	**S3 - Low Carbon Concrete**	**S4 - Timber frame (sawn timber)**	**S5 - Low Carbon Facades**	**S6 - Low Carbon Int. Finishes**
STRUCTURE						
Frame (Columns/Beams)	Timber		Timber	Timber	Timber	Timber
Foundation	Footing foundation		Footing foundation	Footing foundation	Footing foundation	Footing foundation
GF slab	Concrete In-situ		Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon	Concrete in situ - Low carbon

GF Insulation	EPS	EPS	EPS	EPS	EPS
Upper floor slabs	Timber	Timber	Timber	Timber	Timber
Upper floor Insulation	Glasswool	Glasswool	Glasswool	Glasswool	Glasswool
Roof slab	Timber	Timber	Timber	Timber	Timber
Staircase	Timber	Timber	Timber	Timber	Timber
Balcony	Timber	Timber	Timber	Timber	Timber
SKIN (External walls, Finishes)					
GF-Insulation	EPS	EPS	EPS	EPS	EPS
Wall - External layer	Brick slips / Mortar	Brick slips / Mortar	Brick slips / Mortar	Treated wood cladding	Treated wood cladding
Wall - Insulation	Rockwool	Rockwool	Rockwool	Glasswool	Glasswool
Wall - Internal layer	Concrete blocks - lightweight	Concrete blocks - lightweight	Concrete blocks - lightweight	Timber frame	Timber frame
Wall - Internal layer	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster	Plasterboard / Plaster
Roof - Covering	Clay roofting tiles	Clay roofting tiles	Clay roofting tiles	Clay roofting tiles	Clay roofting tiles
Roof - Insulation	Glasswool	Glasswool	Glasswool	Glasswool	Glasswool
Ext. Windows	Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Aluminum frame	Triple Glazed - Timber frame	Triple Glazed - Timber frame
Ext. Door	Wood	Wood	Wood	Wood	Wood
SPACE (Internal walls, ceilings, floors, doors)					
Internal wall	Load bearing block wall	Load bearing block wall	Plasterboard on timber studs / Paint	Plasterboard on timber studs / Paint	Plasterboard on timber studs / Paint
Internal wall - Insulation	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm	Glasswool 100mm
Floor finish	Carpet tiles (80%)	Carpet tiles (80%)	Carpet tiles (80%)	Carpet tiles (80%)	Linoleum
Floor finish	Ceramic tiles (20%)	Ceramic tiles (20%)	Ceramic tiles (20%)	Ceramic tiles (20%)	Ceramic tiles (20%)
Ceiling finish	Plasterboard	Plasterboard	Plasterboard	Plasterboard	Plasterboard
Internal doors	Wood	Wood	Wood	Wood	Wood

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