STRIDE TREGLOWN

ASSESSING THE EMBODIED EMISSIONS FOR HOMES AT GWYNFAEN

MARCH 2021

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1. Introduction

Background to project and LCA requirements

Gwynfaen central green

1.1. Background

Coastal Housing Group and Pobl Group are collaborating to deliver a new housing development of approximately 144 homes to the west of Swansea. The site, known locally as Gwynfaen Farm, is located adjacent to the villages of Loughor and Penyrheol, overlooking the Gower Peninsula.

The site is formed by two contiguous parcels of undeveloped land to the west of Gower View Road currently owned by the Welsh Government and the City and County of Swansea. It has been identified as a site for housing development within the Local Development Plan.

Coastal and Pobl are aiming to deliver a high quality residential development underpinned by a strong vision of a place with a Green Infrastructure led masterplan. There are high aspirations in respect of the decarbonisation agenda; the dwelling design will be a key component of this approach.

The project is part funded by the Welsh Government's Innovative Housing Programme (IHP) Round 3. Homes are to be split as two thirds affordable (split between, Intermediate rent, low cost home ownership and Social Rental Housing) and one third market housing.

1.2. Client brief

Coastal and Pobl sought an architect to work hand in hand with the scheme masterplanners to develop the scheme and design house type designs for the project. The house type design requirements can be summarised as follows:

- All homes designed to meet an EPC 'A' and a SAP score of 96 or above
- The dwellings should take a fabric first strategy to design, with energy conservation and sustainability at its core
- Architectural proposals should be of a high quality and reflect local vernacular, but avoid pastiche design, and utilise local materials
- Consideration of the Well-being of Future Generations Act and its implications for the design and specification
- Consider integration of low carbon technologies and/or Passivhaus type principles
- Consider capital/lifecycle cost conscious design
- Design homes which meet Development Quality Requirements (DQR Wales), Lifetime Homes and Secured by Design.

1.3. Innovative Housing Programme

The IHP funding programme has been developed to help inform the Welsh Government about the type of homes it should financially support in the future. It is open to schemes across Wales from registered social landlords (RSLs) and local housing authorities (LHAs), including local authority owned companies, and both private sector organisations and social landlords.

Schemes are evaluated against the Technical Specification by an Independent Assessment Panel. They will make recommendations to Welsh Ministers on the schemes to be supported. Supported innovations in Year 3 need to demonstrate innovations that have not been previously tested (or demonstrate a significant scaling up of previous innovation in ways that are cost competitive), and drive local benefits and to do this in a way that aligns the design and delivery of affordable housing with the seven goals of the Well-being of Future Generations (Wales) Act (WFGA).

Successful projects were required to demonstrate innovation in one, but not more than three of seven possible focus areas. Gwynfaen focused on CO2, Energy and Place. The following pages set out the proposals in relation to each focus area in turn. Part of the innovation also links to decarbonisation and health agendas – selecting products that have a lower CO2 impact and are breathable to promote healthier buildings internally.

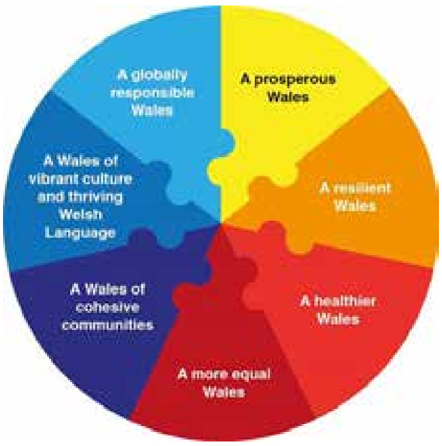
1.4. Life Cycle Asessment

At Stride Treglown we always aim to design with a fabric first approach in mind and with SAP or Passivhaus methodologies it is possible to quantify and verify the performance of our buildings in terms of operational energy use.

Up until now we have had to rely on intuition and limited information in order to specify materials, processes and products which we believe to be inherently low in embodied energy and carbon. As a result we have found it increasingly frustrating that we are not able to rely on a similar standard of assessment in order to ascertain the most appropriate options for each given project. We wish to find a way of generating an understanding of embodied energy figures in the same way that we currently do for operational energy data.

The carbon impacts related to the production of materials and construction stages of a building are significant, in some cases accounting for half of a new building's whole life carbon impacts. By tackling these carbon impacts initially with conscious design and specification, a staged approach may be set to arrive at Net Zero Carbon Buildings. This approach is supported by the UK Green Building Council as published in 'Net Zero Carbon Buildings: A Framework Definition'. The concept is to design buildings with very low operational energy requirements so that the amount of carbon emissions associated with a building's product and construction stages up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy.

To this end we have undertaken whole life carbon assessments to determine the carbon impact, in line with the RICS Professional Statement 'Whole life carbon assessment for the built environment'. This would provide a clearer picture of a building's embodied energy emissions. In this we are considering transport emissions concerns, we aim to source materials as locally and sustainably as possible, therefore reducing the embodied energy of the materials and products by minimising transportation emissions and road miles.



The Well-being of Future Generations Act became law in Wales on the 29th April 2015. The Act puts in place seven well-being goals (above).

The goals mapped to benefits associated with housing with resulting IHP focus areas (right). Source: Innovative Housing Programme Delegate Pack Feb 2019, Welsh Government.

1.5. Timber frame and Welsh timber

It is proposed homes at Gwynfaen will be constructed using a local timber frame manufacturer using timber sourced from Welsh forests. Using UK or Welsh grown timber reduces embodied energy and contributes to the local culture and economy and stimulates the expansion of managed forests to absorb CO2.

Research has been undertaken supported by Woodknowledge Wales to identify the range of timber construction systems or techniques that are available for use in Wales and to identify the extent to which Welsh-grown softwoods could be utilised in their production.

Timber frames can be designed to accommodate significant thicknesses of insulation within a supporting structure to allow low U-values to be delivered. Timber construction permits increased productivity and higher build quality through prefabrication of panels within controlled factory environments independent of site conditions. Mechanisation, production line working and improved working conditions can reduce waste and increase work rates by using modern methods of construction (MMC); combining efficient design, factory assembly and rapid erection of structures.

It was found wall construction methods such as, open panel, closed panel and twinwall can be utilised for mass housing by mainstream Welsh timber engineering firms using Welsh-grown C16 strength graded Sitka spruce or larch from BSW Timber Ltd at Newbridge on Wye and Pontrilas Sawmill near Hereford. Consistency of timber quality, availability of supply and traceability has been raised as potential pitfalls by some timber engineering firms and these issues will need to be worked through at technical design stages.

1.7. Reducing waste

Although construction waste and end of life waste disposal only contribute a relatively small proportion of the overall energy emissions figures, they remain an important consideration. Where possible we have strived to minimise waste through responsible design to limit material wastage. For example designing with the size of sheet materials and standard timber lengths in mind. In addition we are considering the use of materials with high recycled content, for example reconstituted slate made from 60% recycled Welsh slate.

1.8. Choice of insulant

Minimising operational energy and taking a fabric first approach to design is essential for low or zero carbon homes. Passivhaus levels of thermal performance (achieving average U-values less than 0.15 W/m2 K) will be a requirement for Gwynfaen. Polyurethane rigid foam (PUR for short) or Polyisocyanurate (PIR for short) are typical high performance insulants employed as a way of achieving U-values less than 0.15 W/m2 K with minimal impact on resulting wall thicknesses. However, there is no doubt that these types of Oil-derived insulation materials have a more notable environmental impact during their life cycle than others. The use of petrochemicals in manufacture causes resource depletion and pollution risks from oil and plastics production. Embodied energy of insulants becomes particularly important when high levels of operational energy efficiency are to be achieved as larger volumes of insulant material will be required.

At Gwynfaen when selecting an insulation material, primacy will be given to performance in the construction context. Very few insulation materials are capable of performing all the functions called for, for example insulants below DPC level need to be water impermeable. Never-the-less the choice of insulation is intrinsic to wall and floor components which are a major contributor to the embodied CO2 impact.

1.6. Materials

Structural C16 timber to be sourced from FSC managed Welsh woodlands.

Highly insulated and airtight offsite prefabricated timber wall panels delivering a U-value less than 0.15 W/m2K and Airtightness of 1 m3/hr/m2.

Home grown timber cladding or render finishes (no masonry).

Reconstituted slate roofs made from 60% recycled slate.

No PUR/PIR foams.

Wood fibre insulation.

1.9. Environmental Product Declarations (EPDs)

Ideally, each material would be accompanied by an Environmental Product Declaration (EPD) which is an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products. In reality, this is nowhere near possible as available data is often limited. Therefore at Gwynfaen we will avoid where possible insulants derived from petrochemicals, select products which have a reduced environmental impact or can provide an EDP, that are less harmful to work with, but also emit no undesirable chemicals once installed.

At the lower target U-value of sub 0.15 W/m2K wall timber frame systems can be offered with wood fibre or cellulose fibre insulants. Standard open or closed timber frame constructions approach 400mm at this U-value but the advantage is these types of products are hygroscopic and provide a degree of humidity control as part of a breathable wall construction. They also sequester CO2 during tree growth.

1.10. Concrete, ground floors and foundations

Foundations, substructures and ground floors can be a large contributor to overall embodied CO2 impact. Most people are aware of the significant contribution to global warming made by the worldwide cement and concrete industry. Yet the very ubiquity of concrete is due to its capacity to provide low cost, strong and durable structures. There are a number of methods we are employing at Gwynfaen to move towards a 'greener' use of concrete.

Considering the reduction of ground floor area is one way in which the amount of concrete required can be reduced. Three storey houses are employed at Gwynfaen, they are footprint efficient and a practical way of providing four or more bedrooms.

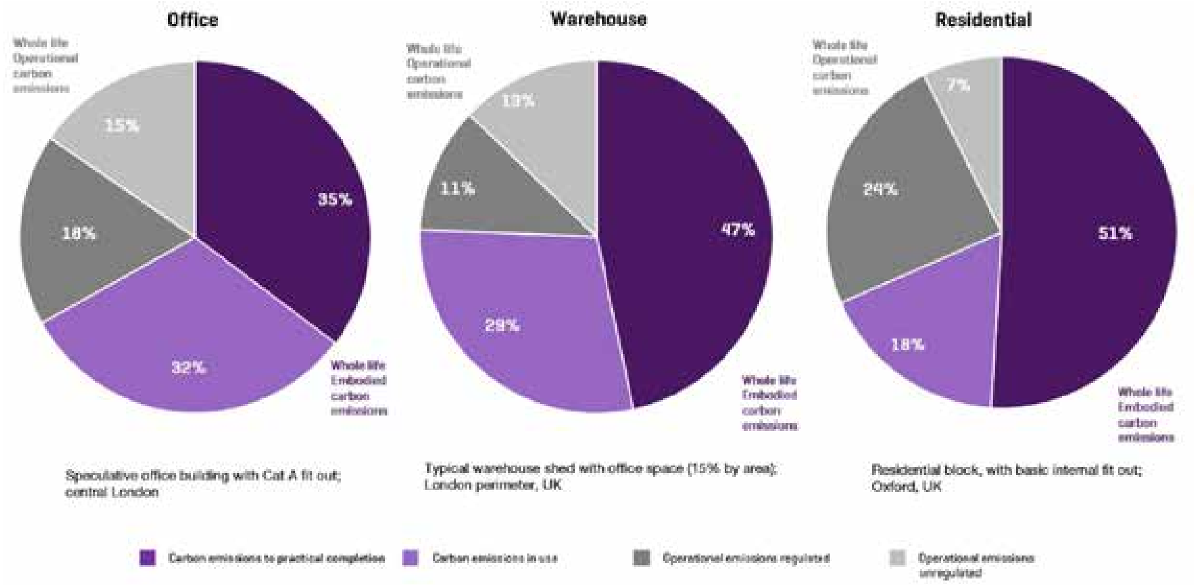
Producing cement uses a great deal of energy, so finding a waste product that can substitute for cement makes good environmental sense. Ground Granulated Blast-furnace Slag (GGBS) is a cement substitute and a by-product of the iron and steel industry. It is always used in combination with Portland cement, typically in the range 70% Pc and 30% GGBS. At technical design stages we will review how substitutes for cement can be used at Gwynfaen.

1.11. Summary

The built environment industry has so far been addressing mainly operational emissions via reduction targets in building regulations (Part L) with the embodied aspect of carbon emissions not being fully addressed. The reduction of operational energy use is still very much the priority but to acquire an overall understanding of a built project's total carbon impact, it is necessary to assess both the anticipated operational and embodied emissions over the whole life of the asset.

Operational emissions result from energy consumption in the day-to-day running of a property, while embodied emissions arise from producing, procuring and installing the materials and components that make up a structure. Considering operational as well as embodied carbon emissions together is a holistic approach which, if employed and embraced widely, may have a better chance of meeting our CO2 reduction targets in the near future. This is because much of the embodied emissions are so called 'upfront' emissions which impact climate change now.

We hope the following analysis of this project may serve to demonstrate that this potential is already within reach, while also being affordable and providing desirable places to live in.



Typical percentages of Whole life carbon for offices, warehouses and residential.

Source: Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017).

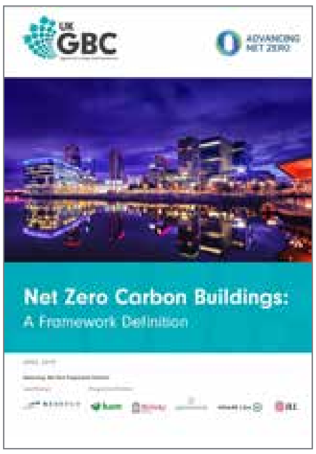
2. Methodology

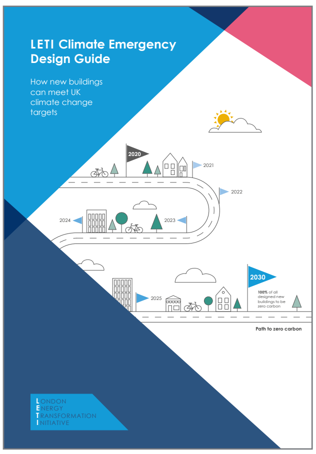
RICS Whole life, BIM and One Click LCA

2.1. RICS Whole Life Carbon Assessment

Life Cycle Assessment (LCA) is a method of evaluating the environmental impact of construction processes and buildings during their life cycle from cradle to grave. It attempts to identify the environmental effects during all stages of the life of a building, and produces figures that represent the environmental and carbon impact.

The publication Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017) is at time of writing the leading methodology based on EN 15978 in the UK and is referenced in the UKGBC framework guidance on Net Zero launched in July 2019 and LETI Climate Emergency Guides. This method has been adopted for the purpose of this analysis.





Above and left: Sources forming the reference point for LCA methodology and reporting: Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017); UKGBC Net Zero Carbon Buildings: A Framework Definition 2019 and LETI Climate Emergency Design Guide Jan 2020.

2.2. BIM and One Click LCA

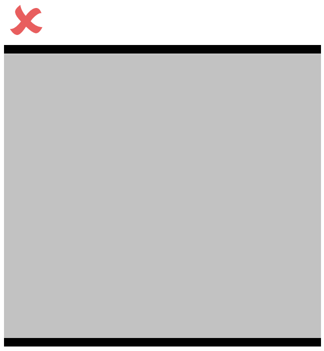
We have been Building Information Modelling (BIM) advocates and operators since 2005. We use Revit software and are the largest licence holder in the UK. Building Information Modelling (BIM) is a process. It is a way of designing, drawing and producing information for the design, construction and maintenance of buildings. It is about the flow of data between stages across the project's life, from inception to demolition. Having Life Cycle Assessment integrated within our architectural work flows has potential to significantly improve our ability to transition to a net zero carbon built environment as decisions of specification can be tested in a live model.

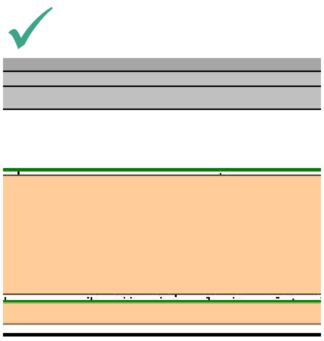
One Click LCA is a web based software and Revit plug-in that runs on Environmental Product Declaration (EPD) data. This is essentially an externally verified and standardized description of the environmental profile of any product. Having an EPD for a product does not necessarily mean that the product is environmentally better than others, but it is a way to obtain transparent information on the environmental impact of the product during its whole lifetime. In addition if the material that you wish to use doesn't have an EPD, and the manufacturer doesn't plan to create one any time soon, One Click LCA allows you to search for an equivalent material or find a generic dataset for it, for example by using the ICE (Inventory of Carbon and Energy) Database.

Material mapping can be associated directly via the Revit plug-in, or the One Click web browser which allows for more refined selections. Over time LCA learns your common selections making the process quicker. LCA One Click recognises Revit materials, calculates the volume of material within the model and maps to your chosen EPD or generic datapoint. One Click LCA incorporates various useful prompters and Workflow checklists to build the required LCA assessment.

3. How does it work?

BIM for LCA purposes





Ensure construction build-ups are as accurate as possible.

3.1. BIM modelling for LCA purposes

Using BIM models to identify the different quantities for LCAs is likely to be less time consuming than a manual take-off. BIM LCA offers the potential to assess multiple options with relative speed and become an integrated part of the design and specification process.

However, the resulting Life Cycle Assessment will only be as accurate as the BIM model itself; the data is used on a "as it is" basis. Therefore rubbish in equals rubbish out!

The main goal is to ensure that the BIM model contains sufficient information for LCA purposes. Great care and precision must be given to the elaboration of the 3D model as it will directly impact on the LCA results.

3.2. Elaboration of the BIM model

Revit models materials in walls and floors monolithically in layers and this is satisfactory for normal usage. However, using direct volumes for LCA work could result in inacurate quantities in some instances. For example, in the case of framed walls a percentage of the volume would be the frame material with the remaining volume either insulation or in some internal walls an air space. Materials also need to be labeled correctly and understandably in the Revit model to enable consistant mapping to EPD databases more easily.

At concept stages external walls may be simplified and presented as a solid material e.g. 'default wall 300mm', even if it consists of at least four discrete layers of materials, possibly more. Suitable construction build-ups need to reflect reality as much as possible which can make concept stage embodied carbon analysis problematic.

For Gywnfaen to ensure confidence in the results detailed modelling was undertaken for certain elements including foundations, substructures, ground floor system and superstructure. This process began at RIBA Stage 3 and was developed further to RIBA Stage 4.

One house typology has been modelled in a far greater level of detail in Autodesk Revit. The following sections detail some of the areas of elaboration of the 3D model to inform typical constituent percentages which were then applied to subsequent house types forming part of the LCA study. A summary of findings is presented in Appendix 1.

Function	Material	Thickness
Finish 2 [5]	Wood_Timber_Cladding_Vertical_Western Red Cedar	25.0
Finish 1 [4]	Structure - Timber Batten Layer	25.0
Finish 1 [4]	Structure - Timber Batten Layer	38.0
Thermal/Air Layer [3]	Insulation - Wood Fibre Batt insulation	100.0
Core Boundary	**Layers Above Wrap**	**0.0**
Structure [1]	OSB Board	11.0
Structure [1]	Structure - Timber /Wood Fibre Insulation Layer	200.0
Structure [1]	SmartPly Airtight Board	12.0
Core Boundary	**Layers Below Wrap**	**0.0**
Substrate [2]	Structure - Timber /Glass Fibre Insulation Layer	38.0
Finish 1 [4]	Finishes - Interior - Plasterboard	15.0
Finish 2 [5]	Finishes - Interior - Plaster	3.0

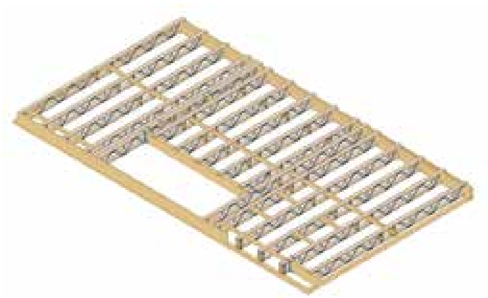
Naming of materials is critical for identification.

3.3. Timber fraction for timber framed external walls

For conventional timber frame construction the default fraction for the timber frame element is 0.15 (15%). This is based on 38mm timbers at 600mm centres for one-storey and two-storey buildings. *Anderson, B., Conventions for U-value calculations, (2006).* For advanced framing this can be reduced circa 12%.

The current supply and production of Welsh-grown softwood is structurally graded at C16. Any innovations with Welsh-grown softwood must work within standard sawn sizes. For the required U-value Sawn Treated Timber of C16 structural class with dimensions (L)4.8m (W)200mm (T)47mm at 600mm centres was required.

One house typology has been modelled in detail in Autodesk Revit based on manufacturer's drawings to generate an accurate timber fraction result of 0.175 (17.5%). Using the One Click LCA 'split function' as part of the software, volumes of frame filled wood fibre has been derived as 0.825 (82.5%) of remaining share.



3.4. Timber metal web floor joists

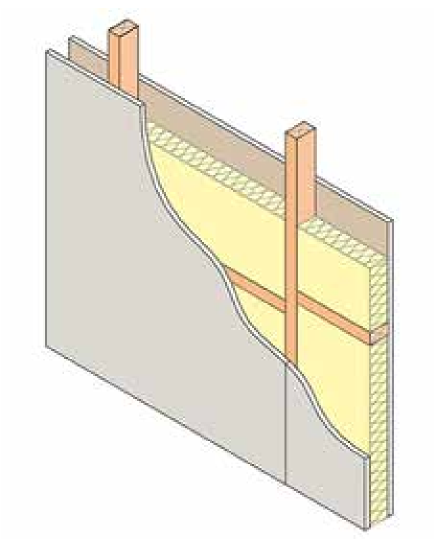
At time of writing an Environmental Product Declaration based on EN 15804 for timber metal web joists was not avaliable. Based on manufacturer's Revit components and manufacturer's drawings, the floor zone was accurately modelled including timber binders, ring beams and noggin supports. This generated the following volume/ material splits for 254mm deep joists at 600 centres:

- Galvanised steel webs/supports: 0.0015 (0.15%)
- Timber chords: 0.110 (11.0%)
- Additional sawn timber: 0.021 (2.10%)
- Air void: 0.8675 (86.75%)

If 100mm thk sound insulation added:

- Insulation: 0.39 (39%) Air Void reduces to 0.4775 (47.75%).

Generic EPD data was then mapped to the material volumes in One Click.



3.5. Internal stud partitions and battening

The timber fraction of internal partitions is typically more than what simple calculations would suggest based on stud size and centres alone. This is due to additional cripple studs and lintels for door openings, top binders and mid-support noggins. The internal partition timber framing was modelled in detail to generate a timber fraction result of 0.135 (13.5%). Where sound proofing is needed the remaining void is filled with glass mineral wool fibre, 0.865 (86.5%).

3.6. Internal batten service voids

Simple calculations were carried out for batten zones forming internal service voids. This was based on (W)38mm x (T)50mm timbers at 600mm centres. This assumed timber fraction of 0.065 (6.5%) with remaining voided filled with glass mineral wool fibre, 0.935 (93.5%).

3.7. Batten and counter battening for cladding and roofing

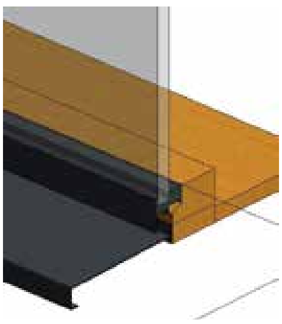
Batten and counter battens form wall and roof ventalition zones for external finishes. The roof was based on (W)50mm x (T)25mm battens at 600mm centres and (W)50mm x (T)25mm tile battens at 250mm centres. Assumed timber fraction of 0.15 (15%) with remaining air void, 0.85 (85%). The wall was based on (W)50mm x (T)50mm battens at 600 mm centres and (W)50mm x (T)50mm counter battens at 600mm centres. Assumed timber fraction of 0.083 (8.3%) with remaining air void, 0.917 (91.7%).

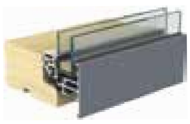
3.8. Insulated, precast concrete flooring system

Based on manufacturer's detail drawings Revit components where modelled to ensure the floor zone was accurately calculated. An Environmental Product Declaration (EPD) was not avaliable for the floor system 'Spantherm'. Specifications for the components were obtained from manufacturer's data sheets and the following volume/material splits were derived via modelling:

- Precast concrete C40/50 (inc. steel reinforcement): 0.175 (17.5%)
- Joint filling concrete C25/30: 0.175 (17.5%)
- Expanded polystyrene, graphite EPS: 0.175 (17.5%)
- Concrete floor screed 75mm thick: 0.175 (17.5%)
- Damp-proof membrane 1200 guage 0.3 mm thick: 0.175 (17.5%).

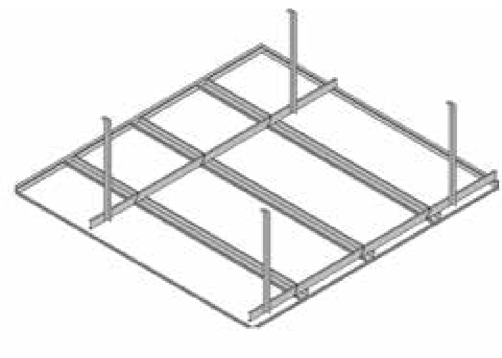
Generic EPD data was then mapped to the material volumes in One Click.





3.9. Windows, external and internal doors

Window and door Revit components are normally simplified as solid blocks. For instance, a 2 layer timber-aluminium composite window might be presented as a solid block even though it consists of solid timber and thin aluminium facings. The same applies to glass; a triple glazed unit maybe modelled as a 32mm thick solid piece of glass but 20mm of that maybe a gas cavity, therefore only 12mm of glass in total. To avoid time consuming remodelling of components, windows and doors were excluded from the model import into One Click LCA. Instead schedules were created to calculate the overall areas of doors and windows and mapped manually to revelant component level manufacturer EPDs as they existed in the database.



3.10. Metal frame ceiling system forming service voids

MF framing forms service voids below separating floors to apartments. Based on manufacturer's detail drawings Revit components where modelled to ensure the suspended ceiling was accurately calculated. This was based on light gauge galvanised steel framing at 600mm primary centres with support tracks at 450mm centres. Uprights and perimeter tracks were also modelled. The volume of steel was compared to the monolithic 'service zone' created by the framing of 263mm O/A depth in this case. The steel fraction was very small just of 0.0012 (0.12%) of the volume. Never-the-less, owing to the high embodied carbon of steel at 21628kg CO2e/m3, this equated to 7kg CO2e/m2 of ceiling area which is not insubstantial as to warrant dismissal.

Metal resilient ceiling bars mounted at 600mm centres as part of sound proofing ceiling layers 30mm deep have a steel fraction of 0.0076 (0.76%) of the volume.

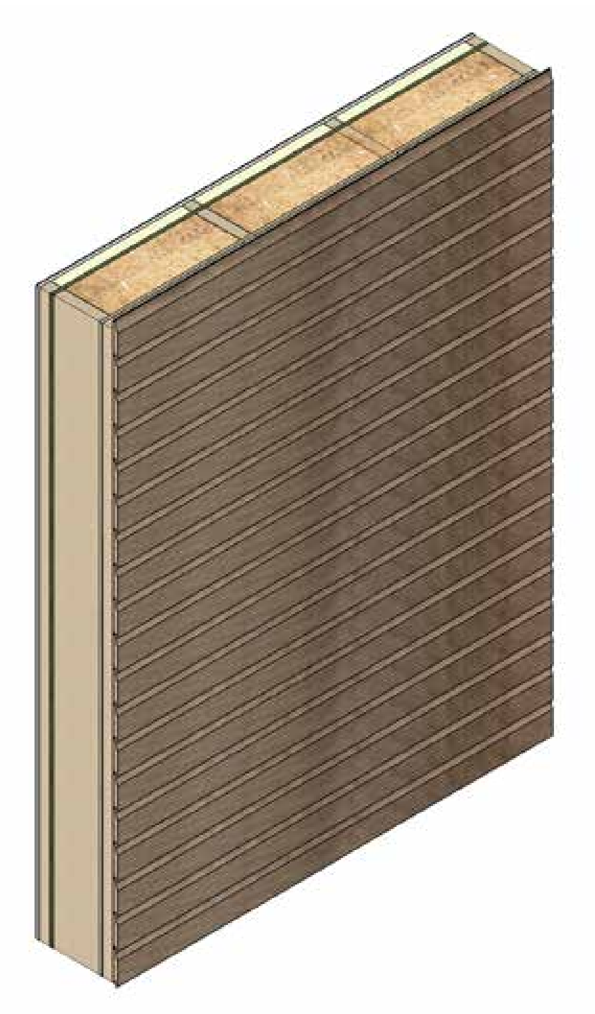
3.11. External wall construction as per square metre of facade basis

A number of external wall constructions were assessed to understand the comparative embodied carbon. Each wall typology has been modelled in detail in Autodesk Revit to generate a value per square metre of facade based on an 4.4m2 test panel.

The analysis has been carried out using the One Click LCA plugin tool covering stages A1-A4, B3-B4 and C1-C4 according to BS EN 15978:2011 for standard 60 year life span. Results for wall constructions used for Gywnfaen are presented overleaf.

4. Wall construction analysis

Timber frame
Timber clad facade
Wood fibre insulation

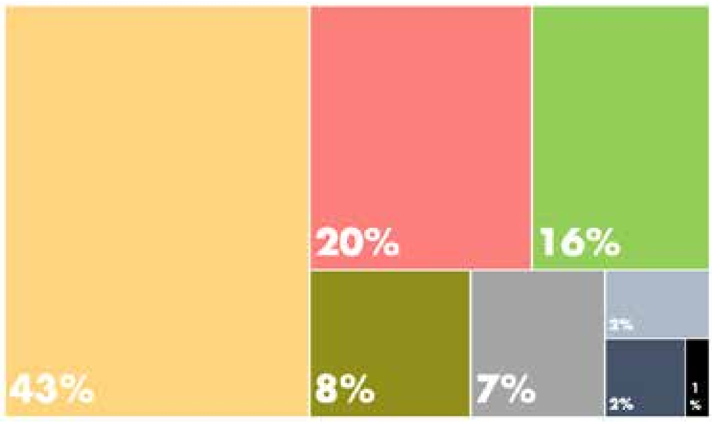


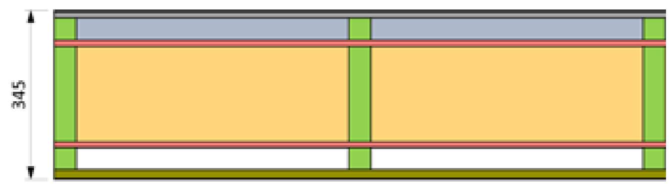
31 **kg CO_2e/m²**

average embodied carbon per m2 of elevational area

Biogenic carbon storage*
103kg CO2e/m²

Embodied carbon impact by material





Materials

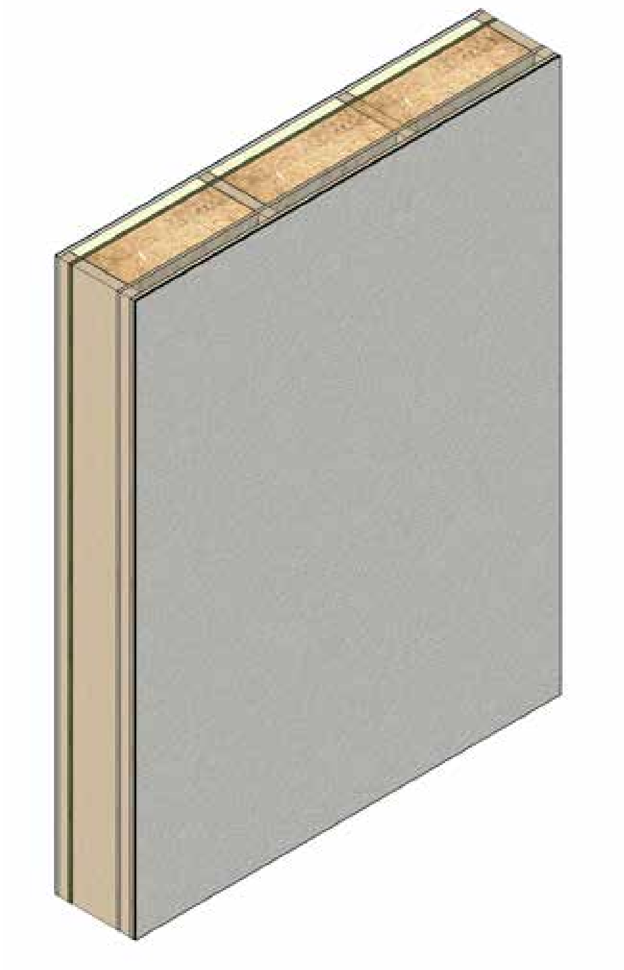
Treated FSC certified timber cladding;
Vertical batten; Breather membrane;
OSB sheathing; Structural sawn timber, kiln dried, planed;
Wood fibre insulation; OSB internal lining;
Batten service zone; Glass mineral wool insulation;
Gypsum plasterboard and skim finish

Methodogy and assumptions

External wall construction case study to assess the comparative embodied carbon considered for a low carbon housing project.

Each typology has been modelled in detail in Autodesk Revit to generate a value per square metre of facade based on an 4.4m2 test panel. The analysis has been carried out using the One Click LCA plugin tool covering stages A1-A4, B3-B4 and C1-C4 according to BS EN 15978:2011 for standard 60 year life span. Assumes service life of timber cladding 40 years and therefore 1 number replacement cycle.

Wall construction has a calculated U-value of 0.15 W/m2K
* Biogenic carbon storage excluded from total



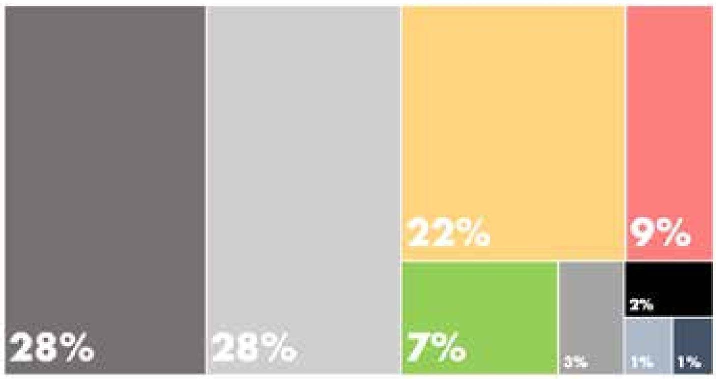
Timber Frame
Render on cement board
Ventilated and drained cavity
Wood fibre insulation

74 kg CO_2e/m²

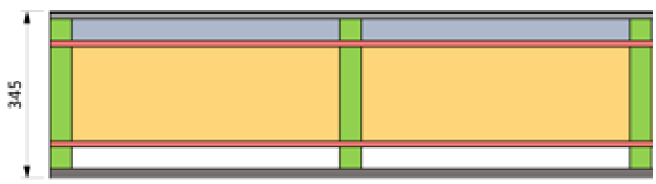
average embodied carbon per m2 of elevational area

Biogenic carbon storage*
90kg CO2e / m²

Embodied carbon by material



- Cement carrier board
- External render
- Wood fibre
- Gypsum board
- OSB
- Timber
- Glass mineral insulation
- Plaster (<1%)
- Membranes/other



Materials

Render, basecoat cement-based, glassfibre scrim reinforced, topcoat silicon-based; Cement Board;
Vertical batten; Breather membrane;
OSB sheathing; Structural sawn timber, kiln dried, planed;
Wood fibre insulation; OSB internal lining;
Batten service zone; Glass mineral wool Insulation;
Gypsum plasterboard and skim finish

Methodogy and assumptions

External wall construction case study to assess the comparative embodied carbon considered for a low carbon housing project.

Each typology has been modelled in detail in Autodesk Revit to generate a value per square metre of facade based on an 4.4m2 test panel. The analysis has been carried out using the One Click LCA plugin tool covering stages A1-A5, B3-B4 and C1-C4 according to BS EN 15978:2011 for standard 60 year life span. Assumes render finish will require annual patch repairs assumed to be 5% of total area per annum.

Wall construction has a calculated U-value of 0.15 W/m2K
* Biogenic carbon storage excluded from total

5. House types studied

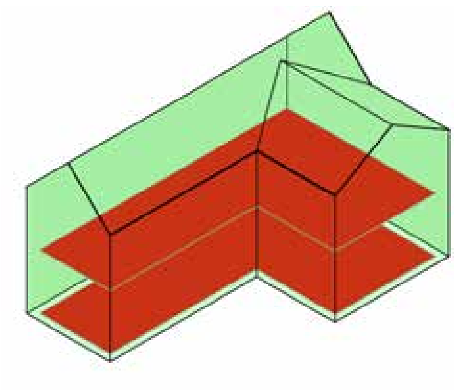
5.1. Summary

Gywnfaen has a range of house types ranging from 2, 3 and 4 bedroom homes and 1 bedroom apartment buildings. It incorporates homes design to the Welsh Development Quality Requirements (DQR) and Lifetime Homes standards along with market homes which are on average 5% to 10% smaller.

Whilst it would not be impossible to assess the entire range, it would be very labour intensive, thus a sample of seven typical types has been assessed to guage the embodied carbon associated with the most common house types. A summary of those types is provided below.

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 13 (V2) The Terrace	74.26m^2	2 bed	4 people	2	3.8	60 years	RIBA Stage 4	Timber frame Render façade
Type 4 (V4) The Semi-Detached	95.70m^2	3 bed	5 people	2	3.5	60 years	RIBA Stage 4	Timber frame Timber façade
Type 6 (V2) The Gate House	120.49m^2	4 bed	7 people	3	2.9	60 years	RIBA Stage 4	Timber frame Timber and render façade
Type 7 (V1) The Long-house	116.16m^2	3 bed	5 people	2	3.5	60 years	RIBA Stage 4	Timber frame Timber façade
Type 2 (V2) The Coach House	94.47m^2	3 bed	5 people	2	4.0	60 years	RIBA Stage 4	Timber frame Render façade
Type 24 (V1) The Long-house 4 bed	122.87m^2	4 bed	7 people	2	3.4	60 years	RIBA Stage 4	Timber frame Render façade
Type 11 Gateway Apartments	536.05m^2	8x (1bed)	8x 2 people (16)	2	2.7	60 years	RIBA Stage 4	Timber frame Render façade

* Similar to Heat Loss Form Factor in Passivhaus, a lower number indicates a more compact building shape.



Note all are taken as detached dwellings. A worked example is shown below.

Type 7 (V1) The Longhouse

$$\text{Form factor} = \frac{\text{Sum of envelope area}}{\text{Gross internal floor area}}$$

$$\text{Form factor} = \frac{411.70\text{m2}}{16.16\text{m2}}$$

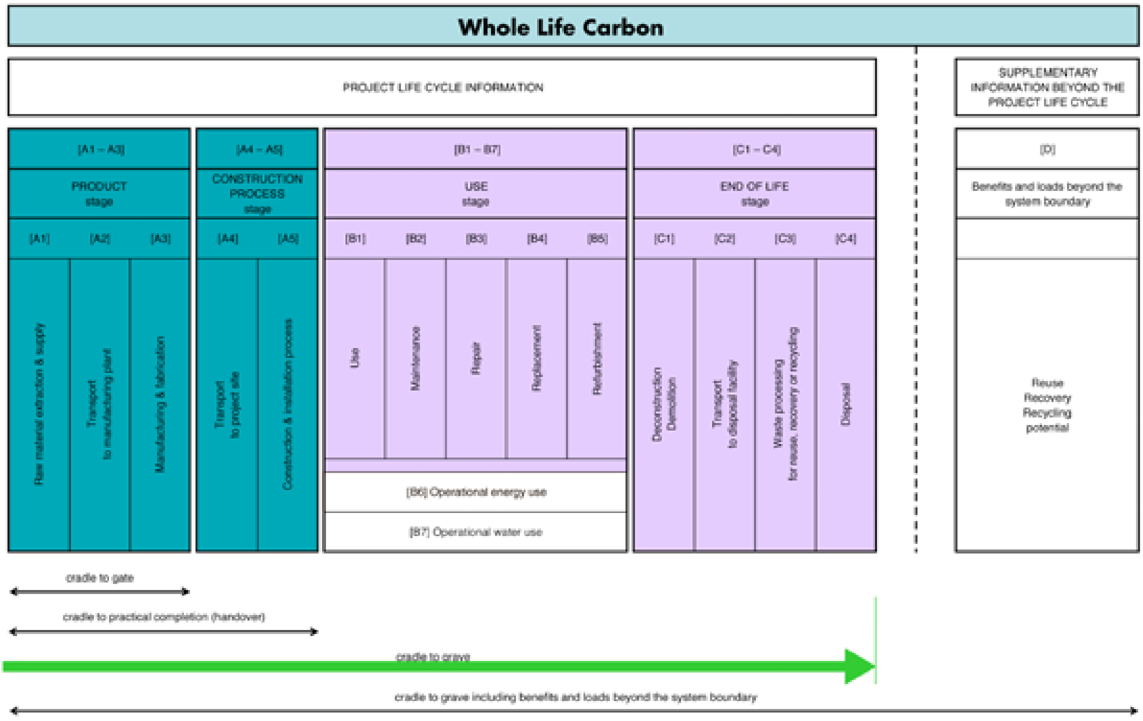
$$\text{Form factor} = 3.5$$

6. Embodied carbon scope

6.1. Life cycle stages

Life Cycle Carbon assessments need to be reliable and comparable. Therefore, consistency in methodology and the assumptions and data used is required. This analysis is performed using the widely accepted environmental performance assessment methodology of EN 15978. The modular structure of the life cycle broken down into different life stages is shown below with the stages assessed indicated.

All results have been prepared using the One Click LCA platform using the Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017). Note in terms of B2 Maintenance, there is no known methodology which provides reasonable B2 emissions for materials. Due to the fact that B2 data is not in the EPDs most of the time, and no methodology being present, B2 is not included in any tool on the One Click LCA platform. B6 and B7 relate to operational energy and water use and are considered outside of embodied carbon reporting.



The minimum scope that must be covered is as follows:

Minimum requirements for whole life carbon assessment	
Building parts to be included – see 3.2.2	**1. Substructure** **2. Superstructure**
Life stages to be included – see 3.2.4	**Product stage [A1–A3]** **Construction process stage [A4–A5]** **Replacement stage [B4]** for facade **Operational energy use [B6]**
Assessment timing	**At design stage – prior to technical design**

Table 2: Minimum requirements for whole life

Note the minimum requirements for assessment in Table 2 within Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017).

This highlights the potential difficulty in comparison between projects where the scope of the assessment is not known.

To provide a holistic view of the GWP, whole life carbon assessments should, where possible, account for all components relating to the project during all life cycle stages.

6.2. Terms

Embodied carbon to practical completion (PC-CO2e)
Comprises stages [A1–A5]. *Sometimes refered to as 'Upfront Carbon'.*

Embodied carbon over the life cycle (LC-CO2e)
Comprises stages [A1–A5], [B1–B5] and [C1–C4].

Whole life carbon (WL-CO2e)
Comprises stages [A to C], with module [D] reported separately.

6.3. Scope of building elements

This section outlines the building parts, elements and components included in the whole life carbon assessment as it relates to EN 15978; 7.5 and pertaining to Table 3 within Whole life carbon assessment for the built environment, by RICS (1st edition, November 2017).

	Building part/Element group	Building element
	Demolition	0.1 Toxic/Hazardous/Contaminated Material treatment
		0.2 Major Demolition Works
0	Facilitating works	0.3 & 0.5 Temporary/Enabling Works
		0.4 Specialist groundworks
1	Substructure	1.1 Substructure
2	Superstructure	2.1 Frame 2.2 Upper floors incl. balconies 2.3 Roof 2.4 Stairs and ramps
2	Superstructure	2.5 External Walls 2.6 Windows and External Doors
2	Superstructure	2.7 Internal Walls and Partitions 2.8 Internal Doors
3	Finishes	3.1 Wall finishes 3.2 Floor finishes 3.3 Ceiling finishes
4	Fittings, furnishings and equipment (FF&E)	4.1 Fittings, Furnishings & Equipment incl. Building-related* and Non-building-related**
5	Building services/MEP	5.1–5.14 Services incl. Building-related* and Non-building-related**
6	Prefabricated Buildings and Building Units	6.1 Prefabricated Buildings and Building Units
7	Work to Existing Building	7.1 Minor Demolition and Alteration Works
8	External works	8.1 Site preparation works 8.2 Roads, Paths, Pavings and Surfacings 8.3 Soft landscaping, Planting and Irrigation Systems 8.4 Fencing, Railings and Walls 8.5 External fixtures 8.6 External drainage 8.7 External Services 8.8 Minor Building Works and Ancillary Buildings

Table 3: Building element groups to be considered (based on the BCIS SFCA)

* Building-related items: Building-integrated technical systems and furniture, fittings and fixtures built into the fabric.

Building-related MEP and FF&E typically include the items classified under Shell and Core and Category A fit-out.

** Non-building-related items: Loose furniture, fittings and other technical equipment like desks, chairs, computers, refrigerators, etc. Such items are usually part of Category B fit-out.

7. Embodied carbon target comparison

7.1. Summary

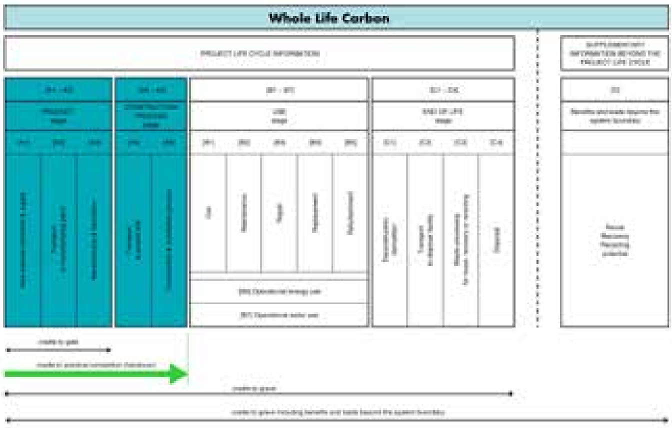
During Gwynfaen's design stages many definitions of net zero emerged. Previous definitions did not even cover upfront carbon [A1-A5] or embodied carbon [A-C] but 2019 saw the emergence of embodied carbon feature in industry spotlight. However, consensus on scope is elusive. The targets (following page) are now regarded as the leading sources for the UK.

UK GBC

Embodied carbon to practical completion

Comprises stages [A1–A5] RICS Building elements (minimum scope)

- Substructure
- Superstructure



Target all buildings Net Zero carbon – construction

0kg CO_2e or negative

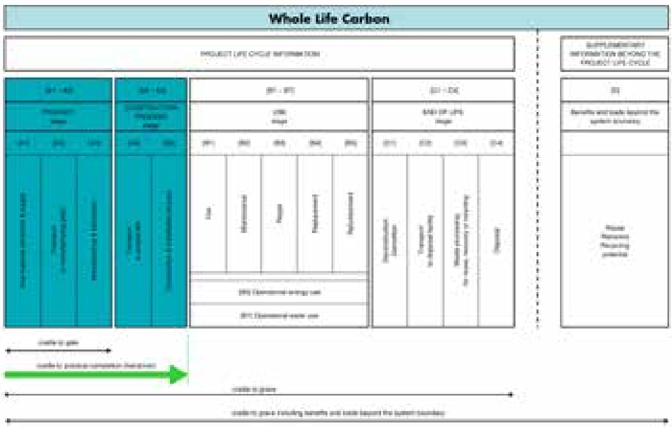
Through using a recognised offsetting framework or the net export of on-site renewable energy. No carbon intensity targets stated as required prior to offsetting.

LETI

'Upfront Carbon'

Comprises stages [A1–A5]. Building elements scope:

- Substructure
- Superstructure
- MEP
- Facade
- Internal finishes



Residential buildings step targets of:

by 2020 = **500 kg CO_2em^2**
400 kg CO_2e/m^2 including sequestration.

by 2030 = **300 kg CO_2e/m^2**

200 kg CO_2e/m^2 including sequestration.

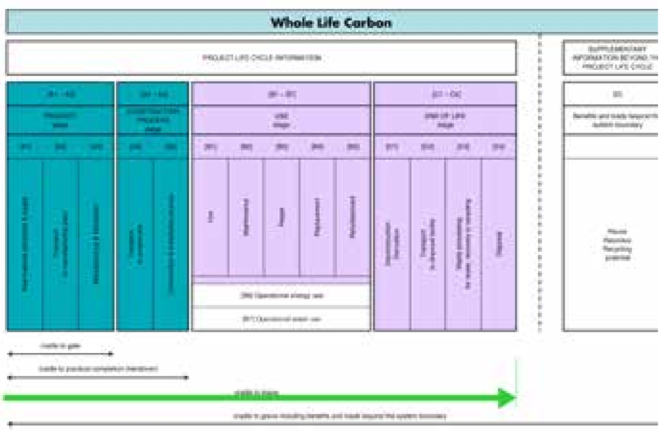
Note: Includes substructure, superstructure, MEP, facade and internal finishes only.

RIBA

Embodied carbon over the life cycle (LC-CO_2e)

Comprises stages [A1–A5], [B1–B5] and [C1–C4]

Using circular economy strategies and minimum offsetting using UK schemes. Building elements scope unknown.



2030 Challenge Residential buildings step targets of:

by 2020 = **<600kg CO_2e/m^2**

by 2025 = **<450kg CO_2e/m^2**

by 2030 = **<300kg CO_2e/m^2**

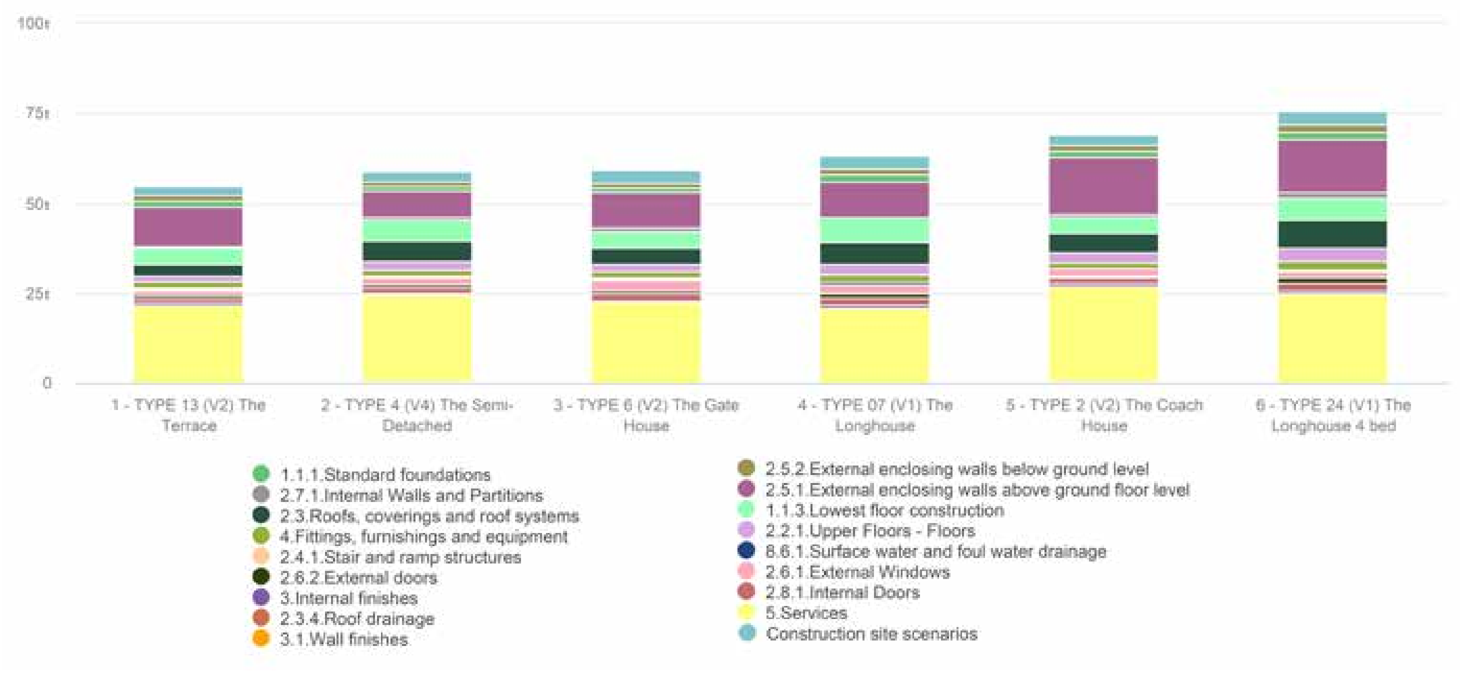
8. Embodied carbon modelling results

8.1. House types considered

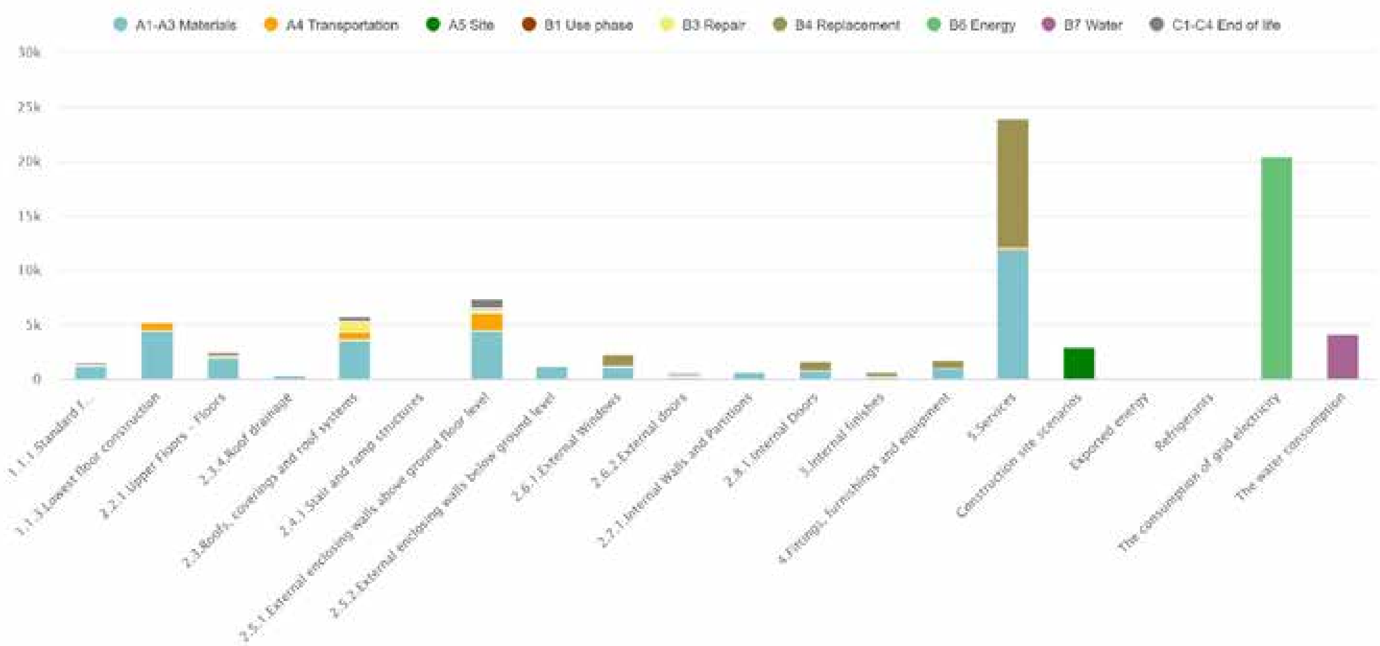
Gywnfaen has a range of house types ranging from 2, 3 and 4 bedroom homes and 1 bedroom apartment buildings. It incorporates homes design to the Welsh Development Quality Requirements (DQR) and Lifetime Homes standards along with market homes which are on average 5% to 10% smaller.

Whilst it would not be impossible to assess the entire range, it would be very labour intensive, thus a sample of seven typical types has been assessed to guage the embodied carbon associated with the most common house types. A summary of those types is provided below.

House type embodied carbon comparison



House Type 4 (V4) Whole Life carbon comparison [A-C]. Note: Grid electricity 60 years based on SAP 10.1 (0.136kg CO2e/kWh)



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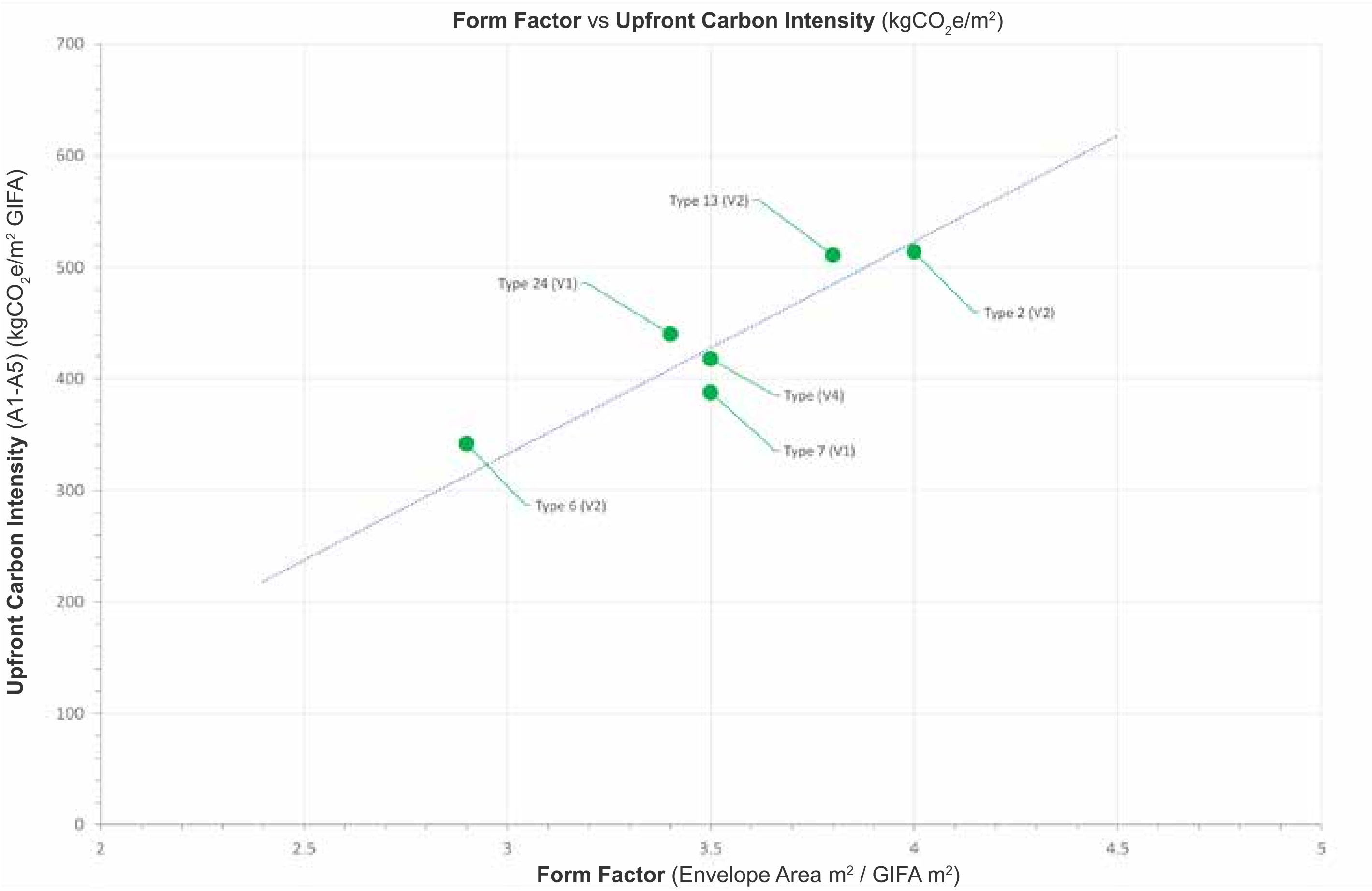
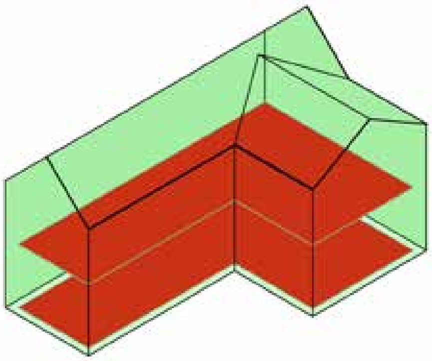
8.2. Effect of form factor on carbon intensity

A range of house types for Gwynfaen was developed to accommodate various tenures with differing space requirements. In addition some house types responded to placemaking objectives, for example the Coach House (Type 2 V2) has an undercrofted carport to conceal parked vehicles (required on key streets), whereas the Gate House (Type 6 V2) is a 3 storey marker building. These decisions can have positive or negative impacts on form factor*. The graph below plots the form factor of each of the six house types studied against their upfront carbon intensity. All types have the same construction methodology of wood fibre filled timber frame cassettes. The lower the form factor, the more inherently efficient the building is and this graph shows how the carbon intensity of internal floor space, increases as the form factor increases. In this example a 0.5 increase in form factor can be seen to increase carbon intensity by approximately 100kg CO_2e/m^2. This is a small sample and warrants further consideration but presents a strong case for considering form factor on both energy use and embodied carbon grounds.



* Similar to Heat Loss Form Factor in Passivhaus but using the enclosing outer envelope area/GIFA instead of heat loss area/treated floor area.



A lower number indicates a more compact building shape. Note all are taken as detached dwellings. Worked example below:

Type 7 (V1) The Longhouse

$$\text{Form Factor} = \frac{\text{Sum of Envelope Area (green)}}{\text{Gross Internal Floor Area (red)}}$$

$$\text{Form Factor} = \frac{411.70\text{m2}}{16.16\text{m2}}$$

Form Factor = 3.5

8.3. Gwynfaen vs 'business as usual'

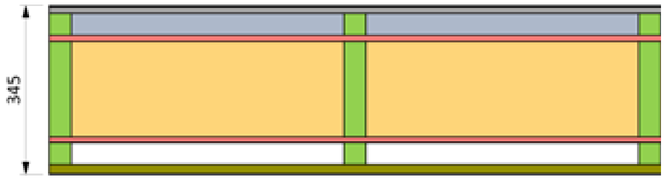
The Committee on Climate Change report 'UK housing: Fit for the future?' (Feb 2019) advocates increasing the number of new homes built in the UK each year using timber frame construction systems which could triple the amount of carbon stored in UK homes to 3 Mt every year by taking CO2 from the atmosphere via biogenic sequestration. At Gwynfaen a 'business as usual' LCA assessment was undertaken to establish the baseline so that the benefits of a switch to using a timber frame construction system filled within wood fibre insulation could be quantified in carbon terms.

To eliminate effects of form factor identical house types were tested on a like-for-like basis with identical servicing strategies. House Type 4 (V4), a typical Semi-Detached 3 bedroom 5 person house (GIFA 95.70m2) was the test subject. The 'business as usual' case was modelled using traditional mansonry cavity wall construction of aircrete blockwork, 120mm PIR (polyisocyanurate) boards, facing brick external skin and an internal parge coat for airtightness. This gave an identical wall U-values of 0.15 W/m²K. The ground floor structure and foundation footings are identical in both instances.

8.4. Wall construction

BAU wall construction materials

Red clay facing brick, cement-based mortar joints;
Partial fill PIR insulation to cavity; Stainless steel cavity ties;
Aerated Concrete Blocks, cement-based mortar joints;
Parge coat; Gypsum plasterboard on dabs, skim finish.



Gwynfaen wall construction materials

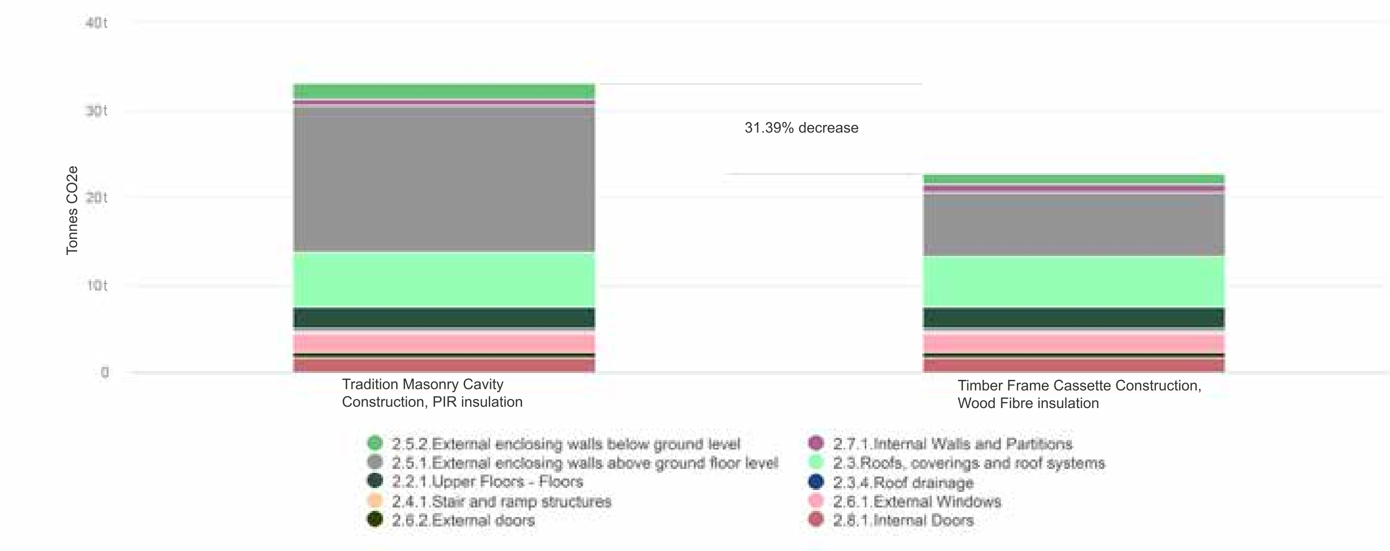
Treated FSC certified timber cladding;
Vertical batten; Breather membrane;
OSB sheathing; Structural sawn timber, kiln dried, planed;
Wood fibre insulation; OSB internal lining;
Batten service zone; Glass mineral wool Insulation;
Gypsum plasterboard skim finish.

8.5. Superstructure comparison - Embodied carbon over the life cycle

(LC-CO2e) Comprises stages [A1–A5], [B1–B5] and [C1–C4] - 60 year life.

The table below compares the superstructure savings of CO2e. The alternative approach demonstrates that 10,392kg CO2e (10.3t of carbon) can be saved per home. This also assumes for complete replacement of the timber cladding after 40 years (which is unlikely), some minor repointing is factored into the mansonry (1% repair).

Biogenic carbon within a building product can be considered as a "negative emission". This means that during the growth stage of bio-based materials carbon is stored into the material. However, according to most LCA methodologies such as (EN15978), at the moment, the most likely end of life scenario for wood products waste handling at end of life is incineration, in which case the stored carbon is released back to atmosphere. This means that carbon is stored for few decades but the total carbon balance over the lifetime is neutral. Because of this One Click LCA does not deduct biogenic carbon from impacts. Nevertheless figures for biogenic carbon data are presented on the following page.



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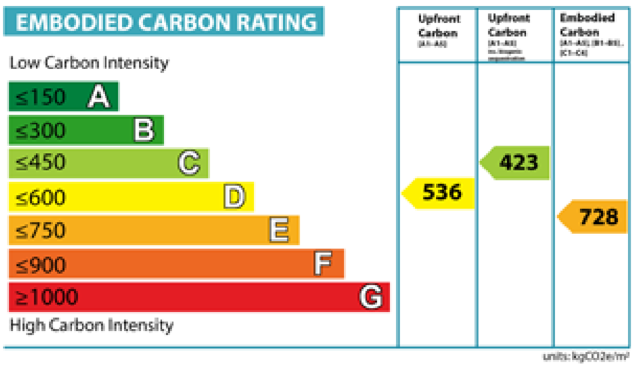
8.6. Gwynfaen vs 'business as usual'

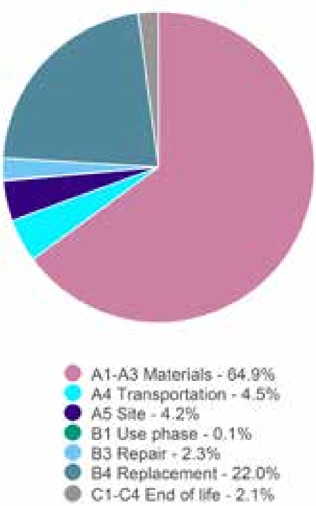
The data below is a whole building comparison in savings of CO2e of embodied carbon in Upfront emissions [A1-A5] and life cycle embodied carbon [A1–A5], [B1–B5] and [C1–C4] based on RICS methodology. Upfront emissions [A1-A5] are shown with and without the subtraction of biogenic carbon sequestration. Masonry built homes still contain timber in the form of partitions, floors, roof and stairs, but the change to timber frame, timber clad and wood fibre insulated construction increases the biogenic carbon stored by over 230%. The effect is a saving in upfront emissions of 37 tonnes of CO2e equating to a 90% decrease over business as usual emissions. For life cycle embodied carbon the assumption that wood based components are incinerated or landfilled at end of life would neutralise the storage effect. Even so a 10.7t saving can be realised over the life cycle.

House type reference /name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design stage (level of detail)
Type 4 (V4) The Semi-Detached	95.70m²	3 bed	5 people	2	3.5	60 years	RIBA Stage 4

Traditional masonry
PIR insulation
Facing brick



Life cycle stage breakdown



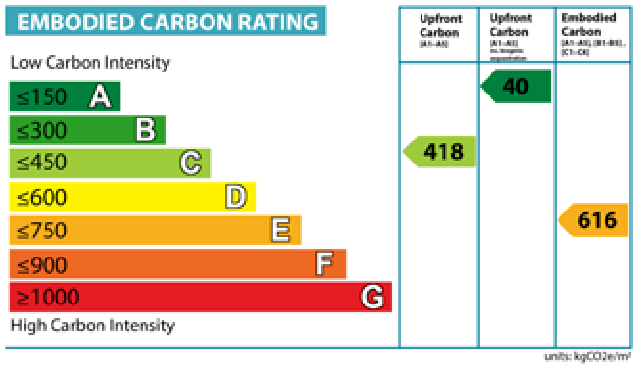
Stage	kg CO2e
A1-A3 Materials	45227
A4 Transportation	3135
A5 Site	2904
B1 Use phase	62
B3 Repair	1590
B4 Replacement	15296
C1-C4 End of life	1458
Total	**69672**

Upfront carbon
51,266kg CO2e [A1-A5]

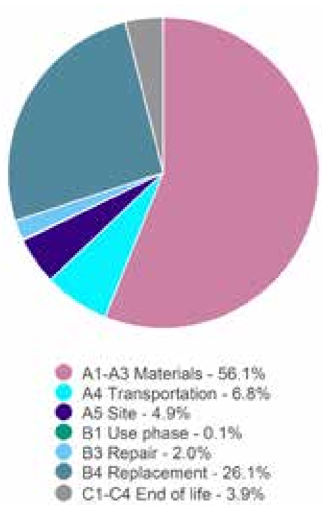
Biogenic carbon sequestration
10,776kg CO2e [A1-A3]

Embodied carbon
69,672kg CO2e (70t CO2e)
[A1–A5], [B1–B5], [C1–C4]

Timber frame
Wood fibre insulation
Timber clad facade



Life cycle stage breakdown



Stage	kg CO2e
A1-A3 Materials	33088
A4 Transportation	4025
A5 Site	2904
B1 Use phase	62
B3 Repair	1198
B4 Replacement	15382
C1-C4 End of life	2317
Total	**58976**

Upfront carbon
40,017kg CO2e [A1-A5]

Biogenic carbon sequestration
36,177kg CO2e [A1-A3]

Embodied carbon
58,976kg CO2e (59t CO2e)
[A1–A5], [B1–B5], [C1–C4]

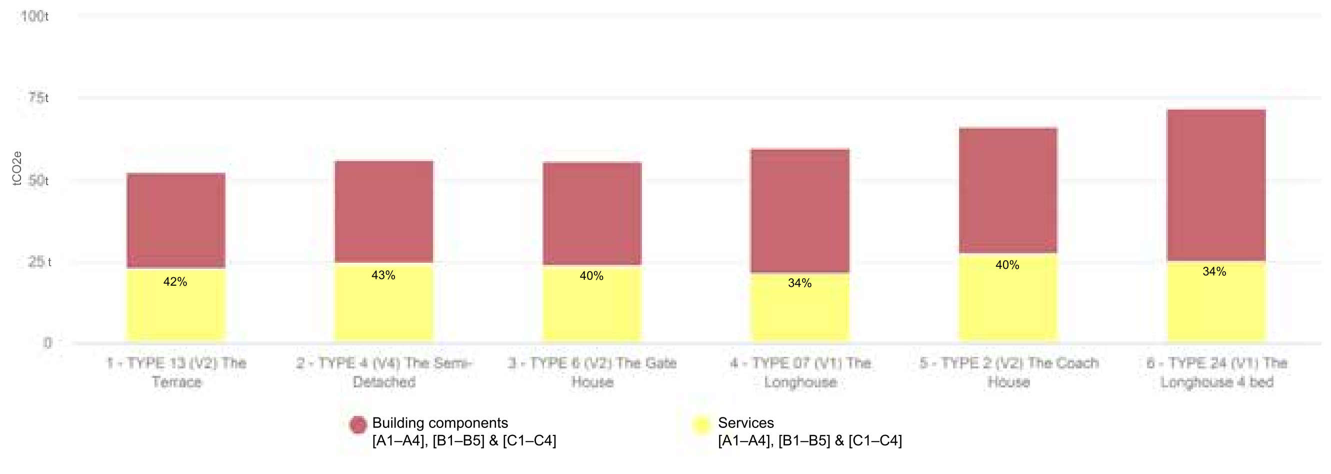
8.7. Embodied carbon of building services

Building services comprise the lighting, power, heating, ventilation energy generation and storage systems. At Gwynfaen the homes have no gas supply instead providing heating with air-to-water source heat pumps in combination with thermal stores. In addition homes combine solar PV and Tesla Powerwall 2 battery technology that work together to generate, store and release energy. This enables solar generated electricity to be used later in the day as it's needed. When less sun is available, the batteries can be charged overnight, which is cheaper than charging during the day or be charged when grid carbon instensity is low. Coupled with fabric improvements these load reduction and load shifting measures ensure an electricity grid-friendly strategy where the majority of energy generated is utilised on-site.

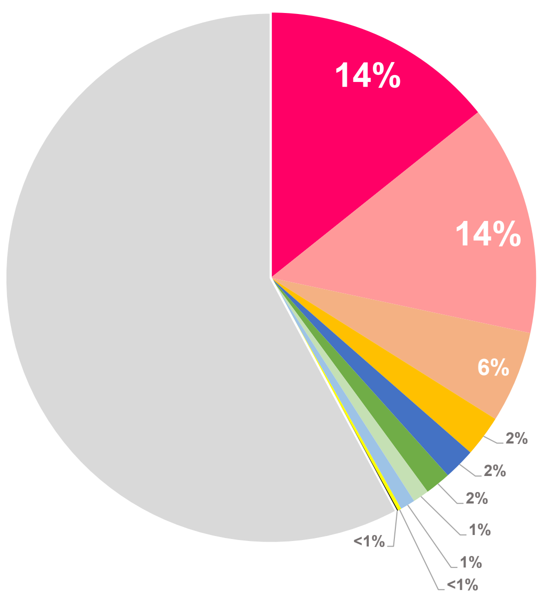
With this type of servicing strategy the immediate question arises regarding embodied carbon. Studies have shown that building services can account for 15% – 49% of embodied carbon. For homes a high impact strategy could account for a large proportion compared to the whole building. In addition, many building services have a much shorter life span than the building itself. White heat pump technology refrigerant leakage can have a large impact on whole life carbon emissions.

To assess this all building services elements were included, from pipes, light switches, MVHR ducts to PV and heat pumps. The material quantities were taken from a detailed RIBA Stage 4 BIM, developed and cross referenced with the MEP engineers schematics and plans. Embodied carbon figures were arrived at using a mixture of Environmental Product Declaration (EPD) data, but more often than not, generic data was used as avaliable in the One Click LCA platform. Due to lack of precise manufacturer-specific EPD data the figures can only be considered an estimate.

8.8. Overview of percentage of embodied carbon attributed to MEP services



The graph above shows an estimate of embodied carbon split between building components and MEP. The six house types studied have shown that building services account for approximately 34% – 43% of embodied carbon. This shows a relatively high impact on embodied carbon. The percentage breakdown of the services element is shown below. The expected lifespan of services/MEP components has been taken as 30 years, this is a generic assumption informed by product system literature and information from BCIS Life expectancy of building components (2006); CIBSE Guide M; Scheuer, Keoleian, and Reppe (2003). This therefore assumes the MEP systems will be replaced once over a 60 year building life.



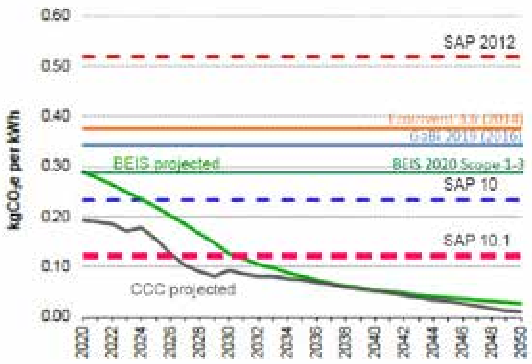
- Solar panel photovoltaic system
- Lithium ion battery
- Air-to-water heat pump with electric compressor 5 kW
- Heat emitters, Radiators, heated towel rails
- Heating distribution system inc. thermal store
- MVHR unit
- Ventilation ducting
- Electrical cabling/power system
- Pipesystem, hot and cold water supply
- Refrigerant Leakage

8.9. Embodied carbon of photovoltaics

Solar PV based electricity has undoubtedly lower carbon emissions than fossil fuel-based electricity. However, it is also known to have a high embodied carbon footprint, particularly for crystalline PV. Specified is a mono-crystalline type PV panel, which has a higher efficiency. No EPD or comparable document is available for this system so due to lack of precise manufacturer-specific EPD data the figures can only be considered an estimate.

There is only a small body of unique evidence on the embodied carbon of solar PV. Many studies are referring back to the same historic data sources for production of the crystalline PV cells. One Click LCA refers to IEA, 2015; ecoinvent V3 providing a figure of 180.2kg CO2e/m2 of PV. Therefore for a typical 20m^2 array this would be 3,604kg CO2e (3.6t).

In terms of carbon payback this relates to the amount of electricity generated by solar PV which dependent upon the panel efficiency and how it has been installed, e.g. orientation, pitch, shading. Outputs therefore vary notably.



Comparing UK assumptions on the electricity carbon intensity.

As an example taking type 13 (V2) from SAP calculations with a southerly faced array it is expected to generate 3,698kWh/yr. According to Defra's GHG emissions factors for company reporting for 2019, UK electricity has an all scopes carbon emissions of 0.316kg CO2e per kWh (2017 data).

The manufacturer states the panel will achieve 90.8% of rated output after 25 years. Factoring an annual degradation of performance of 0.4% this would be 104,739 kWh (assuming an operational lifetime of the system of 30 years) equating to 33 tonnes of CO2 saved againat a 3.6t outlay.

SAP 10.1 was published on 10 October 2019 and included a grid carbon factor for electricity of 0.136kg CO2e/kWh reflecting the dramatic fall predicted for grid carbon intensity. Looking into future trends can only ever be an estimate and has an inherent uncertainty but taking this lower figure still results in 14.2 tonnes of CO2 saved verus a 3.6 ton initial expenditure. In fact for a break even point to be reached the grid would need to decarbonise to 34g or 0.034kg CO2e/kWh which is unlikely before 2045 according to current projections.

8.10. Heat pump and refrigerant

One Click LCA contains several manufacturer EPDs for Air-to-water heat pump of various power ratings. Reference for a 5kW ASHP gives 1426 kg CO2e/unit (EDP number: INIES_DPOM20191113_145710, 12869) which has been used in mosts instances. For air source heat pumps (ASHP), carbon equivalent emissions from refrigerant leakage make up a large proportion of the CO2 because the global warming potential of refrigerants currently most commonly used is higher than that of CO2.

At Gwynfaen the proposed heat pump uses R290 a refrigerant grade propane with a very low GWP of 3. An annual leakage rate of 3.5% is assumed with an end of life leakage rate of 10%. The heat pumps contain between 0.6 or 0.9kg of refrigerant. It is assumed the ASHP has a lifespan of 30 years amounting to 60kg CO2e which is negligible compared to the whole building. Note if R410a was used a common ASHP refrigerant this would increase by 4733% to 2,933kg CO2e. The choice of heat pump and refrigerant is therefore an important consideration in terms of whole life carbon.

8.11. Embodied carbon of home lithium ion batteries

The case/benefits for lithium ion batteries are usually as follows:

- Storing excess generation from the homeowner's solar system during the day
- Buying cheap off peak electricity at night and storing it for use in the day
- Storing grid electricity at time of low carbon intensity when solar generation is low. For example on windy nights
- Interacting with the grid to provide grid balancing services and wholesale electricity trading via 'demand response' schemes
- Providing a back-up in the event of a power cut

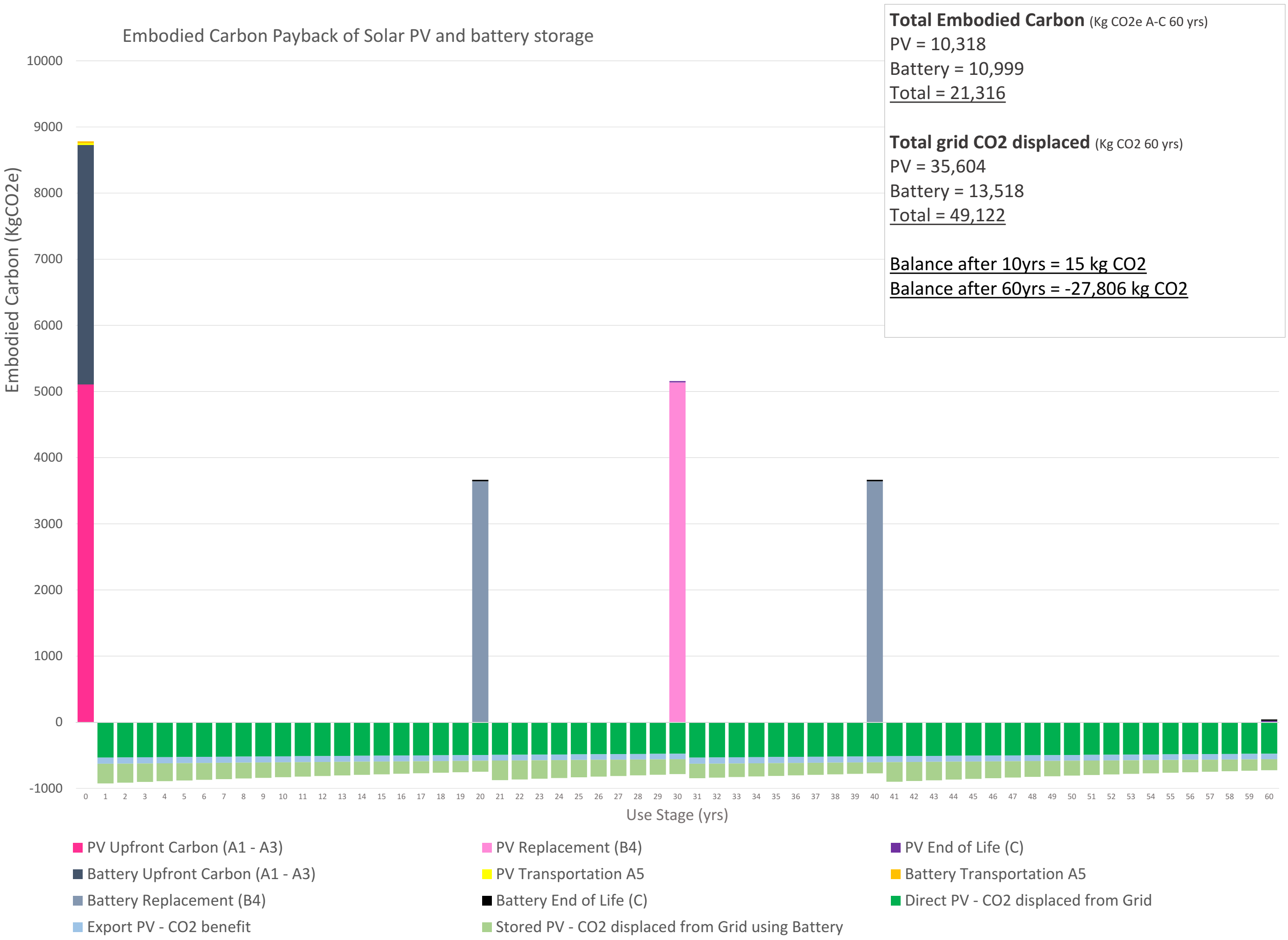
The carbon case is more challenging as whether renewable energy is stored or fed directly into the grid, this may provide a benefit in terms of avoiding transmission and distribution losses. They undoubtedly enable homes to make the most of renewable electricity, at Gwynfaen 90% of the generated solar energy is predicted to used on-site, with around 10% exported to the grid. With the rapid expansion of wind energy generation, grid curtailment where surplus energy may have to be dumped or the power output turned down will be a growing issue. If batteries are implemented across the power and transport sectors, this clearly could contribute to the overall decarbonisation of the grid to allow use of power from variable renewables.

Giga Nevada (Gigafactory 1) in Storey County, Nevada, U.S

Specified at Gwynfaen for every home is a Tesla Powerwall 2 with 13.5kWh energy capacity using lithium-ion technology. Again no EPD or comparable document is available for this system so due to lack of precise manufacturer-specific EPD data the figures can only be considered an estimate. One Click LCA refers to 268.04kg CO_2e/kWh of storage for a Lithium iron phosphate (LiFePO4) battery (Oekobau.dat 2017-I). This was based on a 12kWh battery but differs in chemistry to the Tesla which is uses lithium-ion with nickel-manganese-cobalt chemistry. The different chemistry will impact the overall emissions. Electric vehicle battery manufacturing emissions have been studied extensively and indicate that battery production is associated with 56 to 494 CO_2e/kWh of battery capacity[2] this could provide a reasonable basis for comparison taking an average of 275kg CO_2e/kWh. The study notes that electricity used in the battery manufacturing processes accounts for roughly half of emissions related to battery production, so increased use of renewable energy and more efficient power plants will lead to cleaner batteries.

The Tesla Powerwall 2 with a capacity of 13.5 kWh and taking a 268-275 kg CO_2e/kWh factor results in between 3618 to 3713kg of CO_2e with transportation amounting to a further 25 kg of CO_2e. Assuming the battery is replaced once during the building's lifespan (60yrs) this would result in a total of 7286kg of CO_2e amounting to 14% of the embodied carbon of the whole building. However, is this assumption reasonable? The battery is warrantied for 5,000 cycles or 10 years at 70% of its original capacity. With an annual degradation of 3% at 30 years the battery would have lost 90% of its capacity. Therefore the chances of the battery lasting 30 years is optimistic with 15 upto 20 years maybe more realistic, effectively doubling lifetime emissions (refer to graph overleaf for an estimate of PV and battery embodied carbon payback).

The benefits of battery technology is accepted but these emissions are nonetheless substantial. It therefore presents an excellent case for inclusion of embodied carbon in the definition of net zero carbon. Manufacturers should be producing more embodied carbon footprint and LCA data, which is chronically lacking. In the future as the home battery industry grows, lifetimes will improve, technology will develop and battery recycling also will become more feasible, all of which will improve the embodied carbon of the technology.



8.12. Estimate of embodied carbon payback

To establish the above results the following assumptions have been made:

- Carbon factors based upon primary energy factor of 1.501, exported PE factor of 0.501 and emissions of 0.136kg CO2 per kW. (Source BRE, SAP 10.1)
- Tesla Powerwall 2 with 13.5kWh energy capacity and estimated embodied carbon intensity of 268.04kg CO2e/kWh. (Source oekobau.de 2018)
- PV embodied carbon intensity 180.2kg CO2e/m2 (source: One Click LCA, database ecoinvent 2015)
- Solar energy accounts for 56% of the total home's energy demand taken from the SAP worksheet
- This is a 4 bed house, 123m² (Type 24)
- 90% of the generated solar energy is used on-site, with 10% exported to the grid as breakdown below (data courtesy of Hoare Lea)
- Equipment energy usage and time-of-day profile is based on average values for a 6 occupant home in the Energy Saving Trust's Government funded document Household Electricity Survey: A study of domestic electrical product usage
- Annual degradation of PV performance taken as 0.4%, Battery storage annual degradation taken as 3%
- Battery storage loss factor taken as 0.9.

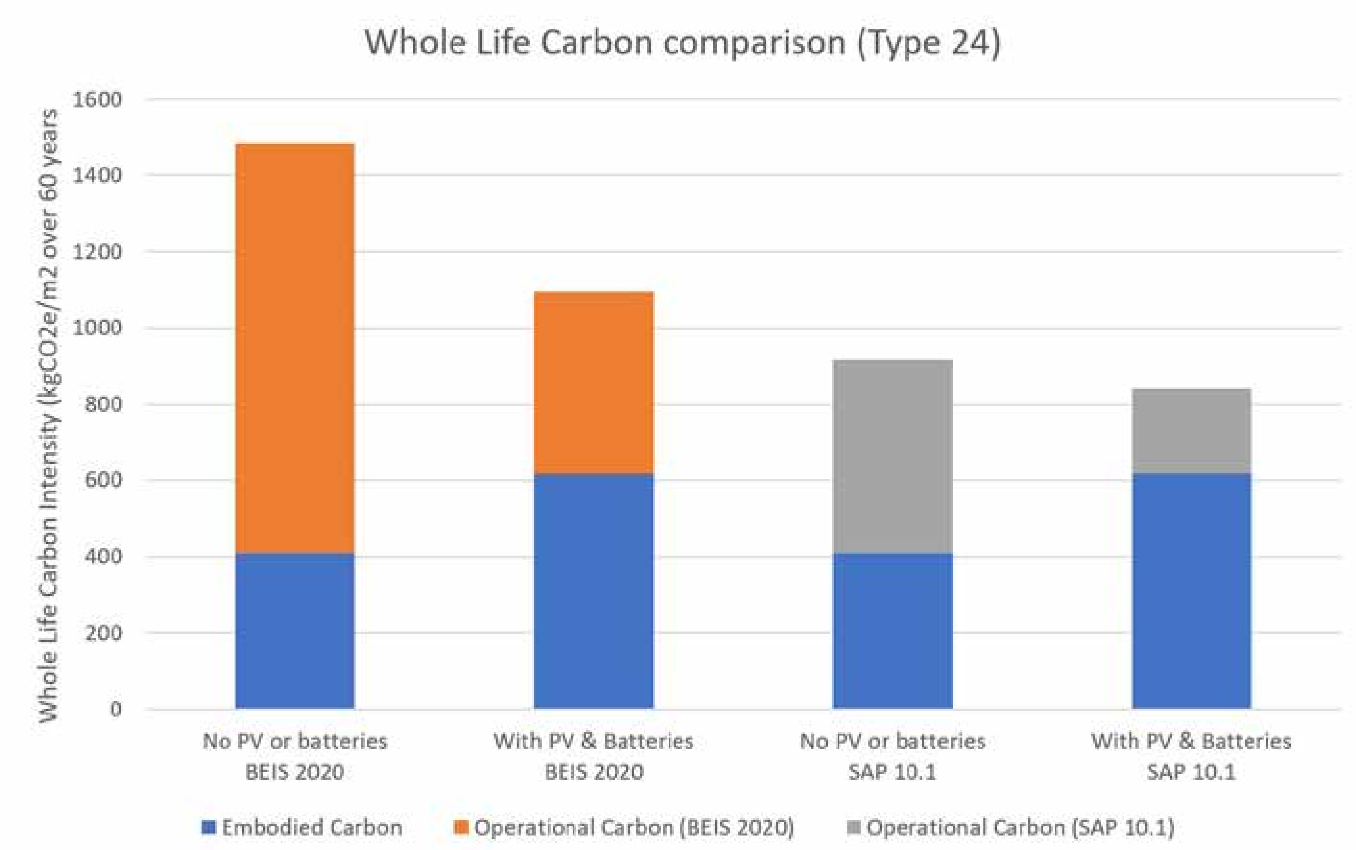
Energy source		Annual energy (kWh)	Percentage of total demand (%)
Home's energy demand		7,624	100%
Solar PV	Used directly	2,041	27%
	Stored in battery	1,613	21%
	Hot water over-heating	579	8%
	Exported	459	6%
	Total generated	4,692	62%
Grid electricity	Used directly	1,961	26%
	Stored in battery	1,430	18%
	Total imported	3,391	44%

The UK electricity grid is decarbonising rapidly and so the comparitive carbon savings are likely to be lower in future scenarios than currently. In the chart below we compared current grid carbon (source: BEIS) and using the value for grid carbon provided in SAP 10.1 as representative of future grid carbon (see p23). This is then used to compare the whole life carbon impact of different operational options.

The house considered has 20m^2 of mono-crystalline PV and 13.5kWh battery storage. Both systems have high upfront carbon, and it is assumed the PV will need replacing in year 30 and the battery in years 20 and 40. In total this equates to 200kgCO2e/m^2 over a 60 year timeframe. However the PV generates electricity amounting to 56% of calculated annual energy demand, reducing the need for grid electricity, and the battery can be used to store PV electricity when the house doesn't need what is generated.

It can be seen that with both grid carbon factors, the option with PV and batteries saves whole life carbon, though the savings using the SAP 10.1 factor are significantly lower. It also raises a paradoxical situation, for the grid to decarbonise we need more renewables, including solar PV and ways of increasing the on site utilisation.

In additon this can only ever be a simple measure, the dynamic nature of carbon intensity means the actual carbon could be less with the benefit of batteries for example by storing grid electricity at time of low carbon intensity when solar generation is low or interacting with the grid to provide grid balancing services and wholesale electricity trading via 'demand response' schemes. These are complex issues worthy of separate study. It's important to not draw the wrong conclusions but the example above provides a good case for including embodied carbon in the definition of net zero carbon.

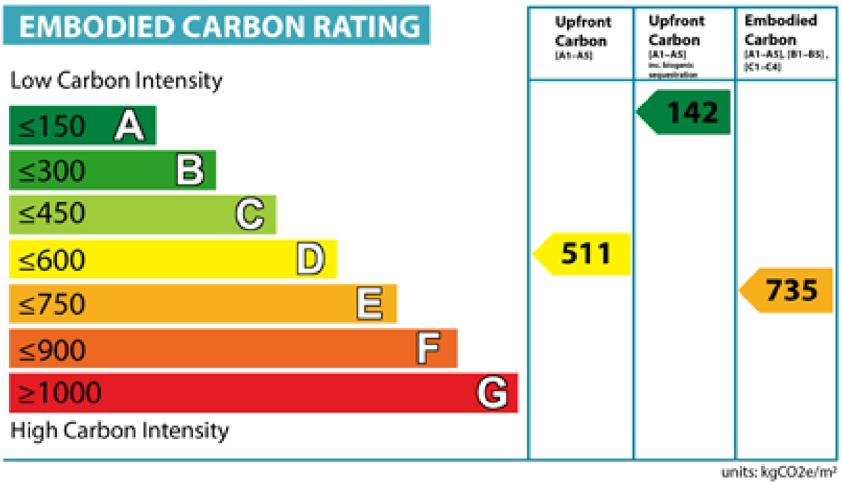


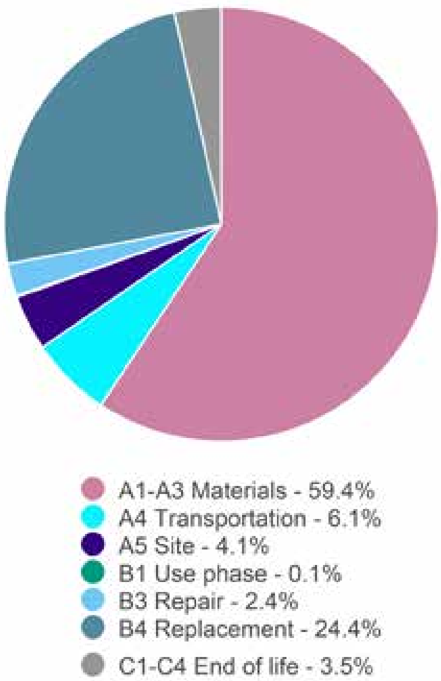
Comparison of Whole Life Carbon with different grid carbon intensities for Type 24, 4 bed dwelling.

9. House type summary results

8.13. Type 13 (V2) The Terrace

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 13 (V2) The Terrace	74.26m²	2 bed	4 people	2	3.8	60 years	RIBA Stage 4	Timber frame Render façade





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	32404
A4 Transportation	3315
A5 Site	2253
B1 Use phase	62
B3 Repair	1323
B4 Replacement	13331
C1-C4 End of life	1904
Total	**54592**

Upfront carbon
37,972kg CO2e [A1-A5]

Biogenic carbon sequestration
27,412kg CO2e [A1-A3]

Embodied carbon
54,592kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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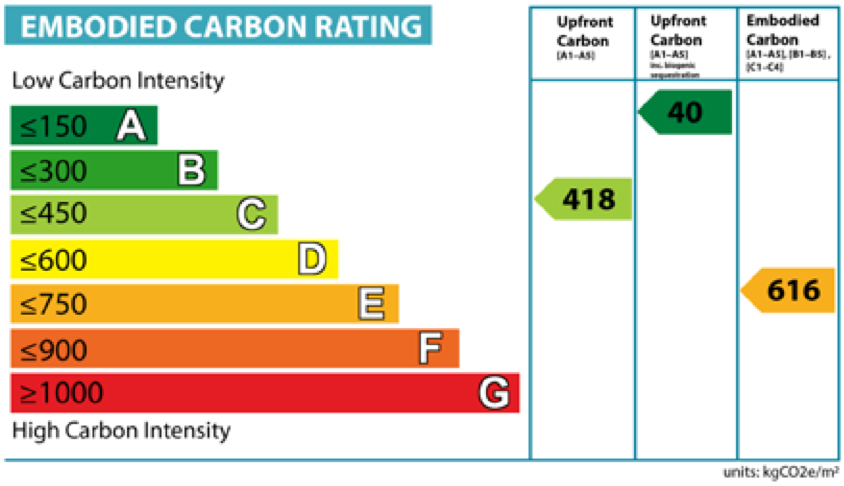
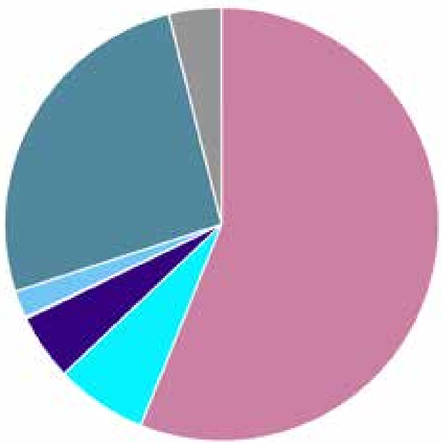
9.1. Type 4 (V4) The Semi Detached

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 4 (V4) The Semi-Detached	95.70m²	3 bed	5 people	2	3.5	60 years	RIBA Stage 4	Timber frame Timber façade



Life cycle stage breakdown



Stage	kg CO2e
A1-A3 Materials	33088
A4 Transportation	4025
A5 Site	2904
B1 Use phase	62
B3 Repair	1198
B4 Replacement	15382
C1-C4 End of life	2317
Total	**58976**

Upfront carbon
40,017kg CO2e [A1-A5]

Biogenic carbon sequestration
36,177kg CO2e [A1-A3]

Embodied carbon
54,592kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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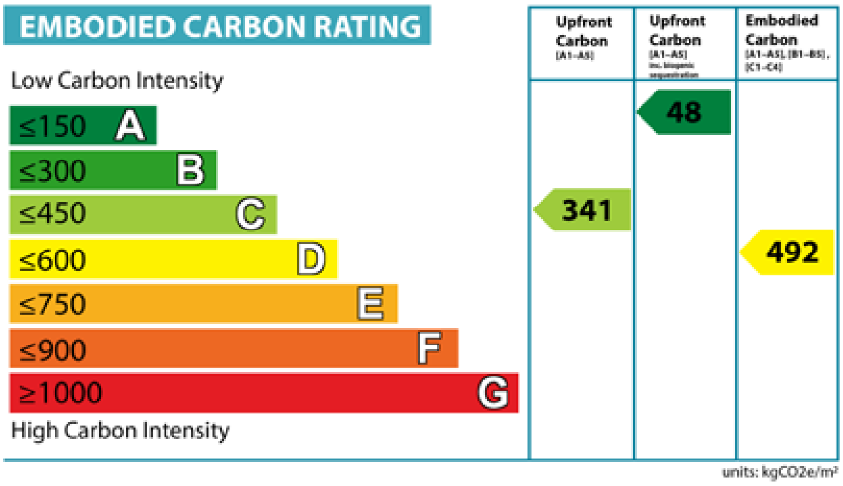
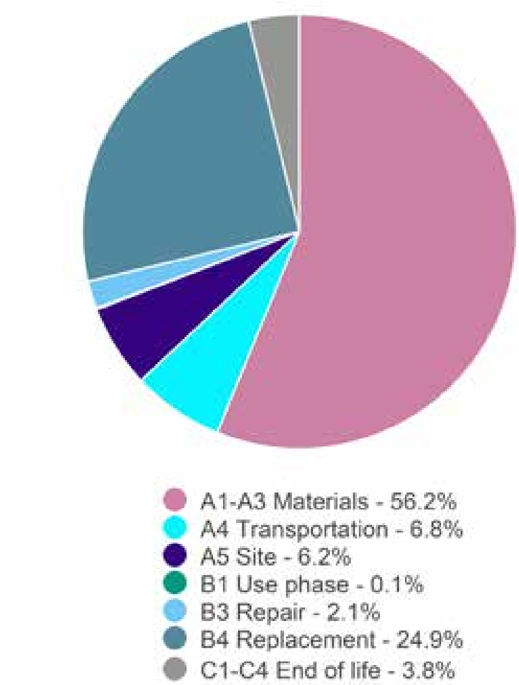
9.2. Type 6 (V2) The Gate House

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 6 (V2) The Gate House	120.49m²	4 bed	7 people	3	2.9	60 years	RIBA Stage 4	Timber frame Timber and render façade





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	33342
A4 Transportation	4036
A5 Site	3656
B1 Use phase	62
B3 Repair	1216
B4 Replacement	14785
C1-C4 End of life	2231
Total	**59328**

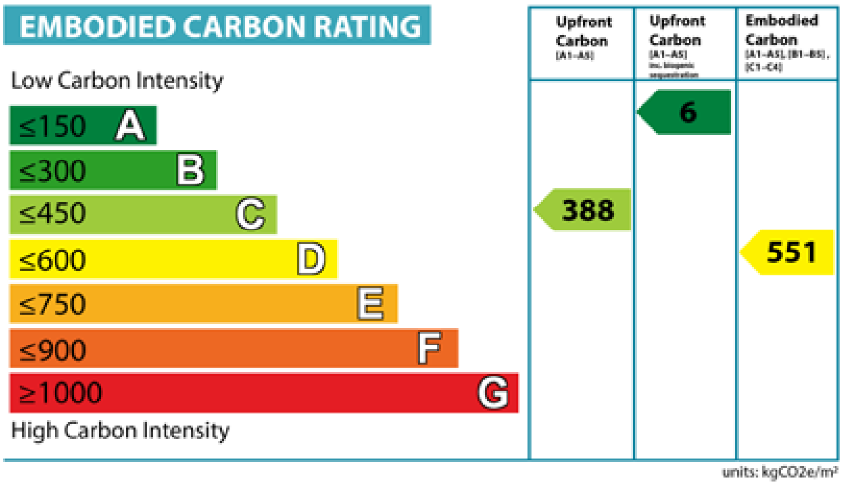
Upfront carbon
41,034kg CO_2e [A1-A5]

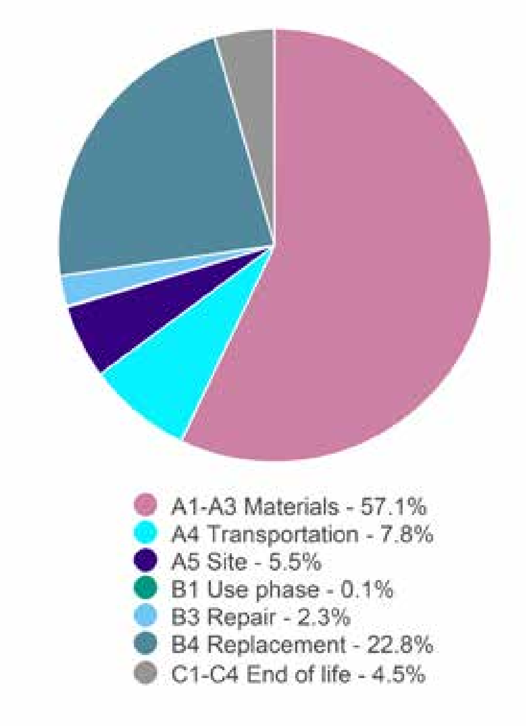
Biogenic carbon sequestration
35,222kg CO_2e [A1-A3]

Embodied carbon
54,592kg CO_2e
[A1–A5], [B1–B5], [C1–C4]

9.3. Type 7 (V1) The Longhouse

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 7 (V1) The Long-house	116.16m²	3 bed	5 people	2	3.5	60 years	RIBA Stage 4	Timber frame Timber façade





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	36573
A4 Transportation	4980
A5 Site	3525
B1 Use phase	62
B3 Repair	1456
B4 Replacement	14588
C1-C4 End of life	2862
Total	**64046**

Upfront carbon
45,078kg CO2e [A1-A5]

Biogenic carbon sequestration
44,348kg CO2e [A1-A3]

Embodied carbon
64,046kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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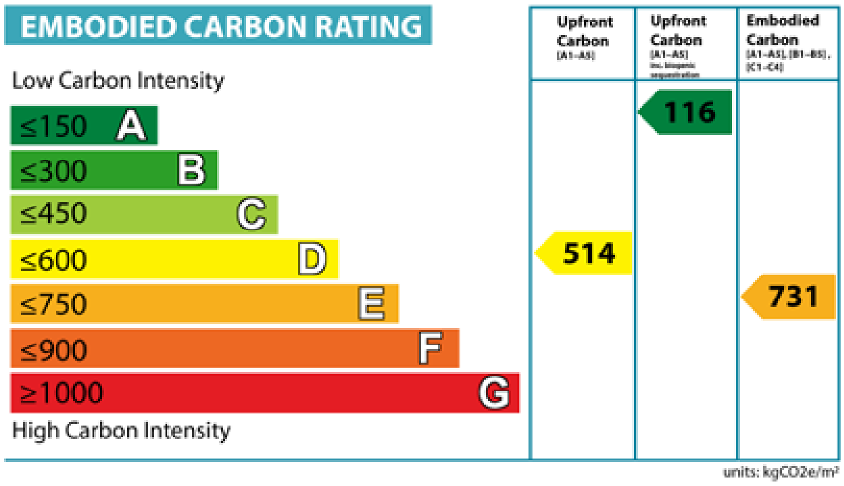
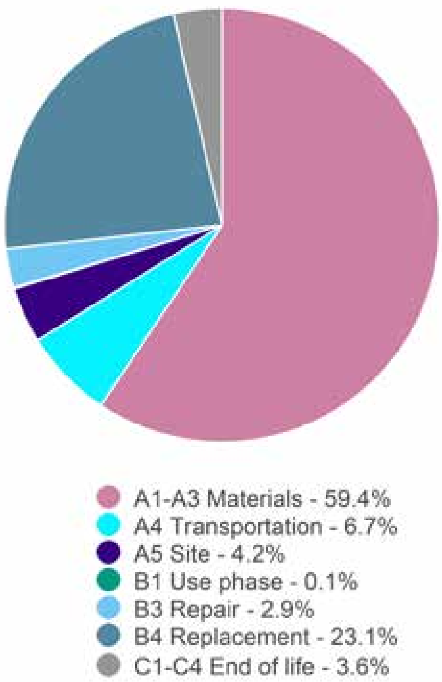
9.4. Type 2 (V2) The Coach House

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 2 (V2) The Coach House	94.47m²	3 bed	5 people	2	4.0	60 years	RIBA Stage 4	Timber frame Render façade





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	41035
A4 Transportation	4629
A5 Site	2867
B1 Use phase	62
B3 Repair	2013
B4 Replacement	15982
C1-C4 End of life	2477
Total	**69065**

Upfront carbon
48,531kg CO2e [A1-A5]

Biogenic carbon sequestration
37,559kg CO2e [A1-A3]

Embodied carbon
69,065kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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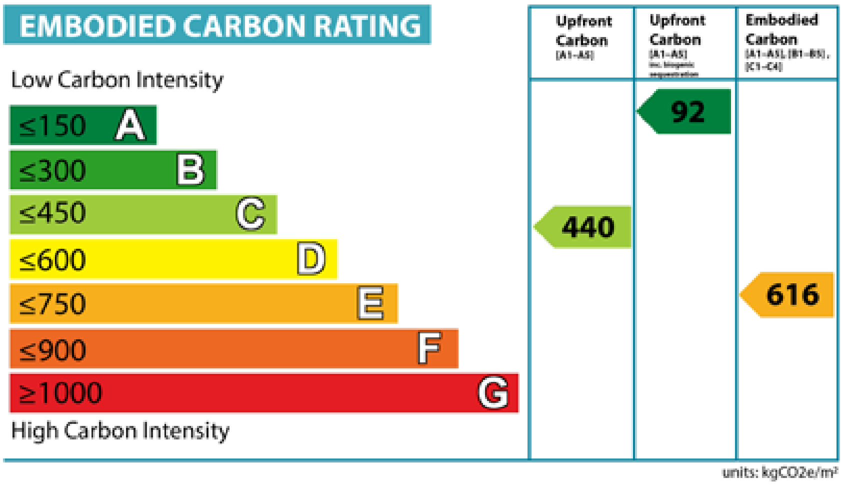
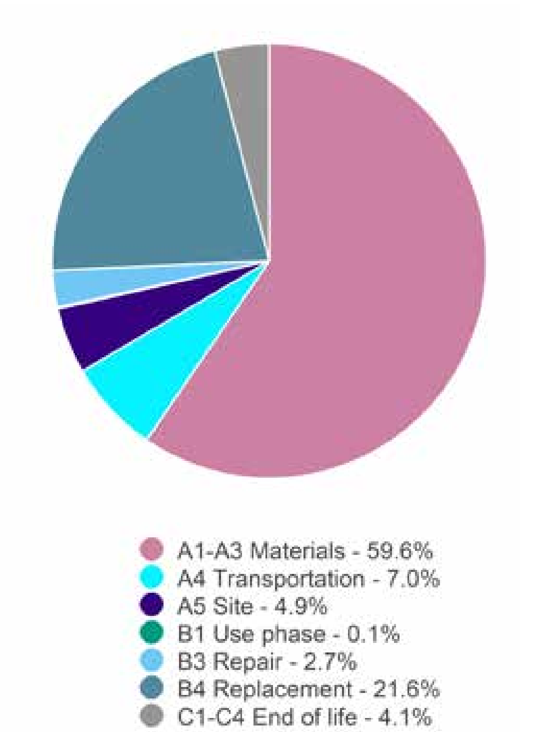
9.5. Type 24 (V1) The Longhouse 4 bed

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 24 (V1) The Long-house 4 bed	122.87m²	4 bed	7 people	2	3.4	60 years	RIBA Stage 4	Timber frame Render façade





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	45084
A4 Transportation	5261
A5 Site	3728
B1 Use phase	97
B3 Repair	2052
B4 Replacement	16364
C1-C4 End of life	3080
Total	**75666**

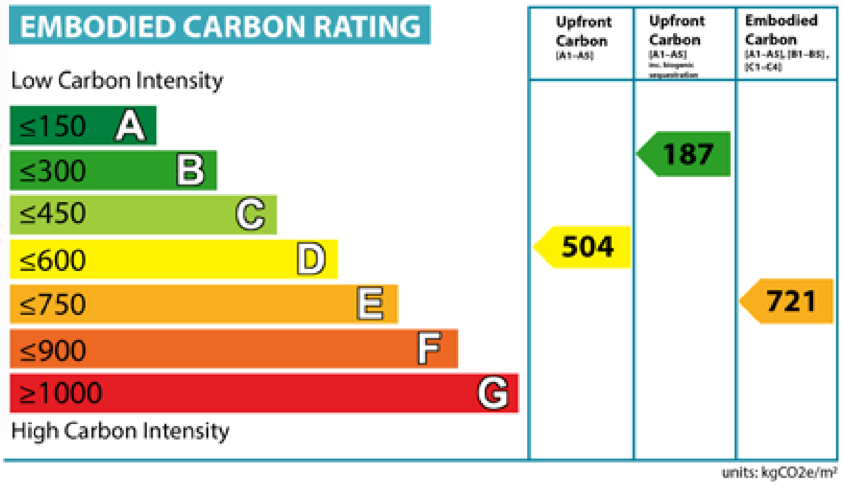
Upfront carbon
54,073kg CO2e [A1-A5]

Biogenic carbon sequestration
42,789kg CO2e [A1-A3]

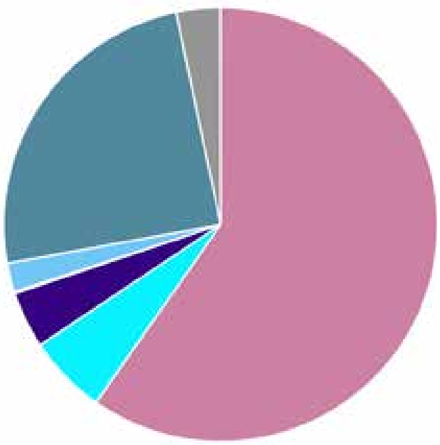
Embodied carbon
75,666kg CO2e
[A1–A5], [B1–B5], [C1–C4]

9.6. Type 11 Gateway Apartments

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 11 Gateway Apartments	536.05m²	8x (1bed)	8x 2 people (16)	2	2.7	60 years	RIBA Stage 4	Timber frame Render façade



Life cycle stage breakdown



Stage	kg CO2e
A1-A3 Materials	230857
A4 Transportation	22829
A5 Site	16264
B1 Use phase	497
B3 Repair	8301
B4 Replacement	94935
C1-C4 End of life	12736
Total	**386419**

Upfront carbon
269,950kg CO2e (A1-A5)

Biogenic carbon sequestration
169,928kg CO2e (A1-A3)

Embodied carbon
386,419kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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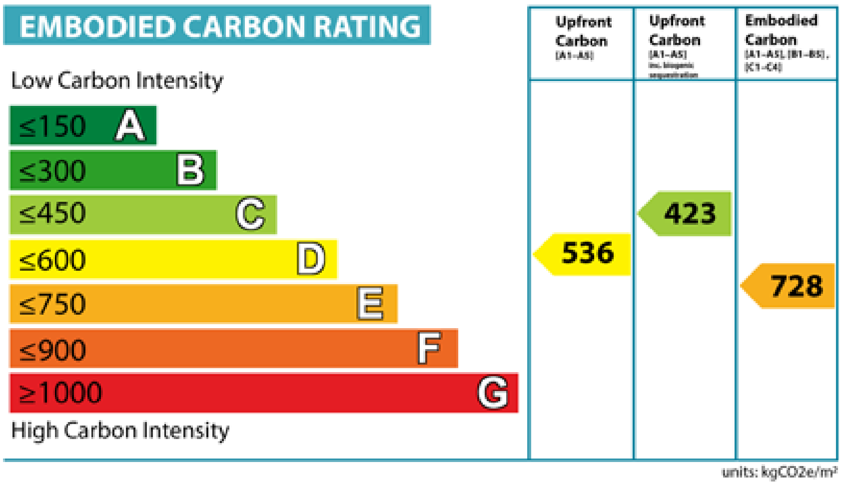
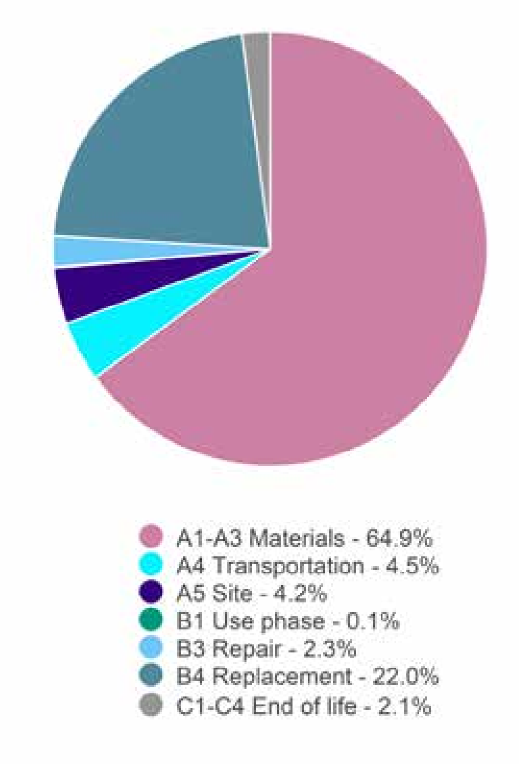
9.7. Baseline 'Business As Usual' Type 4 (V4) The Semi Detached

House type reference/ name	Gross internal floor area (RICS)	No. of bedrooms	Occupancy	Storeys	Form factor*	Reference life for assessment	Design Stage (level of detail)	Description
Type 4 (V4) The Semi-Detached	95.70m²	3 bed	5 people	2	3.5	60 years	RIBA Stage 4	Brick/block masonry PIR insulation





Life cycle stage breakdown

Stage	kg CO2e
A1-A3 Materials	45227
A4 Transportation	3135
A5 Site	2904
B1 Use phase	62
B3 Repair	1590
B4 Replacement	15296
C1-C4 End of life	1458
Total	**69672**

Upfront carbon
51,266kg CO2e [A1-A5]

Biogenic carbon sequestration
10,766kg CO2e [A1-A3]

Embodied carbon
69,672kg CO2e
[A1–A5], [B1–B5], [C1–C4]

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10. Key findings

10.1. 10.1 Summary

This case study has generated a number of key findings that can guide future efforts in reducing embodied carbon on projects, these are summarised below:

- The average upfront carbon intensity of the homes studied is 436kgCO2e/m2 with the average embodied carbon intensity over the life cycle [A-C] being 637kgCO2e/m2. This serves to demonstrate how stretching both the LETI and RIBA climate challenge targets are. Homes at Gwynfaen are low rise and light weight, clearly these targets will prove a challenge to meet when considering the constraints of mid to high rise homes.

- Compared to traditional masonry construction using oil based insulant, homes at Gwynfaen increase the biogenic carbon storage by over 200%. The effect is a saving in upfront emissions of approximately 30 tonnes of CO2e per home.

- For life cycle embodied carbon, it is standard practice to assume that wood based components are incinerated or landfilled at end of life, and this would neutralise the storage effect. Whether this is realistic in the future is a topic of debate amongst LCA practitioners, but even without this benefit up to 10 tonnes of CO2e can be saved per home. Timber construction and wood based insulation derived from sustainably managed sources are fundamentally lighter in terms of impact on our planet than other methods of construction.

- Form factor, (taken as a measure of enclosing outer envelope area/gross internal floor area), would appear to have a significant influence in the homes in this study. A 0.5 increase in form factor can be seen to increase carbon intensity by approximately 100kgCO2e/m2. This is a small sample and warrants further consideration but presents a strong case for considering form factor on both energy use and embodied carbon grounds.

- Considering the above we could question whether reporting intensity of upfront emissions with the benefit of sequestered biogenic carbon included is appropriate. There is potential for this type of target figure to drive inefficient design or an overuse of materials.

- A genuine surprise was the range of carbon intensity figures. There are a few vagaries which are influencing the outputs:

  The amount of PV on the roof – this varies by house type/ demand. Given % impact this will influence results

  Some homes are timber clad, some rendered – the extra carbon storage impacts the second column in the results

  Form factor as described

  Smaller dwellings impacted greater on a sq. m. basis. Same M+E kit, kitchen/sanitary just in a smaller area.

- To arrive at meaningful results takes an elaboration of the BIM model beyond the usual level of detail required. This presents an issue for calculations made at early concept stage and could lead to misleading results. Unfortunately this is exactly the time when decisions which have most influence on embodied carbon are made. As a solution it helps to establish relative impacts between different wall and floors of common constructions and applied on a square metre basis initially (using same U-value). In tandem carbon budgets could be established for building elements factored by various building types. In time a natural feel for carbon intensity will emerge once it is embedded within design workflow.

- The effect of building services should not be underestimated. The six house types studied have shown that building services account for approximately 34% – 43% of embodied carbon. This shows a relatively high impact, albeit admittedly these are highly serviced dwellings with large PV arrays and energy storage. Calculating the benefit in carbon is difficult, the electricity grid is evolving and its carbon intensity is dynamic with limited data on the embodied carbon of MEP services. Never-the-less the benefits of these technologies should not be overlooked despite the substantial impact. It therefore presents an excellent case for inclusion of embodied carbon in definitions of net zero.

- Embodied carbon has only recently featured in the industry spotlight, consensus on the scope of measurement is elusive, but to begin to compare buildings in embodied carbon terms this consensus needs to be established. Never-the-less I'm in favour of the stretching targets being put forward. This could drive innovation in design techniques, measurement tools and an evolution in genuinely low impact products and materials.

Appendix 1

Typical material splits

Quick reference for using the One Click LCA split function to factor percentages of materials modelled in Revit as a monolithic for example; timber stud walls.

Construction	Typical % split
Standard brickwork laided in Stretcher bond face size (length x height) of 215x 65mm	Brick = 0.826 (82.6%) Mortar = 0.174 (17.4%)
Standard blockwork laided in Stretcher bond face size (length x height) of 440 x 215mm	Block = 0.931(93.1%) Mortar = 0.069 (6.9%)
Standard blockwork laided flat face size (length x height) of 440 x 100mm	Block = 0.882 (88.2%) Mortar = 0.118 (11.8%)
Solid timber joists (W)45mm x (T)195mm timbers at 600mm centres	Timber = 0.077 (7.7%) Insulation/air space = 0.923 (92.3%)
Solid timber internal partitions (W)38mm x (T)89mm timbers at 600mm centres	Timber = 0.135 (13.5%) Insulation/airspace = 0.865 (86.5%)
Roof battens based on (W)50mm x (T)25mm battens at 600mm centres and (W)50mm x (T)25mm tile battens at 250mm centres	Timber fraction = 0.15 (15%) Air space = 0.85 (85%)
Cladding battens based on (W)50mm x (T)50mm battens at 600mm centres and (W)50mm x (T)50mm counter battens at 600mm centres	Timber = 0.083 (8.3%) Air Space = 0.917 (91.7%)
Metal resilient ceiling bars mounted at 600mm centres as part of sound proofing ceiling layers 30mm deep	Steel fraction = 0.0076 (0.76%)
Battens forming service voids. Based on (W)50mm x (T)50mm timbers at 600mm centres	Timber fraction = 0.065 (6.5%). Insulation/void = 0.935 (93.5%)

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