PROSIECT CARTREFI O BREN LLEOL

THE HOME-GROWN HOMES PROJECT

ZERO CARBON HOMES

Zero Carbon Timber Solutions for Wales

Cefnogir y prosiect hwn gan Gronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig
This project is supported by the European Agricultural Fund for Rural Development

PROSIECT CARTREFI O BREN LLEOL

THE HOME GROWN HOMES PROJECT

This publication has been issued by WoodKnowledge Wales as part of the Home-Grown Homes project 2020.

Written by Dr. Rob Thomas (Hiraeth Architecture Ltd) and James Moxey (Woodknowledge Wales)

Hiraeth. Architecture Ltd.

woodknowledge WALES

CONTENTS

Purpose of the Study

What is the zero carbon timber solution for Wales?

The Home Grown Home project has taken this objective as our initial and primary goal. Firstly through examining and analysing an appropriate and future proofed definition for 'zero carbon', then through design and calculation developing an understanding of the quantifiable factors of embodied and operational carbon. An examination of existing and alternative timber construction methods, materials and systems offers a range of developed timber solutions that are capable of meeting the target fabric specification. Results to a range of investigations are presented, culminating in whole carbon emission and offsetting calculations for a range of key typologies, shown overleaf, demonstrating the routes to Zero.

Who Is It For

The detailed report presents interim findings including actions for further detailed design, training and skills, technical development and testing, design and modelling tools. The findings may be relevant for designers, manufacturers, specifiers and clients.

Glossary of key terms

Embodied Carbon (kgCO_2e) - The carbon emissions associated with the extraction and processing of materials and the energy and water consumed in producing products and constructing the building.

Operational Carbon (kgCO_2e) - The carbon dioxide and equivalent global warming potential (GWP) of other gases associated with the in-use operation of a building including both regulated and unregulated energy uses.

Form Factor - Ratio of heat loss area to treated floor area

Space Heating Demand (kWh/m^2.yr) - Active heating input required to heat the home.

Modern Methods of Construction - innovative construction methods both on and offsite to build better quality homes more quickly and efficiently.

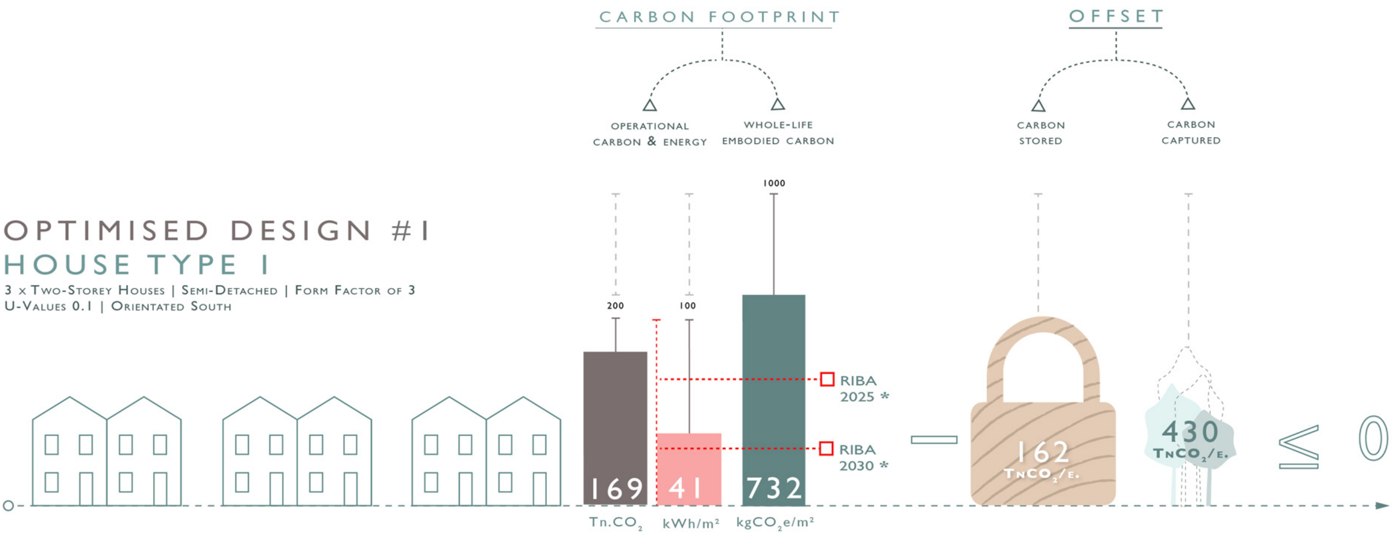
Passivhaus Standard - International energy performance standard for buildings focussed on the dramatic reduction of the space heating and cooling demands through a fabric first approach.

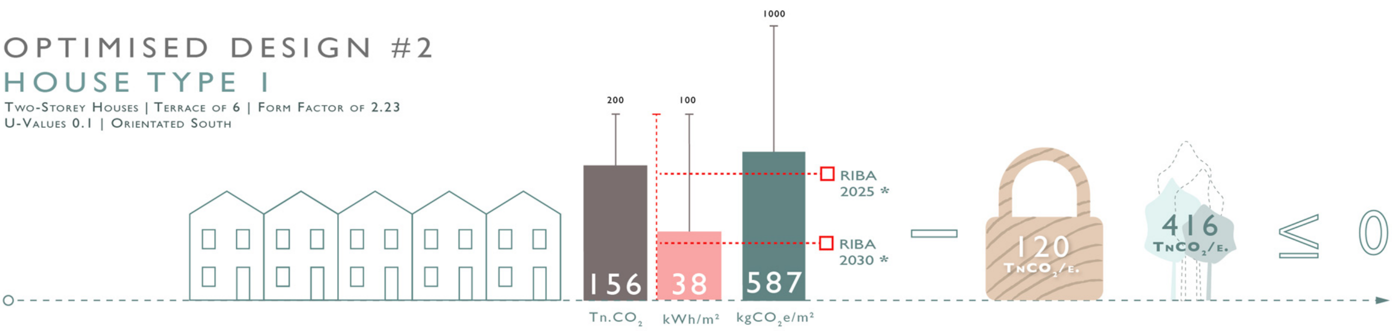
Carbon Offset - Schemes designed to make equivalent reductions of Carbon Dioxide in the atmosphere.

Whole Life Carbon - The carbon emitted over the whole life of the building through materials and construction, the operation of the building, including maintenance, and the disposal of the building and its components at the end of life (assumed as 60 years).

Key Findings :

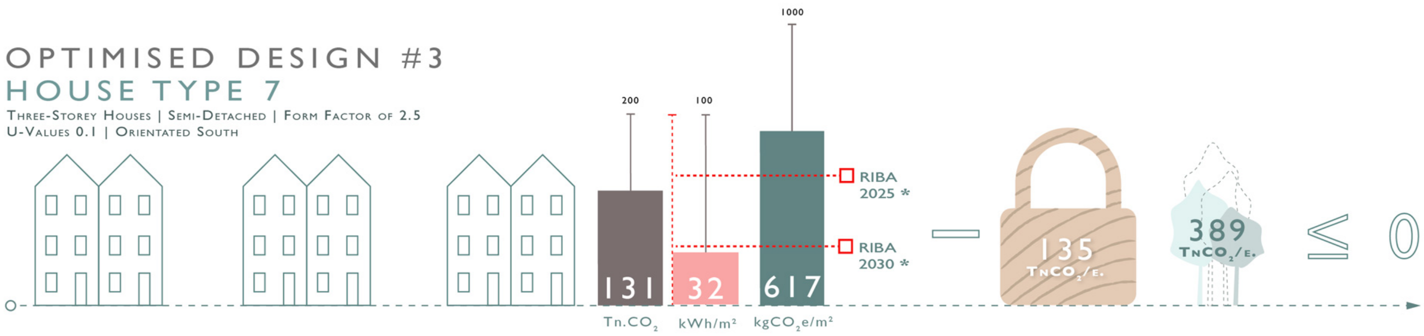
When arranged as a semi-detached structure, **House Type 1** (a traditional 2-storey home designed for four people) presents a significant challenge in terms of reducing total energy demand and in reducing the overall carbon footprint, even when combined with an exceptionally high performance fabric. The large form factor and the disconnected arrangement reduces the energy and material saving benefits that a terrace would provide. The consequence of higher carbon emissions (via materials used and high energy requirements) is that a greater offset is required to compensate if a development is to reach net-zero whole life carbon. A terraced arrangement both reduces the heating demand and the overall carbon footprint so offsetting requirements are reduced significantly.

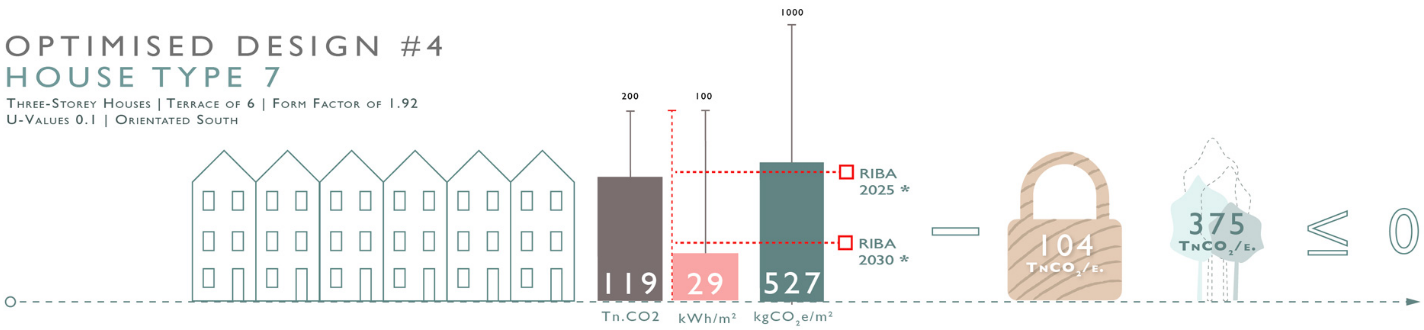




DETAILED FINDINGS

House type 7 is designed as a town house; with a smaller footprint, and is taller with the same quantity of space allocated over three storeys. This performs better as a semi-detached than house type 1 but when arranged as a terrace the total energy demand is significantly below the RIBA targets for 2030, 10 years ahead of schedule. The embodied carbon impacts however are still challenging and we need to work much harder to reduce these if we are to achieve the targets established by RIBA. Structural timber solutions and renewable insulation products offer significant potential savings, particularly in upfront carbon, and store more carbon within the building's fabric for the life of the building. These solutions are supported by a rigorous process of evidence gathering. The detail is presented in our report.





Minimise Operational Energy Demand

Key Results:

1. **Integrate Energy Modelling into Design:** We have remodelled a typical 2-Bed, 4-person home so that its Total Energy Use Intensity is less than 35 $kWh/m^2/yr$ and its Space Heating Demand is designed to be less than 15 $kWh/m^2/yr$.
2. **It's in the Detail:** RIBA's 2030 target of a space heating demand of 15kWh/m^2 is challenging but can be achieved using a high quality, high performance airtight fabric with U-Values in the region of 0.1W/m^2k which is thermal bridge free.
3. **High Form Factor comes at a Cost (Money and Carbon):** Less compact designs (e.g. bungalows, detached and semi-detached) have higher form factors so require either a higher performing fabric (i.e. $< 0.1W/m^2k$) to achieve the desired 15 $kWh/m^2/yr$ or will require a higher rate of energy to heat them.
4. **Maximise Solar Energy through Glazing:** Rethinking the orientation of structures and layouts including glazing allows us to maximise the use of the sun's energy to heat our homes whilst managing overheating risk. Our modelling shows benefits in the region of up to 3.5 kWh/m^2 through optimising orientation and layout.

Minimise Embodied carbon

Key Results:

1. **Achieving Targets is Challenging:** We have modelled 5 advanced timber frame panels which emit up-front carbon of less than **69kg** CO_2e/m^2 and whole-life embodied carbon of approximately **180kg** CO_2e/m^2, reductions of over 60% and 23% respectively over a standard timber frame solution.
1. **Focus on Up-Front Carbon:** The most important time to reduce CO_2 emissions is now. Carbon emitted during construction, also known as Up-Front Carbon, must be minimised.
2. **Timber helps us get there:** Achieving up-front CO_2 emissions of less than 300kgCO_2e/m^2 is challenging but can be achieved if high-value timber components are employed in the manufacture and construction of housing.
3. **Consult then Procure:** Clients should consult with the supply-chain to ensure that fabric solutions can be delivered that achieve both embodied carbon and operational energy targets.

EMBODIED CARBON

Only Renewable Energy

Key Results:

1. **Energy Creation:** Micro-renewables such as solar panels installed on a roof will create energy that can be used to heat a home, to charge an electric vehicle or to sell energy to the national grid. Solar panels and heat pumps also reduce the reliance of our homes on energy derived from burning fossil fuels. They therefore have the potential to reduce CO_2 emissions.
2. **Renewables also Emit CO_2:** However there is no such thing as clean energy – there is a carbon footprint incurred in manufacturing and installing pumps, panels and batteries, and like all emerging technologies their predicted lifetime can be shorter (and thus have a higher carbon footprint) than designed.
3. **Inefficiencies through SAP:** The existing SAP calculation method relied upon by Building Regulations incentivises the use of renewables to achieve a high EPC rating whilst the fabric performance (in terms of both embodied carbon and operational energy demands) of that building may be neglected.

RENEWABLES

Minimise the Performance Gap

Key Results:

1. **Joined up Thinking about Quality:** A performance gap is created when the building stage of a project (including manufacturing) deviates from the specification and design based predictive modelling. There are ways in which the performance gap can be minimised which includes ensuring a level of joined up thinking between client, designer, main contractor, manufacturer(s), and any sub-contracted businesses.

2. **Appoint a QA Tsar:** The energy performance gap must be closed through the adoption of a strict and contractually robust quality assurance system. It is crucial to identify a key member of the team who can assure quality. One way to address this would be to appoint an individual whose responsibility is to ensure quality at all levels including monitoring final material choices, manufacturing processes, construction detailing, and key performance characteristics such as levelling, airtightness, and moisture ingress. This individual should be qualified and trained to analyse in detail the impact of any changes and report deviations to the client. They should at least:

   - Adopt post-occupancy evaluation to verify and disclose performance
   - Measure energy consumption after at least 1 year of occupation and report building annual peak energy demand
   - Verify embodied carbon data and report average annual carbon content of the heat supplied ($KgCO_2$ /kWh)

3. **Utilise Standardisation and Building Information Modelling:** Through the combination of standardised and repeatable specifications for fabric proposals and the development of repeatable housing models it is possible to employ Building Information Modelling incorporating detailed whole life cycle carbon modelling. In addition to offering opportunity for economies of scale, establishing repeatable models ensures consistency and familiarity from design modelling through manufacture to delivery.

Offset to Below Zero

Key Results:

1. **Offset as a Last Resort:** To achieve net-zero an offset is required but only after every effort has been employed to reduce CO_2 emissions through design including material choices and construction methods.
2. **The Numbers:** As an example a development of 100 homes would emit approximately 8000 tonnes of CO_2, would store around 2500 tonnes of carbon in the form of timber products and would therefore need an offset planting scheme that captures the remaining 5500 tonnes. This is equivalent to a 30 hectare woodland containing a mix of broadleaf and conifers.
3. **The Cost of Offsetting:** Our modelling suggests an offset, through the creation of a UK Forestry Standard woodland planting scheme that costs around 1.5% of development costs if the proposed reductions are delivered to embodied and operational carbon emissions - and of course the woodland is an asset that remains in your ownership

OFFSET

EXTENDED GLOSSARY

Carbon terms

Biogenic Carbon: carbon derived from biomass

Carbon dioxide equivalent / CO_2 equivalent (CO_2e): unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide

Carbon Footprint: sum of greenhouse gas (GHG) emissions and GHG removals in a product system, expressed as CO_2 equivalents (CO_2e) and based on a life cycle assessment using the single impact category of climate change. The carbon footprint of a house is equivalent to its Whole Life Carbon. The carbon footprint of a brick is equivalent to its Embodied Carbon

Carbon negative: an activity that goes beyond achieving net zero carbon emissions to actually create an environmental benefit by removing additional carbon dioxide from the atmosphere. The same thing as “climate positive”

Carbon Offset: mechanism for compensating embodied or Operational Carbon through the prevention of the release of, reduction in, or removal of an amount of greenhouse gas emissions in a process outside the product system under study Carbon positive is how organizations sometimes describe Climate Positive or Carbon Negative. As it is confusing, we don’t recommend its use

Embodied Carbon (kgCO2e): Embodied Carbon emissions are the GHG emissions associated with materials and construction processes throughout the whole life cycle of an asset (Modules A1-A5, B1-B5, C1-C4)

Upfront Carbon (kgCO2e): Upfront Carbon emissions are those GHG emissions associated with materials and construction processes up to practical completion (so product manufacture, transport and construction) (Modules A1-A5)

Operational Carbon (kgCO2e): Operational Carbon emissions are those GHG emissions arising from all energy and water consumed by an asset in use, as projected or measured, over its life cycle (Modules B6-B7)

Operational Energy Carbon: Operational energy carbon emissions (Module B6) are those GHG emissions arising from all energy consumed by an asset in use, as projected or measured, over its life cycle

Operational Water Use Carbon: Operational water emissions (Module B7) are those GHG emissions arising from water supply and wastewater treatment for an asset, as projected or measured, over its life cycle

Whole Life Carbon: Whole Life Carbon emissions are the sum total of all asset related GHG emissions, both operational and embodied over the life cycle of an asset including its disposal. Overall Whole Life Carbon asset performance includes separately reporting the potential benefit from future energy recovery, reuse, and recycling (Module D). Whole Life Carbon = Operational Carbon + Embodied Carbon and Module D (Modules A1-A5, B1-B7, C1-C4 & Module D)

Net Zero Terms

Net Zero Embodied Carbon: A 'Net Zero Embodied Carbon emissions' asset is one where the sum of Embodied Carbon (Modules A1-A5, B1-B7 & C1-C4) and offsets equals zero

Net Zero Upfront Carbon: A 'Net Zero Upfront Carbon' Asset is one where the sum total of GHG emissions from material sourcing, transport, manufacture and construction (Modules A1-A5) plus offsets equals zero

Net Zero Operational Carbon: A 'Net Zero Operational Carbon' asset is achieved when those GHG emissions arising from all energy and water consumed by an asset in use (B6, B7), as projected or measured over its life cycle, plus offsets, equals zero

Net Zero Whole Life Carbon: A 'Net Zero Whole Life Carbon' Asset is one where the sum total of all asset related GHG emissions, both operational and embodied, over its life cycle including disposal (Modules A1-A5, B1-B7, C1-C4) plus offsets equals zero

Net Zero Carbon Asset: A 'Net Zero Carbon Asset' is one where the sum total of all asset related GHG emissions, both operational and embodied, over its life cycle including disposal (Modules A1-A5, B1-B7, C1-C4) plus offsets equals zero

Net Zero - Carbon Neutral: For simplicity and consistency, 'Net Zero' and 'Carbon Neutral' are considered to be interchangeable.

Energy Terms

Embodied energy: total of all the energy consumed in the processes associated with the production of materials and products

Zero energy - Energy neutral: where a building produces as much energy from onsite renewables as it consumes.

Energy positive: where a building produces more energy from onsite renewables than it consumes

Other terms

Biomass: material of biological origin excluding material embedded in geological and/or fossilized formations

Circular economy: an economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles

Climate positive: an activity that goes beyond achieving net zero carbon emissions to actually create an environmental benefit by removing additional carbon dioxide from the atmosphere. The same thing as "carbon negative"

Design team: architects, engineers and technology specialists responsible for the conceptual design aspects and their development into drawings, specifications and instructions required for construction of the building or facility and associated processes. The design team is a part of the project team

Element unit quantity (EUQ): a unit of measurement that relates solely to the quantity of the element or sub-element itself (e.g. the area of the external walls, the area of windows and external doors and the number of internal doors)

Element: part of a construction containing a defined combination of construction products (e.g. ground floor, roof, external wall)

Energy Use Intensity (kWh/m2.yr): total energy consumed in a building annually including both regulated energy and unregulated energy.

Energy Performance Certificate (EPC): the adopted method for demonstrating a building's energy efficiency rating in the UK. EPCs employ a rating system of A to G with A representing an energy efficient building.

Environmental Product Declaration (EPD): An EPD provides environmental information about a product in a standardised format using an consistent methodology. For construction products in Europe, the European standard EN 15804 provides the format and methodology

Global warming: a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants

Greenhouse gas (GHG): gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds

Gross internal area (GIA): Gross internal area is the area of a building measured to the internal face of the perimeter walls at each floor level

Life Cycle Assessment (LCA): compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

Mechanical Ventilation with Heat Recovery (MVHR): mechanical ventilation system including air distribution with energy recovery delivering fresh air which has been preheated (or precooled) using heat recovery from exhausted air.

Modern Methods of Construction - innovative construction methods delivered both on and offsite to build better quality buildings more quickly and efficiently.

Passivhaus: Passivhaus buildings provide a high level of occupant comfort while using very little energy for heating and cooling. They are built with meticulous attention to detail and rigorous design and construction according to principles developed by the Passivhaus Institute in Germany, and can be certified through an exacting quality assurance process

Passivhaus Planning Package (PHPP): software package developed by the Passive House Institute to calculate energy use and CO2 emissions as a design, verification and certification tool associated with and required to comply with the Passivhaus Standard.

Radiative forcing: an externally imposed perturbation in the radiative energy budget of the Earth's climate system – causes global warming

Regulated Energy: Energy used in the operation of a building to -

a) maintain comfort conditions via heating and/or cooling
b) provide hot water
c) provide lighting and run pumps and fans associated with heating, cooling and hot water

Space Heating Demand (kWh/m2.yr): Active heating input required to heat the home.

Standard Assessment Procedure (SAP): The calculation methodology employed in the UK to calculate the energy performance of self contained dwellings and individual flats to demonstrate compliance with Part L of the Building Regulations.

Unregulated Energy: Energy used in the operation of a building to power appliances such as white goods, ICT and small power.

01
THE CONTEXT

CHAPTER 1 SUMMARY :

The following section will set out the context in which this research study has been undertaken and seek to interpret the key definitions, terminology, and methodologies employed in the subject area and present a review of the current industry position.

- Net Zero Carbon is where the sum total of all carbon emissions generated from both operational and embodied, over its life cycle including disposal plus offsets equals zero.
- Achieving Net Zero Operational Carbon addresses a small proportion of a building's whole life carbon emissions and includes significant opportunity to underestimate.
- A performance gap between modelled performance and actual in use carbon emissions is a primary contributor to this underestimation.
- The replacement of steel, concrete and masonry with timber frame including advanced modern methods of timber construction offers a holistically beneficial opportunity to reduce embodied carbon emissions, improve fabric performance and close the performance gap whilst building on a robust existing circular economy.
- Delivering Net Whole Life Zero Carbon in housing is complex and currently unregulated but through the development of increasingly standardised approaches including building specifications, typologies, supply chains and calculation methodologies, the social sector offers a 'quick win' opportunity to lead the world towards the 2050 Net Zero target.

1.0. The Team

Being presented with the challenge to develop a zero-carbon solution for Wales is an opportunity both exciting and nail-biting. The challenge is significant, with different flavours of zero-carbon in the market-place and the need for an evidence-based approach. We were set a research question to develop a timber-based solution that worked for both housing clients and the supply chain in the context of a widely declared climate emergency. So for the last three years we have focussed on this challenge. This report is the story of that journey.

A multi-disciplinary team was drawn together with the expertise needed to harvest ideas and gather the evidence to support the research and to develop workable solutions. Their expertise, whether in design, embodied carbon analysis, application of passive house principles, engineering timber frame, building physics modelling, or housing procurement was fundamental in constructing a holistic research programme. Without this team there would have been significant gaps in our knowledge and we would have struggled to achieve the results that we did.

The project lead Woodknowledge Wales (WKW) made a conscious decision to start at RIBA stage 0: the strategic definition stage. The purpose was to unpick then reassemble our original brief. We were not confident that the problem proposed to the team was the right problem to be explored. A series of early workshops were therefore held to find the right questions which would guide the teams investigations. A consequence was that the UK Green Building Councils zero-carbon framework provided a valuable guide to underpin the research. During the course of the project other organisations such as

The Project Team

Alan Clarke	Energy and Building Services	Elemental Solutions
Beth Williams	Structural Engineer | Passive House Designer	Build Collective
Diana Waldron	Passive House Designer	Cardiff Metropolitan University
David Hedges	Housing Advisor	Woodknowledge Wales
Eilidh Forster	Embodied Carbon Assessor	Woodknowledge Wales
Gary Newman	Forestry and Timber Housing	Woodknowledge Wales
James Moxey	Project Lead	Woodknowledge Wales
Jane Anderson	Life Cycle Analysis	Construction LCA
Kasper Maciej	Building Physics | Passive House Designer	Greenguage
Nick Grant	Passive House Consultant	Elemental Solutions
Rob Thomas	Architect | Passive House Designer	Hiraeth Architecture
Rob Wheaton	Architect | Passive House Designer	Stride Treglown

RIBA reinterpreted the UKGBC framework into targets that again provided some guiding principles.

Managing this team presented a unique challenge. Our individual experts came to the project with a variety of starting points and priorities. Our agreed focus was to adopt *fabric first principles*. This would allow us to model both the embodied carbon and space heating demand impacts of different fabric options. Another key consideration was to develop a portfolio of fabric designs (five in total) that aligned with the timber frame solutions that were being manufactured by the supply chain in Wales. We were adamant that any innovations would be developed in partnership with our national manufacturing base.

The same could be said of housing design. We took as our starting point a classic two-bed, four-person house design that is typically procured by Housing Associations in Wales. We then re-envisaged this in various different footprints, orientations, and combinations (e.g. semi-detached versus terracing). Our investigations allowed us to re-evaluate the impact of these variations in house-types in terms of space heating and embody carbon impacts.

During the course of the project we took an important change of direction. We moved from the development of a demonstrator house towards investigating the development of a set of zero-carbon housing solutions. This was supported by feedback form the PAR team which we believe has made the project much stronger and has provided a platform for wider engagement with the housing sector.

The lockdowns in 2020 did not adversely affect the project. Missed opportunities to visit offices and factories were compensated by multiple online meetings with representatives of housing associations and off-site manufacturers. We were also successful in developing relationships with Welsh Government officers with a remit to deliver zero carbon housing in Wales. This has led to securing funds through Welsh Government's Innovative Housing Programme to take this work forward into the next stage of development – supporting eleven stock-holding Local Authorities across Wales to deliver zero carbon housing solutions using timber.

We have learnt many things along the course of this research journey, which are presented in the report and require further investigation. One particular lesson which we feel is important for clients to consider is that developing the right zero-carbon solutions requires not just a multi-disciplinary approach but one which is evidence-based gathered though openness, collaboration and scrutiny. The alternative route, often encouraged by the restrictions of current procurement practice, generates a risk that individual *disconnected* sub-contractors aren't able to help you achieve your goals. The supply chain should not be engaged at the last minute but if possible, from the start.

1.1. The Brief

In its report *Zero Carbon Homes*, WoodKnowledge Wales presented to Welsh Government a strategy for the integration of the Welsh forest industries supply chain with offsite timber construction. Focussed particularly on home-grown timber, the strategic action plan set out a series of key actions to transform the use of home-grown timber in house building through increasing supply chain integration, encouraging a focus on producing high-value construction products and addressing the lack of tree planting in Wales.

In the period since publishing, the call for a zero carbon off-site timber construction solution has grown louder in Wales and from a wider audience, encompassing manufacturers, housing associations and the construction industry. Whilst a number of Welsh timber frame manufacturers have the experience and capability to deliver advanced high performance timber systems capable of meeting Passivhaus equivalent fabric performance, this is far from the norm. Local and national policy has focussed attention on the increased use of Modern Methods of Construction, the climate change emergency has added to the essential need for a swift and dramatic improvement of energy performance in new build construction, and the innovative housing programme has continued to highlight both the immense opportunity available for the Welsh supply chains and the fundamental issues associated with design and procurement.

This presents the simple question...

What is the zero carbon timber solution for Wales?

The Home Grown Home project has taken this objective as our initial and primary goal. Firstly through examining and analysing an appropriate and future proofed definition

Action...

A key 'Action for Manufacturing' arising from the *Zero Carbon Homes* report recommended:

The creation of a standard specification for timber-frame housing to improve efficiency of delivery, quality of outcome and reduce costs.

Such a specification would enable a diffuse SME based industry to operate as if it were a large factory, producing a standardised output but have the advantage of remaining agile and resilient to demand fluctuations. This specification should be resolved for both low operational carbon (e.g. Passivhaus) and low embodied carbon but allow for design, creativity and flexibility to adapt to different aesthetic expectations. Critically, a standard specification backed up by a quality assurance process would enable the rapid mobilisation of supply and provide the demand-side certainty necessary to unlock investment in adding-value processes.

for ‘zero carbon’, then through design and calculation the research study has sought to develop an understanding of the quantifiable factors of embodied and operational carbon and the potential implications for typical working methods. An examination of existing and alternative timber construction methods, materials and systems presents a range of developed timber solutions that are capable of meeting the proposed target fabric specification. These are analysed in terms of opportunities and constraints and consideration given to future development, prototyping and manufacture.

The analysis is conducted with a focus on one of the primary house types delivered for affordable housing purposes in Wales – a 2-bed, 4-person two storey house delivered either as a semi detached or small terrace arrangement. The focus on such a standard house type presents the opportunity to consider the role of design in the delivery of a cost effective, carbon effective affordable housing solution.

1.2. Why Net Zero Whole Life Carbon?

We know that the built environment is responsible for 40% of Wales' energy related carbon emissions with housing contributing approximately 78% of this. In addition, actual carbon emissions from new build housing are consistently evidenced to be significantly higher than the expected carbon emissions calculated during design stages, generally referred to as the performance gap. The Welsh Assembly Government in line with the wider UK picture has committed to reduce all carbon emissions to net zero by 2050. And declared an ambition for all public bodies to be carbon neutral by 2030. As presented by the Committee for Climate Change, the next decade is key to delivering this target.

One of the simplest, holistically beneficial and most cost effective opportunities to reduce this contribution is to address publicly financed affordable housing. The latest estimates of housing need in Wales indicate we need to build 8,300 new homes each year. In 2018-19 Wales constructed 5,777 new homes of which 1,288 were new social sector dwellings.

In its Climate Emergency Design Guide, the London Energy Transformation Initiative (LETI) provides guidance for how to design and build zero carbon buildings. It sets out a trajectory to net zero carbon with the conviction that:

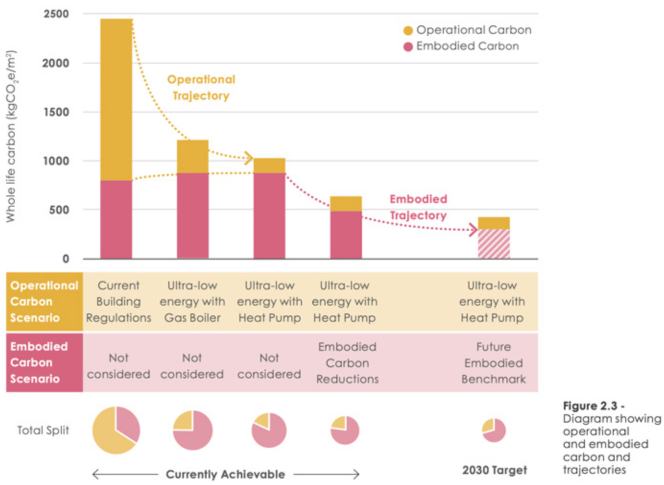
- *By 2025, 100% of new buildings must be designed to achieve net zero operational carbon.*
- *By 2030 all new buildings should be built and operate at net zero carbon.*

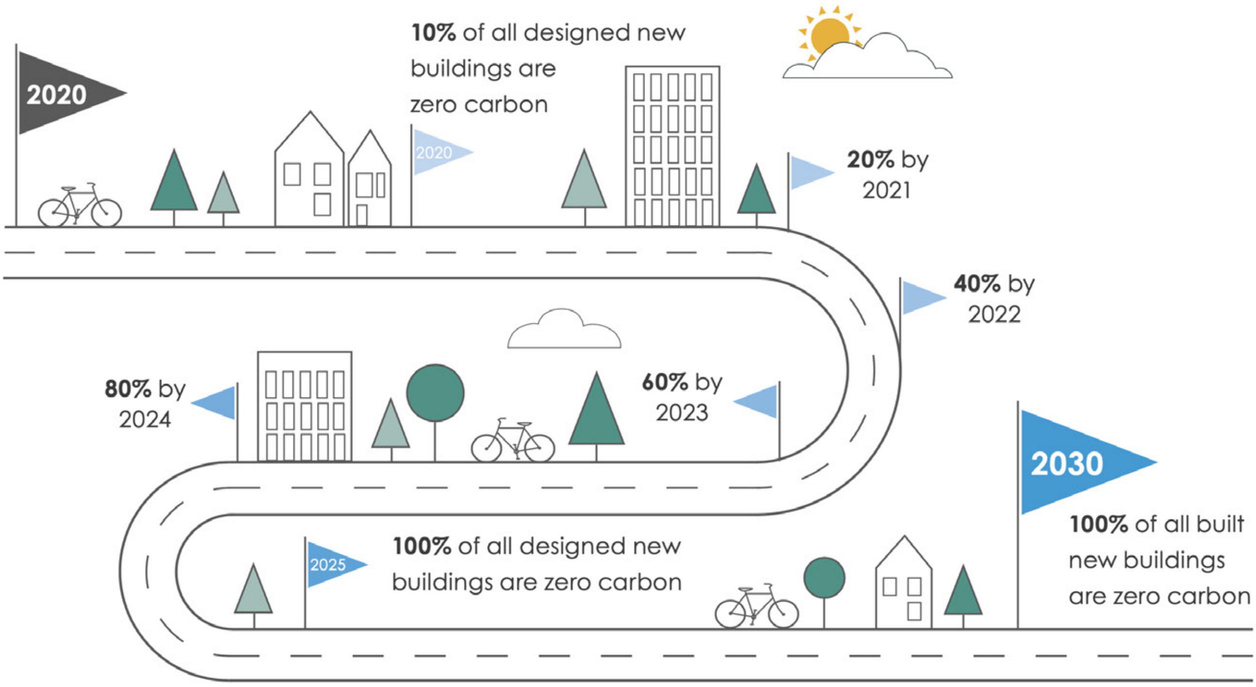
The critical assumption is that the industry requires a transition period where delivery can catch up with design and specification. To be on this path we need to be designing to net zero carbon immediately.

The industry is currently actively seeking strategies to achieve net zero operational carbon. In basic principles this equates to establishing a balance between improved fabric performance (reducing energy demand) and on-site renewable energy generation (low carbon energy supply).

Operational carbon currently contributes between 40 and 65% of a building's whole life carbon (LETI Climate Emergency Design Guide, p38). It is therefore the first focus of a zero carbon strategy. However focusing on an approach of 'balancing out' energy

Fig 1.2.1 Diagram showing operational and embodied carbon and trajectories (LETI)





demand and supply has the potential to generate high carbon outcomes unless we introduce other considerations.

As illustrated in **Figure 1.2.1** by LETI, as operational carbon is reduced, the contribution of embodied carbon becomes increasingly important. With the introduction of whole life embodied carbon targets, decision making regarding materials choice, fabric performance, on-site and off-site energy generation, design and orientation become wholistic. The option of large numbers of photovoltaics, which currently would generate a significant quantity of associated embodied carbon, in order to meet the energy demand of a poor performing house fabric is simply not a viable approach.

We believe that this trajectory, shown in **Figure 1.2.2** similarly matched by the RIBA's Climate 2030 declaration shown in **Figure 1.2.3** must set a framework by which the publicly funded housing sector and timber frame industry in Wales, and the rest of the UK, align their practices and immediate interests. The industry must focus on essential investment, development and learning, training and skill development, supply chain development and critically the development of supportive procurement methodologies. Such a trajectory requires immediate action and uptake.

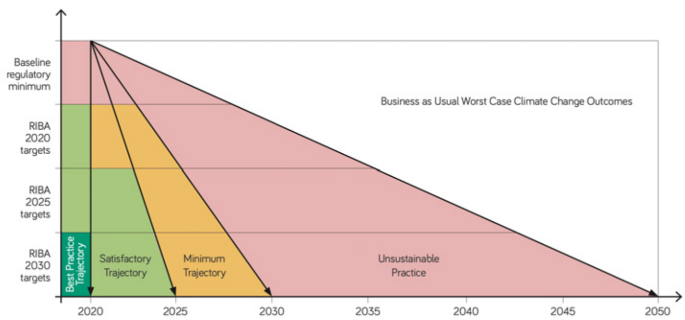


Fig 1.2.3 RIBA Climate Challenge Trajectories

1.3. Why timber?

We don't think the argument for timber is a hard one to make:

- Steel and cement alone are responsible for almost 50% of UK's industrial carbon emissions.
- Every cubic metre of wood used as a substitute for materials like steel, aluminium, concrete or plastics based products reduces CO_2 emissions by an average of 1.1 tCO_2. Added to the 0.9t of CO_2 sequestered, a cubic metre of wood saves a total of $2tCO_2$. A 10% increase in the number of homes constructed of timber in Europe would produce CO_2 reductions equivalent to 25% of the reductions prescribed by the Kyoto Protocol.[1]
- Substituting timber frame for masonry in housing can reduce embodied carbon by 1.7-3.2 tCO2e per unit dependent on house type, equivalent to approximately a 20% reduction. An additional 2.0-4.2 tCO2e can be stored as sequestered carbon in timber frame built housing over a masonry equivalent. (Biocomposites Centre, Bangor University, Wood in Construction in the UK, page 11). Where timber cladding is also used to replace a masonry outer skin, a further 5.6tCO2e in embodied carbon emissions is possible based on a detached house type, and an additional 2.1tCO2e is sequestered.
- Timber construction systems contribute 80% of all new homes built in Scotland but accounted for approximately only 25% of new housing starts in 2016 across the UK.
- Of the nearly 4000 new build homes currently listed in the Passive House Database, over 40% are of timber frame construction. Although for a wide variety of reasons, this high proportion is a reflection of the potential for timber frame to accommodate and deliver the exceptional levels of insulation, airtightness and thermal bridging necessary to achieve the required fabric performance.
- Modern methods of construction (MMC) utilising both simple and advanced methods of off-site manufacturing is proven to dramatically improve construction quality, reduce waste, and improve speed of construction. Focused on quality alone, the future of low carbon construction requires a much greater degree of accuracy in thermal continuity and airtightness to both address the existing performance gap and therefore deliver the dramatic fabric performance improvements required to meet energy reduction targets. The only solution to deliver net zero whole life carbon housing at scale requires the advancement of offsite MMC. The scale of opportunity for MMC is recognised at a national level and is the subject of the Welsh Government's 'Re-imagining social house building in Wales - A Modern Methods of Construction Strategy for Social Housing' published in February 2020'.

- Recent figures shows that one in three homes in Wales are now built from timber frame and more than 3,250 panellised timber frame homes were manufactured in Wales in 2018. Welsh manufactured timber frame for social housing has grown from 445 units in 2016 to 752 in 2018, an increase of 69%. The Welsh timber frame construction sector is estimated to provide over 350 direct jobs.
- The current Welsh offsite manufactured timber-frame sector is characterised by many (over 20) small companies with relatively low levels of automation. The sector operates at very low profit margins but is agile, creative and receptive to change. We believe that these companies have a key role to play in moving to net zero whole life carbon housing in a way which is appropriate for Wales, commercially robust and sustainable over the long-term.

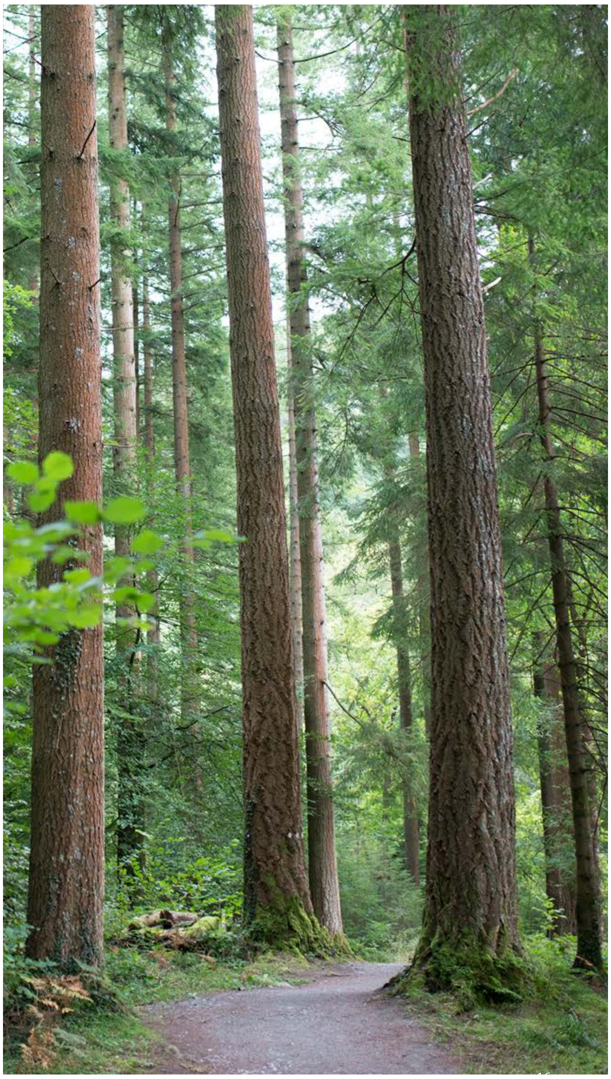
But we are biased - we like trees, and we want more of them in Wales. More trees means an opportunity for a strong and valuable industry to use the trees, while in turn a strong and valuable industry means we plant more trees. And we like timber homes, we like the way they feel - the right combination of natural materials is proven to improve indoor air quality, offer fantastic acoustic quality, be robust and perform well throughout its life, whether in terms of energy performance, robustness and fire. And when a timber building is no longer fit for purpose there exists a wide range of positive uses for the materials - they can be recovered, reused, recycled or allowed to naturally biodegrade. Timber has always been an essential and valuable element of the Welsh resource. As other industries come under increasing pressure - the use of timber in construction offers a growth potential of exceptional scale.

We don’t think there is any alternative that can offer the holistically beneficial opportunities that a net-zero whole life carbon timber solution can for the housing industry. But we are not only interested in the materials that provide the structure of our homes - this study will consider the insulations, internal and external finishes, windows and doors, and seek to not only identify the opportunity but also provide the data to support the selection and specification of timber based solutions.

Welsh Timber or Any Timber?

The development and use of Welsh timber resources sits at the heart of Wood Knowledge Wales and the Home Grown Home project:

- Wales hasn't always been the king of steel. 200 years ago, locally-grown larch was the building material of choice. In 2018, 1.6 million m^3 of timber was harvested in Wales, creating £530 million for our economy and supporting the employment of between approximately 8,500 and 11,300 people in planting, harvesting, management and timber processing. This is equivalent to almost 4 green jobs per 100 hectares of managed forest or put another way, 6 green jobs per 1000m^3 of harvested timber.
- While the majority of the harvested logs could be graded for construction, most leave for other markets such as pallets, packaging and fencing. According to estimates from WoodKnowledge Wales, Welsh housing would require up to 200,000m^3 of harvested logs to meet annual housing targets, ie 12.5% of the total harvested in 2018.
- The UK imports two thirds of the timber it needs, the remainder is supplied from home-grown suppliers. Only China imports more wood than the UK. In construction over 80% of total usage is imported. WoodKnowledge Wales have calculated that in order to produce sufficient timber to satisfy the current demand in construction without diverting from other markets, a further 45,000 hectares of productive forest is required in Wales.



- Manufacturing homes with timber from Welsh forests provides an opportunity to exceed the objectives outlined in a Prosperity for All: A Low Carbon Wales (March 2019) to sequester atmospheric carbon through forest planting and the construction of homes as carbon stores.

However in considering the brief and specification for timber construction products, great thought has been given regarding current and future opportunities and constraints. Whilst it is recognised that there is substantial opportunity for the application of Welsh timber resources and products within a high performance construction system, there remains areas of development required to generate confidence, robust and competitive supply chains, and Welsh timber products and systems. This will take time and two specific conclusions have been reached in developing this brief –

For the purpose of this study, the specific use of Welsh timber and Welsh timber products has not been set as a key performance indicator, however in the development of solutions the role of current and future Welsh timber resources and products will be given great consideration and opportunities identified.

Action...

a. The priority today is to develop a high performance, multi-layered net-zero whole life carbon timber housing solution which can be delivered preferably through local supply chains regardless of primary sources.

b. The establishment of robust and secure procurement, and delivery of timber solutions at scale will create substantial opportunity for the development of supply chains and the creation of Welsh timber based products and solutions to compete in existing markets, both in Wales and in the rest of the UK.

1.4. What is a low / zero carbon building?

The principle of zero carbon in construction is one which remains confusing and challenging to define, specify, regulate and deliver. It is widely accepted that the UK must lead by example to fundamentally reduce emissions from our built environment however there continues to be a failing of consensus regarding the methods by which this is achieved. The HGH project team have therefore been presented with the question of what is a zero carbon house and challenged to establish a defined and clear brief.

For some, the notion of a zero carbon building means we must generate as much energy as we use i.e. to heat and light our homes and provide hot water. Taken to the extreme this means that even the poorest fabric can achieve 'net zero operational carbon' with enough renewable energy generation. Current Building Regulations set a limit to fabric performance via the Target Fabric Energy Efficiency concept. As calculated by the Passivhaus Trust however, a notionally 'zero carbon home' according to current Building Regulations Part L, would emit 18Kg CO_2/m2.year and so an average 68m2 new home would need 28 solar panels to realise a zero net operational carbon emissions – far greater than the roof space available.[2] **(See Figure 1.4.3)**

Unfortunately on-site renewable and a proportion of off-site renewable energy generation is not delivered in a way that makes this simple concept of offsetting operational energy use a reality.

> # Action...
>
> In Zero Carbon Homes, Wood-Knowledge Wales recommended :
>
> **Adopt the UK Green Building Council's (UKGBC) Net Zero Carbon Buildings:**
>
> A Framework Definition (February 2019). This definition provides a framework to set the industry on a consistent pathway towards achieving net zero whole life carbon and should be applied throughout all levels of policy and regulation.

> *Therefore, whether through legislation, commercial interests, ethical interests or simple sensible thinking, the construction industry is being challenged to dramatically improve building fabric performance to reduce energy use.*

By delivering the same house to Passivhaus levels of fabric performance, the energy requirement of our previous example would be halved – this time requiring just 14 solar panels. **(See Figure 1.4.4 overleaf)**

> *If we consider the building's whole life carbon emissions however, we need to consider more than operational impacts but also emissions associated with the materials and construction processes used through-out a product/process life cycle.*

Fig 1.4.1 Average new build energy demand - current situation from 2020 with an ASHP

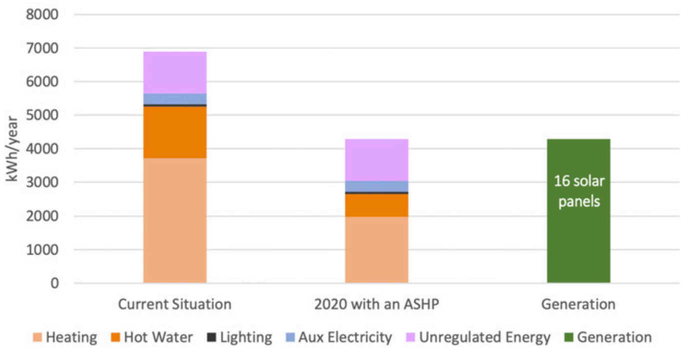


Figure 1 - Average new build energy demand - current situation and from 2020 with an ASHP

Fig 1.4.2 Average new build energy demand - impact of the Performance Gap

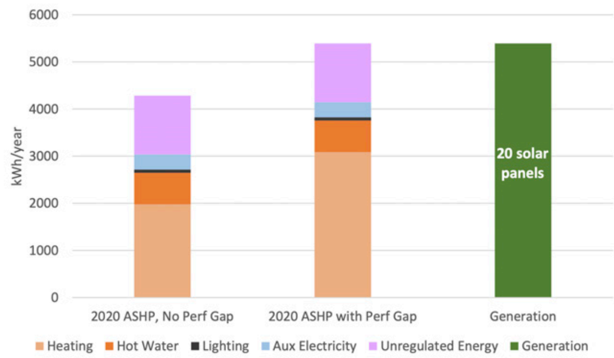


Figure 2 - Average new build energy demand - impact of the Performance Gap

Fig 1.4.3 Average new build energy demand - impact of storage losses

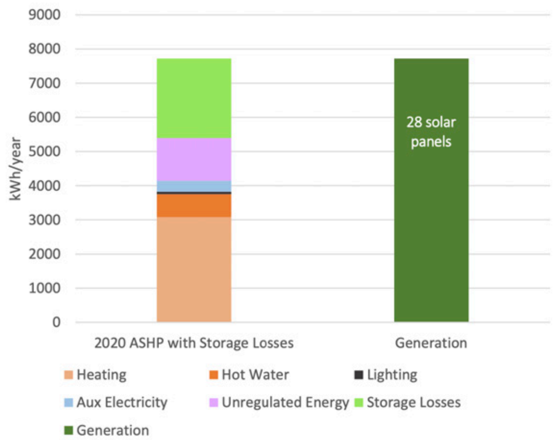


Figure 3 - Average new build energy demand - impact of storage losses

Fig 1.4.4 Average new build energy demand vs Passivhaus

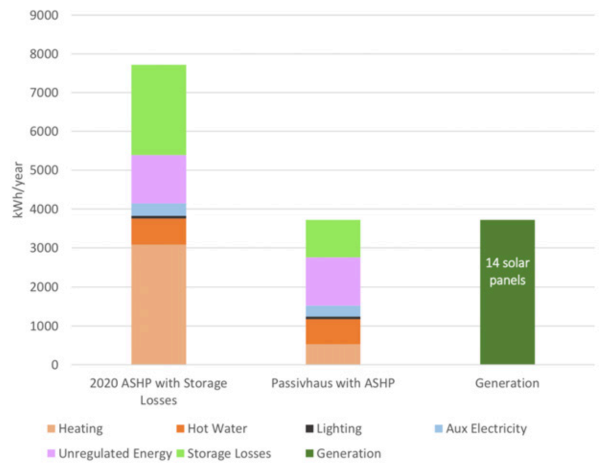


Figure 4 - Average new build energy demand vs Passivhaus

Studies undertaken by the Passivhaus Trust in their publication - Passivhaus: The Route to Zero Carbon

Estimates for embodied carbon emissions as a percentage of whole life emissions of a house are in the range 20 - 27%, although this varies due to the different calculation methodologies employed.

As operational carbon drops, embodied carbon becomes increasingly significant.

Research presented by LETI suggests that embodied carbon of an ultra-low energy building with heat pump will make up 70% of a building's Whole Life Carbon.

In developing the brief for the work reported here, we adopted the **UKGBC Zero Carbon Framework** and its guiding principles to guide our research and development activities. These **principles are**:

1. Reduce the embodied carbon of buildings.
2. Reduce the operational energy demands of the building whilst in use.
3. Maximise the energy used from renewable sources.
4. Conduct a whole life carbon assessment to understand the total emissions of each building.
5. After implementing 1-4, undertake activities to offset the emissions calculated in (4) to achieve net-zero whole life carbon.

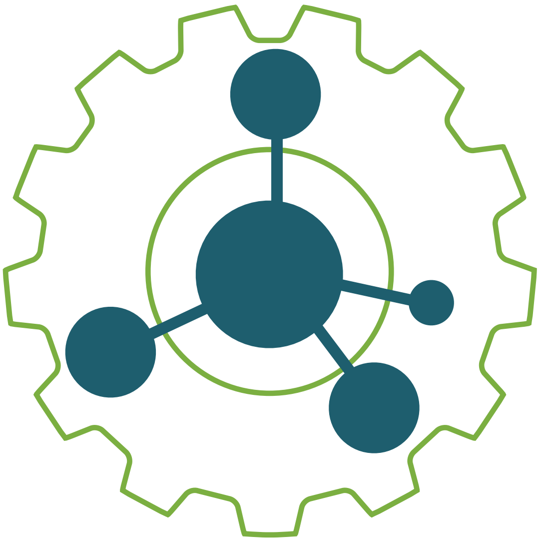
Albeit with minor incremental improvements, the industry, both timber and other construction types, have had a period of relatively consistent performance requirements to meet Building Regulations. For timber-framed wall design this has meant using an assembly with a 140mm solid stud with foam insulation and a vapour control component to meet the required thermal performance requirements. If a slightly improved specification is required, it is possible to make incremental improvements by increasing stud depths to 170 or 190mm, using reflective membranes or providing an insulated service void to the interior. They can be accommodated within existing manufacturing techniques and detailing.

For a large majority of the timber frame constructions realised currently the associated supply chains, processes, training and competitive tendering are subsequently relatively straightforward and consistent. However, the broad and immensely complex factors involved in the design and specification of 'zero carbon' timber frames is a significant challenge and currently represents a barrier to a mainstream high volume offering. Exceptionally high performance fabrics are subsequently typically bespoke designed, procured and manufactured.

Action...

In collaboration with design professionals and the timber industry, the following study and guidance will look to apply the UKGBC framework and supplementary targets and principles to the specific application of social sector housing for Wales. This will seek to develop -

- an understanding of existing and required methodologies to model, design, calculate and deliver to zero.
- a manufacturing strategy to meet zero through the development of a high performance fabric specification or range of specifications using timber.



Operational carbon

The way a building uses energy and subsequently emits carbon can be categorised as follows:

a) to maintain comfort conditions via heating and/or cooling
b) to provide hot water
c) to provide lighting and run pumps and fans associated with heating, cooling and hot water
d) to power appliances such as white goods, ICT and small power.

Types (a) to (c) are classed as 'regulated energy' and used in calculations to meet building regulations. These categories of energy use, whilst also associated with user activities and comfort expectations, can be directly affected by building design and performance, and the specification of energy systems. Category (d) by contrast is largely associated with user activities and the energy demand is generally considered to be falling due to the improving energy efficiencies of appliances.

A net zero operational carbon building is one which provides all the building's regulated and unregulated energy requirements without CO2 emission via the burning of fossil fuels.

This approach may achieve net zero without significant improvement of the building fabric, instead relying on a decarbonising national energy grid coupled with the provision of on-site micro-renewables. Projects such as the 'Homes as Power Stations' project are exploring the potential to achieve regulated energy, and in some cases unregulated energy needs via on-site renewables including photovoltaics, heat pumps, batteries and smart systems. Whilst feasible, particularly in the context of a decarbonising national grid, this premise is challenging and complex. In isolation of dramatic reductions in regulated energy demands, and more robust energy modelling, there is scope to significantly underestimate the point of operational carbon balance. This is examined in further detail in Passivhaus: The Route to Zero Carbon by the Passivhaus Trust, and illustrated in **Figures 1.4.1 - 1.4.4** (shown previously).

The principle is also considered in detail by the UK Committee on Climate Change which describes a number of key factors that reinforce the need for fabric performance improvements even where homes are equipped with on-site renewable technologies. With significant oversimplification - the electrification of surface transport and heating loads will generate a significant increase in electricity demand, particularly in terms of 'peak demand' which often occurs on cold winter evenings, typically coinciding with periods of reduced supply from renewables such as wind and solar. A high performance fabric coupled with precision engineered components and detailing ensures that heat losses through the fabric are much reduced over current levels. This provides two key benefits:

- Homes require less energy to achieve comfort levels thus reducing the peak demand;
- Homes stay warmer longer, allowing smart heating, where heating systems can draw on energy when it is available, outside of peak periods to 'smooth' the peak demand and reduce carbon intensity.

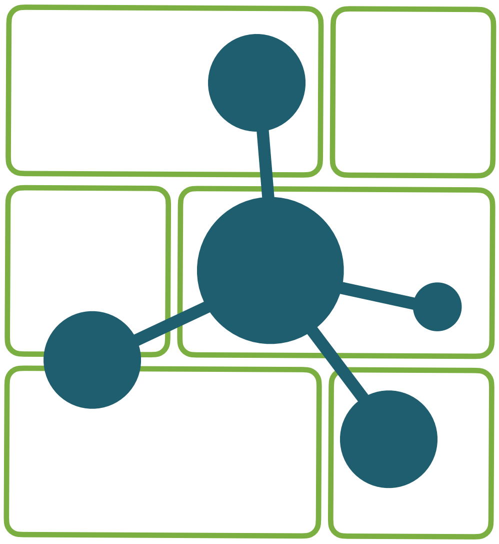
In establishing an operational energy strategy, LETI advise that this must subsequently be driven by a top-down and bottom up approach whereby the energy a building needs to operate (top-down) must be reduced and matched by the amount of renewable energy that can reasonably be made available to that building both on-site and offsite (bottom up). This second variable is progressing quickly and therefore a 'point in time' must be considered following the changing future carbon intensity of the grid.

LETI have subsequently set out a net zero operational target date of 2030 encompassing:

a) Following a fabric first approach, all energy consumed in the home for both regulated and unregulated energy will be met by renewable energy generated both on-site and off-site.
b) Two target metrics are used to establish targets for operational energy which can subsequently be translated via primary energy fuel factors to Operational Carbon:
   - Space heating demand is the energy required to heat a building and usually expressed in kWh/m2/yr.
   - Total Energy Use Intensity is the total energy consumed in a building annually including both regulated energy and unregulated energy. It can also be expressed in kWh/m2.yr.

When establishing these targets and considering metrics it is critical to also understand the calculation methodologies employed. Current methods of calculation to meet the purposes of Building Regulation compliance are based on percentage improvements over benchmark levels and

EPCs. This is discussed in further detail in the Passivhaus Trust's EPCs as Efficiency Targets which states that although accurate when modelled against PHPP for standard levels of performance, the EPC format becomes less accurate as technical performance diverges from the default assumptions within SAP. EPCs provide metrics based on the cost of energy use per unit floor area in £/kWh/m2 and emissions of CO2 in CO2/m2. As concluded by the UKCCC, it is subject to fuel price variations over time and can lead to perverse incentives where emission saving measures involve a switch in fuels. Targets should focus on the actual space heating demand and energy consumed in the building. Space heating demand with units kWh/m2.yr is already an output of SAP software, however the accuracy of this methodology is questionable when applied to the high performance targets being examined here and compared with the Passivhaus Planning Package (PHPP). As such in parallel with establishing consistent and comparable targets there is a need to consider how better to improve the accuracy of modelling of a compliance tool.



Embodied Carbon

To account for the whole life carbon emissions of a home, we must consider both operational emissions (as described above) and embodied emissions: carbon emissions associated with the transport, processing, manufacture and assembly of products and resources in the construction of a home, its maintenance and its disposal at the end of it's life.

As shown in **Figure 1.4.5** (overleaf) whole life embodied carbon emissions can account for a significant proportion of the carbon emitted in a building's life.

As operational carbon reduces through improved fabric performance and low carbon energy sources, the proportional contribution associated with embodied emissions becomes more critical.

Upfront embodied carbon is CO2 emitted today in the construction of the dwelling, locked in for the life of the building without potential to be reduced. By contrast,

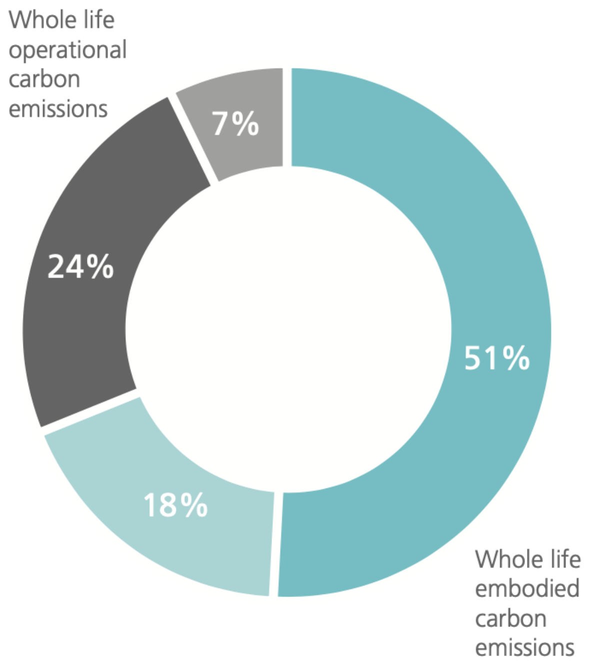


Fig 1.4.5 Whole life operational carbon emissions for a residential block with basic internal fit out

operational emissions are spread over the course of the building's life with some potential to reduce emissions through retrofit and decarbonisation. DEFRA Data shows that a kg of CO2 saved over the next 5 years will have a greater environmental value than it will in 10 or more years time.

However this is an area of carbon that is largely being overlooked in current house building as there are no current statutory requirements or consistent modelling methods.

As shown in **Figure 1.4.6** Embodied Carbon is categorised into 4 stages, with a 5th added if we adopt a circular economy approach. Stages A1 – A5 describe 'Upfront Carbon' i.e. carbon emitted today in the delivery of the home: the supply of materials; the construction and manufacturing activities and the transportation of products and components. Embodied upfront carbon is calculated by collating all material, product and energy inputs required in these stages. The data provided in Environmental Product Declarations of construction materials combined with modelling tools allow us to calculate the embodied carbon emissions of buildings.

There is no current adopted standard for calculating either upfront carbon or whole life embodied carbon, and there exists a wide range of modelling tools and databases that offer alternative techniques, with varying accuracy, to present whole life carbon data for a building. Whilst hugely significant steps have been taken to develop internationally agreed standards for construction product databases and Environmental Product Declarations there remains a gap in knowledge and understanding about their application and interpretation within design and specification processes.

Specifiers often make both informed and instinctive decisions regarding embodied carbon through our selection of materials, identifying natural material alternatives within the thermal envelope for example, or considering how materials might be reclaimed for reuse. However these decisions are rarely evidenced by objective data.

There is a sufficient body of analysis to conclude that the increased regulation and *calculation of embodied carbon emissions will highlight the positive contribution that timber products make in reducing upfront carbon emissions in construction.*

Data presented by the UK Committee on Climate Change indicates that timber frame construction can reduce embodied carbon emissions by up to around 3tCO2e per home compared with a masonry alternative. When applied to the UK housing stock, the potential for reductions associated with favouring timber could reduce embodied emissions in the sector by 0.5-1MtCO2e per annum in 2050. As such the UK Committee for Climate Change recommend a substantial increase in the use of wood in construction.

The development of Whole Life Carbon thinking is discussed in further detail in Wood Knowledge Wales' Embodied Carbon Reduction Guidance produced in collaboration with Construction LCA and the ASBP.

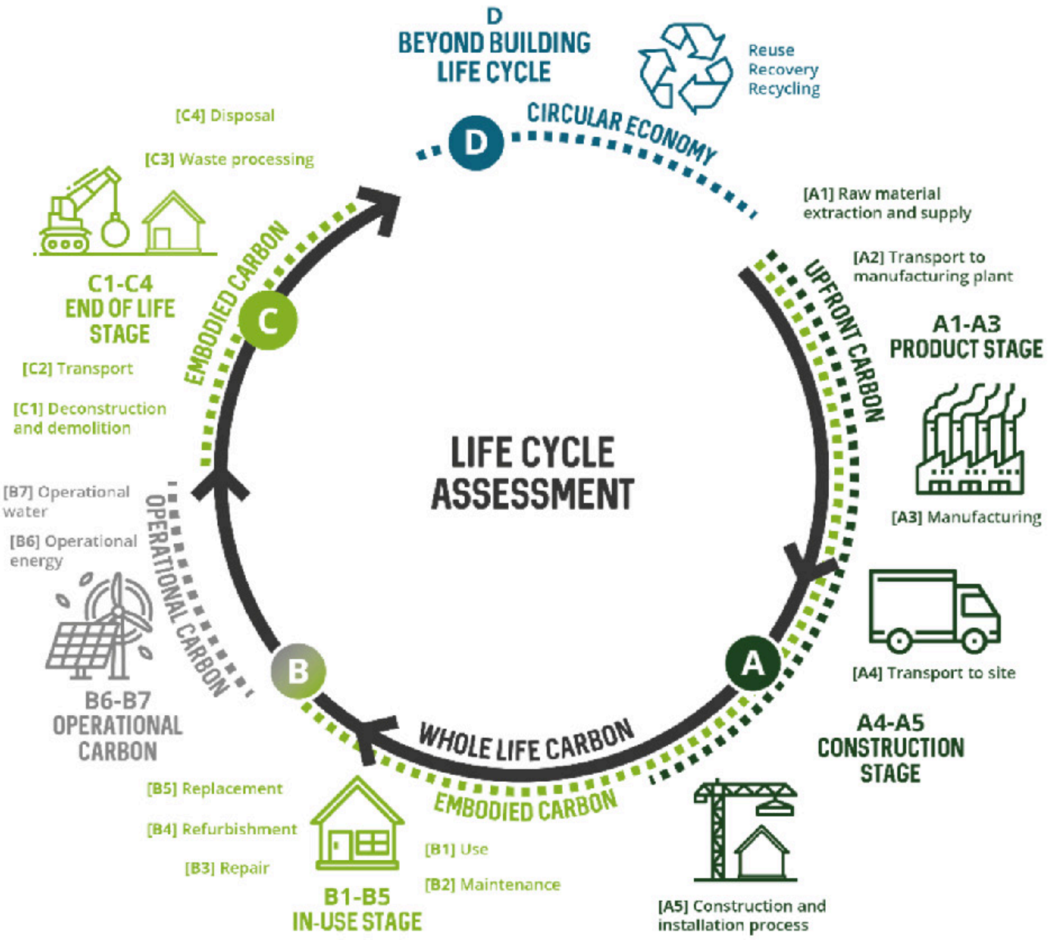


Fig 1.4.6 Life Cycle Assessment

1.5. The Energy Performance Gap

Based on analysis of completed buildings in use, there is evidence of a significant gap between the energy use calculated during a building's design via modelling and the actual energy used by occupants.

A number of studies by organisations such as Innovate UK and Zero Carbon Hub have analysed evidence collected from buildings completed over the last 30 years. Whilst it is acknowledged that these studies might not accurately reflect recent improvements in the industry, it is widely accepted that buildings are performing far more poorly than originally designed, resulting in higher energy demands to achieve comfortable living environments.

Building performance is currently assessed and approved based on design stage modelling and key stage site inspections. The nature of this existing statutory approval process relies on the accuracy of assumptions at design stages and limited assessment of site quality. No further assessment of compliance is undertaken at an 'as-built' stage. Subsequently modelled energy savings, and carbon emission reductions associated with new buildings may be significantly overestimated.

Factors that have been commonly attributed with contributing to the performance gap include:

- Incorrect modelling of anticipated user activities, such as number of occupants, lifestyle factors and perception of comfort. These parameters are rarely reviewed post-completion and assumptions may subsequently not properly reflect the in-use behaviour of occupants.
- Poor quality of construction particularly in regards to the thermal envelope with often unseen defects such as gaps in insulation, or in the seals around joints and services allowing heat loss in excess of modelling which would otherwise assume continuity. Site practices that have been the accepted norm for decades no longer meet the required standards.
- Current mechanisms of performance modelling are often based on default building performance assumptions and average data which can present significantly inaccurate results. Examples include generic climate data and default building performance such as thermal bridge calculations.
- Poorly procured, commissioned, maintained and used mechanical and electrical systems which are often complex to operate increase the potential for discrepancies between occupant modelling and in use reality.
- A lack of consequence - through both will and ignorance there is little consequence for designers, contractors and suppliers when energy performance fails to meet intended specifications within the current system of Building Regulations.

The Passivhaus Trust calculate that the average home is likely to use around 40% more energy than predicted, with heating demand sometimes 200-300% greater.

However as performance requirements increase (particularly in regards to airtightness, continuity of insulation, and reduction of thermal bridging) construction quality and following the details becomes of increasing important and impact.

The Energy Performance Gap and Timber Frame

Common areas of vulnerability that are specific to timber frame include:

- Inaccurate assumptions modelled for repeating thermal bridges such as structural stud work at openings, cripple studs, internal and external corners , or panel and sole plates, allowing an overestimate of building fabric performance.
- Poorly fitted insulations such as rigid insulation installed poorly supported and with gaps, or semi-rigid batts and rolls, over-compressed or allowed to slump.
- Improperly taped and fixed membranes which may be acting as vapour control layers, reflexivity membranes or airtightness layers.
- Poorly sealed service connections through the fabric.

Further details can be found in 'Making the Right Choices; A guide to improving the build quality of new build timber frame social housing' by Trada on behalf of WoodKnowledge Wales.

Action...

The energy performance gap must be closed through the adoption of a strict and contractually robust quality assurance system. This can be assured through the design, specification and installation of materials and systems evidenced to comply with required and modelled performance data, during construction through a monitoring and recording process with modelling reviewed in line with as built, and on completion through pre and post occupancy monitoring. Passivhaus Certification presents a model for quality assurance that has been evidenced to deliver in use performance at or better than modelled levels.

Current Building Regulations do not place any specific requirement on contractors or clients to assure on-site quality. And building performance evaluation methods - evidencing actual building performance is currently limited to as built airtightness testing. Whilst informed clients and consultant teams may impose contractual obligations and incentives to promote quality there remains a fundamental issue associated with the management of quality and assurance and evidencing of actual performance in use. To evidence the opportunity for improvement, Passivhaus offers a relevant comparative model with in use data demonstrating that it is possible to design and deliver high performance targets with no measurable performance gap through the application of a robust quality assurance methodology.

The majority of homes delivered by the affordable housing sector must be delivered in accordance with an insurance backed warranty provider. Similarly to the Building Control procedures, warranty providers employ a plan based checking service for compliance and critical stage inspections. Unlike Building Control, warranty providers typically demand a significantly more constrained technical approach based on well proven construction types. These are presented as technical manuals of performance specifications, typically evidenced to ensure a robust solution to fulfil the 10 year timeline of the warranty. Whilst this is generally recognised as a method for reducing robustness related defects, warranty providers do not currently assess energy performance in design, construction and use.

1.6. Performance Monitoring

Current Building Regulations require minimal checks during construction, on completion and during commissioning of systems, particularly in regards to operational energy performance. On occupation, there are no regulatory requirements to monitor the performance of a dwelling unless triggered by serious concerns. Building performance evaluation is subsequently currently undertaken predominantly during design stages as assumption based modelling in the form of the Standard Assessment Procedure. Modelled assumptions are used as a compliance tool at point of submission but there is no formal or regulatory procedure for evidencing modelled assumptions as built through the regulation approval process. Manufacturers, contractors, consultants and clients are therefore responsible for managing all substitutions or deviations from this modelling. Airtightness testing is an exception to this position with a mandatory requirement for airtightness testing to be undertaken on all or a sample of constructed new dwellings to confirm compliance.

As previously discussed the existing lack of formal requirements for as built building performance evaluation is associated with aspects of the evidenced performance gap present in new build housing. As higher performance requirements are demanded, the role of quality assurance becomes of critical importance and it is essential that a methodology and regulatory framework is developed which implements a robust programme of building performance evaluation and in use monitoring. The topic is discussed in further detail in Wood Knowledge Wales' Building Performance Guidance produced in collaboration with the Good Homes Alliance.

In developing an understanding of the current context, the project team have paid close attention to the quality assessment requirements associated with the design, construction and certification of existing building performance targets including the AECB Silver Standard, Energiesprong and particularly the Passivhaus Standard. These standards are compared with current Building Regulations and a number of other considerations in 'Building Standards Comparison' by the Good Homes Alliance. This includes an analysis of assumed performance gaps associated with each approach.

As previously discussed, via a broad portfolio of assessed completed buildings, the PH Standard is evidenced to accurately deliver design stage modelling in construction and use, frequently delivering better than expected performance. This could be attributed in part to the motivations, commitment and specialist training commonly present in the client, construction professional teams that embark on this type of project. However there are a number of robust mandatory requirements in design, construction and occupation to demonstrate compliance prior to the award of the PH Standard. The quality assurance methodology that all PH buildings must meet are set out and explained in 'Claiming the PH Standard' by the Passivhaus Trust with some of the key relevant factors including -

- Use of the Passivhaus Planning Package as a design and compliance modelling tool, maintained throughout the course of the project with rigorous requirements for the accuracy of data entry.
- A network of specialist trained designers and certifiers with certification awarded only where compliance is confirmed by calculation and review of construction information by an approved Certifier.
- Requirements for building performance evaluation including airtightness testing .
- The application of tested and certified products, systems and materials with supporting equivalent performance data. Where non certified products are tested, conservative default values ensure underestimations result from their use.
- Quality assurance methods in construction include record keeping, including photographic records and material/product evidence including for all substitutions, and site inspections.

02

DEVELOPING A FRAMEWORK

CHAPTER 2 SUMMARY :

During the course of the research project, a number of frameworks, guidance documents and commitments have set out a route and methodology for delivering Net Zero Carbon. However there does not currently exist an accepted model which will inform regulatory change for the social housing sector in Wales. The following section will outline a proposed set of targets and principles along with a methodology, to be applied and tested in the design of net zero carbon social housing for Wales.

- The Net Zero Housing framework proposed for Wales builds on existing frameworks, targets and principles to set out a common approach to delivering Net Zero Carbon. It has been developed with specific consideration of the context of Wales, politically, socially, economically, climatically and geographically.
- Targets of **15kWh/m2/yr** for Space Heating Demand and **35kWh/m2/yr** for Energy Use Intensity are proposed in order to minimise operational energy demand and associated carbon emissions.
- Targets of **300kgCO2e/m2** and **350kgCO2e/m2** for upfront and whole life embodied carbon emissions are proposed.

In consultation with experts from across the UK, the Home Grown Home project team have developed a net-zero whole life carbon guide (**Figure 2.1**) to inform the delivery of sustainable housing in Wales. On commencement of the project two key frameworks informed initial discussions – the UK Green Building Council's Framework for Net Zero Carbon Buildings and the Passivhaus Standard. However during the course of the project a number of seminal studies have been presented including –

- UK Housing : Fit for the Future, Committee on Climate Change, Feb 2019
- LETI Climate Emergency Design Guide, Jan 2020
- CIBSE Steps to Net Zero Carbon Buildings, Aug 2019 and
- CIBSE Climate Action Plan, July 2019
- RIBA 2030 Climate Challenge June 2019.

All adopt the UK Green Building Council's Framework and a trajectory that recommends that all new homes are ***designed*** as net -zero (whole life) carbon by 2025 and all new homes ***to be*** net zero in operation from 2030. Each document reflects on the need to re-think Part L and SAP to ensure methodologies are accurate to actual operation and include all energy (including unregulated energy.) **Figure 2.1** shows the first iteration of this guide. The following section sets out how this guide has been arrived at.

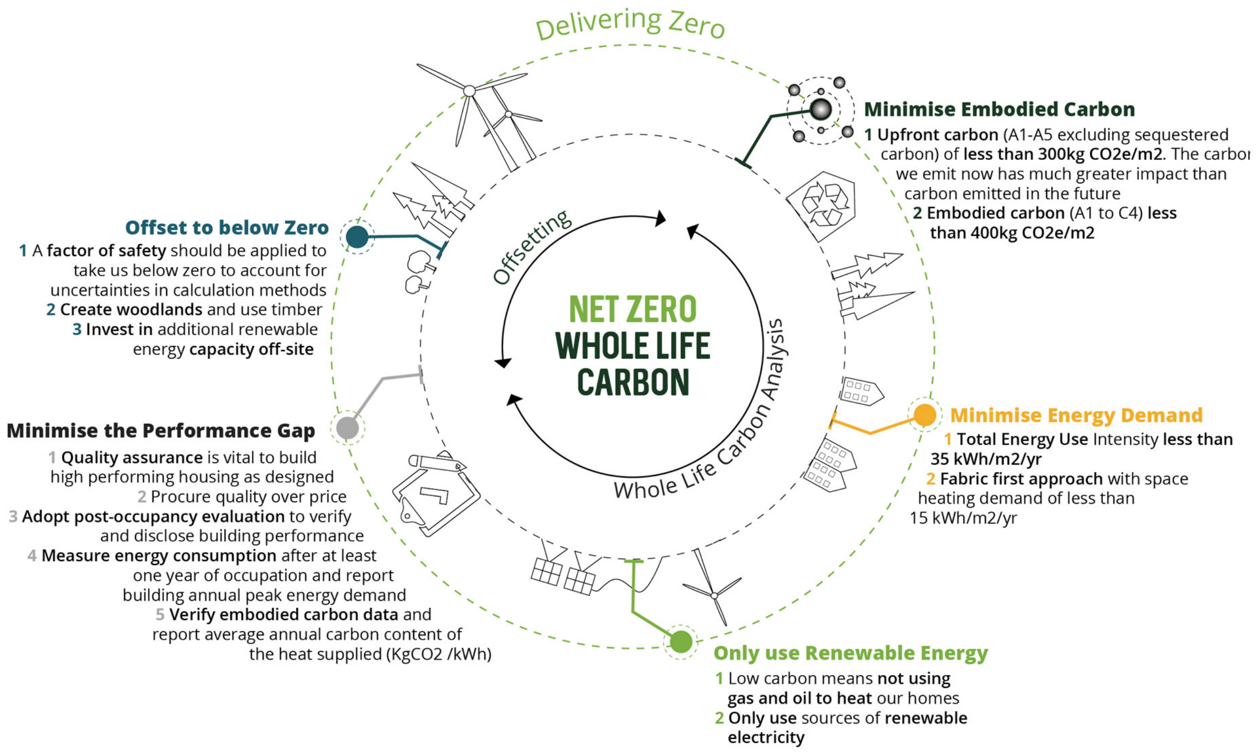


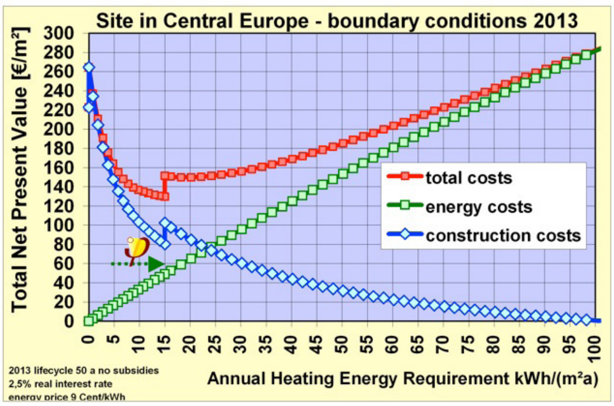
Fig 2.1 Net Zero Housing: Whole Life Carbon Guide

Application of the Targets

The UKGBC Framework for Net Zero Carbon Buildings presents 5 key principles arranged to suggest an ordered approach of application. By contrast the principles set out above are arranged in a circular manner. This approach is important in our consideration of how the design and delivery process should be developed to embrace the principles. Minimising Embodied Carbon and Energy Demand, which form the primary focus areas for this research must be applied from first principles, ie RIBA Stage 0. Although applied predominantly in parallel, application of these principles will have different levels of relevance and focus as a project progresses through the RIBA Work Stages and the following investigations will consider the relationship of these two pillars particularly.

The principles of Renewable Energy and Performance Gap are relevant and critical to each and every project and therefore essential to set out clear project objectives and strategies at RIBA Stage 0. However they will also involve much broader actions beyond the scope of individual projects, involving both short term and long term objectives and with the need for regulatory action. The principles established in the guidance subsequently set out actions typically beyond the scope of individual project specification. Although touched upon in this research, further work is required across the industries to implement the necessary change.

Offsetting, whilst certainly not the last pillar to implement, is considered within this matrix as the final opportunity of the commitment to bring emissions to below Zero. Offsetting is critically important in this route map however it is essential to consider and apply it as a life-saving measure, used only after all other measures have been employed to their greatest potential. There is a potential that offsetting will instead be employed as a crutch, used as a relatively easy way out to relax more harder delivered aspects of this proposal. Whilst offsetting will offer an essential and immensely positive aspect of the drive to Zero, particularly when delivered as woodland planting, it does not lock in carbon today and therefore is of lesser value in meeting today's climate emergency than the other methods presented. Innovative work is being undertaken within the scope of this project, and this will be touched upon later in the study. Final calculations will subsequently be presented to demonstrate the full carbon picture of delivering zero through applying the targets set out above, and the role of offsetting.



Source: Feist (editor) 'Economy of Energy Efficiency', working group on cost efficient passive houses, 42, Passive House Institute, Darmstadt, 2013

Fig 2.2 Graph showing construction cost profiles for alternative space heating demands

Operational Carbon

Passivhaus sets a Space Heating Demand of **15kWh/m2/yr.** This level is a key performance indicator along with peak energy load and informed by an analysis of both construction and energy cost during the life of a building. A graph can be presented of total net present value against annual heating energy requirements **(see Figure 2.2)**. This shows that at 15kWh/m2/yr an optimum is reached whereby below this level, the construction cost of attaining the proposed fabric performance levels simply aren't recoverable through energy cost savings during the course of the building's life. By contrast, energy consumption above 15kWh/m2.yr will require larger or more complex mechanical systems to achieve target comfort levels. This will result in increased energy costs and (up to a point), increased construction cost and complexity.

UK Homes Fit for the Future presents a target of 15 – 20kWh/m2/yr as soon as possible, "and by 2025 at the latest", which has formed the basis of the RIBA's Climate Challenge targets. LETI adopts 15kWh/m2/yr as a target level to ensure building fabric performance is prioritised. LETI also proposes the additional metric of Total Energy Use Intensity, set at 35kWh/m2.yr for small scale housing excluding any contributions from renewable energy. This figure is derived from analysis of (1) the available renewable energy budget at 2030 and 2050 (top down) and (2) modelling of realistic theoretical energy demands (bottom up). These metrics have formed the basis of our initial investigations to consider the feasibility and deliverability of such ambitious targets applied specifically to low density typologies required by the social housing sector in Wales.

Target:
Operational Energy

Space Heating Demand < **15kWh/m2/yr**

Energy Use Intensity < **35kWh/m2/yr**

RIBA Sustainable Outcome Metrics	Current Benchmarks	2020 Targets	2025 Targets	2030 Targets	Notes
Operational Energy kWh/m²/y	146 kWh/m² /y (Ofgem benchmark)	< 105 kWh/m²/y	< 70 kWh/m²/y	< 0 to 35 kWh/m²/y	UKGBC Net Zero Framework 1. Fabric First 2. Efficient services, and low-carbon heat 3. Maximise onsite renewables 4. Minimum offsetting using UK schemes (CCC)
Embodied Carbon $kgCO_2e/m^2$	1000 $kgCO_2e/m^2$ (M4i benchmark)	< 600 $kgCO_2e/m^2$	< 450 $kgCO_2e/m^2$	< 300 $kgCO_2e/m^2$	RICS Whole Life Carbon (A-C) 1. Whole Life Carbon Analysis 2. Using circular economy Strategies 3. Minimum offsetting using UK schemes (CCC)
Potable Water Use Litres/person/day	125 l/p/day (Building Regulations England and Wales)	< 110 l/p/day	< 95 l/p/day	< 75 l/p/day	CIBSE Guide G

Fig 2.3 RIBA 2030 Climate Challenge target metrics for domestic buildings

Embodied Carbon

There are no current adopted embodied carbon emissions targets within Building Regulations. Previous standards for housing such as the ***Code for Sustainable Homes*** which credited the selection of sustainable construction methods is also no longer applicable. LETI have set two embodied carbon emissions maximum targets of 500kgCO2e/m2 by 2025 and 300kgCO2e/m2 by 2030. These apply to the Life Cycle Analysis (LCA) stages A1-A5, ie cradle to practical completion. The RIBA Climate Challenge have adopted an ambitious target of below 300kgCO2e/m2 for LCA stages A-C **(Figure 2.3).**

Whilst it is critical that LCA is employed to consider carbon in use, reducing carbon emissions today has a greater impact on climate change than the same amount of carbon released in the future. In addition, we think assumptions regarding the end of life stage emissions for timber frame and other natural building products under consideration in the work misrepresent the potential for alternative end of life options. Creative design and problem solving should allow us to rethink and challenge existing presumptions about the end-of-life of our building products which currently assume the complete release of all carbon stored at the end of life. Subsequently two metrics have been proposed a target for upfront carbon stages A1 - A5 verified during design and construction stages and a target for Whole Life Embodied Carbon for stages A1 – C4.

Target:

Embodied Carbon

Upfront Carbon (A1-A5) < **300kgCO2e/m2**

Whole Life Carbon (A1-D) < **350kgCO2e/m2**

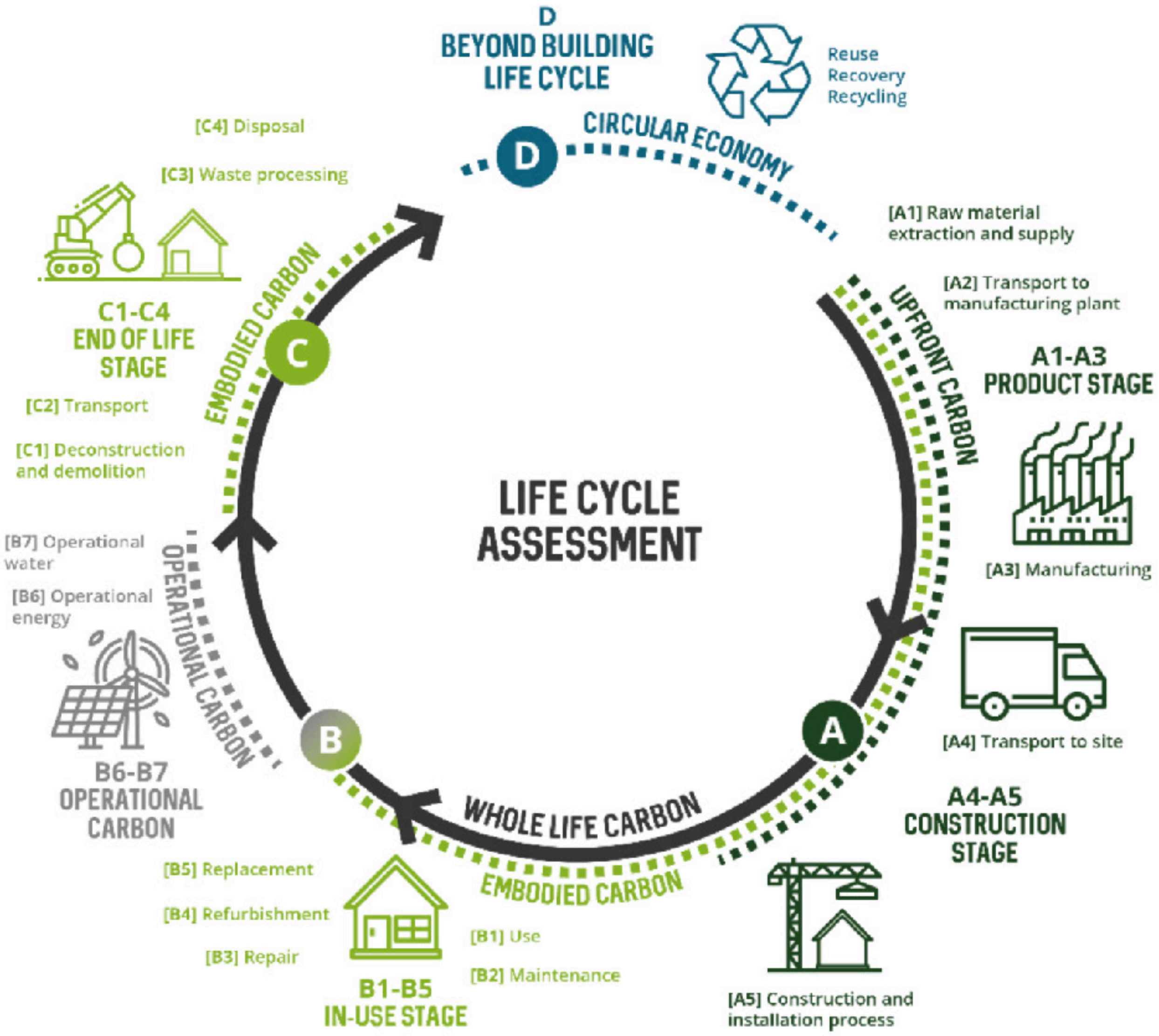


Fig 2.4 Life Cycle Assessment

03

DESIGN + OPERATIONAL CARBON

SECTION 3 SUMMARY :

Translating a space heating demand and energy use target into a fabric specification is challenging, and dependent on a number of factors outside of the technical design. However standardising a fabric solution offers the potential to improve quality, reduce costs through economy of scale and familiarity, develop supply chains and procurement, building economic certainty.

- Form Factor is a key design factor determining the efficiency of a building type. The higher the form factor, the harder the fabric must work to maintain the same energy demand. Alternative house types have subsequently been modelled and analysed for efficiency with existing common models of semi-detached 2 storey house patterns offering significantly poorer form factors than more compact 3 storey arrangements.
- This suggests clients and professional teams should identify opportunities within development portfolios to deliver higher density schemes and typologies to develop initial learning and achieve some 'quick-wins'
- The required fabric performance to deliver existing low density and inefficient typologies such as detached bungalows are likely to be prohibitively expensive and taking a one size fits all approach for fabric performance is likely to result in some house types over performing and others under performing significantly.
- A Space Heating Demand of 15kWh/m2/yr is extremely challenging and requires innovation throughout all elements of design, technical delivery, quality control and procurement. Analysis to date has confirmed that this target level is correct for a broad holistic set of reasons, however if low density house typologies are likely to remain as popular and frequently applied as currently, further work is required to establish the implications of relaxing the space heating demand.

3.1. Designing for 15kWh/m²/yr

Operational Energy

Space Heating Demand < **15kWh/m2/yr**

Energy Use Intensity < **35kWh/m2/yr**

Anticipated Building Fabric Performance

U-Values -
Walls | floors | roofs ≤ 0.15 W/m2K Windows + Doors (installed) ≤ 0.85 W/m2K

Thermal bridges -
linear (2D) thermal bridges psi (Ψ) value ≤ 0.01 W/mK

Airtightness -
0.6 air changes per hour (0.6ac/h@50Pa)

A review of existing research and performance standards have helped to establish an initial indicative performance specification aligned with the operational energy targets as presented above.

Whilst these established performance targets or thresholds are expressed as relatively simple and measurable values, translating them into house types and fabric specifications is extremely complex and presents a range of challenges for clients, designers and manufacturers. This has presented a primary objective for the study with the opportunity of a precise repeatable performance specification offering the ability to achieve standardisation, and repetition whilst building familiarity. This contrasts with the highly bespoke nature of high performance building specifications currently being specified and procured via the Welsh Government's Innovative Housing Programme (IHP).

Currently in the delivery of affordable housing the majority of units are delivered following a fairly recognisable and standard design approach in conjunction with detailed performance specifications. Although the Welsh Design Quality Requirements (DQR) (soon to be *Beautiful Homes and Spaces*) do not suggest a 'Pattern Book' approach the majority of housing development teams and designers have a limited palette of standard house types. These are developed to meet DQR, Lifetime Homes and Secured By Design whilst also simplifying design and delivery to ensure cost effectiveness.

Delivering low and zero carbon performance objectives places considerable additional demand on building design and tests this traditional pattern book response. Via the IHP we can see a range of design approaches in response to these aspirations. The responses tend to fall into two categories -

- Design for low operational energy demand and low embodied carbon through a response to site and orientation, then developing effective building forms and layouts including mechanical systems. This should result in - reduced demand of the fabric, reduced risk of overheating, and highly efficient energy systems.
- Or utilisation of standard design typologies and site design approaches that are:

➡ proven and tested to meet space standards, and user requirements,

- achieve site flexibility and density,
- Are well known and recognised by users and clients.
- This results in a fabric that must do all of the work to reduce energy demand, and protect against overheating, in combination with less efficient systems.

Both of the above are strategies that can potentially deliver a low carbon outcome, but they present different challenges in terms of deliverability, cost and procurement. Both strategies have been adopted to some degree in the delivery of the range of IHP funded projects. In the following section we look to model and calculate the impact of best practice design principles on fabric design specification.

In this study, a series of investigations have been undertaken to model and translate performance targets into fabric specifications when applied and tested against common Welsh housing models and then through the consideration of alternative models. Investigations have employed the Passivhaus Planning Package (PHPP) methodology.

PHPP has been employed rather than SAP due to the greater specificity of the modelling tool.

Although SAP can provide an accurate modelling tool, the more a model diverges from the standard assumptions within SAP, the less accurate the modelling becomes. The Passivhaus Trust explains that the more the fabric performance of the dwelling improves, the more the accuracy of factors such as Internal Heat Gains and Mechanical Ventilation and Heat Recovery (MVHR) systems become. For further information, WoodKnowledge Wales in collaboration with the Good Homes Alliance and the Passivhaus Trust, have presented two studies, *Energy Performance Certificate (EPC) as Energy Efficiency Targets* and *Building Standards Comparison*.

The use of PHPP has enabled the development of macro based dynamic investigations allowing a large range of automated iterations. Although developed as an investigative tool, this method of exploring design variables offers a range of valuable early stage energy design tools.

To limit the number of potential variables, the project team have initially focussed on a 2 bedroom - 4 person house type. Analysis of 11 council house building programmes revealed that 2 bed- 4 person houses account for approximately 27% of the current house building programme.

Property Types	Total	%
1 b 2 p f	584	33.5%
1b 2 p b	11	0.6%
2b 3p f	239	13.7%
2b 3p b	41	2.4%
2b 4 p h	476	27.3%
3b 5p h	324	18.6%
4 b 6p h	67	3.8%
	1742	**100%**

Fig. 3.1.1 Typical house types constructed by Local Authorities

Example floor plans from each Council area are similar in arrangement but vary quite significantly in terms of gross internal area with the current Design Quality Requirement being 83 sqm (**see Figure 3.1.2**).

The study will subsequently employ a standard House Type 1 based on the 2 bed 4 person typical layout shown below as a baseline for investigation. Employed typically as a semi detached and short terraced form the following study will explore the effect of layout, form and orientation on operational carbon.

Council Area	GIA
Cardiff	85
Carmarthenshire	84
Denbighshire	76
Flintshire	80
Pembrokeshire	87
Powys	84.4
Vale of Glamorgan	83
Wrexham	87.4
Average	**83.2**

Fig. 3.1.2 Example floor areas of typical 2B4P house models by local authority area

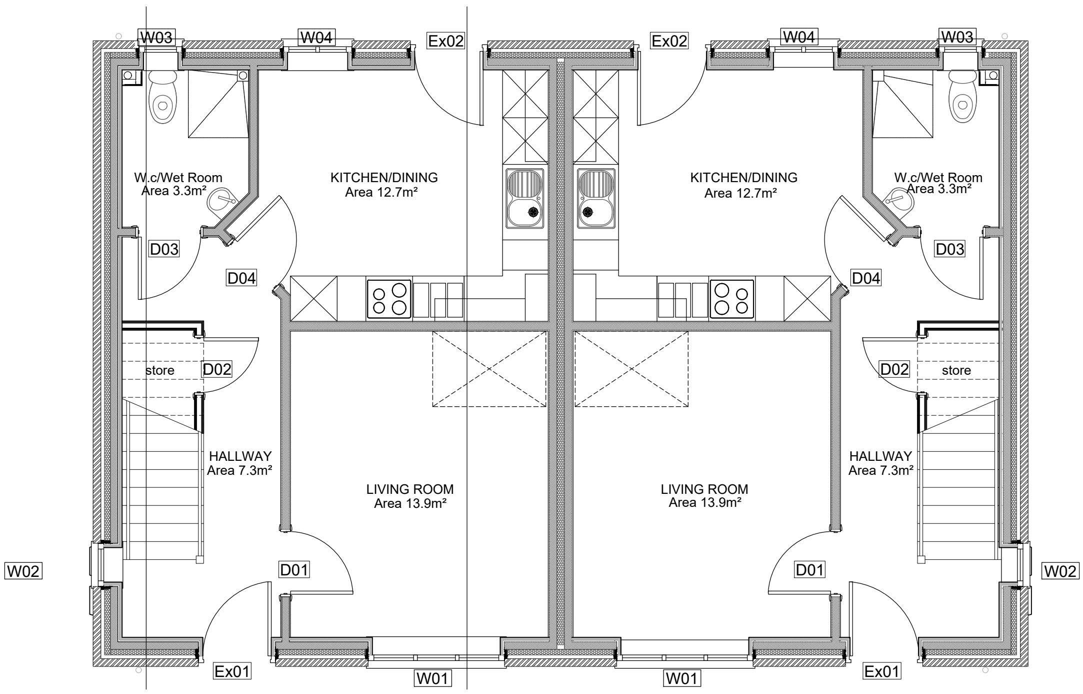


Fig. 3.1.3 Example 2 bed 4 person typical ground floor plan prepared by Carmarthenshire County Council Property Services

3.2. The effect of form factor on operational and embodied carbon

The term **Heat Loss Form Factor** is the ratio of external surface area of a building to the internal treated floor area.

Heat Loss Form Factor = Heat Loss Area / Treated Floor Area

For Passivhaus purposes this is calculated as the usable heated floor area excluding stairs, internal walls, doors and unusable spaces. In simple terms this calculation reflects that the larger the external surface area is in relation to the usable floor area, the greater the heat loss area is and therefore the higher the performance of the fabric needs to be to achieve the same space heating demand.

Form Factor is therefore a metric for design efficiency, with compact and efficient building forms offering dramatically easier and therefore cheaper and lower carbon building fabric specifications.

The graph in **Figure 3.2.1** describes the relationship between form factor and required U-value. To achieve the Passivhaus Standard, it is recommended that the Heat Loss Form Factor should be below 3. LETI specify a form factor of 1.7 - 2.5 for small scale housing.

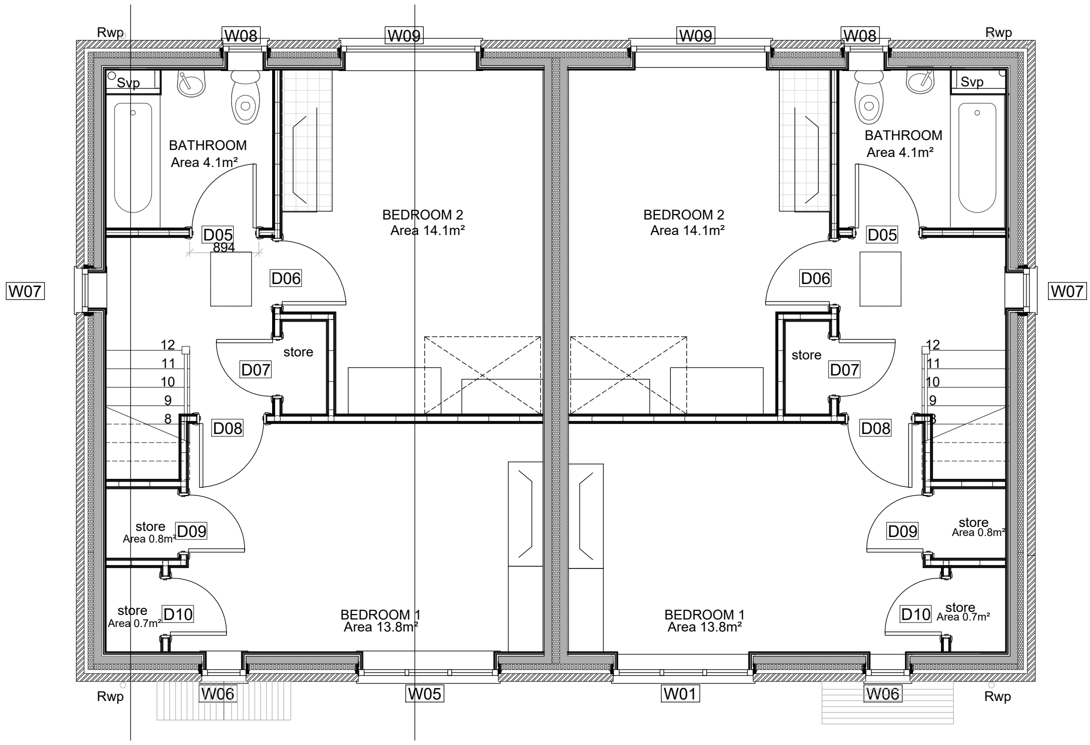


Fig. 3.1.4 Example 2 bed 4 person typical ground floor plan prepared by Carmarthenshire County Council Property Services

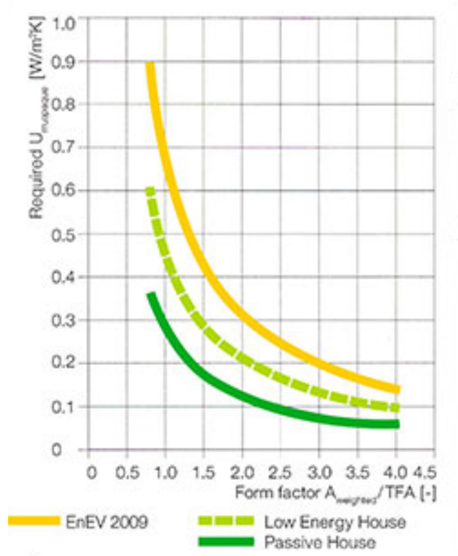


Fig 3.2.1 Graph of Form Factor vs Required Fabric U-Value. Source Passivhaus Institute

Building typology is a key factor when considering required fabric performance - LETI have suggested 4 'Archetypes':

- ***Small scale residential:*** *terraced or semi-detached houses (up to 3 storey, including flats)*
- ***Medium and large scale residential:*** *four floors and above*
- ***Commercial offices***
- ***Schools:*** *Primary or secondary*

The majority of affordable housing projects in Wales are in the small scale residential category. Common types delivered include low density housing - detached, semi-detached, terraced two storey houses and bungalows, and small scale apartments over 2-4 storeys. Whilst there are cases of multi-

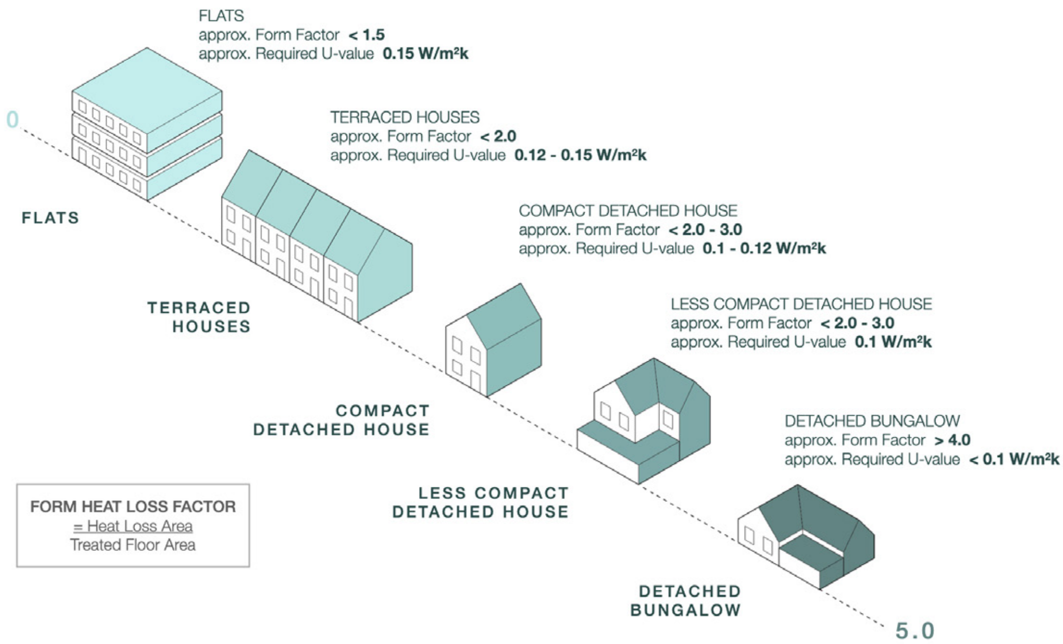


Fig 3.2.2 Rule of thumb comparison of house typologies and approximate required fabric U-value

storey affordable housing over 4 floors these are not, and are unlikely to be, the norm for local authority development programmes.

In order to develop an understanding of the required fabric specifications our investigation has focused on form factor, and the orientation and proportion of glazing, both in terms of its effect on space heating demand and potential for overheating. A wide range of iterations have been evolved and dynamically modelled in PHPP.

3.3. Three House Types

Figure 3.3.1 presents a range of house typologies that have been delivered by the Welsh affordable housing sector. This portfolio of patterns are predominantly capable of meeting the spectrum of statutory and non-statutory requirements governing the sector including Design Quality Requirements, Lifetime Homes and Secure by Design. We have selected and developed House Types 01, 04 and 07 as the focus of this study.

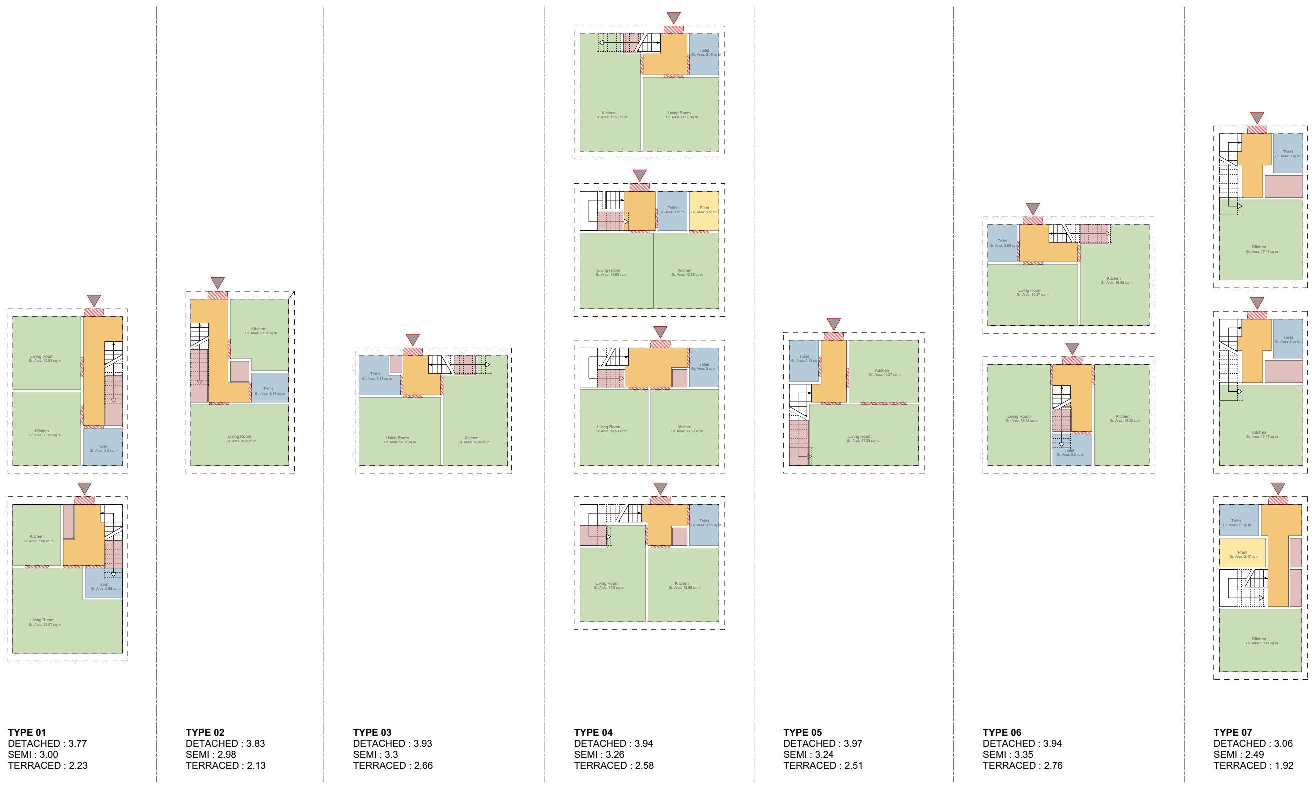


Fig 3.3.1. Pattern book of 2 bed 4 person house types

House Type 01

A compact dual aspect arrangement based on the standard 2 bed 4 person house type commonly delivered by housing associations in Wales

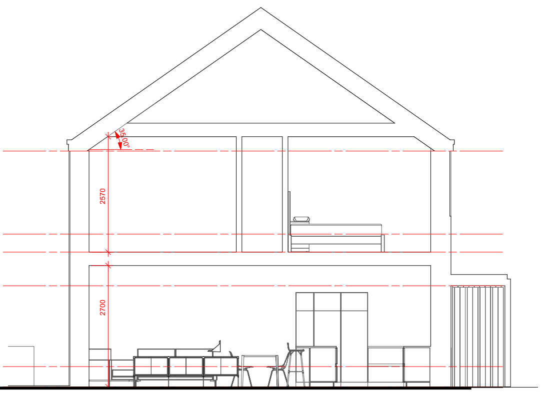
Features

- Compliant with Design Quality Requirements in Wales and Lifetime Homes
- Dual aspect arrangement suitable for terracing with habitable rooms faced to the primary and secondary elevations.
- Variety of roof options with most common being a deep plan low pitch roof with insulation at first floor ceiling level and unheated loft space above.
- Frequently delivered as a semi-detached arrangement.

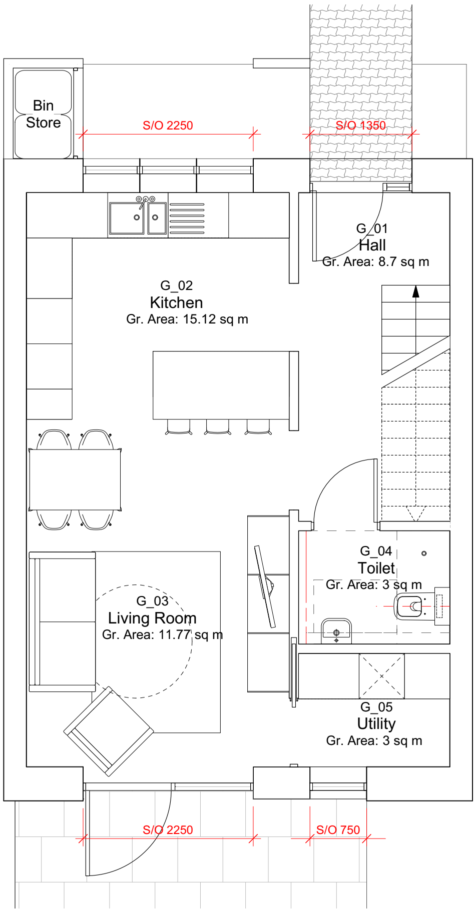
Wall Area		
	Primary Elevation	10.4sqm
	Secondary Elevation	10.5sqm
	Total :	**20.9sqm**
Gross Internal Area		
	Ground :	43 sqm
	First :	40.3 sqm
	Total :	**83.3 sqm**
GIA : Glazing Ratio		25%
Wall : Glazing Ratio		
	Primary Elevation	30.5%
	Secondary Elevation	31%
	Side Elevations	0%
Treated Floor Area		78.65 sqm
Form Factor		
	Detached	3.77
	Semi Detached	3.00
	Terraced	2.23

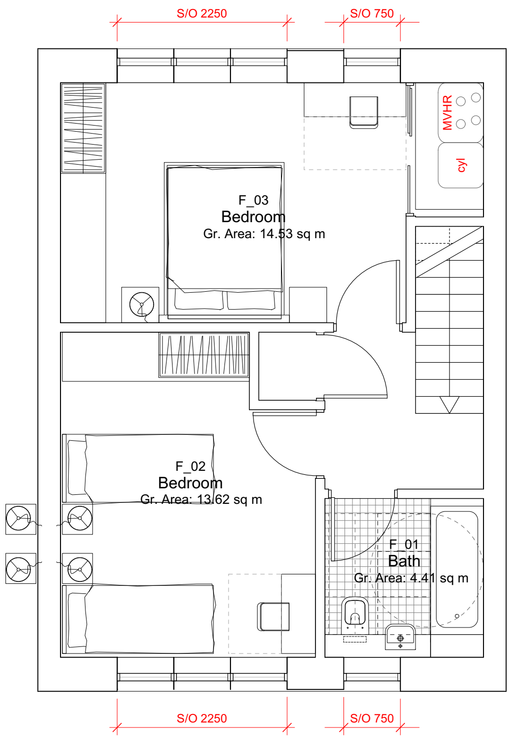
P 318.4 FRONT ELEVATION

P 318.5 REAR ELEVATION



P 318.6 SECTION AA


Bin Store
S/O 2250
S/O 1350
G_01
Hall
Gr. Area: 8.7 sq m
G_02
Kitchen
Gr. Area: 15.12 sq m
G_03
Living Room
Gr. Area: 11.77 sq m
G_04
Toilet
Gr. Area: 3 sq m
G_05
Utility
Gr. Area: 3 sq m
S/O 2250
S/O 750


S/O 2250
S/O 750
MVHR
cyl
F_03
Bedroom
Gr. Area: 14.53 sq m
F_02
Bedroom
Gr. Area: 13.62 sq m
F_01
Bath
Gr. Area: 4.41 sq m
S/O 2250
S/O 750

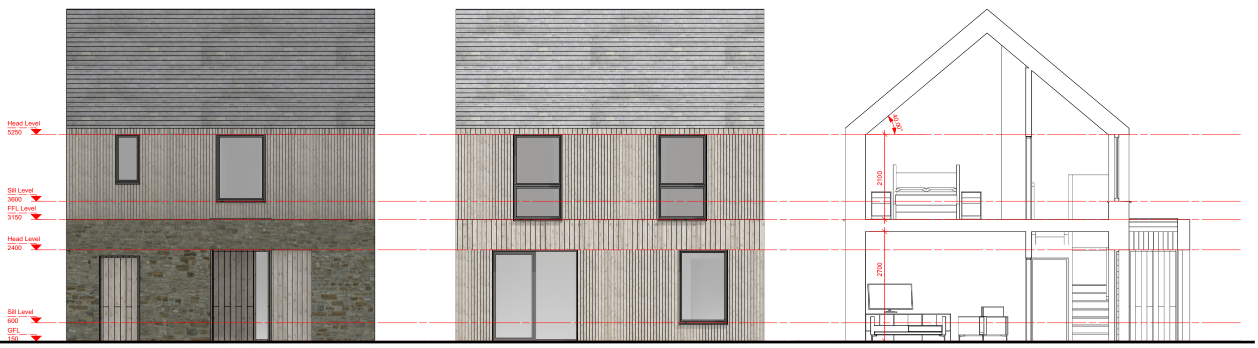
House Type 04

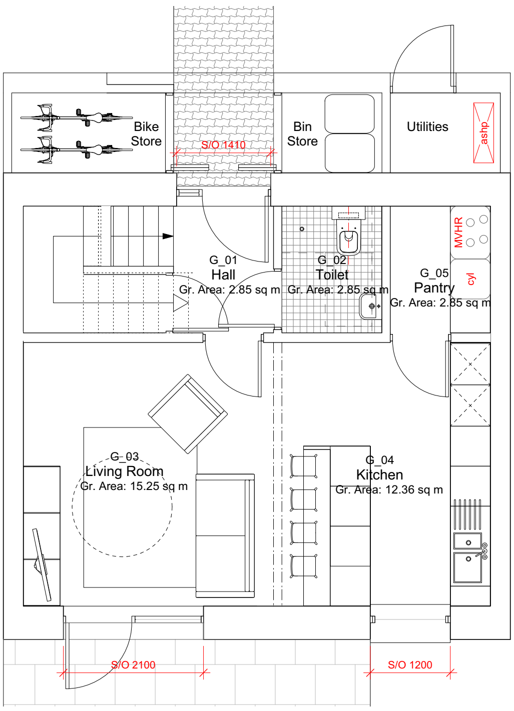
A 2 bed 4 person house type with compact form factor when arranged in a mews or town house style arrangement

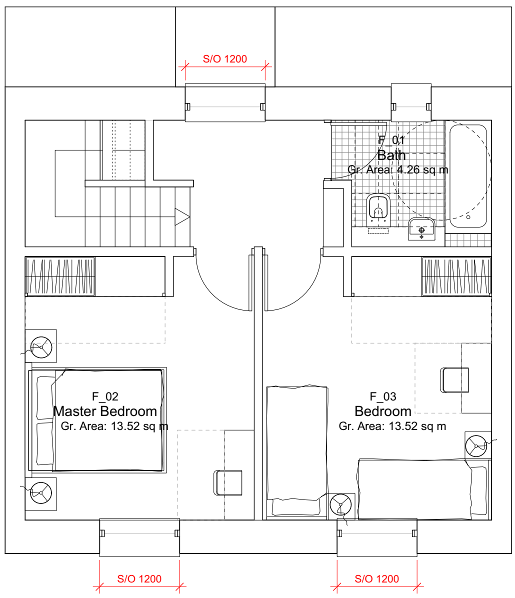
Features

- Compliant with Design Quality Requirements in Wales and Lifetime Homes
- Single aspect arrangement suitable for terracing with habitable rooms faced to the secondary elevation and entrance and minimal openings to the primary elevation.
- Roof proposed as a pitched arrangement with low eaves. Roof insulated and airtight at rafter level.

Wall Area	
Primary Elevation	5.9sqm
Secondary Elevation	11.9sqm
Total :	**18.8sqm**
Gross Internal Area	
Ground :	42.5 sqm
First :	38.5 sqm
Total :	**81.0 sqm**
GIA : Glazing Ratio	22%
Wall : Glazing Ratio	
Primary Elevation	14.75%
Secondary Elevation	29.75%
Side Elevations	0%
Treated Floor Area	73.15 sqm
Form Factor	
Detached	3.94
Semi Detached	3.26
Terraced	2.58




Bike
Store
S/O 1410
Bin
Store
Utilities
ashp
G_01
Hall
Gr. Area: 2.85 sq m
G_02
Toilet
Gr. Area: 2.85 sq m
MVHR
cyl
G_05
Pantry
Gr. Area: 2.85 sq m
G_03
Living Room
Gr. Area: 15.25 sq m
G_04
Kitchen
Gr. Area: 12.36 sq m
S/O 2100
S/O 1200


S/O 1200
F_01
Bath
Gr. Area: 4.26 sq m
F_02
Master Bedroom
Gr. Area: 13.52 sq m
F_03
Bedroom
Gr. Area: 13.52 sq m
S/O 1200
S/O 1200

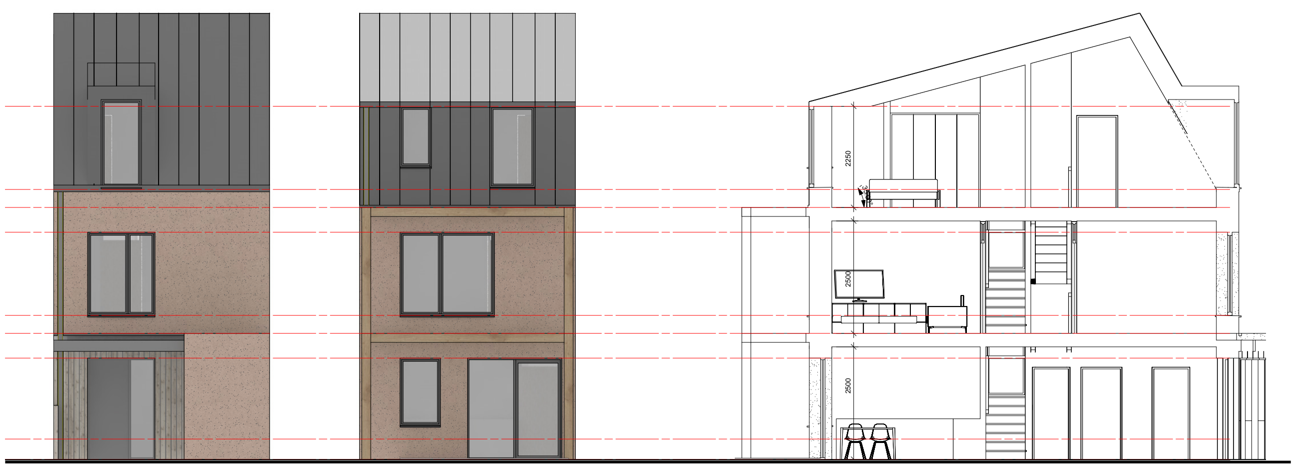
House Type 07

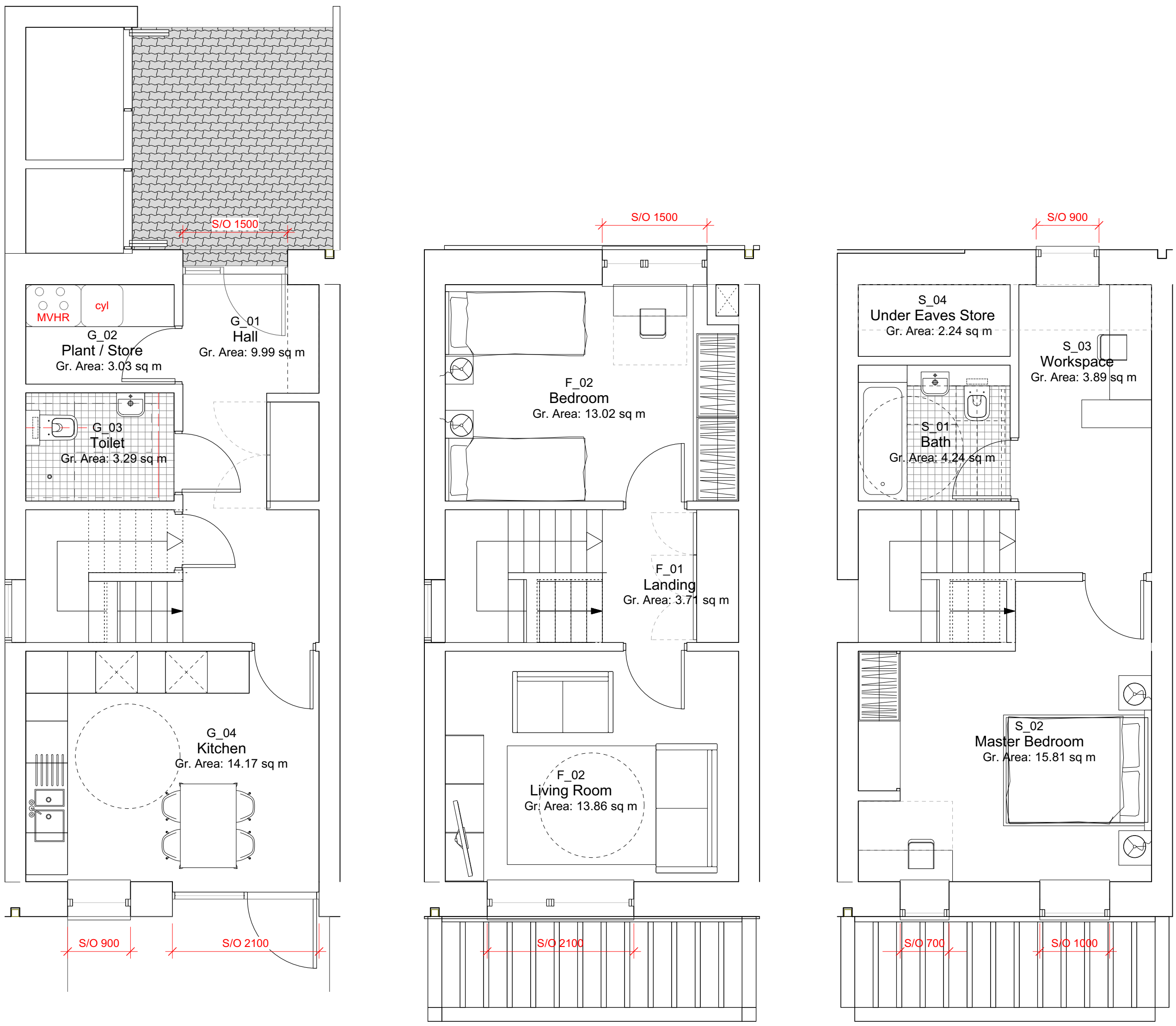
A 2 bed 4 person house type with compact form factor when arranged in a mews or town house style arrangement

Features

- Compliant with Design Quality Requirements in Wales and Lifetime Homes
- Single aspect arrangement suitable for terracing with habitable rooms faced to the secondary elevation and entrance and minimal openings to the primary elevation.
- Roof proposed as a pitched arrangement with low eaves. Roof insulated and airtight at rafter level.

Wall Area		
	Primary Elevation	7.7sqm
	Secondary Elevation	12.7sqm
	Total :	**20.4sqm**
Gross Internal Area		
	Ground :	36.4 sqm
	First :	31.6 sqm
	Second :	29.0 sqm
	Total :	**97.0 sqm**
GIA : Glazing Ratio		21%
Wall : Glazing Ratio		
	Primary Elevation	23.6%
	Secondary Elevation	33.25%
	Side Elevations	0%
Treated Floor Area		90.5 sqm
Form Factor		
	Detached	3.06
	Semi Detached	2.49
	Terraced	1.92




S/O 1500
MVHR
cyl
G_02
Plant / Store
Gr. Area: 3.03 sq m
G_01
Hall
Gr. Area: 9.99 sq m
G_03
Toilet
Gr. Area: 3.29 sq m
G_04
Kitchen
Gr. Area: 14.17 sq m
S/O 900
S/O 2100
S/O 1500
F_02
Bedroom
Gr. Area: 13.02 sq m
F_01
Landing
Gr. Area: 3.71 sq m
F_02
Living Room
Gr. Area: 13.86 sq m
S/O 2100
S/O 900
S_04
Under Eaves Store
Gr. Area: 2.24 sq m
S_03
Workspace
Gr. Area: 3.89 sq m
S_01
Bath
Gr. Area: 4.24 sq m
S_02
Master Bedroom
Gr. Area: 15.81 sq m
S/O 700
S/O 1000

3.4. Investigation 1 : Form Factor

Aim: To record the effect of form factor on U-value requirements via a comparison of 2 bed 4 person house types.

Methodology : Utilising the PHPP each house type has been tested in a range of combinations -

- As a detached home
- As a pair of semi-detached homes
- As a terrace of homes.

The study has initially considered House Types 1 and 4 that are similar in approach;

- **House Type 01** is the standard commonly utilised dual aspect house type,
- **House Type 04** by contrast adopts a number of Passivhaus and low energy mantras regarding the concept of wrapping up to the north and turning to the sun - ie small and few openings to the north, with primary habitable rooms occupying the south elevation with generous openings. This requires a wider plot width and would suggest a greater focus on orientation.

Both house types represent typologies that have been used by the sector including in recent IHP funded projects targeting high performance including Passivhaus.

To further develop these investigations, a third alternative house arrangement has been proposed and modelled. **House Type 07** promotes a fairly radical alternative for the 2 bed 4 person house type. It is conceived as a significantly reduced plan area with narrow frontage. Making the most of a habitable roof space, accommodation is spread over 3 floors with living and kitchen

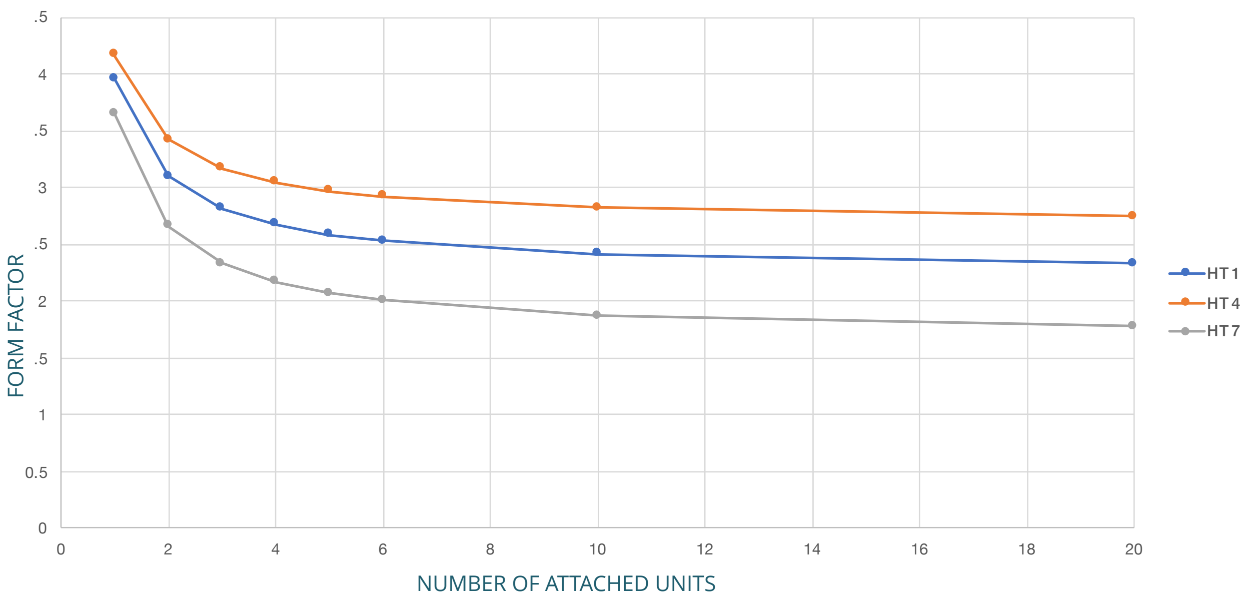


Fig 3.4.1. Comparison of house type form factor for increasing attached units

accommodation broken over two levels. The proposed house type dramatically reduces form factor, particularly when arranged in terrace forms. The proposal would represent a significant divergence from industry and vernacular norms other than in larger urban areas, but compact house types such as these are frequently employed in open market housing as 'town houses', enabling a reduction in footprint, and subsequently, requiring less site area.

In undertaking the assessment, combinations have been tested for a range of fabric U-values from 0.09 – 0.15W/m²K for walls and roof fabric. The proposed ground floor buildup has been maintained as consistent throughout the modelled house types at 0.1W/m²K. All other considered factors are fixed as shown in the following list of assumptions.

Element	Part L 2013 minimum	Part L 2020 minimum	Part L 2020 notional	Suggested fabric
External wall	0.30	0.26	0.18	0.15
Party wall	0.20	0.20	0.00	0.00
Floor	0.25	0.18	0.13	0.10
Roof	0.20	0.16	0.11	0.10
Windows	2.00	1.60	1.20	0.8
Doors	2.00	1.60	1.00	1.00
Air tightness	10	8	5	<3
	↑ Bad	↑ Still bad	↑ Better - but these u-values are meaningless without FEES	↑ LETI's suggested fabric targets

Fig 3.4.2 Comparison of Elemental U-values (Source LETI)

Note that this fabric performance range is significantly higher than stated in **figure 3.4.2.** taken from the LETI guidance.

U-value iterations were 'hard coded' U-values, ie changes do not alter the thickness of the wall build up.

Ventilation MVHR unit - Zehnder 350 - was selected. For terraced iterations a custom MVHR was created in "Components" tab. The custom unit has efficiency of 80% and increased operating range. 80% was calculated from Zehnder 350 installed in detached property with 1.5m ducts with 30mm insulation (k=0.034). Night time and window ventilation is set at 0.1.

Climate location was selected as Wales with altitude of 75m

Thermal bridges were added with very conservative values taken from SAP (Approved values)

Ground floor assumed to be slab on Grade and U-value of 0.1

Green Building Store Triple Glazed windows employed assumed (g-value: 0.5, Ug-value: 0.7, Uf: 1.02, installation Psi-value: 0.06)

No shading has been inputted with a default of 75% accepted for heating case.

Air change rate assumed to be 0.6 ach

No allowance has been made for internal gains input such as direct hot water and aux electricity.

Improved gas boiler assumed as a heat source for heating and direct hot water.

3.5. Investigation 1 : Detailed Findings

House Type 01

Figure 3.5.1 shows that a detached house, at a U value of 0.09W/m2K to walls and roof, with orientation optimised and glazing set at 25% of gross internal area, is capable of reaching a space heating demand of 27 kWh/m2/yr. When combined as a semi detached pair this reduces to 19.2 kWh/m2/yr.

A number of scenarios fall below the 15kWh/m2/yr target with this house type,

- A terrace of 5 houses or above with wall and roof U-values of 0.09W/m2K – 14.9 kWh/m2/yr
- A terrace of 10 houses and above with wall and roof U-values of 0.10 W/m2K – 14.5 kWh/m2/yr
- A terrace of 20 houses and above with wall and roof U-values of 0.11 W/m2K – 14.5 kWh/m2/yr

The initial findings demonstrate that even with significant improvements to the building fabric performance, it is extremely challenging to achieve the space heating demand target.

A depth of insulation in the region of 400 - 420mm will be required to achieve a U-value of 0.09W/m2k if using natural and recycled insulation products such as blown Warmcel recycled cellulose. By contrast to deliver U-values of 0.15W/m2K, an insulation depth of 240mm will be required.

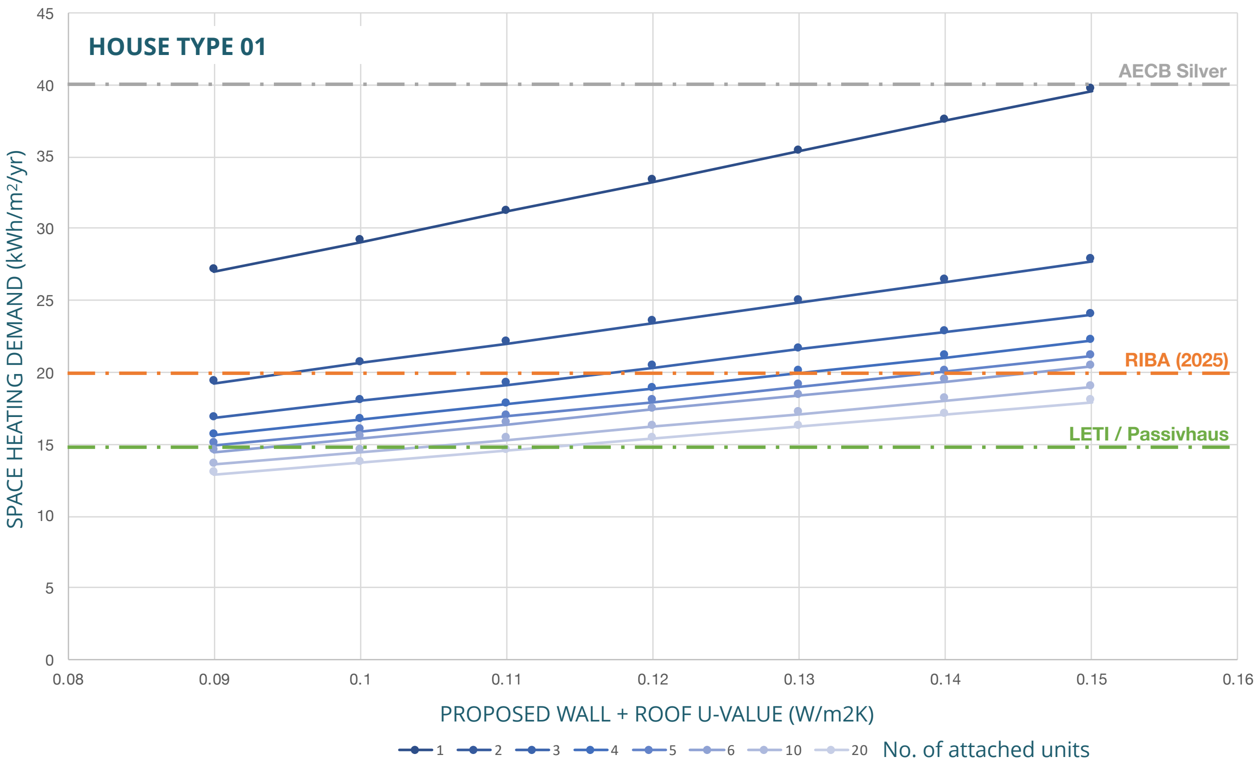


Fig 3.5.1 Graph of Space Heating Demand vs fabric U-Value for alternative House Type 1 arrangements

House Type 01 vs House Type 04

Analysis of House Type 04, as shown in **figure 3.5.2** presents very similar results to House Type 01. When comparing House Type 01 and House Type 04 the following conclusions can be drawn -

- Improving U-values can have a more dramatic improvement on the space heating demand for House Type 04 than House Type 01

➡ **House Type 01 -** Each 0.01 W/m2.K improvement in U-value generates a **4.9%** reduction in Space Heating Demand with a reducing affect the lower the U-value gets and the higher the number of units.

➡ **House Type 04 -** Each 0.01 W/m2.K improvement in U-value generates a **5.5%** reduction in Space Heating Demand with a reducing affect the lower the U-value gets and the higher the number of units.

- Space Heating Demand on a detached dwelling is lower for House Type 04 than House Type 01 – 39.34 vs 39.62 but this reverses as the number of units increase ie form factor improves to 20.02 vs 17.93. This demonstrates the importance of getting the form factor and housing typology combination right.

The design of House Type 4 does offer a marginal improvement in space heating demand if deploying detached or semi detached units where it is possible to optimise orientation to enable habitable

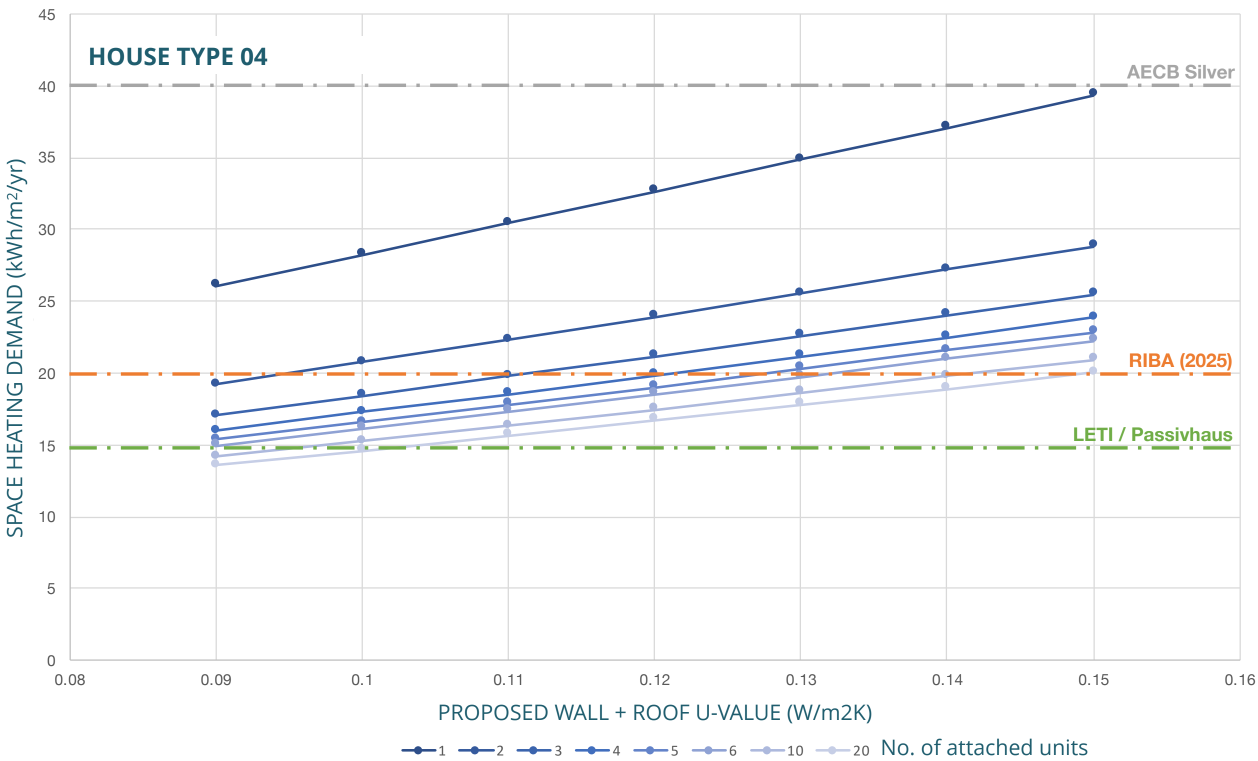


Fig 3.5.2 Graph of Space Heating Demand vs fabric U-Value for alternative House Type 4 arrangements

rooms to face south. However this opportunity is largely consistent between the housing types when arranged as terraces.

Further work should look at the optimisation potential of each house type as it is expected that dependent on arrangement and typology there will be varying degrees of impact through optimising factors such as glazing U-Values and window sizes.

This data suggests that the design ambitions informing House Type 4 have offered limited benefit at this scale over the typical house type. Both house types are within reach of delivering the RIBA 2025 target, with limited further development of the fabric and both house types are capable of meeting the AECB Silver standard with U-values of 0.15W/m²K. It confirms that current house types require significant improvements to fabric performance if the target of 15kWh/m²/yr is adopted.

House Type 07

As previously stated, House Type 07 represents a fairly radical approach to the affordable 2 bed 4 person house type. In response to the disappointing findings above, House Type 07 explores the potential offered by focusing directly on form factor, delivering the same accommodation but with a reduced heat loss area in the most efficient manner possible.

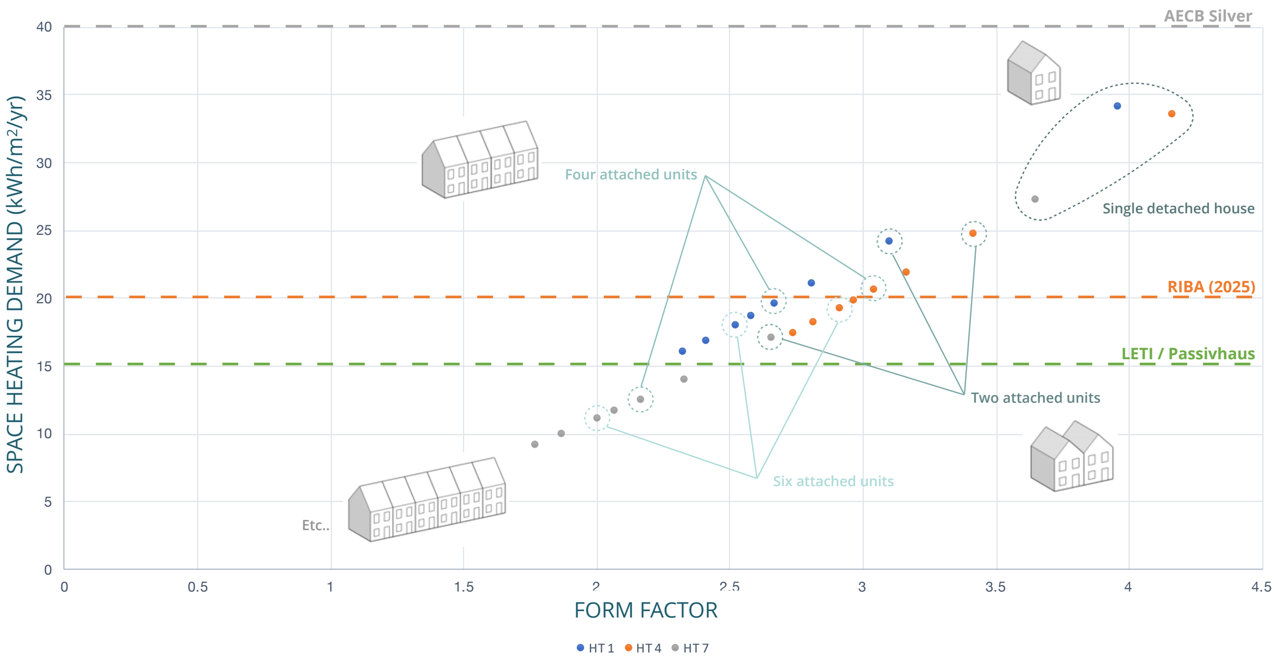


Fig 3.5.3 Graph of Space Heating Demand vs Form Factor for House Types 1 , 4 and 7 based on alternative detached, semi detached and terrace arrangements.

Figure 3.5.4 shows the relative space heating demand associated with this approach.

- For a semi detached dwelling, a fabric with a U-Value of 0.11W/m²K is within a margin of error of the space heating target at 15.36kWh/m².yr. This represents a 30% reduction over the equivalent House Type 01.
- For a terrace of 4 and above, the space heating demand is met with a fabric performance of 0.15W/m²K.
- And a terrace of 6 houses with fabric of 0.1W/m²K in line with previous suggestions would be 40% below the target space heating demand.
- Similarly to House Types 01 and 04, space heating demand reductions tail off above 6 units with a 10% reduction and 8% reduction in space heating demand between 6 and 10 units and 10 and 20 units respectively.

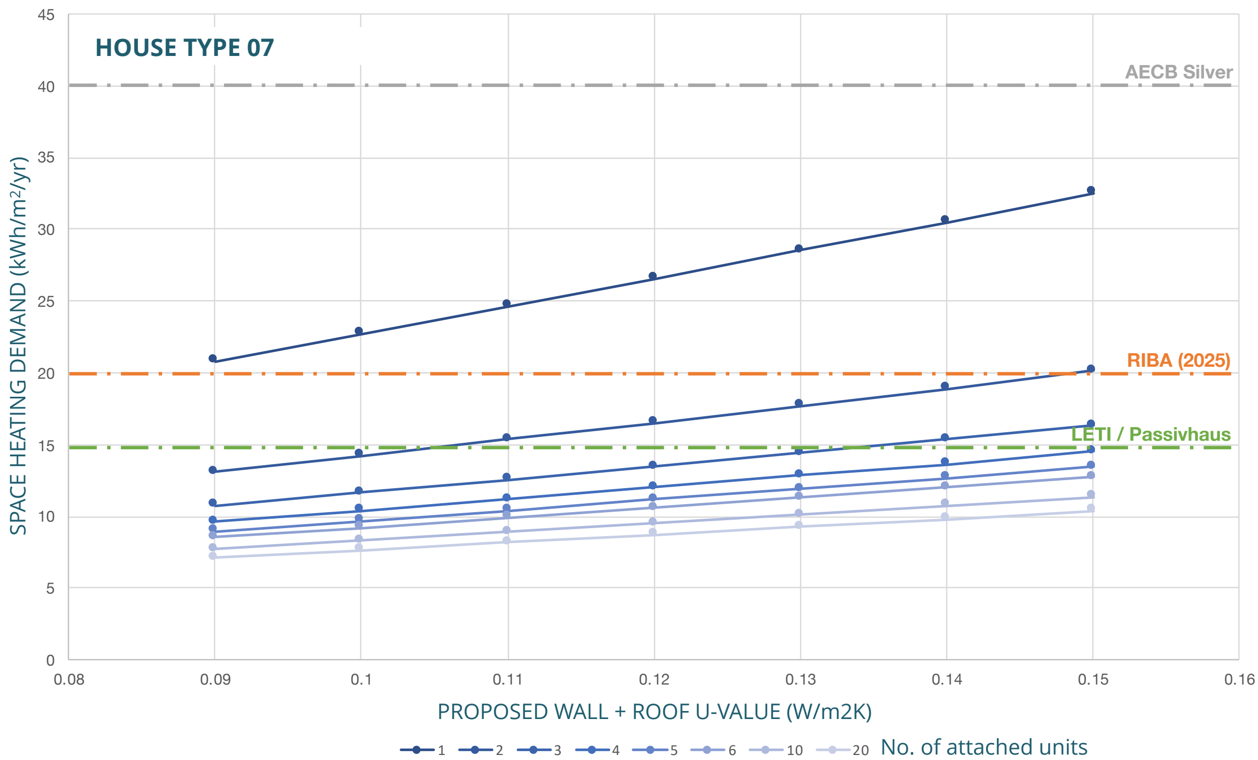


Fig 3.5.4 Graph of Space Heating Demand vs fabric U-Value for alternative House Type 7 arrangements

3.6. Investigation 1 : Conclusions

Figure 3.6.1 demonstrates the direct relationship between form factor and space heating demand – the higher the form factor, the greater the requirement for a high performance fabric. This is a simple concept – detached houses have a much greater heat loss area than a mid terrace property sharing two party walls with neighbours, which can be suitably designed with a 0.0W/m^{2}K U value. Heat loss area is reduced by 20.5% (diagram) per gable.

Whilst the relationship between form factor and space heating demand is linear, form factor does not reduce in a linear manner as the number of units increases. The improvement in space heating demand subsequently begins to level off as units increase due to heat loss through the walls having a lesser impact but floor, roof and window losses remaining fairly constant regardless of number of units.

- Converting the most common cases ie a semi detached arrangement to a 6 home terrace with a fixed U-value of 0.1W/m^{2}K, reduces space heating demand per unit from 20.64 to 15.43 for house type 1 and 20.76 to 16.12 for House Type 4 a reduction of 25.25% and 22.4% respectively. In carbon terms this equates to a reduction in carbon emissions of 3.5 tonnes CO2 over the 60 year life of the building (assuming electrical fuel factor of 0.136kgCO_2/kWh SAP10.1) or a reduction of 25%.
- By contrast increasing terrace unit numbers from 6 to 10 and 10 to 20 presents an associated carbon emission reduction of 6% and 5% respectively.

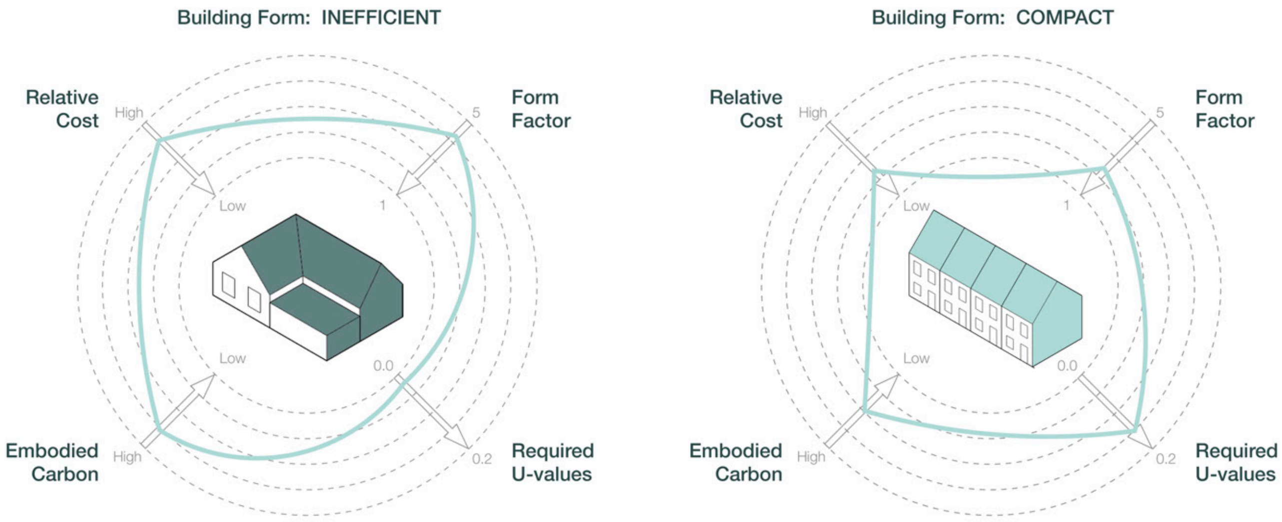


Fig 3.6.1 Comparison of fabric characteristics associated with two form factor typologies to deliver the same space heating demand.

This graphic also shows the changing contribution to heat loss that each fabric element has in relation to form factor.

- Up to 6 units, walls consistently offer the greatest opportunity for heat loss reduction contributing nearly double the heat loss of the roof area and 2.5 times the ground floor area.
- As unit numbers increase this becomes increasingly balanced with roof area becoming a greater heat loss contributor than walls over 10 units.
- This evidences the importance of the above ground thermal envelope and suggests areas of focus for improved specification related to typology.

Form Factor + Embodied Carbon

Further analysis will be presented in section 04. that will provide further insights into embodied carbon. However similar to the relationship between form factor and operational carbon, housing typology and form factor have a direct relationship with embodied carbon. Increased form factor means the proportion of heat loss area is greater per m² of treated floor area. A high performance fabric is required to this heat loss area to maintain the space heating demand. This incurs a greater carbon intensity, as heat loss area increases a bigger carbon footprint is created. This has been

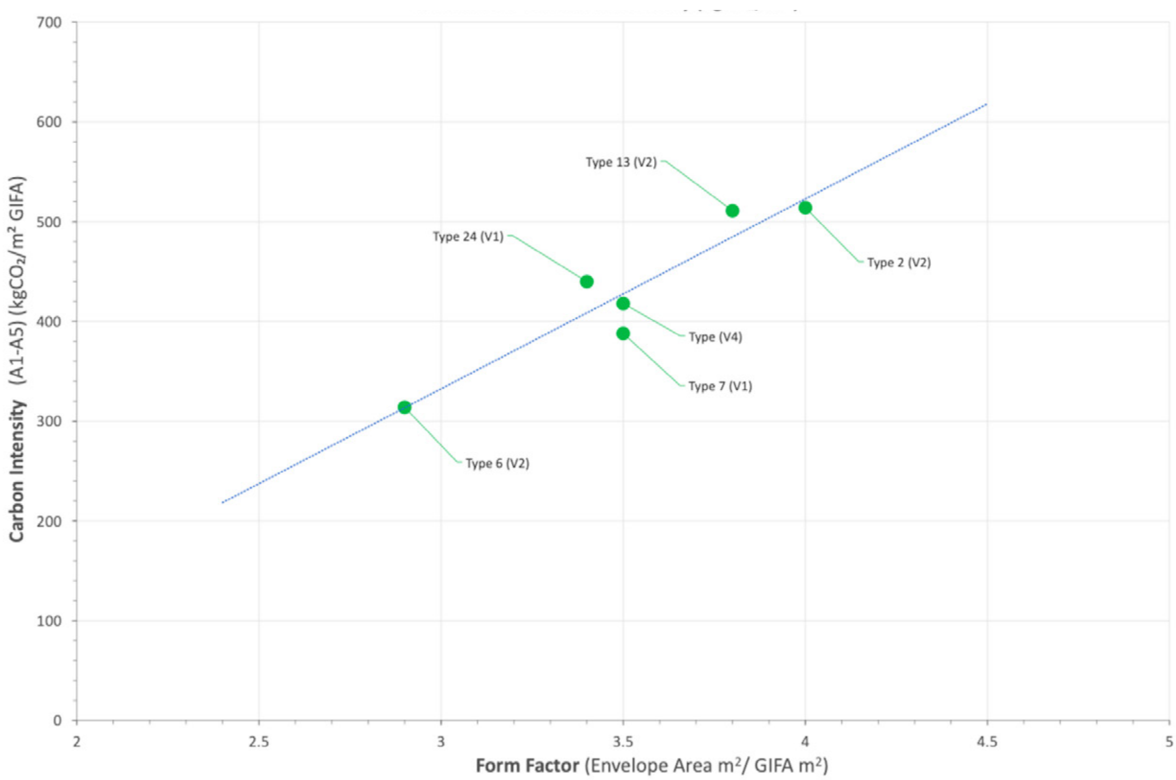


Fig 3.6.2 Calculation of Upfront Embodied Carbon for alternative house type form factors prepared by Stride Treglown for the Glynfaen Farm development.

considered in further detail by Stride Treglown Architects in development of the Innovative Housing Project Gwynfaen Farm, Swansea, as shown in **Figure 3.6.2.** in relation to a range of house types highlighting the critical relevance of embodied and upfront carbon considerations in early design thinking.

Site + Orientation

When modelling using SAP, climatic data is used based on national weather data for the whole of the UK. By comparison PHPP as a default will employ one of 22 regional data sets available for the UK. For Wales we typically subsequently employ climate data for one fixed climatic location based on data provided for Sennybridge, Brecknockshire. Whilst it is possible to create local data climate models and it may be advisable to do so for particular sites, it is fair to anticipate that this will not be cost effective for many affordable housing developments. Therefore it is generally considered acceptable to use generic regional data. This presents considerably greater accuracy than the current SAP methodology. Altitude however is established on a site by site basis. Altitude has a direct and linear relationship with space heating demand when modelled in PHPP resulting in an increase in space heating demand of approximately 3kWh/m^2.yr per 100m increase above sea level.

Orientation is a key factor in this consideration as shown in **Figures 3.6.3 - 5**. For the same fabric performance, orientation has a pronounced effect on all of the house types that have been investigated. The data suggests:

- At the 'worst case' orientation, and altering only fabric specification, a terrace of 6 x Type 1 houses would require a fabric U_Value of 0.1W/m^2K to achieve the same space heating demand as that of a terrace orientated to south with a U-Value of 0.13W/m^2K
- Similarly a terrace of House Type 4 houses would require a fabric U-Value of 0.1W/m^2K to achieve the same space heating demand as that of a terrace orientated to the south with a U-Value of 0.15W/m^2K.

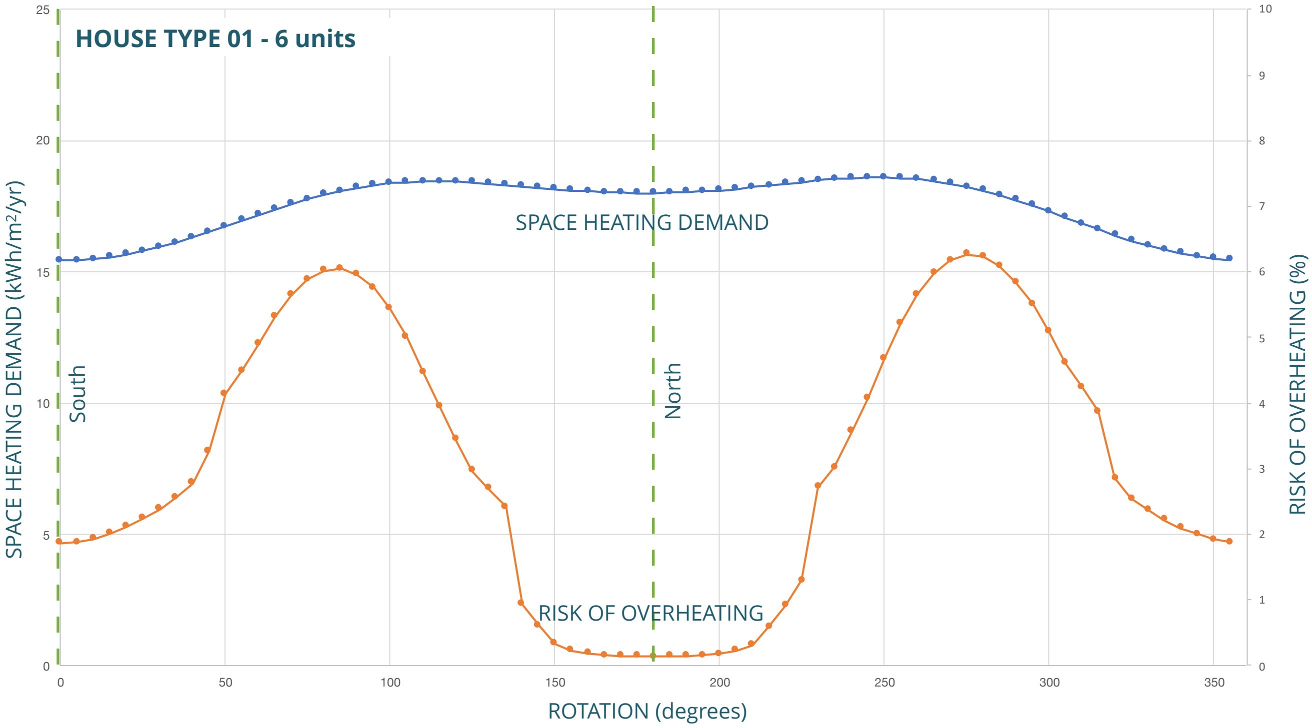


Fig 3.6.3 Space heating demand of House Type 01 Terrace of 6 with fabric U-value of 0.1W/m2K 0 = Primary Glazing South.

House Type 1 has an increasingly pronounced 'double peak' when plotting space heating demand in increments of 5 degrees from North. This is due to the benefits of the dual aspect arrangement. There is a marginal improvement when primary elevation hits due south.

- Space heating demand peaks at 110 -120 degrees from north and 215-250 from north with the latter generating the greatest point of difference.
- The worst case orientation generates an increase on average in space heating demand of 3.2kWh/m².yr or the equivalent of over 2 tonnes of CO_2 over the buildings life.
- This is consistent regardless of form factor but the impact on space heating demand increases from 10% to nearly 19% as unit numbers increase.

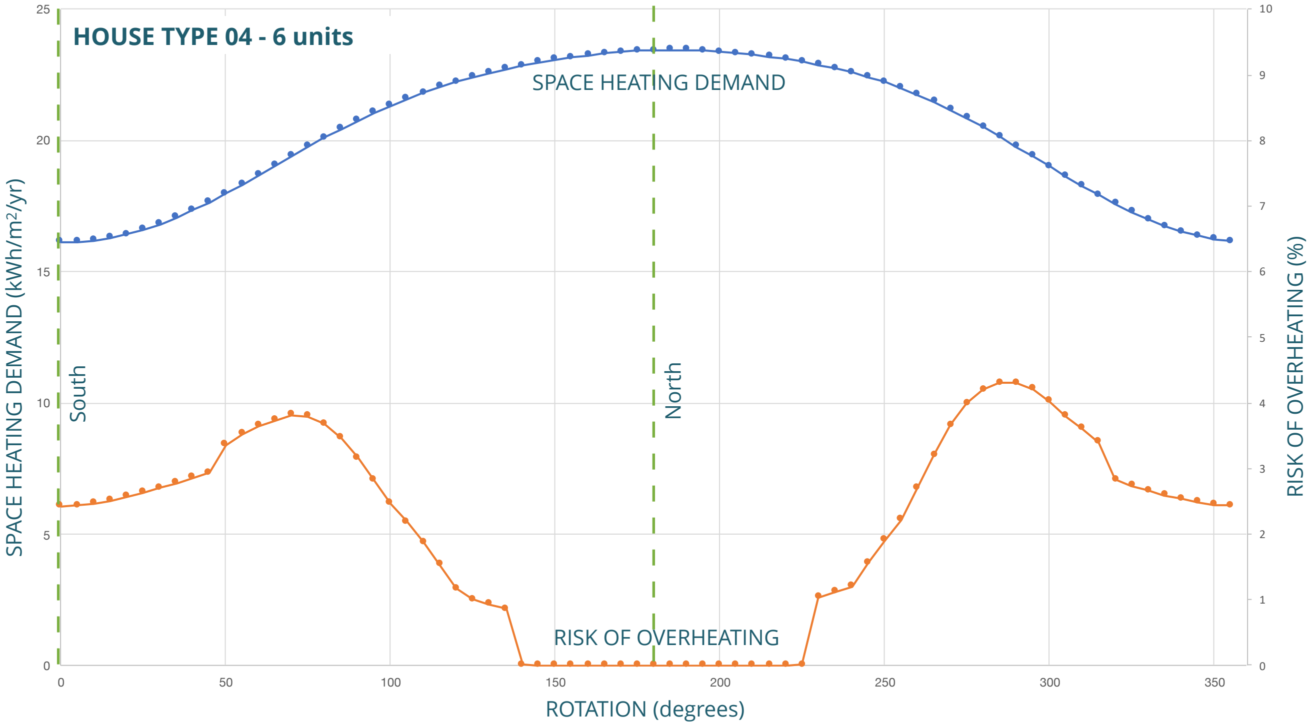


Fig 3.6.4 Space heating demand of House Type 04 Terrace of 6 with fabric U-value of 0.1W/m2K 0 = Primary Glazing South.

House Type 4 does not display a similar double peak as the primary openings and habitable rooms are consolidated on the secondary elevation generating an almost single aspect arrangement with only small openings to the primary elevation. Space heating demand subsequently increases in a bell curve centred on a 180 degree rotation whereby the primary openings would be facing north and achieving much reduced solar gains.

- Space heating demand peaks at 180 degrees from north.
- The worst case orientation generates an increase on average in space heating demand of over 7.5kWh/m^2.yr or the equivalent of just under 5 tonnes of CO_2 over the buildings life.
- There is a much broader range of impact on space heating demand with a single detached dwelling increasing by over 8.65kWh/m^2.yr when rotated 180 degrees compared with 7.07kWh/m^2.yr for a terrace of 20. This generates a range of 23-33% difference in space heating demand, displaying a greater relative impact on terraces of 20 than a single unit.

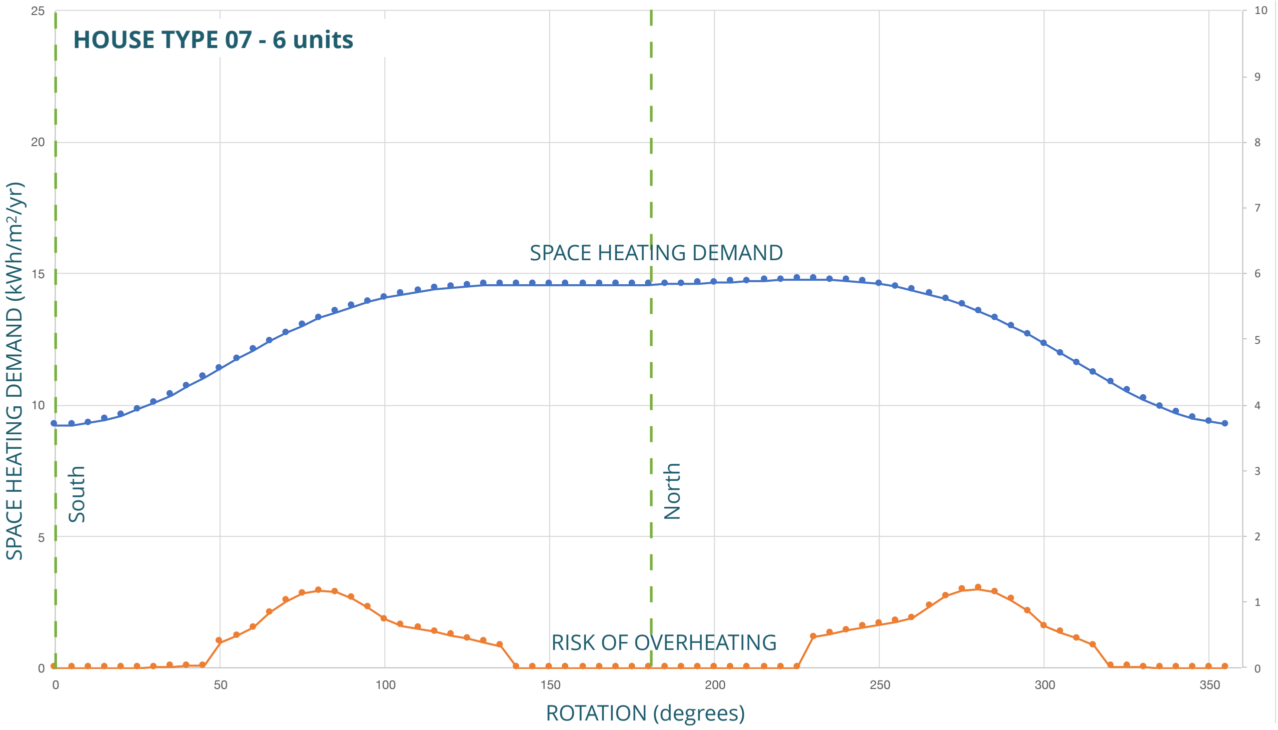


Fig 3.6.5 Space heating demand of House Type 07 Terrace of 6 with fabric U-value of 0.1W/m2K 0 = Primary Glazing South.

House Type 7 presents a similar double peak profile to match House Type 1 however there is a much less dramatic range of results due to the improved heat losses -

- The worst case orientation generates an increase on average in space heating demand of 5.56kWh/m^2.yr or the equivalent of over 4.4 tonnes of CO_2 over the buildings life.

This assumes the same arrangement of openings regardless of orientation and therefore there is an opportunity to optimise arrangements to orientation which has not been investigated fully in this exercise. This may reduce the impact on space heating demand however there is a delicate balance between solar gains, natural daylight requirements and heat losses to be struck which must also be considered in the contact of standardising design solutions across a site.

3.7. Reflection

In the Net Zero Framework we set out a strategy to adopt a fabric first approach, dramatically reducing energy demand (and specifically space heating demand) through a significantly improved thermal and airtight envelope. Regardless of technology, the home will live with its fabric for its 60 year design life with limited and expensive scope for improvement. We subsequently established a Space Heating Demand target of less than 15kWh/m^2.yr in line with LETI, RIBA and the Committee on Climate Change.

The analysis to date demonstrates just how challenging it is to achieve the target space heating demand of 15kWh/m^2.yr particularly when applied to low density small scale housing. It is anticipated that this exercise has presented a relatively conservative analysis of the space heat modelling with conservative estimates and assumptions employed in some areas of the modelling where testing and advanced design modelling would be required.

The potential to deliver these performance requirements and typologies in the social housing sector is evidenced by consideration of the number of successfully realised Passivhaus Certified housing scheme. **Figure 3.7.1** illustrates a timber frame housing scheme at Callaughton's Ash, Much Wenlock by Architype in partnership with Lowfield Timber Frames for South Shropshire Housing Association. This is a mix of 1,2 and 3 bedroom homes in low density semi-detached arrangements. A 270mm Warmcel blown cellulose insulated Larsen Truss timber frame achieves U-values of 0.13 W/m^2K and meets the Passivhaus airtightness of 0.6ach @ 50 Pa. The scheme is Passivhaus Certified and should act as a reminder that through intelligent design and targeted optimisation of the building fabric, design proposals and mechanical systems, the 15kWh/m^2/year target is deliverable.

It follows subsequently, that in the delivery of a net zero solution at scale, expertise and bespoke design comes at a cost which is unlikely to be borne across the sector. The conservative nature of these investigations are tailored to reflect realistic assumptions when applied at scale.

There are however a number of areas of potential optimisation that require further development, either on a project by project basis or in the course of developing fabric and house designs -

- Optimisation of Window and Door losses through higher performance components and bespoke glazing arrangements generated from site and orientation perhaps using dynamic modelling.
- Thermal Bridge PSI Calculations available for all critical junctions enabling thermal bridge entries of 0 throughout.
- Improved ventilation losses through an improved performance MVHR system including insulated ducts.
- Increased fabric performance related to windows, doors and ground floor construction.

Figure 3.7.2, calculated in this case for House Type 01 is an analysis of potential gains and losses, calculated in terms of

Fig. 3.7.1 ***Callaughton's Ash, Much Wenlock***
South Shropshire Housing Association

Size: 12 units
U-value: 0.13
Air tightness: 0.6ach @50 pascals Completed: July 2018

System used: 270mm Larsen Truss with Warmcel Insulation

Space Heating Demand for a series of design and performance factors. The baseline is based on the initial modelling assumptions and informing the observations and conclusions drawn previously. Reductions refer to the calculated reduction to Space Heating Demand deemed possible if the measure is applied exclusively. The Gain being the possible increase in Space Heating Demand. The calculation method is based on exclusive measures applied to the house type. Measures applied in parallel will likely have a reduced impact than the values calculated. Based on this data, in combination with the previously considered graphs describing site and orientation, we can begin to identify some quantified opportunities to 'optimise' proposals whilst also understanding some of the main threats.

Opportunities

- Improved U-values - Improving windows and doors to 0.8 and 0.72 offer a marginal improvement of 1.5 and 0.9 kWh/m2a respectively but in combination with centre pane u-value could offer as much as 3.1kWh/m2a. The cost of these increased specifications is likely a key consideration as well as the availability of appropriate products.
- By contrast improving the floor U-value from 0.1 to 0.08 offers a 1.5kWh/m2a reduction and is likely to be relatively easy and cost effective to deliver using the same processes and details and therefore represents a reasonably easy variable.
- MVHR efficiency is dependent on both system design and system specification and therefore care, familiarity and good design can in this case offer potential for cost neutral improvements. Improved specification MVHR units can be expensive and therefore a cost benefit analysis will need to be undertaken.
- Thermal bridges represent a significant area of opportunity with fabric design proposals offering great potential to remove default thermal bridge allowances to zero through modelling. This offers the potential of a 5kWh/m2a saving and through approved consistent detailing can be repeatable across projects offering great value for money at scale.

Threats

The analysis also demonstrates the sensitivity of demanding such high performance targets. Whilst some factors can be managed through quality control and sound technical design principles such as airtightness factors such as the site altitude are clearly out of the hands of the delivery team. The assumed baseline occupies a site at 75m above sea level, the average elevation in Wales is 81m. Altitude is therefore a key consideration in space heating demand with an increase to 150m resulting in a space heating demand increase of 2.3kWh/m2a.

These areas of opportunity and threat make fundamental differences to the potential space heating demand and therefore should be focus areas for future work.

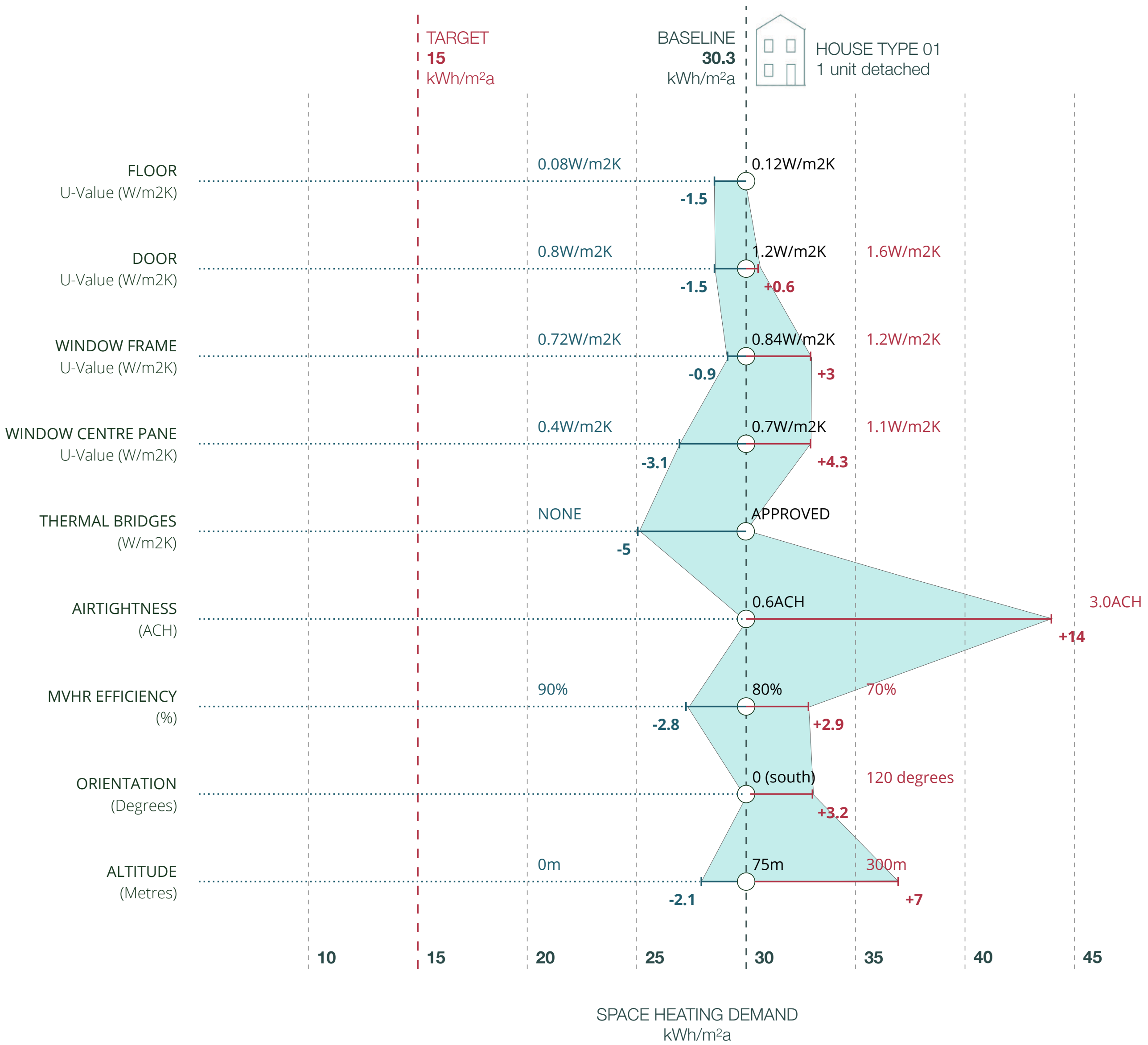


Fig 3.7.2 Space heating demand of House Type 04 Terrace of 6 with fabric U-value of 0.1W/m2K 0 = Primary Glazing South.

3.8. Design Recommendations

In the context of Welsh housing development there are some critical decisions to be made around both performance aspirations and the flexibility and appropriateness of house types. Although not modelled in this exercise and requiring further work, multi dwelling buildings containing apartment and maisonette developments up to 3 storeys represent a significantly less demanding scenario to meet a specified space heating demand of 15kWh/m^2.yr. This places considerably less demand on fabric specification. In combination with a compact form factor and an intelligent response to site and orientation it is wholly feasible that wall U-values of 0.13 W/m^{2}K to 0.14 W/m^{2}K may be sufficient to achieve the target 15kWh/m^2.yr.

By contrast however even with U-values of 0.09W/m^{2}K to roof and walls, a detached dwelling in any of the arrangements tested here is extremely unlikely to be optimised to meet this target. It is feasible that semi detached dwellings may be optimisable through a combination of the measures above however U-values of 0.1W/m^{2}K require an improvement of 5.6 kWh/m^2.yr based on the best case orientation, suggesting this is extremely ambitious. Short terraces of 3 – 6 houses appear to be feasible at U values of 0. 1W/m^{2}K, and there appears limited differences regarding house type arrangements if orientation, and the provision of windows and doors **is optimised.**

Action...

Further work should be undertaken to consider the carbon benefits of applying a single space heating demand target to all housing typologies. A graduated system based on dwelling type ie detached, semi detached, terraced, multi dwelling building may apply more flexible and deliverable targets but should be analysed in regards to whole life carbon cost and economics, mechanical and electrical systems and the implications for quality assurance.

This is an area of consideration that presents a great deal of concern for the project team. A single space heating demand target sets a clear target for the industry and ensures decision making that is holistically driven towards zero carbon objectives. At the level of 0.15kWh/m^2.yr the demand is considerable, requiring massive industry learning in terms of design, procurement, construction quality, and end occupiers. In the face of a climate emergency, this demand is considered wholly justifiable, and these levels of performance, evidenced by decades of delivery as the Passivhaus Standard, deliver a distinct, measurable and deliverable target to limit operational carbon. Should a graduated system be employed, any increase in operational carbon will need to be offset, either through reduced embodied carbon, increased renewable energy contributions or via offsetting, all with associated costs.

Based on the existing data set, semi detached and detached dwellings will struggle to meet 15kWh/m2.yr. A consistent fabric performance far all house types in the region of 0.09 – 0.10 W/m²K would more likely achieve 20kWh/m2.yr. This begins to generate some consistency around fabric performance for the typologies most common in the Welsh context.

It is recommended that a number of scenarios be modelled and tested to assess the use of a graduated target for Space Heating Demand in conjunction with other robust specification limits such as elemental fabric performance targets such as **airtightness.**

Action...

A dynamic modelling tool should be developed to support standard house type models that can provide indicative estimates of the space heating demand and risk of overheating introduced by orientation. Site studies should analyse the impact on site densities when energy efficient orientations are promoted.

This assessment must consider 'unintended consequences' – whereby the model enables a relaxing of focus on quality and zero carbon aspirations onsite.

Client bodies should subsequently undertake a review of the barriers to improved form factor typologies. Barriers may include existing standards such as design quality requirements, planning contexts and development directives such as density **targets**.

Action...

Improved form factor developments such as multi-unit terraces, townhouse arrangements and multi dwelling buildings present 'quick-wins' in getting to zero without radical fabric innovations. This could form the first phase in a stepped approach.

Action...

Based on the typical low density development types currently employed, fabric U-values for floors, walls and roof should target a minimum performance level of **0.1W/m2K** in order to deliver **15kWh/m2**, should be **thermal bridge free** and deliver an airtight construction of below **0.6ach**. Alternative housing typologies such as multi-unit dwellings may enable a lower performance fabric.

3.9. Designing Zero Carbon Communities... the next steps

This investigation has demonstrated the challenge that such demanding requirements place on house form and typologies, and generates a really important narrative regarding the design of homes and communities for Wales.

On paper the exercise of optimising form, materials, glazing and orientation to meet space heating targets and manage whole life carbon is extremely demanding. However in the context of physical site constraints, opportunities of built, natural, and community context, and the realities of economic and development feasibility this challenge may appear to be insurmountable. Whilst data suggests the need to employ a range of house types and arrangements with more efficient forms and greater densities, the applicability of higher density options is recognised as being site limited.

The sector must also meet the challenge of creating exceptional places to live, creating integrated communities and sustainable economic and social environments. This must consider identity and context, responding to the many varied, physical, social and cultural contexts presented across Wales. This requires all of the skills of our building professional services as well as the wider community, and there is an essential need for design teams through training and application, to integrate whole life zero carbon thinking within their design methodologies.

The application of a pattern book of house types may offer an opportunity to standardise and extend economies of scale through a more consistent standard offering. But due to the rich and varied context of Wales, the application of a pattern book of housing models should be treated with caution. The sector must strive to find a new balance of focus for development, balancing placemaking, community, economic and social needs, and regional and local identity with carbon cost. This requires a fundamental shift in the provision of professional expertise for the industry, requiring training and improved aspirations within the professional services and a fundamental shift in the way projects are procured, designed and delivered. The design of Zero Carbon developments and communities require a different approach to design development throughout the work stages. Advanced design, manufacturing and construction teams must be established that are capable of assessing and managing zero carbon aspirations throughout the project delivery, led by informed and aspirational clients.

Regardless of front end design aspirations, there is an opportunity to standardise technical solutions and overcome significant technical barriers through collaboration to enable a greater consistency of technical delivery, create opportunities for economies of scale, generate foundational economies and provide a foundation for net zero carbon design.

The rest of this study will focus on technical solutions to meet the proposed performance requirements, tested for appropriateness against a range of house types, but considered as relatively independent of design solution, applicable to small housing typologies as described previously.

04

FABRIC + EMBODIED CARBON

SECTION 4 SUMMARY :

To deliver the high performance fabric necessary using low embodied carbon materials requires a radical shift in offsite timber frame design. Whilst this requires innovation, the Welsh timber frame industry has experience with these fabric types albeit typically as a bespoke specialist product.

- The existing Welsh industry is extremely well positioned to adapt to new processes with great potential to generate circular economy and local supply chain growth around new and advanced products.
- Increased offsite fabrication offers potential to reduce waste, increase quality and performance, improve diversity and increase employment opportunities and in turn reduce the whole life carbon of the supply chains and products.
- 5 alternative fabric types are proposed for future research and development, with the lowest modelled upfront carbon representing a 68% reduction over the typical benchmark equivalent.

4.1. The Current Industry

The current Welsh offsite manufactured timber-frame sector is characterised by a large number of relatively small companies creating approximately 350 direct jobs. This industry has relatively low levels of automation compared to industries across northern Europe and Scotland.

The primary product of the sector is open panel timber frames consisting predominantly of nom. 150x50mm timber stud frames employing a mix of imported C24 softwood and homegrown C16 softwood with an internal or external sheathing of 9mm OSB. Load bearing walls are made up offsite as single storey panels, with overall dimensions set by manufacturing table dimensions, lifting capacities and transport.

The method of timber frame construction generally used in Wales is known as platform frame and is based on the assembly of open panels using solid section timber as studs, rails, lintels and plates in combination with sheathing panels that have been manufactured in a factory environment. These panels form single storey walls of varying lengths and are assembled on a preformed platform of concrete based foundations. A horizontal top plate forms a load bearing shelf on which intermediate floor components are assembled providing a platform for further

wall panels and roof elements. Pitched roofs are typically formed from prefabricated trussed rafters arranged at even centres on load bearing walls with sheathing and membranes installed on site.

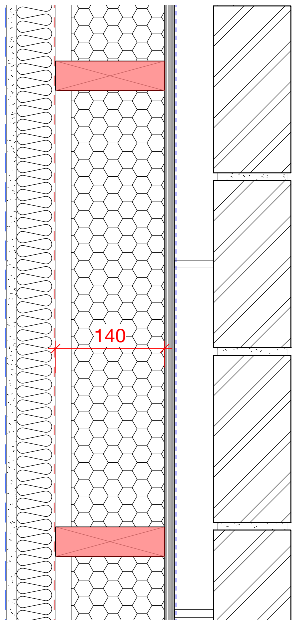
Higher levels of offsite fabrication are available from the existing industry with manufacturers capable of delivering 'closed' and 'advanced panels' where insulations, services, membranes, battens, internal and external finishes, and windows and doors, are installed in the factory. Recent innovation projects have also advanced the development of offsite volumetric construction using timber, an area of MMC which has typically been focused on primary steel structures.

Whilst these capabilities are available within the Welsh industry there remains a dominance of open panel manufacturing particularly where building fabrics are at minimum compliant levels.

Based on a nominal 150x50mm solid stud structural frame, considered to be readily available from the existing Welsh industry, alternative combinations of insulation materials achieve U-values ranging between approximately 0.13W/m^{2}K and 0.18W/m^{2}K.

Perhaps the most common combination of materials is shown in **Figure 4.1.1** (overleaf) describing two alternative approaches –

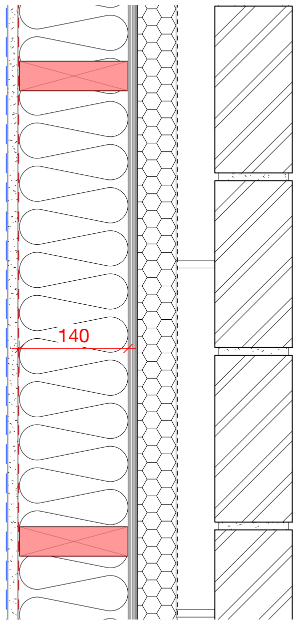
- An open panel of nom. 150x50mm timber studs with an external sheathing of structural OSB. Between studs, rigid foil-faced insulation boards (e.g. PIR, PUR or phenolic) or a rigid batt high performance mineral wool is tightly fitted typically as a 120mm board within the 140mm structural depth allowing for fixing of panels. To the interior a vapour control membrane layer is lapped and sealed to prevent the movement of water vapour into the building structure. A service void is formed to the interior with either a zone of battens with mineral wool between or a lamination of rigid insulation with facing plasterboard. In combination with advanced reflective membranes applied as an external breather membrane and or foil vapour control layer U-values of 0.13-0.14W/m^{2}K can be achieved.
- Alternatively an open panel of nom. 150x50mm timber studs with an external sheathing of structural OSB. Between studs, rigid foil-faced insulation boards (e.g. PIR, PUR or phenolic) or a rigid batt high performance mineral wool is tightly fitted typically as a 120mm board within the 140mm structural depth allowing for fixing of panels. To the interior a vapour control membrane layer is lapped and sealed to prevent the movement of water vapour into the building structure. A service void may be employed or plasterboard finishes applied directly to the structural studs. To the exterior, typically partially filling the masonry cavity, a layer of continuous insulation is installed over the sheathing either as a rigid insulation board of a semi rigid fibre batt with breather membrane to the exterior. Again in combination with advanced reflective membranes applied as an external breather membrane and or foil vapour control layer U-values of 0.13-0.14W/m^{2}K can be achieved.



WALL TYPE A : Between + Inside Studs

U-value 0.18 W/m2K

1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of 50x50mm battens with, 50mm Earthwool Frametherm 38 (0.038W/m2K) insulation between
3. low emissivity vapour control layer
4. primary structural panel of C16/C24 nom. 150x50mm structural studs with 120mm rigid PIR insulation (0.022W/m2K) between and an external sheathing of 12mm OSB/3
5. to the exterior of the sheathing, a relective breather membrane
6. minimum 50mm ventilated cavity with 100mm external facing brickwork



WALL TYPE B : Between + Outside Studs

U-value 0.17 W/m2K

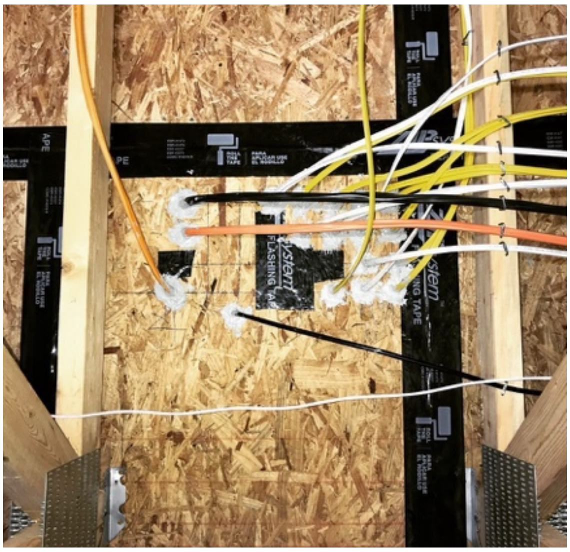
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. low emissivity vapour control layer
3. primary structural panel of C16/C24 nom. 150x50mm structural studs with 140mm semi rigid mineral wool batt insulation (0.035W/m2K) between and an external sheathing of 12mm OSB/3
4. to the exterior of the sheathing, a rigid foil faced PIR insulation (0.022W/m2K) with breather membrane
5. minimum 50mm ventilated cavity with 100mm external facing brickwork

Fig 4.1.1 Common Wall Types prevalent in the Welsh timber frame industry

- These open panel timber frame solutions are widely accepted approaches, tried and tested and well evidenced and technically described by insurance backed warranty providers. They are robust for transportation and site assembly and relatively easy and safe to fix in a broad variety of site scenarios.
- With combinations of high performance insulations and low emissivity membranes, it is possible to achieve high performance fabric levels capable of delivering fairly ambitious reductions in space heating demand. Minor changes specifically related to improved levels of airtightness and the reduction of thermal bridges in combination with compact building forms, carefully considered orientation of openings and high performance windows and doors can on paper get close to Passivhaus levels of performance. However there are a number of challenges associated with

these solutions that have informed the assessment –

- Significant levels of construction are required to be delivered onsite, often by non-timber specialists resulting in a range of common issues including –
  - ➡ Poor installation of vapour control and airtightness layers specifically at junctions and service penetrations resulting in potentially harmful vapour penetration of the fabric and excessive energy loss through the fabric.
  - ➡ Poorly fitted rigid insulation products ,leaving gaps and connecting voids, enabling thermal bypass of the thermal barrier via air circulation and convection currents.
  - ➡ Without efficient sequencing, increased onsite assembly activities result in slower realisation of a weathertight fabric leaving timber components exposed to inclement weather.
- To achieve high performance fabrics using solid stud systems, there is typically a requirement to employ high



performance petrochemical based insulations such as PIR insulations in combination with reflective membranes.

- Solid stud based panels are limited in their adaptability to high levels of fabric performance, as the insulation zone depth is determined in the simplest form by the depth of structure. Subsequently as performance demands there is a greater reliance on high performance petrochemical based insulations such as PIR insulations in combination with reflective membranes.
- Where natural insulations are preferred, the increased thickness requirements typically exceed readily available timber sizes **(as seen in figure 4.4.1)** and / or result in structural depths exceeding the structural requirements leading to structural and material inefficiency.
- As structural timber typically passes through the majority / whole thermal envelope, a degree of thermal bridging occurs at key junctions requiring additional layers of internal or external insulation.

Further details for consideration can be found in 'Making the Right Choices; A guide to improving the build quality of new build timber frame social housing' by Trada on behalf of WoodKnowledge Wales.

4.2. A Step Change Approach

During the course of the project, our work and wider Home Grown project teams have considered a strategy to deliver net zero whole life carbon. This has included the development of interim technical solutions capable of supporting a step change approach to enable upskilling, manufacturing investment and the necessary technical and procurement advancements. Key target areas that such a phased delivery would seek to address are -

- ***Airtightness*** *- introducing an interim airtightness target exceeding current building regulations such as 3m^3/hr @ 50Pa would require upskilling and a shift in procurement and quality management. A shift to airtight construction would also demand the use of mechanical ventilation systems enabling the development of the industry, systems, and user familiarity.*
- ***Improved thermal performance based on low embodied carbon materials*** *- a shift away from high carbon petrochemical based products such as insulation products would result in a rethinking of current supply chains, and develop current manufacturing solutions to maintain similar or marginally improved fabric performance.*
- ***Improved thermal bridging requirements*** *- in conjunction with airtightness this would deliver significantly improved space heating demands.*
- *Address the Performance Gap between modelled energy use and in use performance.*

A step change approach requires time and we are in a climate change emergency. It also requires investment particularly where technical solutions are advanced. It is therefore a great concern that an interim solution, invested in today, will result in delaying the necessary future phases to achieve the required advances.

An alternative approach is proposed by LETI. A 'Zero Carbon Trajectory' sets out a number of key milestones which are fast approaching

2025 :

- All new buildings designed to be net zero operational carbon.
- All buildings (new and existing) to disclose energy use data.

2030 :

- All new buildings to operate at net zero operational carbon.
- All new buildings to achieve a 65% reduction in embodied carbon emissions.

This trajectory sets out an ambitious target by 2025 that can be met by significant fabric advances in the next 4 years and upskilling of the professional services in zero carbon design. The following period of 5 years allows a window to iron out delivery issues, including addressing the performance gap, building supply chains, developing foundational economies and developing whole life carbon modelling tools and skills.

The next decade will set out the course for regulating and defining Zero Carbon both politically and technically. There remains a number of potentially competing routes to delivering these aims, with the role of renewables and energy decarbonisation, offsetting and the fabric led approach set out here all offering routes to a type of Zero. Whilst interim solutions are possible to enable an incremental improvement of the fabric, there is sufficient evidence to suggest that a fabric led high performance timber MMC solution can provide the core of the Net Zero Carbon solution, particularly for housing. It is therefore critical that ambitious and radical progress is made immediately, demonstrating the potential of this path and ensuring that the necessary regulatory and political will and commitment is on the fabric before all other measures.

An interim fabric performance at this stage encourages the potential to undermine this path, evidencing that compromising fabric performance can be acceptable if other measures such as offsetting and energy decarbonisation are relied upon to meet Zero and / or focus remains on addressing the Operational Carbon story only.

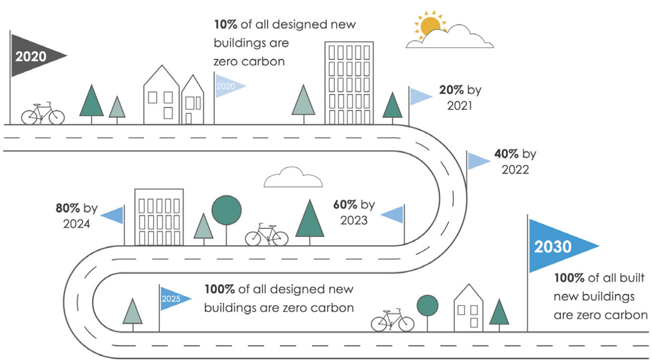


Fig 4.2. 'Getting to Zero' (LETI)

4.3. Materials, Moisture + Embodied Carbon

In addition to thinking about timber, the project team have looked in detail at the role of material selection within the structural and thermal envelope and in the selection of systems, products, internal and external finishes. A number of key subject areas are considered essential to the timber frame industry particularly -

- **Embodied Carbon** - carbon emissions associated with the sourcing, transportation, processing, manufacturing, assembly and disposal of materials, systems and products used in the home and its operation.
- **Healthy Buildings** - the materials and systems we use in our homes influence the internal air quality, and comfort that we experience in our home. This may be through the release of chemicals, gases and harmful substances from manufacturing or in use, it may be through the control of indoor air temperature fluctuations, or the formation of mould due to condensation, as well as the management of acoustics both within and from outside.
- **Fire** - fire presents an immensely challenging topic area for the construction industry as a whole, but particularly for the timber frame industry, whether through misconception or technical reality. Material selection and the assembly of buildings must consider particularly spread of flame and structural integrity in construction and in use.
- **Moisture** - moisture in construction and use presents a significant threat to timber frame construction, whether in regards to construction delays and defects, long term performance and robustness, or the provision of healthy buildings. The primary common causes of moisture issues relate to improper protection during construction, building fabrics that trap moisture due to poor diffusivity, and poor protection and continuity of vapour control layers. All can generate systematic catastrophic failures to the degradation of structural elements exposed to dangerous levels of moisture.

In the development of fabric solutions there is an overlap between a number of these areas particularly in the specification of thermal elements. Natural building products such as cellulose insulations, wood fibre and sheep's wool offer alternatives to products derived from the chemical and petrochemical industries.

Embodied Carbon of Materials

Graphs such as **figures 4.3.1 & 4.3.2** opposite help to make quantifiable decisions around the selection of materials and products informed by the associated whole life embodied carbon. The primary source for comparative embodied carbon data is found in European Product Declarations. Further guidance is provided in WoodKnowledge Wales's Embodied Carbon Guidance prepared in partnership with Construction LCA and the Alliance for Sustainable Building Products.

The accessibility of embodied carbon information is critical to the integration of low embodied carbon design into an already complex and pressured design development process.

In this case **figure 4.3.1** presents the thickness of alternative insulations required to deliver a U-value of 0.15 W/m2K (when considered as part of a consistent buildup). **Figure 4.3.2** subsequently quantifies the embodied carbon associated with this thickness of insulation by product. To the top, natural and timber based products have low embodied carbon values in comparison to petrochemical manufactured insulations such as mineral wool and polyurethane. Although not given quantified consideration in calculations currently, the sequestered carbon associated with each product is also presented and demonstrates the ability for selected products to become a carbon store rather than emitter for the life of the building. A number of additional useful products are omitted from this list including cellulose insulations which are anticipated to present a similar performance as wood wool board.

Moisture in construction

Typical timber frame design in the UK employs a vapour control layer to the inside of the frame and a racking board commonly of OSB to the exterior. This system works in theory based on two assumptions,

a) the vapour barrier remains intact for the life of the building,

b) construction materials including insulations and timber are dry during assembly and enclosure i.e. have a moisture content below that which they will decay.

In practice timber frame construction, and any exposed insulation products, are allowed considerable exposure to rain during transport, storage and construction.

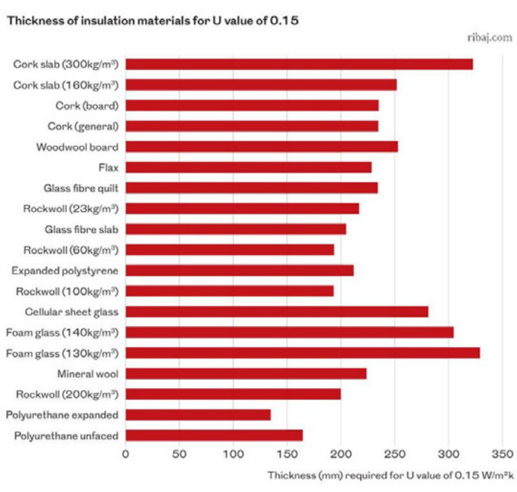


Fig 4.3.1 Graph showing thickness of insulation materials for U value of 0.15 (RIBAJ)

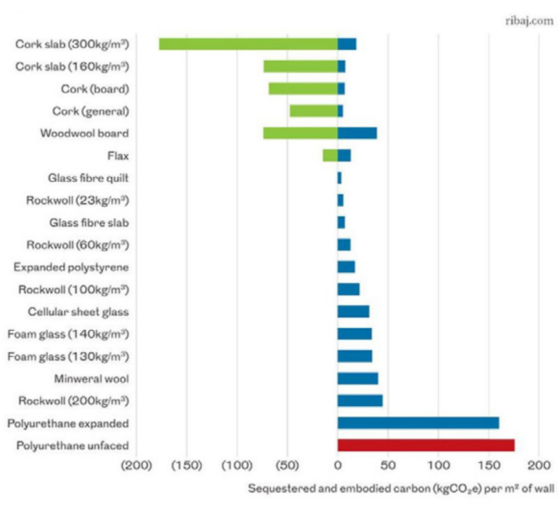


Fig 4.3.2 Graph showing embodied and sequestered carbon of insulation materials per m2 (RIBAJ)

Once VCL and OSB are installed onsite moisture within the fabric is largely trapped with limited potential for moisture to escape either to the interior or exterior. Trapped moisture remains within the wall buildup and is absorbed by hygroscopic materials including the timber frame and insulation materials, and / or is condensed on cold elements. In both cases, the presence of moisture is likely to cause decay, encourage the growth of mould and reduce thermal resistivity. It is increasingly common where positive airtightness layers are proposed for a void to be formed to the interior using 25mm or 38mm battens to create a zone for services to be distributed. This wall build up is considered acceptable when tested for interstitial condensation risk.

In combination with non-hygroscopic materials such as PIR insulations, and non-breathable closing layers of sheathing and membranes, any moisture present in the structural frame, either due to defect in use or residual from construction, will remain trapped. This will subsequently progress towards the one hygroscopic material within this buildup being the timber. To reduce risk of decay impregnated treatment products are often used and there is a broad range of best practice guidance informing how to protect timber frame from moisture in manufacture, transportation and construction all of which should be applied. However in general principles, if materials are combined that are responsive to moisture the risk catastrophic failure and / or poor health conditions arriving from fungal decay are substantially mitigated. In considering materials and technical solutions the following principles have subsequently been adopted -

- *Modern methods of construction will seek to dramatically reduce the exposed construction period onsite through increased levels of offsite manufacture.*
- *The outer surface of the fabric will be suitably detailed to ensure moisture penetration is not possible, either from precipitation or contact with the ground.*
- *A ventilation strategy will ensure that indoor air quality and moisture levels are maintained within acceptable parameters.*
- *To the exterior of the timber frame a vapour permeable sheathing or sarking will be employed to enable the wicking of moisture from the thermal envelope.*
- *To the interior of the timber frame a robust and consistent vapour resistant and airtight line will strictly limit the potential of warm moist air penetrating the external fabric.*
- *Insulation enclosing the primary structural elements will be hygroscopic and vapour permeable ensuring moisture arising from construction is not concentrated within the timber structure.*

There are scenarios however specifically related to fire integrity such as construction close to site boundaries where it may not be possible to utilise vapour open sheathing materials and membranes. Moisture vapour and condensation risk calculations should be carried out using a number of different external sheathing layers to determine what products and systems may be suitable for such scenarios.

Other areas for consideration include systems such as windows and doors, internal and external finishes.

4.4. Five Fabric Solutions

Following analysis of the previously described material properties, a library of insulation products and materials has been selected as the basis of fabric designs, including -

- Blown cellulose such as Warmcel - 0.038W/m.K
- Wood fibre semi rigid batts such as Steicoflex and Pavaflex - 0.036 - 0.038W/m.K
- Wood fibre rigid boards such as Steicotherm and Pavatherm - 0.038 - 0.043W/m.K
- Mineral wool such as Earthwool Frametherm - 0.032 - 0.038W/m.K

Five fabric wall types have been proposed -

A) Wall Type 01 (WT01) – Larsen Truss

B) Wall Type 02 (WT02) – Engineered I-beam

C) Wall Type 03 (WT03) – Twin section stud with intermittent gussets

D) Wall Type 04 (WT04) – Twin section stud with continuous web

E) Wall Type 05 (WT05) – Open panel timber frame with external wall insulation

And in combination, two complementary roof types have been considered -

1) Roof Type 01 (RT01) - advanced closed roof panels, insulated at roof level,
2) Roof Type 02 (RT02) - Prefabricated trussed rafters with raised heel, insulated at ceiling level.

As discussed previously, insulation products to walls and roofs are typically accommodated in three locations -

a) To the interior of the primary structure behind internal finishes.

b) In the primary structural zone between studs and rafters.

c) To the exterior of the primary structure, typically as a continuous insulate sheathing.

Depth of insulation within the structural zone is typically aligned with the required structural depth, determined from required structural capacity. It is feasible to use low thermal conductivity petrochemical insulations with lamda (λ) values in the range of 0.22 - 0.32W/mK in combination with a structural timber of nom. 150 - 200mm. However in order to deliver the same level of performance using non-petrochemical based insulation it is not possible to source readily available structural timber sections of this size. This requires an alternative approach to typical open panel construction either through layering of the structural envelope or through the creation of a greater depth structural zone.

The five proposed fabric solutions explore different arrangements to deliver this increased structural and thermal depth, whilst enabling improvements to repeating thermal bridging. Although different to the norm, none of the proposed solutions are particularly innovative or exceptional. These fabric types are commonplace internationally and a number of the timber frame manufacturers consulted had experience with some or all of the alternative proposals.

The proportion of offsite manufacturing undertaken by the existing timber frame industry varies from

- Prefabricated components and advanced onsite assembly - prefabricated engineered components such as engineered joists and studs, trussed rafters etc assembled on site.
- Open Panel systems - the most common product of the Welsh industry, whether as sophisticated automated and mechanised manufacturing or manual assembly offsite with panels delivered to site a structural frame with sheathing board aped ready for site finishing and insulating.
- Advanced Panel systems - which can from simply installing windows within an open panel system to reduce transport costs, or installing membranes, insulations and finishes offsite.

	Type	Thermal conductivity W/mK	Comparative thickness to achieve 0.1W/m2K
Warmcell	Blown Cellulose	0.038	435mm
Steicoflex	Wood Fibre Batts	0.036	420mm
Pavaflex 038	Wood Fibre Batts	0.038	435mm
Steicofloc	Blown Wood Fibre	0.038	435mm
Ty Mawr Thermafleece	Wool Slabs	0.038	435mm
Earthwool Frametherm 32	Mineral Wool	0.032	390mm
Rockwool Timber Frame Slab	Stone Wool	0.034	400mm
	With 15% thermal bridging factor		

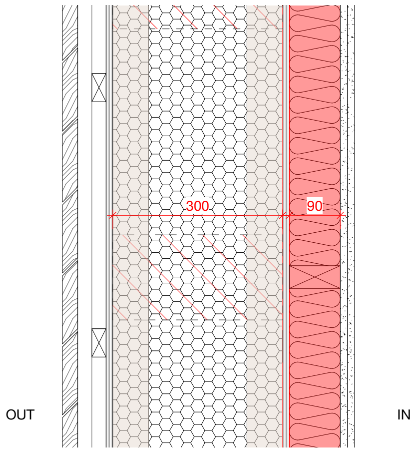
Fig 4.4.1 Common Wall Types prevalent in the Welsh timber frame industry

- Or Timber Volumetric - where modules are assembled in a factory environment with potential to install and complete all internal services, finishes and fittings offsite.

Consultation with the industry revealed that there are different drivers that influence the extent of offsite assembly both on a project specific basis and in terms of company commercial interest and setup. These factors include existing skill sets, supply chains and methodologies employed, manufacturing infrastructure, site location, topography and context, building typology and scale and often the nature of the project procurement path.

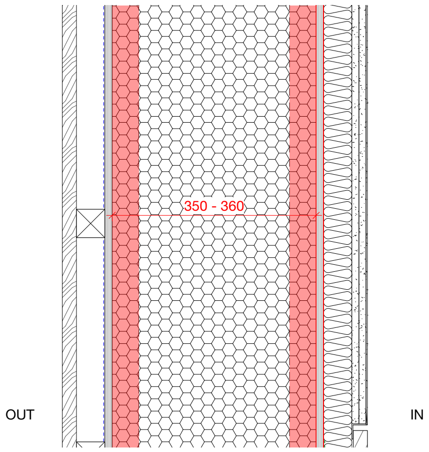
All fabrics have subsequently been considered in relation to their manufacturing and build ability and to varying degrees enable the proportion of offsite fabrication to be flexible.

The 5 fabric types



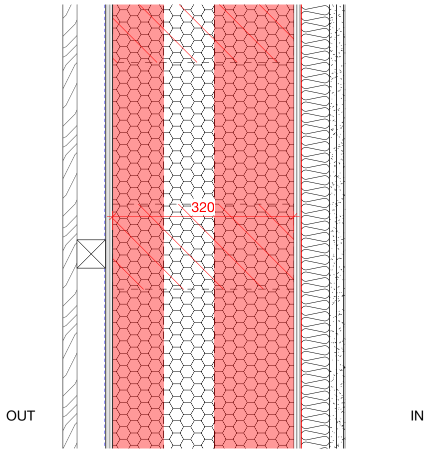
WALL TYPE 1 : Larsen Truss
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.102 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. an internal load bearing structure of nom. 100x50mm solid C16 sw timber with, 90mm Earthwool Frametherm 38 (0.038W/mK) insulation between
3. an airtight sheathing board such as 12mm Durelis Unilin, to the exterior providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. to the exterior of the sheathing, an insulated 'container' formed of 63x38mm C16 sw and 12mm WBP ply gussets, infilled with 300mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens



WALL TYPE 2 : Engineered I-Beam
SCALE 1:5 @ A1, 1:10 @ A3

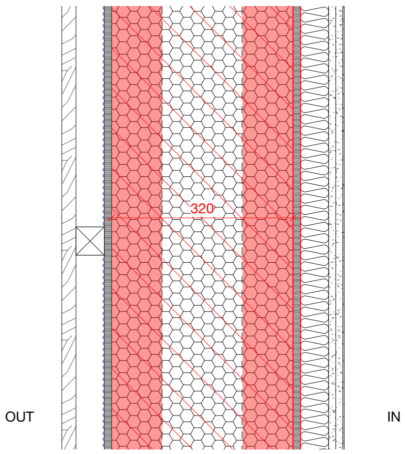
U-value 0.097 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 350-360mm engineered Ibeams, Masonite or similar at 600mm centres, infilled with 350-360mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens



WALL TYPE 3 : Twin section stud with intermittent gussets
SCALE 1:5 @ A1, 1:10 @ A3

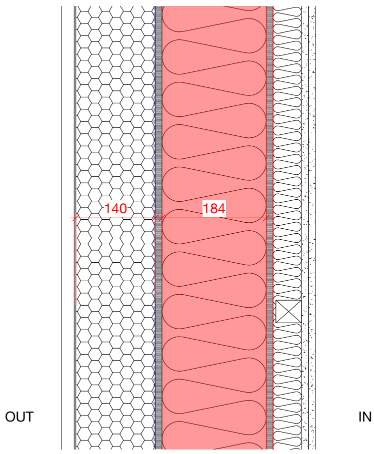
U-value 0.107 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 150x50mm loadbearing studs connected to 100x50mm secondary studs at regular centres with plywood gussets giving a total depth of 320mm, infilled with 320mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens

Fig 4.4.2



WALL TYPE 4 : Twin section stud with continuous web (C-beam)
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.107 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 100x50mm loadbearing studs connected to 100x50mm secondary studs with a continuous web to form a 'C-Beam" giving a total depth of 320mm, infilled with 320mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens



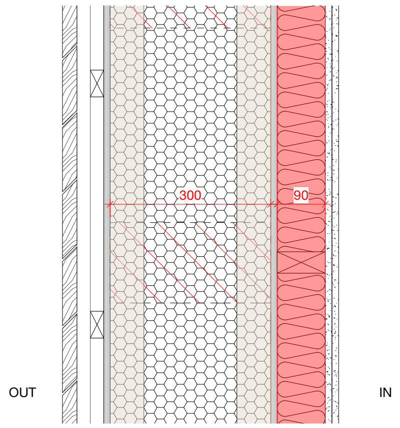
WALL TYPE 5 : Solid stud with external wall insulation
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.105 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of nom. 200x50mm loadbearing C16 sw studs (184x38mm), infilled with 184mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. a continuous layer of external wall insulation, SteicoProtectDry or similar (0.040W/m2K) with direct applied reinforced render system

Fig 4.4.2 (continued)

Fabric Type 01 : Larsen Truss

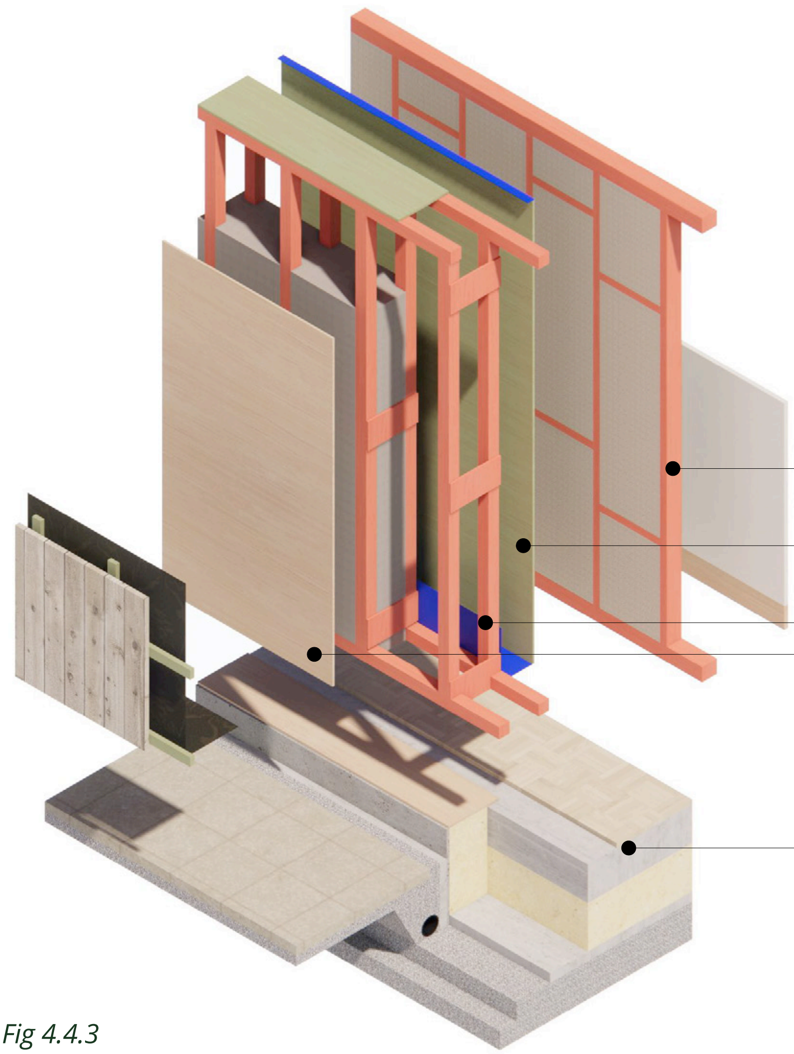
Larsen Truss adopts a two part structure and thermal envelope combining a common open panel load-bearing timber frame to the interior, with a container for insulation and supporting external finishes to the exterior. This container is made up small section timber with limited thermal bridging and the capability for adjustment to any required depth.



WALL TYPE 1 : Larsen Truss
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.102 W/m2K

1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. an internal load bearing structure of nom. 100x50mm solid C16 sw timber with, 90mm Earthwool Frametherm 38 (0.038W/mK) insulation between
3. an airtight sheathing board such as 12mm Durelis Unilin, to the exterior providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. to the exterior of the sheathing, an insulated ‘container’ formed of 63x38mm C16 sw and 12mm WBP ply gussets, infilled with 300mm blown cellulose such as Warmcell (0.038W/mK),
   closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens



Primary structure of load bearing C16/C24 sw stud frame with blanket batt or roll insulation between

Airtightness and vapour control structural sheathing board taped and sealed to achieve airtightness target

Small section sw 'Larsen' frame tied with plywood gussets forming container for blown, loose fill or batts of insulation

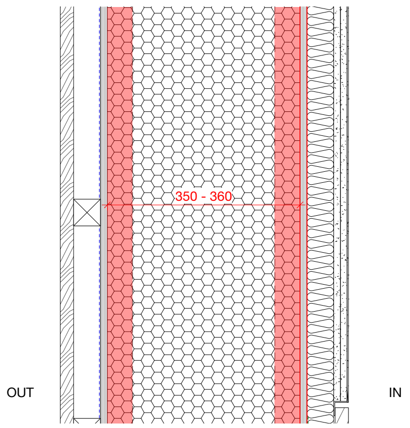
Vapour permeable sheathing board

Thermal bridge free raft foundation with below slab loadbearing and shuttering insulation

Fig 4.4.3

Fabric Type 02 : I Beam

I beam is in essence the same as a solid section stud panel - a structural element sets up the depth of the thermal envelope with insulation between and membranes and / or boards to the interior and exterior. The structural element is an engineered and manufactured I shaped stud supplied by a number of international manufacturers including James Jones & Sons of Stirlingshire, the primary UK supplier.



WALL TYPE 2 : Engineered I-Beam
SCALE 1:5 @ A1, 1:10 @ A3

<u>U-value 0.097 W/m2K</u>

1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 350-360mm engineered Ibeams, Masonite or similar at 600mm centres, infilled with 350-360mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens

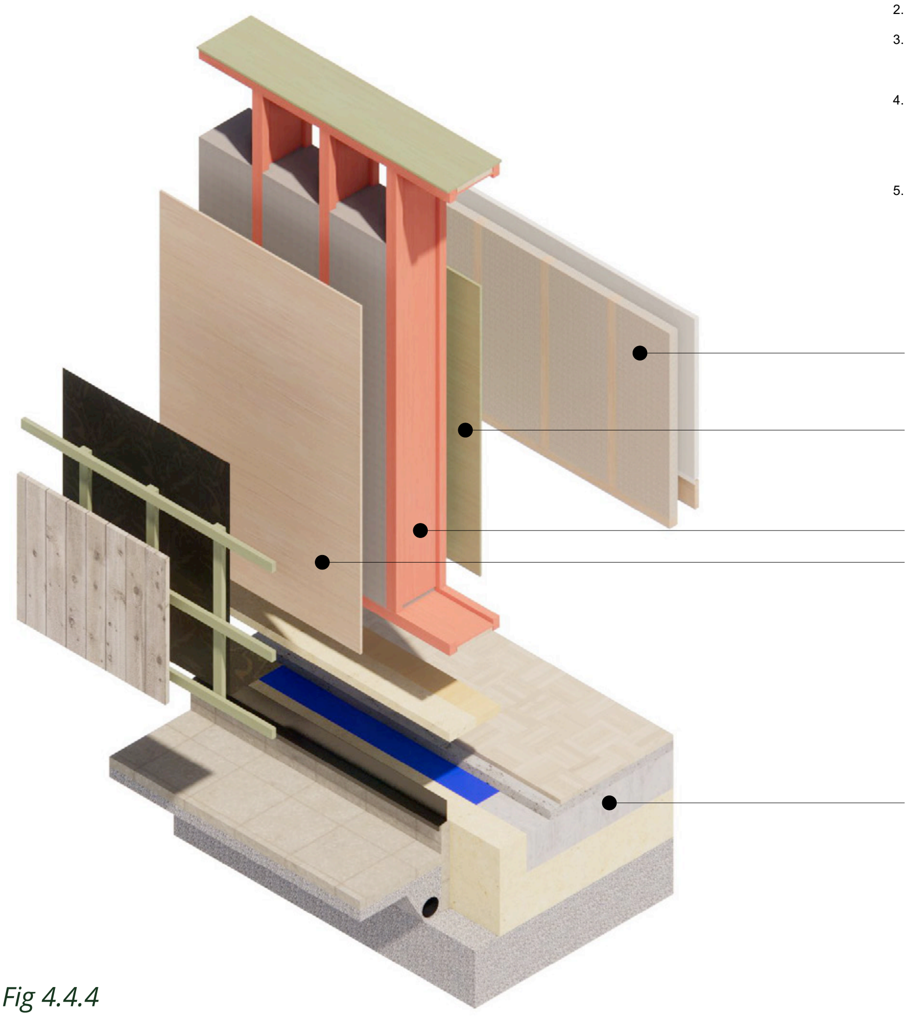
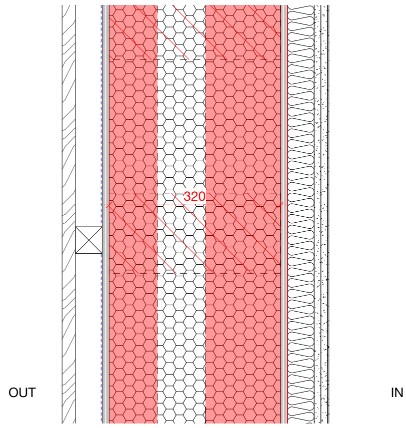


Fig 4.4.4

Fabric Type 03 : Twin Wall 1

Twin Wall 1 employs a similar methodology as an I beam however the primary structural element is replaced by a simply assembled ladder stud or twin wall - two timber members spaced to the thermal depth and connected with intermittent plywood gussets. Primary loads are carried primarily on the larger section internal stud.



WALL TYPE 3 : Twin section stud with intermittent gussets
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.107 W/m2K

1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 150x50mm loadbearing studs connected to 100x50mm secondary studs at regular centres with plywood gussets giving a total depth of 320mm, infilled with 320mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens

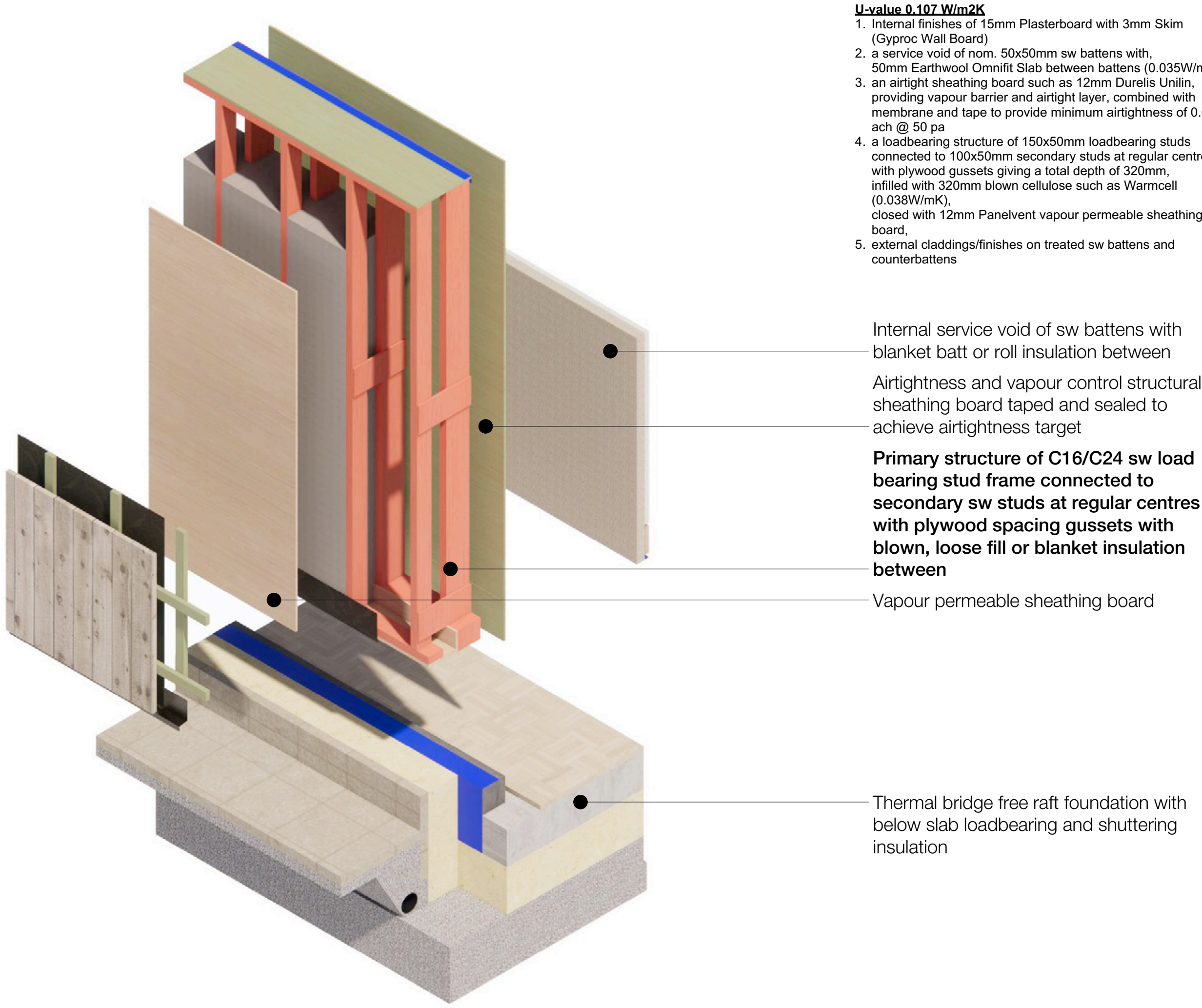
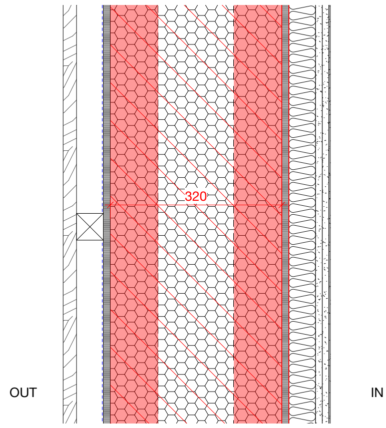


Fig 4.4.5

Fabric Type 04 : Twin Wall 2

Twin Wall 2 is equally similar in approach with the primary structural element provided by a simply assembled 'C beam' or made up twin stud. - two timber members spaced to the thermal depth and connected with a continuous plywood or OSB web. Primary loads are carried primarily on the internal stud but the structural membrane by testing may work as a component more similarly to an I beam or truss.



WALL TYPE 4 : Twin section stud with continuous web (C-beam)
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.107 W/m2K
1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of 100x50mm loadbearing studs connected to 100x50mm secondary studs with a continuous web to form a 'C-Beam" giving a total depth of 320mm, infilled with 320mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. external claddings/finishes on treated sw battens and counterbattens

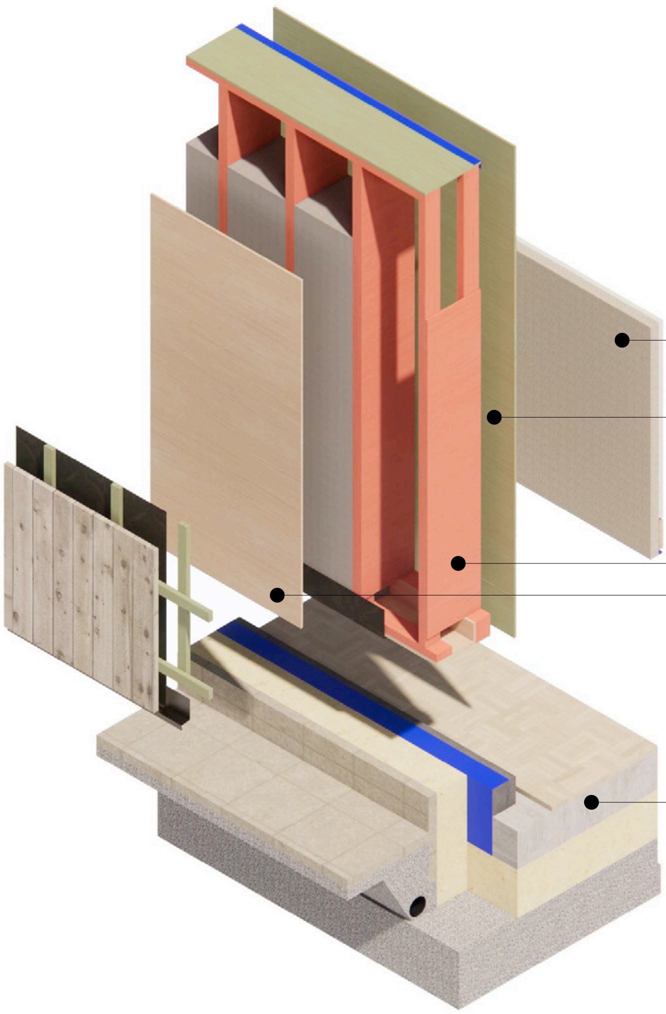
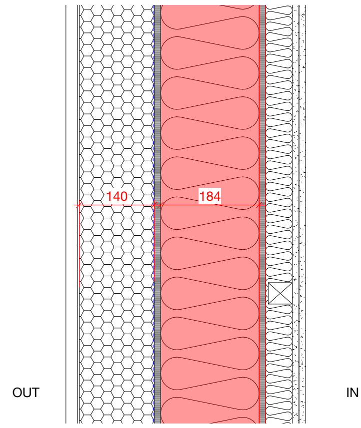


Fig 4.4.6

Fabric Type 05 : Solid Stud

The Solid Stud fabric proposal maintains the current open panel assembly methodology - insulations are installed within a large section timber frame with sheathing and airtightness layers closing the panel. An external wrap of rigid board breathable insulation along with an internal service void with insulation between increases the thermal performance and reduces thermal bridging to the target levels.



WALL TYPE 5 : Solid stud with external wall insulation
SCALE 1:5 @ A1, 1:10 @ A3

U-value 0.105 W/m2K

1. Internal finishes of 15mm Plasterboard with 3mm Skim (Gyproc Wall Board)
2. a service void of nom. 50x50mm sw battens with, 50mm Earthwool Omnifit Slab between battens (0.035W/mK)
3. an airtight sheathing board such as 12mm Durelis Unilin, providing vapour barrier and airtight layer, combined with membrane and tape to provide minimum airtightness of 0.6 ach @ 50 pa
4. a loadbearing structure of nom. 200x50mm loadbearing C16 sw studs (184x38mm), infilled with 184mm blown cellulose such as Warmcell (0.038W/mK), closed with 12mm Panelvent vapour permeable sheathing board,
5. a continuous layer of external wall insulation, SteicoProtectDry or similar (0.040W/m2K) with direct applied reinforced render system

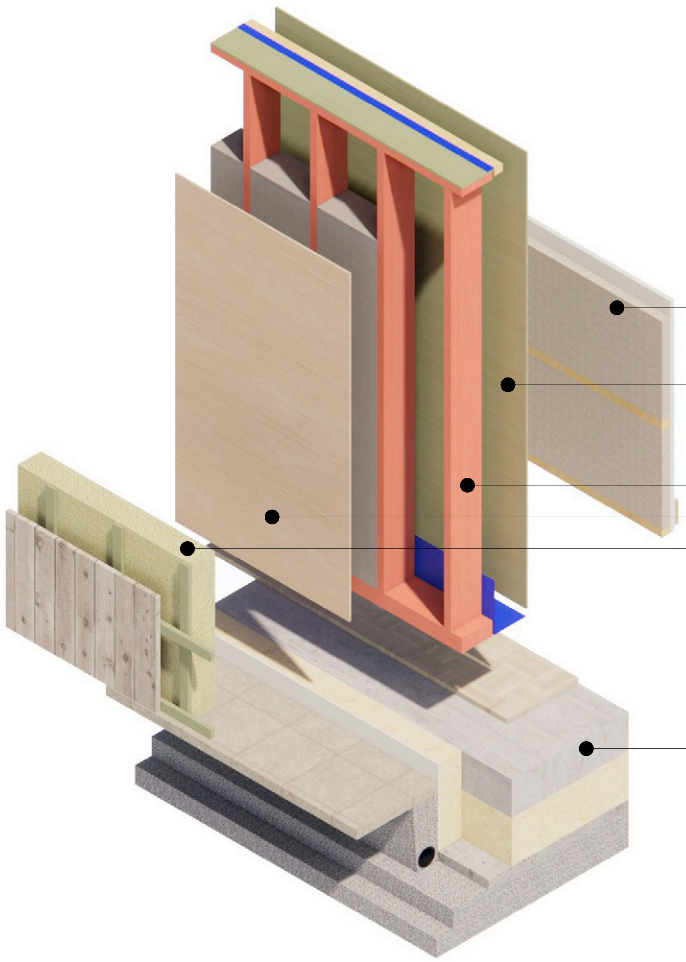
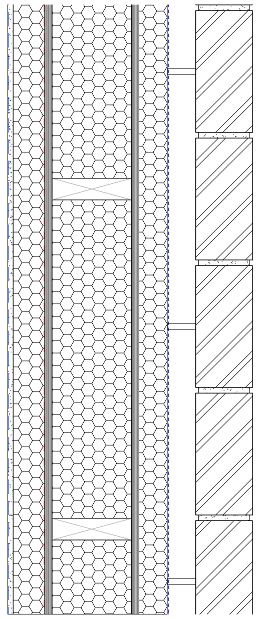


Fig 4.4.7

Benchmark Wall Type

As a benchmark for calculation, embodied carbon calculations have been prepared for an example 'typical' open panel timber frame arrangement, with thermal performance upgraded to achieve 0.1W/m2K in accordance with the other fabric types. This employs 235mm thickness of Polyisocyanurate insulation as layers to the interior, between structural studs and to the exterior as a sheathing.



- External Brickwork Leaf
- 50mm Cavity
- Breather Membrane
- 50mm Rigid PIR Insulation Board (Celotex GA4000) [0.022 W/m.K]
- OSB Sarking / Racking Board
- Solid Timber (Ex. 150mm typically)
- 120mm Rigid PIR Insulation Board (Celotex XR4000) between studs [0.022 W/m.K]
- Airtightness Board / VCL
- 65mm Laminated thermal plasterboard and skim [0.023 W/m.K]

U value 0.102 W/m2K

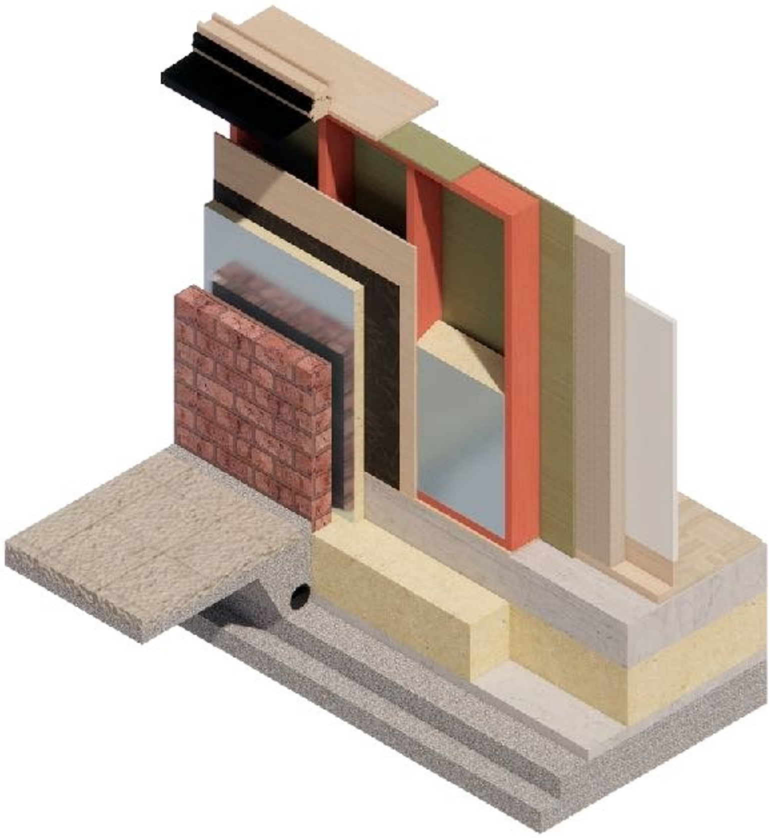


Fig 4.4.8

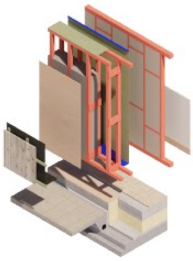
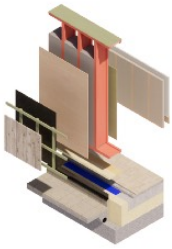
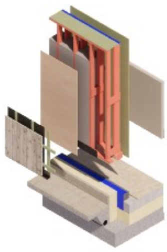
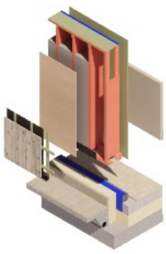
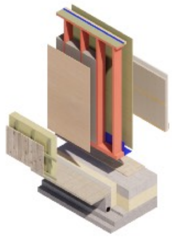
		Manufacturing + Buildability		Materials + Products	
		Off site	**On site**	**Embodied Carbon**	**Material / Product Location**
Fabric Type 01 : Larsen Truss		Presented as a relatively simple evolution of the solid stud construction method employing similar manufacturing methods - currently manufactured as two open panels combined on site.	Construction approach follows a similar manner to solid stud open panel with similar levels of onsite activities, ie installation of membranes and insulations on site. Airtightness presents challenging build ability consideration.	Cradle to grave presents the lowest EC of the 5 fabrics with upfront matching the average. Both present significant savings over benchmark timber frame. Further work on solid timber EPD offers opportunity to refine further.	Ability to make use of readily available home grown timber products.
Fabric Type 02 : I Beam		If assembled as advanced closed panels, panels require turning during assembly. I beams can be purchased cut to length ready for assembly or as standard length components ready to cut. Concern regarding the susceptibility of LVL based I beams during transport and storage. Fixings including edge distances and skew screws panel fixings are often not installed in accordance with manufacture and engineers recommendations.	As advanced panels construction methodology has been demonstrated to be extremely quick to achieve a weathertight fabric. I beams are used to close panels and act as devices to provide contained zones for cellulose insulation offering good potential to achieve and maintain consistent density whether installed onsite or offsite. Concerns raised regarding the protection of panels from water ingress which requires further consideration.	I beam results in an increase to cradle to grave EC. Upfront and carbon storage associated however offer the most positive solution.	Only current manufacturer in UK of I beams is Scottish. Majority of supply is International.
Fabric Type 03 : Twin Wall 1 Intermittent Gussets		Intermittent gusset twin wall trusses require additional manufacturing activities - systems may be developed as two mirrored internal and external open panels connected on site with plywood gussets or arranged as twin wall ladders as part of a closed panel arrangement. If advanced panels, additional sheathing is required to close panel edges.	Working processes may follow a similar manner to existing open panel timber frame or an advanced panel assembly method offering a greater speed to weather tight fabric.	Increased timber volume results in higher than average upfront carbon with storage and cradle to grave results meeting the average. Further work on solid timber EPD offers opportunity to refine further.	Potential to employ home-grown timber for structural timbers. Insulation products including wood fibre and cellulose offer potential growth areas.
Fabric Type 04 : Twin Wall 2		The twin wall component offers an opportunity for additional manufacturing streams as a component. Panels can be assembled as advanced or open panels. Fixing details for closed panels are considered to be offer more robustness than I beam options. Advanced panels require additional lifting facilities and bench systems to turn panels.	Speed of assembly follows a similar path to I beam systems with potential to resolve neat details to close panels using the C-beam element. As closed panels, closed voids are formed between beams for filling with blown insulation onsite or offsite.	All 3 characteristics meet the average of the proposed types offering perhaps the best balance.	
Fabric Type 05 : Solid Stud		Manufactured using typical manufacturing processes as an open panel timber frame with internal airtight sheathing. Typical framing details applied.	On site construction processes are familiar but typically slower than advanced panel processes due to increased work required on site. More susceptible to inclement weather.	Upfront and carbon storage meet the average however cradle to grave carbon associated with wood fibre insulations specifically result in an extremely high whole life result. Further examination of end of life options might offer improved results.	Works with the majority of existing supply chains including potential for home grown timber. No manufacturers of rigid wood fibre insulations available in the UK.

Fig 4.4.9

		Technical				
Foundational Economy	**End of Life**	**Structural Stability**	**Thermal Performance**	**Moisture Risk**	**Airtightness**	**Fire**
Potential supporting manufacturing industries could include cellulose and wood based insulations. Systems employing prefabricated engineered components including I beams and more simply assembled twin wall systems offer potential for supporting manufacturing industries at various scales of investment.	Potential for primary structure and insulations to be recovered for reuse or biodegrade.	Structurally, essentially the same as a solid timber solution. Fixing back of cladding options requires consideration.	Potential to achieve thermal bridge free construction due to consistent external layer of insulation. Insulation layer is adaptable to large range of insulation depth.	Dependent on position of airtightness layer - if to the exterior of the primary structure, care needs to be taken regarding moisture content of primary structure prior to enclosure.	Airtightness layer to the exterior of the primary structure has limited access making on site taping and jointing challenging.	Issue regarding suitability of external timber elements as substructure to cavity barriers, testing required.
	End of life options for primary structure are limited.	Solid stud is replaced by single I beam element. Internal and external sheathings are proposed but testing is required to evidence if external sheathing is capable of providing racking stability.	I beam reduces repeat thermal bridges however non repeating bridges including sole and head plates require development. Thermal depth governed by range of available I beam sizes.	Potential to achieve a vapour permeable fabric. However concerns raised regarding the long term durability of I beams in exposed locations.	Airtight layer can be installed offsite in controlled environment as a closed, advanced panel or onsite as a rigid board or membrane. Junction at intermediate floor requires consideration regarding balloon frame / platform frame arrangement.	Issue regarding suitability of Ibeams as structural closures as substructure to cavity barriers, discussions required with manufacturers.
	Primary structural timbers suitable for recovery and reuse. Insulation materials offer potential continued value either through decomposition releasing carbon into the soil or through recycling processes. Primary structural timbers suitable for recovery and reuse. Insulation materials offer potential continued value either through decomposition releasing carbon into the soil or through recycling processes.	Timbers sized to act as a solid stud frame with all load carried by internal stud work. Further investigation required regarding the usefulness of external sheathings in racking.	Intermittent gussets and split lintels reduce repeating and non repeating thermal bridges. Capable of achieving zero bridging. Structural depth can be tailored to any U-value requirement	Potential to achieve a vapour permeable fabric. With care in storage and construction untreated structural timbers should be sufficient.		Twin wall systems are not currently evidenced by publicly available fire testing and therefore bespoke testing would be essential.
		Timbers will be sized for internal stud to act as loadbearing element however subject to testing component may act similarly to I beams. Geometry must be symmetrical around both axes to be considered as a composite section.	Similar to I beam and twin wall. Potential to split internal and external lintels sole and head plates including at intermediate floor to improve thermal bridging. Structural depth can be tailored to any U value requirement.			
Opportunity to develop low carbon external wall insulation systems with relevance for the retrofit market.		In accordance with current standard calculation methods. Primary structural zone is restricted to readily available structure timber sizes. Cladding options are limited by fixing back options associated with external wall insulation.	Thermal bridging calculations must accurately reflect timber structure including for localised strengthening such as cripple studs. Contribution of structural zone insulation is restricted by readily available timber sections. Bridging of external wall insulation by fixings must be calculated.	Vapour open materials are employed throughout the buildup. Materials including render finishes to the exterior of the primary structure should be vapour open otherwise there is potential for interstitial condensation.	Rigid airtightness layer can be installed offsite as an open or closed panel arrangement. Intermediated floor junction, eaves and ridge beams present the greatest risk areas.	Further investigation is required in regards to the use of external wall insulation options in combination with fire barriers.

Continued

4.5. Structural Design Philosophy

Structural design for this project has been completed to Eurocode design standards, and relevant manufacturers' information and details, where applicable. This is particularly relevant with regards junctions between elements, metalwork (such as screws, brackets, joist hangars), edge distances for fixings. Where manufacturers wish to deviate from this guidance, we recommend that load testing be carried out on the proposed junction/detail in line with British and European Standards, and other relevant design codes, to establish structural parameters such as (but not limited to) bending, shear and axial strength and stiffness, serviceability limitations, and long term durability.

Structural engineers engaged for timber projects should be experienced using timber as a structural material. It is worth noting that engineers can leave university with usually around 1 hour's timber specific teaching over a 4-year master's degree. Chartership is not always a guarantee of experience either, as it is possible (and common) to gain the qualification with both Institutions with no timber project experience. A training standard and directory could be developed to help manufacturers easily identify engineers with the requisite skills for structural timber projects.

The following analysis presents concept stage analysis of the proposed fabric types when applied to the 3 alternative house types. This investigation focuses primarily on structural stability in the context of employing lightweight claddings. The application of an external masonry leaf significantly reduces the demand placed on the independent stability of the timber frame and subsequently this is considered a 'worst case scenario'.

Common issues with timber structural design

- Overall stability & holding down
- Timber connections – edge distances, timber capacity
- Structural movement – shortening of sawn timber over time causing serviceability issues (cracking).
- Poor damp proof detailing or assumptions about moisture content of timber during construction – avoid details like valley gutters over party walls and ensure breathable construction (preferably to outside).
- Overhanging eaves, flat roofs, solar panels, solar shading canopies, balconies attached to the primary building frame all add uplift to the timber frame, which can be tricky to deal with.
- If flat roof construction is used, a green roof build-up can be used to add weight, and solar panels should be ballasted, not mechanically fixed to roof.

4.6. Structural Stability

Overall Stability - Limitations of Calculations

Overall stability should be assessed on a case-specific basis; this includes site specific wind and snow load calculations, as well as site specific geotechnical analysis. This analysis has been completed using Eurocode design standards, and is subject to the following limitations:

- Maximum altitude = 300m above mean sea level
- Minimum distance to shoreline = 5km
- Site is not situated near any significant orography (i.e. escarpments, cliffs, hilltops, or ridges)
- Site is in 'country' terrain (i.e. less than 1km within a town)
- Basic wind speed, $v_{b,map}$ = 23.5 m/s (from EC1-4)

General Observations

- Floor joists need to run front -> back to put enough vertical (downwards) load on the critical racking panels on front and back elevation.
- Generally, short wide units (Type 4) are easier to deal with from a racking perspective, than narrow deep units (Types 1b & 7), due to the greater available wall to opening ratio.
- Calculations are based on a cut roof structure with ¼ of roof being support on front and rear elevations, and ½ on the ridge beam.
- Structural stability is generated on a single dwelling basis with no transfer of loads between dwellings due to differential settlement, acoustics and fire.

House Type 1 (Fig.4.6.1)

- Current arrangement of openings demonstrate an efficient use of timber in wall studs – windows line up FF to GF.
- There is potential to reduce kitchen window size to add racking capacity to front elevation.
- Internal dividing wall between kitchen and living room is critical to stability in most cases. Where employed it can also be used to support the ridge and avoid the need for a glulam ridge beam.

Number of units in terrace for racking stability (not using steel frame and without continuity of panels across units):

- As drawn (floor joists running side – side, no internal wall) : **Min 9 units** in terrace.
- As drawn with internal wall (floor joists running side – side) : **Min 5 units** in terrace.
- Floor joists running front – back, no internal wall : **Min 8 units** in terrace.
- Floor joists running front – back & with internal wall : **Min 4 units** in terrace

Fig 4.6.1. House Type 1 Elevations

House Type 4 (Fig. 4.6.2)

- The easiest option to make stability work.
- Potential to use structural wall to support roof – no glulam ridge beam.
- Roof structure: if joists span perpendicular to pitch (i.e. as purlins) with no intermediate support such as a structural wall, primary spanning elements would need to be I-joists.

Number of units in terrace for racking stability (not using steel frame and without continuity of panels across units):

- Min. 3 units in a terrace (floor joists spanning front to back).
- Potential to work as semi-detached arrangement with smaller living room window.

Fig 4.6.2. House Type 4 Elevations

House Type 7 (Fig. 4.6.3)

- Recommend any external solar shading is completely self-supporting to avoid putting additional uplift forces onto primary timber frame.

No of units in terrace for racking stability:

- As drawn (floor joists running front – back): Min 7 units in terrace.

Options for Semi-Detached and Detached Properties

The above recommendations are based on terraced units. Options to achieve overall stability on semi-detached or detached homes would be:

- Integrated steel frame: Easy way to achieve stability, but adds potential thermal bridge and expense of rectifying that issue.
- Hold down straps: Stability design is subsequently limited by racking capacity of panel, so doesn't add significant capacity to panels with openings. Exclusively this would not add sufficient capacity to enable Type 7 to work as semi.
- Brick external leaf: An easy opportunity to address stability concerns but introduces issues such as differential movement between timber & masonry.
- Increased dead load at intermediate and/or roof level such as cementitious panels, also offering potential to act as a thermal store. Considered to offer a limited load benefit.

Fig 4.6.3. House Type 7 Elevations

- Racking wall product such as Simpson-Strong-Tie StrongWall: although expensive, products can be very effective – about 6x the racking capacity of a similar sized timber panel.
- Steel cross bracing within timber wall (as per cold rolled steel framing): greater capacity than racking panel, but limited by steel to timber connection capacity. Also, requires holding down straps.
- Potential to use timber compression bracing within timber panel (as per American practice): makes boxes tricky to fill with blown insulation. And requires holding down straps.

Whilst there are structural solutions that are resolvable, many of the easier fixed described above come a considerable carbon compromise therefore recommendations proposed later will promote finding alternatives to the introduction of steel and high carbon structural solutions.

4.7. Foundation Types

Figures 4.7.1 - 4.7.3 show a typical raft slab arrangement using a performed insulated shuttering system. This permanent shuttering is installed over compacted hardcore layers and where necessary piles or strip foundations. A raft of typical 200mm thickness with reinforcement is subsequently cast within the shuttering. Whilst it is common to provide a further screed layer, no additional insulation is required and the primary concrete slab could be left as your primary floor.

- Pretty versatile to site conditions
- Is shallow so good if site geotechnical conditions are hard rock.
- Sites with ground conditions which vary significantly across the building may need piles or strip below raft.
- May need edge thickening for some situations. Note: NHBC has a minimum

Fig 4.7.1- 3 Preformed thermal bridge free insulated slab system by Raftherm.

raft slab edge thickness of 450mm. This is for frost protection purposes, so theoretically is not required when externally insulated however this may require justification and evidencing to persuade warranty providers.

- EPS insulation design: critical to include long term creep deformations (squashing over time) as this is usually the critical design criteria.
- Holding down – without external masonry leaf, this becomes a critical design criteria.
- Where an external masonry leaf is required this can in some scenarios be supported on the insulation toe or alternatively supported on a separate foundation. Allowing for differential movement between masonry and timber frame is critical.

4.8. Structural Recommendations

The proposed analysis has been considered for house types and fabric solutions up to an equivalent level as RIBA Work Stage 3. There remains key areas of development that require additional analysis and calculation which would follow the typical course of Stage 4 Technical Design. To progress any of the proposed fabric types it is recommended that technical design focuses on a number of project scenarios in order to consider the range of small residential typologies and ensure a flexibility is built in. Other considered areas for development include;

1. Stability of timber buildings: Timber racking panels, braced timber panels, etc. There's a particular gap in research on the performance of racking panels with deep I-joist wall studs, especially when combined with low-thermal bridge foundation details:
    a) Does the depth of stud affect racking capacity when considering really deep studs (300 – 400mm)?
    b) Differences in performance of deep timber racking panels with internal and external racking board, or just internal racking board (and external breather membrane).
    c) Effect of partially fixed sole plate on the above performances.
2. Lateral torsional buckling of C-beams. (Section not symmetrical). Potential for physical component testing in combination with theoretical calculation.
3. Development of low-thermal bridge and airtight timber frame details including : roof to wall, floor to wall and wall to foundation details as proposed elsewhere with specific focus on maintaining a positive structural connection around all these junctions whilst minimising thermal bridging, and enabling greater levels of offsite assembly. Dependent of selected fabric type this should also consider
    a) The performance of long timber fixings through deep insulation.
    b) Panelised connection details with low-TBs considering the sequence and

efficiency of assembly and disassembly.

4. Engineered I-joists used as portal frames: there are a number of questions regarding the assumed and /or tested capacity and stability of moment connections being used in I-joist frame connection. Physical load testing is recommended to prove their capacity and failure mechanisms i.e. unzipping of the glued joint between web and flanges.

4.9. Investigation 2 : Embodied Carbon

Aim : Calculate the embodied upfront and whole life carbon emitted by alternative equivalent fabric types to identify the embodied carbon cost per sqm.

Initial carbon analysis has focused on a comparative investigation considering the 5 proposed fabric solutions and a benchmark in line with current manufacturing. All fabrics are designed to meet the same fabric performance, ie to meet a U-value of 0.10W/m2K and airtightness of 0.6ach. All wall types are modelled excluding external finishes and with assumed details regarding structural timber spacing and quantity.

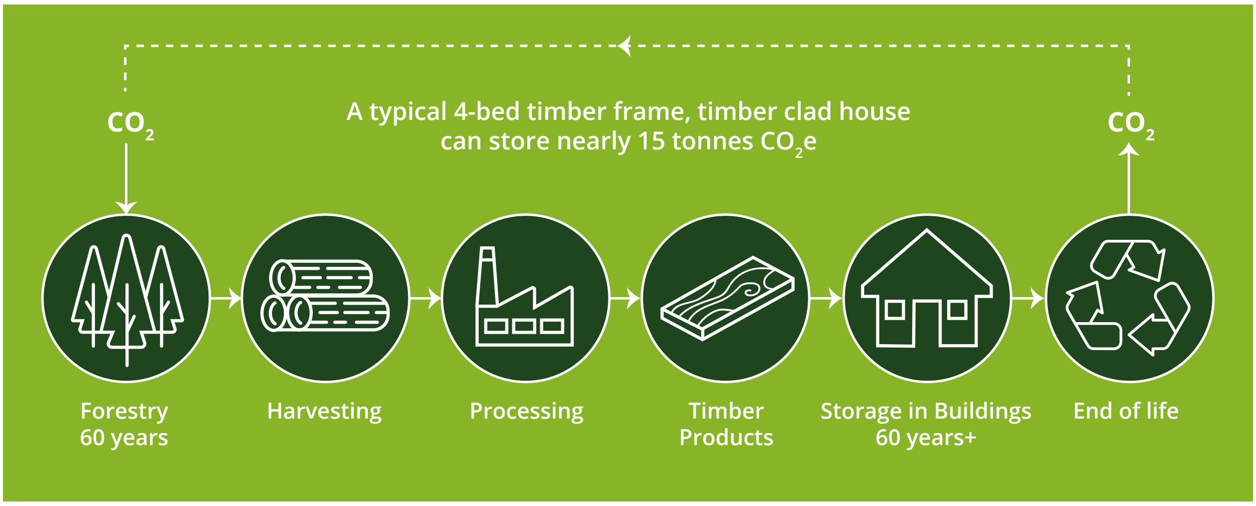
The project team has employed the Eccolab Whole Life Carbon tool to model the fabric types. This involves the creation of a library of products, populated with data provided by European Product Declarations. Unlike some WLC tools, this library is based on real product data where possible and generic material EPDs where products are not specifically available. Following creation of a material and product library, assemblies of components are created in line with the detailed buildups shown in **Figure 4.4.2.** recording depths of components.

To generate comparative data, these components have subsequently been applied to a consistent building form of comparative shape and geometry to House Type 1.

4.10. Investigation 2 : Detailed Findings

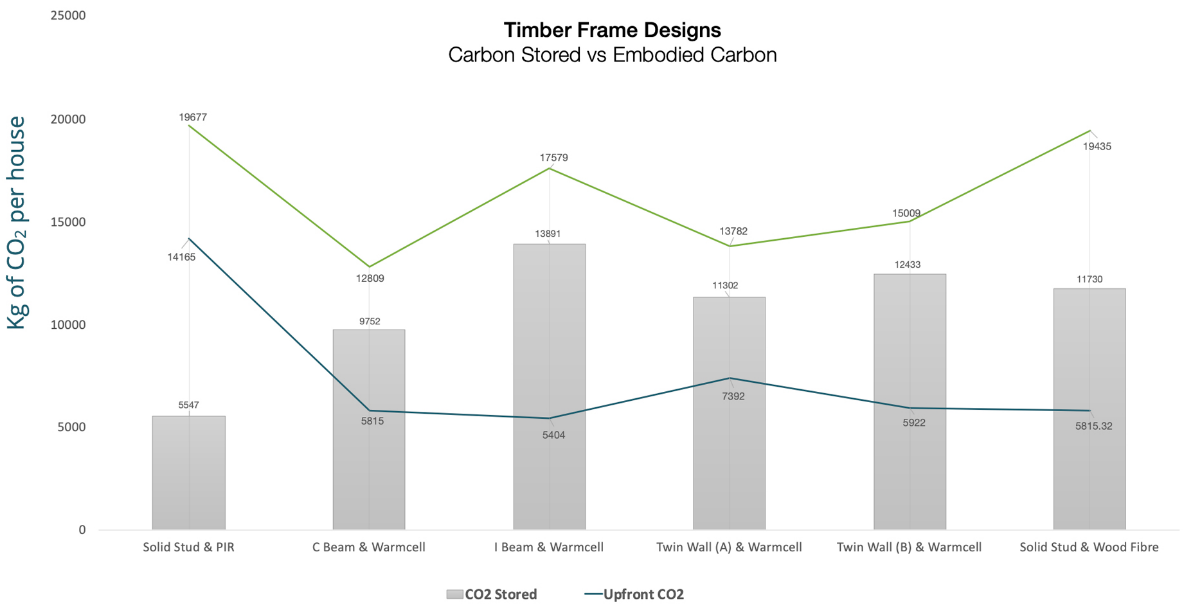
Figures 4.10.2 - 4 show the comparative results produced for upfront embodied carbon and whole life embodied carbon.

- Of the 5 proposed fabric types, the Fabric Type 02 Ibeam based approach has the lowest upfront carbon at 73% of the emissions associated with Twin Wall 1. However at 209.3 kgCo2 per m2 it has the highest associated cradle to gate emissions.
- On average the proposed wall types generate just 43% of the upfront embodied carbon emissions caused by a polyurethane insulated benchmark.
- Fabric Type 05 offers very minimal reduction in cradle to gate emissions when compared to the benchmark. By contrast however both fabrics 01 and 03 offer over a 30% reduction.
- On average the proposed naturally insulated fabrics store or sequester over twice as much carbon as the benchmark.
- There are some interesting unanticipated figures which require further investigation, particularly in regards the carbon storage benefit associated with Ibeams over solid timber. It is anticipated that a number of these areas might be associated with the EPD employed.
- We have presented the argument that carbon emissions reduced and even stored today are of more critical value than potential emissions over the whole life cycle of the home. Based on these figures the use of natural non-petrochemical based insulations generate reductions both upfront and cradle to gate whilst locking in more carbon than the benchmark existing approach. The combination of upfront reductions and increased stored carbon results in significant improvements in carbon emitted today.



Further analysis is required to understand the specific causes of the observations above, particularly in regards the variations between proposed fabric types.

Figures 4.10.3 - 4 below plot these results as both a single house type and a per m2 rate of gross internal area.



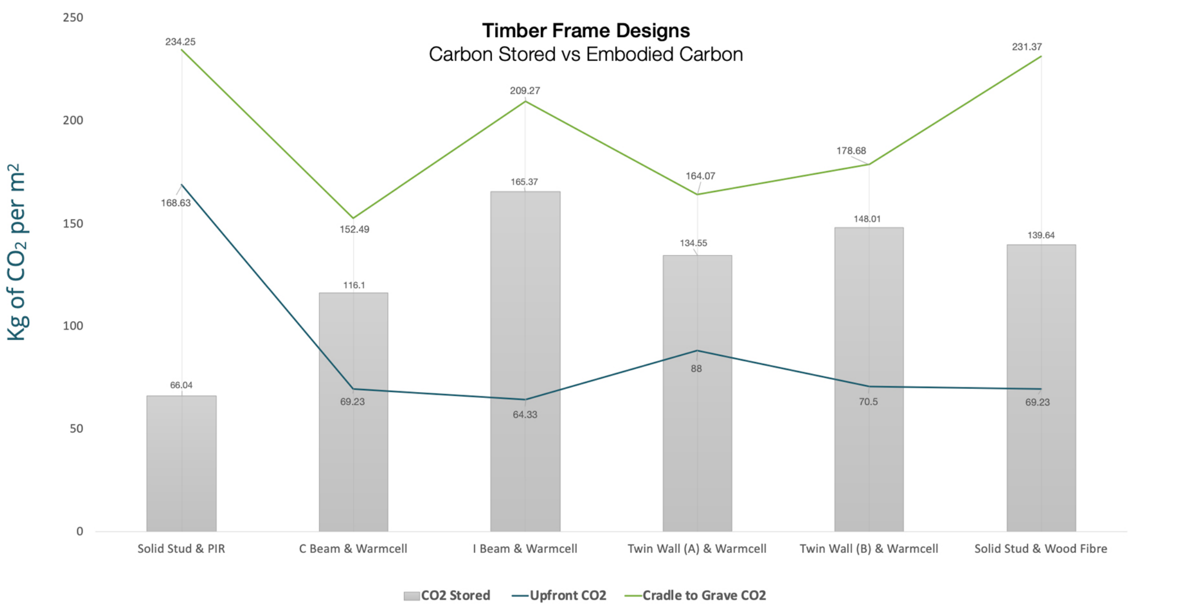


Fig 4.10.1 The potential benefits of carbon storage for a house (timber framed timber clad house designed for Gwynfaen Farm, data from Stride Treglown (2020)

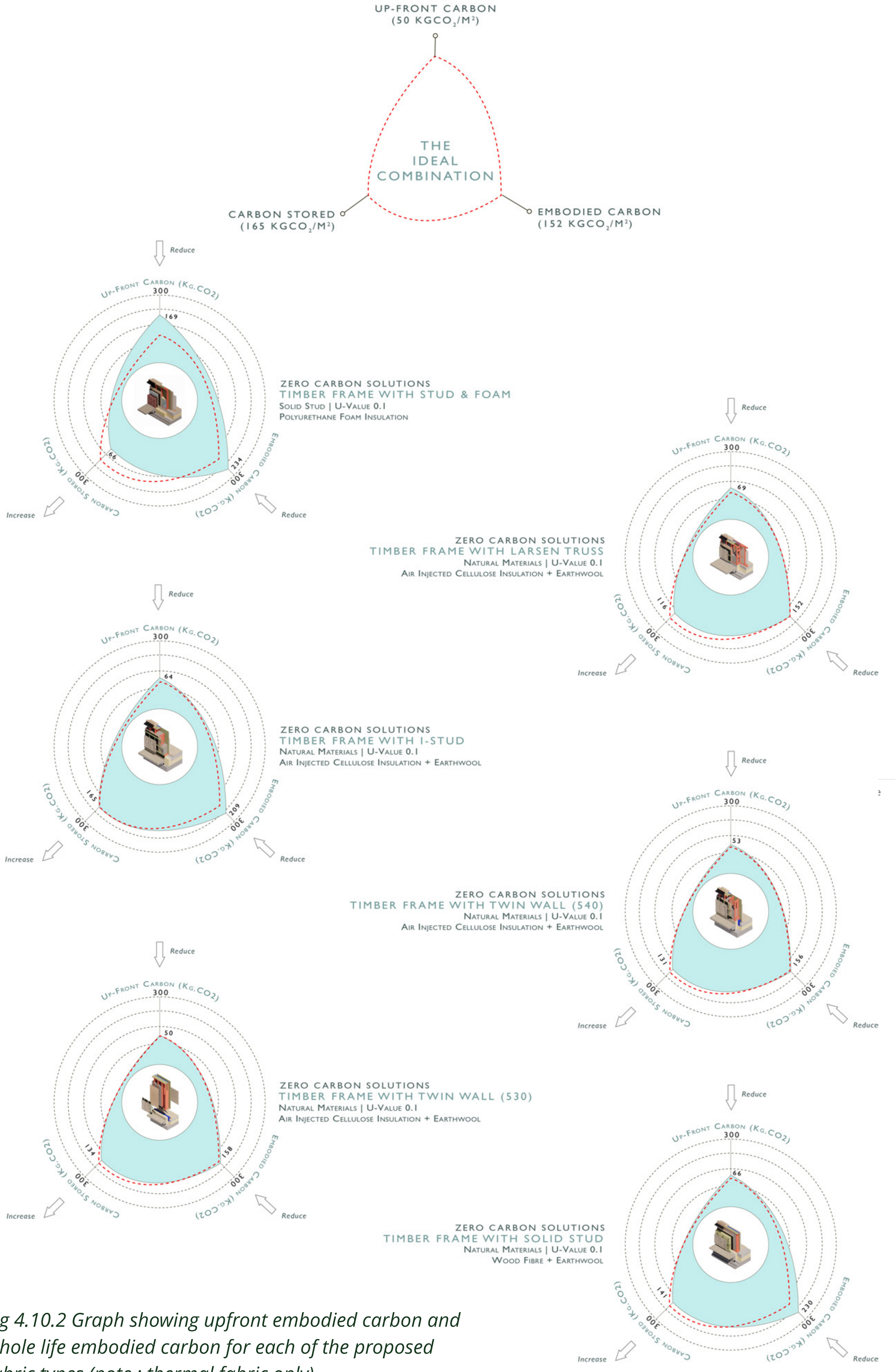


Fig 4.10.2 Graph showing upfront embodied carbon and whole life embodied carbon for each of the proposed fabric types (note : thermal fabric only)

4.11. Embodied Carbon Recommendations

Action...

It is essential that materials being proposed for use within our proposed fabrics are available with comparable and consistent data to enable whole life carbon analysis. It is therefore essential that a database or library of product performance data is collated in a consistent and accessible manner to enable early interaction with carbon considerations as part of the materials selection process.

Environmental Product Declarations are the established medium for material passports however the availability and comparative included data is widely variable.

In developing comparative data for wall typologies, a relatively simple challenge when considering the complex nature of the whole building system, the team have found the process of collating a library of EPDs for the selected construction materials and products to be a laborious and challenging process. EPDs for commonly used building products are often not readily available, and emerging products that are both innovative and essential to high performance fabrics such as airtightness membranes and boards have been particularly difficult to source. Although EPDs follow a supposedly 'verified, objective and detailed information' as set out by ISO 14025, the methodology still enables enough variability in the presentation of data to make direct comparisons between materials very difficult.

Fig 4.10.3 - 4 Comparison of Kg of CO_2 emitted and stored by fabric type calculated per m^2 of gross internal area (bottom) and for an indicative house equivalent to House Type 1 (top)

Action...

The application of consistent product and material specifications through standardised fabric proposals, in conjunction with Building Information Modelling and a pattern book of standard house types may initially provide a route for upfront and whole life embodied carbon analysis to become an accessible element of design development for the sector, reducing the burden of project specific calculations.

For designers there are undoubtedly concerns with this rigid theoretical basis, not least associated with the need for design processes to adapt to and respond to contextual factors such as materiality, regionality and landscape in addition to local supply chains and foundational local economies. However, it is without doubt that when considering the increasing complexity of designing low and zero carbon affordable homes, standardisation offers the greatest opportunity to address the associated additional cost, whether that be material and labour costs or consultant expertise. The sector presents an extremely challenging basis for consultant expertise and therefore design efficiencies through standardisation are already commonplace despite the removal of the official Welsh Government 'Pattern Book' of house types. As targets are set that require embodied and whole life carbon analysis on a project by project basis, the associated specialist consultant fees will, at least initially, place a considerable burden on a project if considered on a bespoke basis. Through Building Information Modelling, the standardisation of building fabrics including materials and products and the development of standard house type models it is

Action...

The process of material and product selection must be developed to robustly integrate embodied carbon calculations.

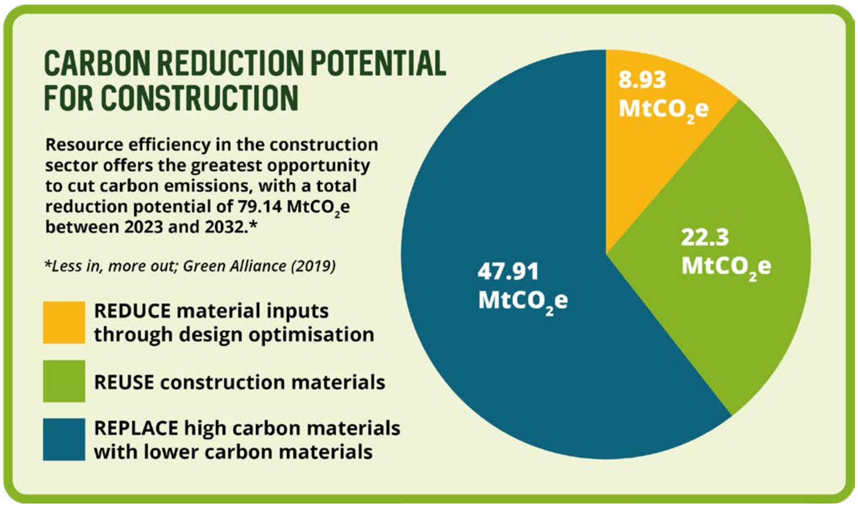


Fig 4.11.1 The carbon opportunity from increasing resource efficiency in construction

feasible that a large majority of data could be embedded within proposals. Factors such as external finishes, specialist ground works, landscaping and perhaps mechanical and electrical systems will undoubtedly require some bespoke thought however it is feasible that a model house might be developed with a large body of the necessary data predetermined.

The existing industry particularly in regards to design and build contracts sees a great deal of material and product evolution through the course of a project whether due to cost, supply chains, personal preference, ignorance and availability. Often the analysis of alternative and equivalence takes into consideration key performance indicators such as thermal conductivity, bearing strength etc. This culture of product evolution presents a key challenge and critical risk area for a 'performance gap' in embodied carbon. As discussed there are significant challenges facing specifiers in identifying, analysing and modelling building materials and components and whilst it is inconceivable that a building will not evolve through the course of construction, all parties will need to evolve processes if embodied carbon targets are to be delivered. We believe that the process of developing standardised fabrics with robustly specified materials and products is a key element of this quality assurance process. The identification and specification of a limited library of materials which allows for alternatives in a selection process can enable flexibility whilst ensuring there is an element of control as we develop both the availability of data and the ability of building professionals to assess embodied carbon factors for equivalence.

Action...

Proposed fabric solutions should seek to achieve zero rated psi values when considered for both SAP and PHPP methodologies by developing certified system psi values for all junctions through dynamic simulation modelling.

End of life

As the embodied carbon of materials has been investigated it has stimulated a lot of consideration regarding the current methods of calculating end of life of materials. Current calculation methods assume that at end of life ie 60 years, all carbon is released from the construction materials. Without further strategic planning this is a sensible and necessary methodology for equalising projects. However as we progress development of technical solutions opportunities to consider disassembly methods, recovery and reuse of materials and recycling are revealed and this eventuality is challenged. The materials being proposed within these technical solutions provide significant opportunities for recovery and future valuable use. Further investigations proposed through the development of technical solutions will consider factors such as;

- the technical solutions for fixing and disassembly of timber components in

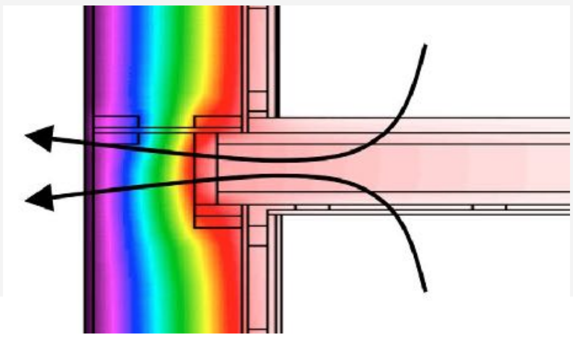
both primary and secondary assembly forms,
- recovery of insulation products,
- alternative carbon release mechanisms of materials such as carbon release in to soils through decomposition,
- waste in construction and maintenance.

Further work with whole life carbon experts is proposed to understand the options for end of life calculation and the options to accurately reflect the cradle to cradle ideals that sit behind the teams aspirations and the material potential.

4.12. Thermal Bridging

Since 2010 calculations have been required under Approved Document Part L for thermal bridging within thermal modelling either in the form of project specific calculations or default allowances. Thermal bridging occurs typically where the insulation layer is reduced due to geometry or arrangement or where an element such as structure passes through the insulation layer. The reduced thermal performance causes heat loss which is calculated as linear thermal transmittance ψ, or the rate of heat flow per degree per unit length of the thermal bridge. Thermal bridges fall into two categories, repeating thermal bridges, such as timber structural studs in a wall frame, where the frequency is known, and non-repeating thermal bridges. Repeating thermal bridges are typically accounted for via U-values by calculating the proportion of bridging element(s) within the insulation layer(s).

Non-repeating thermal bridges however are much less predictable and are therefore typically accounted for in performance modelling via employing predetermined junction designs with calculated and certified Psi values provided by system or manufacturer libraries or through schemes such as Accredited or Enhanced Construction Details. Alternatively Psi values



focus and the role of both repeating and non-repeating thermal bridges become a critical element of the fabric design. This consideration is in regard not just to the need to minimise thermal bridges and their associated effects, but also in regards to the accuracy of the calculation and modelling method employed during design, and the subsequent quality of construction. Poor assumptions and modelling of both non-repeating and repeating thermal bridges are a contributing factor to the identified performance gap as discussed previously. Examples include –

- Poor accuracy in the assumption of repeating bridges formed by the quantity and frequency of studs in an open panel, typically reflected as a %. Calculations often underestimate allowances for bridging created by additional cripple studs, corner studs, noggins, sole and head plates.
- The use of default Psi calculations based on library or manufacturer assumptions are often not dynamic allowing for alternative project specific minor alterations to junctions, perhaps through use of a different insulation, blockwork density, connection or structural requirement. Commonly this approach is used as a reasonable approximation which can significantly misrepresent the accuracy and relevance of the Psi calculation.

In SAP, the calculation methodology considers thermal bridges based on internal dimensions and therefore heat loss is typically underestimated. By contrast the PHPP methodology considers heat loss based on the external dimensions of the element and as such typically overestimates total heat loss. The current methodologies employed in space heating demand may also contribute to the performance gap.

Performance modelling is frequently used as a vehicle to criticise the cost of progressing a route for Passivhaus certification, with the

Fig 4.12.1-2 Thermal bridging analysis of an intermediate floor junction and bridging seen through a thermal imaging gun

fees associated with project bespoke Psi calculations presenting what may be a significant extra over cost. For innovative system manufacturers the development of system specific modelling also represents a

Action...

Fabric design and detailing should aim in design and construction for a fully airtight building envelope with on and offsite quality control methods developed to drive significant focus on airtightness in construction.

prohibitive expense particularly considering systems may be employed in a broad variety of project specific scenarios.

The project team have therefore consulted thermal modelling specialists Greenguage, authors of online thermal bridging database Advanced Details. The database is a searchable web-based database offering high-performance details for a full range of standard junctions. Compared to the standard details, using the service can cut the Dwelling Emission Rate by 10%, and by

25% compared to using default Psi values – without the need to make significant changes to the design.

It is advised that any system developer aiming for ultra low fabric performance must approach thermal bridging calculations for their system in a similar manner. This could take a number of forms, from simple 2 dimensional calculations for a limited number of junctions using specific products, finishes and scenarios. Whilst useful this would have a limited number of applicable uses and inevitably limit design options if employed across multiple projects. Alternatively a dynamic modelling method as developed by Greenguage, would offer batch simulations of 2 dimensional models allowing for the quick comparison of thousands of iterations with alternative materials and geometries. Available as an open source in support of the available building solutions, this could enable designers to employ and model with a much greater accuracy than currently feasible without significant project based cost.

4.13. Airtightness

Fig 4.13.1 An airtightness membrane taped and sealed including around services capable of meeting target airtight values.

Airtightness is a descriptor for the amount of uncontrolled air movement through the building fabric either as air leakage or air infiltration, through unintended gaps and holes. Common areas of weakness are at junctions between changes in materials, such as at floor junction and roof junctions, window and door openings, and any area where an object such as a pipe or service connection passes from inside to outside. These areas can account for up to 50% of heat loss through the external envelope and can also lead to significant building defects where warm moist air escaping through the fabric can condense on cold surfaces and materials. In timber frame this a particular threat to building durability.

Current Part L regulations require a minimum of 10 m3/hr/m2 but employ a notional value of 5 m3/hr/m2 in the DER / TER calculations. Data from the Air Tightness Testing and Measurement Association (ATTMA) from 2017 suggests that the average airtightness in new build construction in the UK is at this notional level.

To reduce space heating demand, air tightness must be reduced to significantly lower levels. Passivhaus employ an alternative airtightness metric known as the n50 value with a level of 0.6ach required, approximately equivalent to the q50 value of 1m3/hr/m2 for a typical dwelling used for building regulations. Simply described the n50 value measures the number of times the volume of air in the house changes whilst the q50 value measures the volume of air as cubic metres leaking through a sqm of envelope area per hour. As a rough metric building regs compliance or 10m3/hr/m2 is typically described as one hole the size of a 20p coin per m3 of envelope compared with a 5p coin per 5m2 in a Passivhaus compliant envelope.

When air tightness levels below 5 changes an hour or approximately 3m3/hr/m2 are designed for, it is typically recommended that a mechanical ventilation system is employed rather than relying on natural ventilation methods. When combined, typically as a single system, with a heat recovery unit, mechanical ventilation with heat recovery extracts warm, stale and moist air from rooms including kitchens and bathrooms, and passes it through a heat exchanger unit which transfers the heat to fresh incoming air. Highly efficient MVHR units recover over 75% of the heat from the exhaust air, dramatically improving indoor air quality and utilising a very small proportion of energy compared with that recovered.

The reality of designing and building airtight buildings to such a low target level is that rather than designing for an allowable level, we should design and build to meet a 100% airtight building, ie no gaps, no holes, or leaky materials and seals, with all difficult areas and junctions designed for. The margins of allowable leakage are so small that quality assurance will inevitably result in this margin being used up without great consideration.

This has been considered by the project team in a number of different ways –

- **Technical Design** – the project team have considered best practice principles when considering the design and detailing of the airtightness layer. The basic principle of maintaining a single clear airtightness line in both plan and section is critical to this idea and the choice of materials used has been an active consideration. Airtight layers can be formed using vapour control layers and in some cases OSB board materials however to achieve ultra airtightness levels in timber frame it is recommended that specific products including airtightness membranes and airtightness boards with complementary tapes and gaskets should be employed. Whilst there is limited and often hard to find data, OSB below 22mm should not be considered as a dependable and evidenced airtight layer as there can be great variation in consistency of alternative products. The fabric proposals generally present the use of rigid sheathing board airtightness products such as Durelis Unilin or SmartPly Propassiv. These products offer great opportunity for increased offsite fabrication and provide a robust solution which is generally found to be more workable than membrane type solutions. Typically however continuity of airtightness will likely require a combination of membrane and rigid board, all taped consistently and thoroughly. It is recommended that taping is carried out off site wherever possible however care should be taken stacking and sliding panels to ensure any snagging of tapes and membranes is repaired.

- **Procurement** - Airtightness of the timber frame package presents a really challenging issue for the industry with different methods of procurement playing a significant factor in the level of risk placed on the sector. This was a key subject area in consultations with timber frame industry representatives and presented a significant area of concern. The fabrics proposed offer a greater opportunity for advanced fabrication offsite and certainly places the airtightness layers into the responsibility of the timber frame supplier. Whilst placing a burden of risk that might be uncomfortable, it is without question that the timber frame supplier and erector has the greatest potential to maximise offsite quality control procedures and onsite buildability to ensure the primary airtightness line is delivered to the point of handover to follow on trades. As is common, if complete handover occurs to follow on trades including mechanical and electrical services and windows and doors, this presents a real challenge to maintain a clear line of responsibility and represents a considerable threat to the timber frame industry in terms of liability. We believe that further work is required to consider stages of airtightness testing, enabling staged handover of the airtightness responsibility. Underpinning this however is the principle that all parties, from timber frame supplier to plumber and principal contractor must partner and share responsibility for the airtightness at all stages and an 'airtightness guru' identified to oversee this throughout the project. This will require a review of contractual terms and procedures and success stories from a range of projects considered. Rewarding all parties based on airtightness as a key performance indicator is also a potential measure.

4.14. Fire Safety

Approved document has been prepared on the basis that, in an emergency, the occupants of any part of a building should be able to escape safely without any external assistance. A key factor in achieving this relies upon the performance of the building materials chosen.

When considering the ability of any construction material to withstand fire, the two main principles are the material's reaction to fire and its resistance to fire. Reaction to fire is the measurement of how a material will contribute to the fire development and spread, particularly in the early stages of a fire during the evacuation process. Fire resistance is the measurement of the ability of a building/construction element to resist, and ideally prevent, the passage of fire from one distinct area/ building compartment to another and the ability of load bearing elements to retain their integrity for a set period of time to allow for the safe evacuation from the building.

Reaction to fire

The inclusion of the reaction to fire regulations within the approved documents aims to inhibit the spread of fire within the building, the internal linings shall:

a) adequately resist the spread of flame over their surfaces; and
b) have, if ignited, a rate of heat release or a rate of fire growth, which is reasonable in the circumstances.
c) In this paragraph 'internal linings' mean the materials or products used in lining any partition, wall, ceiling or other internal structure.

Reaction to fire results are expressed as an Euroclass classification to EN 13501-1 or as BS 476 Class 0 or 1. E.g Flame retardant treated wood can achieve Euroclass B or C reaction to fire classifications depending on species and thickness.

Resistance to Fire

Resistance to fire measures how any element of the building fabric performs in containing the fire, preventing it from spreading elsewhere. Resistance to fire rating become critical once the fire has grown and fully developed, since at this stage the building fabric are required to contain the fire within the specified locations as per the building compartmentalisation strategy.

Resistance to fire is measured according to three criteria.

- R – Supporting Capacity. This looks at the capacity of the constructive element to resist mechanically without losing its structural properties.
- E – Integrity. Capacity of the product to prevent the passage of fire and hot gases into an area not affected by the fire
- I – Insulation. Capacity of the product to prevent the temperature increase in the face not directly exposed to the fire.

The R, E and I of a wall build up are indicated as a duration. Whether the product can resist fire and prevent it from spreading to the opposing side for 30,60,90 or 120 minutes.

For Load bearing elements the aim is to prevent premature failure of the structure by provisions for loadbearing elements of structure to have a minimum standard of fire resistance, in terms of resistance to collapse or failure of loadbearing capacity. The purpose in providing the structure with fire resistance is threefold, namely:

- to minimise the risk to the occupants, some of whom may be unable to make their own escape if they have become trapped or injured;
- to reduce the risk to firefighters, who may be engaged in search or rescue operations; and
- to reduce the danger to people in the vicinity of the building, who might be hurt by falling debris or as a result of the impact of the collapsing structure on other buildings.

The REI rating of the building fabric is a result of testing on the building fabric as a whole and not on the individual elements of the fabric. Each wall/floor/roof build up that requires a specified fire resistance as stated in approved document B requires testing as a full system, Many manufacturers have already undertaken testing on specific systems that use their products, these however are often limited to the 'common' building approaches and as new building methods are developed testing on these will be required.

Fire Safety Bill

The increased focus on fire safety in construction and in use following the Grenfell disaster has raised challenging questions for the construction industry and not least the timber frame industry. The draft Fire safety bill (2020) states that the new Fire Safety Order applies, when the premise is a building containing two or more sets of domestic premises, and applies to the building's structure and external walls and any common parts. It has created the following duties on responsible persons (fire safety professional):

- General fire precautions, risk assessments, fire safety arrangements;
- Elimination or reduction of risks from dangerous substances;
- Ensuring fire fighting detection and emergency routes and exits were appropriate;
- Procedures for dangerous areas and emergency measures in respect of dangerous substances; and
- Maintenance works, safety assistance, provision of information and training.

Looking forward this will result in any multiple occupancy building requiring an Fire risk assessment being carried out at all stages of the build process, effecting small to medium sized projects and not just large scale multi story (18m+) builds. This must be considered when specifying any building fabric. Many products with a reaction to fire rating B-F may become unusable as consequence.

Manufacturers of key product groups have reviewed fire related specifications and adopted a cautious approach particularly when applied to timber frame. This has had a significant impact on the timber frame industry although it is fully anticipated that this impact has been lessened by the continued application of previously acceptable methodologies where current evidence is perhaps no longer available. Of particular relevance is the withdrawal or alteration of plasterboard supporting documentation for use in structural integrity buildups.

> **Action...**
>
> Undertake a review of current fire legislation and available data information for timber frame systems and working with a specialist fire consultant to identify a strategy for fire compliance including testing where necessary.

The Structural Timber Association have recognised this challenge and in collaboration have undertaken physical testing, supporting analysis and research of a number of standard timber frame buildups in relation to fire performance. This open source best practice guidance provides an evidenced support piece to provide confidence and enable compliance with warranty providers and building regulations. It does not guarantee performance and does not cover fire in construction safety requirements. The pattern book was first published in June 2020 and will be subject to frequent review with the ambition to add new bespoke systems to the library as the come forward.

The proposed typologies presented and tested by the STA do not reflect the proposed typologies in the main and therefore the data would not support any of these applications specifically. However the guidance presents a formula which should be followed to ascertain the performance of the proposed system. It is extremely likely that innovative and advanced systems such as the 5 fabric solutions will require bespoke fire testing. Fire testing can be slow and laborious, and due to the extent of testing and retesting required to assure industry and market confidence, commissioning fire tests has a slow turnaround time.

05

RENEWABLES + OFFSETTING

SECTION 5 SUMMARY :

Although not within the direct scope of this study, consideration has been given to the role of renewable technologies within a Net Zero Carbon Solution and subsequently the principles and mechanisms of offsetting to or below Zero.

- Engagement with the client base, both in the form of delivery partners, maintenance teams and end users has demonstrated the need to support new low carbon technologies and systems with training for all parties. This includes a level of cultural change developing how we experience comfort, including warmth and 'fresh air', and the associated functional activities.
- Onsite micro renewables should be assessed for their whole life carbon cost including embodied carbon associated with the manufacture, maintenance and end of life of key systems.
- Carbon offsetting is an important emerging area of activity. The requirement for offsetting is calculated by adding operational carbon and embodied carbon emissions together. The resultant carbon cost must be brought to or below zero to be 'net zero carbon' and there are a number opportunities for timber and woodland to be at the forefront of this.

5.1. Mechanical + Electrical Systems

> *"...New homes must be built to be low-carbon, energy and water efficient and climate resilient. The costs of building to a specification that achieves the aims set out in this report are not prohibitive, and getting design right from the outset is vastly cheaper than forcing retrofit later. From 2025 at the latest, no new homes should be connected to the gas grid. They should instead be heated through low carbon sources, have ultra-high levels of energy efficiency alongside appropriate ventilation and, where possible, be timber-framed. A statutory requirement for reducing overheating risks in new builds is needed, alongside more ambitious water efficiency standards."*

This recommendation by the Committee on Climate Change (CCC) presents a clear picture for the required changes to our new build housing programmes. Whilst much will be achieved through innovations to our building fabrics in conjunction with improved quality assurance to close the performance gap. The role of fuel, systems and user activities is critical to deliver the necessary reductions in carbon emissions. In this recommendation the CCC have set out a trajectory for a fundamental shift in the way we power our homes which requires immediate action.

As space heating demands reduce, airtightness improves, and fuel factors reflect the decarbonising electrical grid leading to increased use of low carbon electric based systems, it is important to recognise that there are significant cultural and technical shifts in the nature of mechanical systems and the way we consider 'comfort' in our homes. This requires the support of training programmes covering user groups, maintenance teams, and building professionals. The social housing sector presents specific challenges to the implementation of these required changes. This is not least in terms of economics and procurement, where there is rarely scope to explore tailored project specific low carbon opportunities.

Mechanical Ventilation and Heat Recovery (MVHR) represents an important

Action...

Low carbon heating systems should be installed for all new build housing - no new build homes should be constructed with gas fuelled heat and hot water.

This requires a massive immediate change in the way we heat our homes requiring training for designers, installers and end user groups. To ensure fuel poverty is not generated from this change, the shift to electric based heating systems must be delivered hand in hand with a dramatic reduction in space heating demand through the improvement of building fabric performance.

development to residential mechanical systems. MVHR systems are deemed necessary at airtightness levels of 3m3/hr and below. At the fabric specification levels proposed in this study and required to deliver the proposed energy targets, MVHR becomes a critical element of the house system. It is essential that these systems are efficient, easy to maintain and operate , and users understand the role that they are fulfilling. It is recommended that simple approaches to MVHR systems are developed hand in hand with house type designs and fabric proposals to ensure build-ability and operability.

Action...

High efficiency Mechanical Ventilation with Heat Recovery in combination with simple mechanical and electrical systems should be incorporated in the design and development of house types to maximise efficiency, reduce losses and simplify the installation, maintenance and operation of the building's energy systems.

House types should be developed that allow for the additional plant spaces required and consideration should be given to minimising inlet and outlet duct runs to ensure that unwanted gains and losses do not result. Where possible a greater consistency of approach should inform proposals and generate a greater standardisation of systems allowing for economies in all aspects of supply, installation and maintenance. Of particular importance is a greater understanding and familiarity for both building operators and users with these systems to ensure that frequently seen issues such as disabling vents due to 'drafts' and improperly maintained filters are overcome.

The target space heating demand as previously highlighted in **Figure 2.2** based on Passivhaus research presents a very different profile for heating systems. Space heating demand set at the proposed level not only delivers a dramatic reduction in carbon emissions associated with operational activities but is set at a level that enables a wholly different approach to heating systems to meet the residual demand. The low level heat input required can be met by simplified low cost systems which during the course of the life of the building can dramatically reduce costs associated with the cost and operation of heating systems. With gas mains connections and relatively high upfront systems such as ground source heat pumps and biomass unlikely to be required or viable, this presents significant potential savings and is important in offsetting increased upfront fabric costs. As presented by the CCC and the Passivhaus Trust this optimal level of fabric performance and space heating demand has potential to balance increased upfront costs over the current specification, and deliver whole life cost savings. Further analysis of in use monitoring is required to assess progress made in this area. The Innovative Housing Programme has began to present data to support concerns that electric based low carbon heating systems in combination with improved fabric performance and photovoltaic arrays in resulting in a significant uplift in fuel costs (electric) anticipated to be associated with poorer than anticipated building performance.

5.2. Micro On-site Renewables

The role of renewable systems has been given great consideration during the course of the project. The project team set out with the objective of considering net zero carbon as a fabric first approach to first and foremost reduce operational energy use and construction impacts. In line with the UK Green Building Council's framework renewable energy supplies are the next part of the jigsaw. Micro renewables form a critical element of the zero carbon picture and as discussed are often employed under the badge of 'Zero Carbon Homes' as delivering an 'operational carbon' balance. This concept is fraught with difficulty and complexity however there is some incredibly innovative work being undertaken in this field by organisations such as Sero Homes.

In developing the consideration of this area, concern has focused on the potential for steady state calculation methods such as SAP to gloss over the carbon intensity of the grid and subsequently enable the equating of energy in and out of the home system as being balanced or even positive. Ignoring or at best averaging 'grid carbon intensity' has the potential to dramatically underestimate the carbon associated with regulated and unregulated energy. The measure for assessment of renewable technologies must therefore be considered in terms of carbon rather than energy and assessments based on a clear assumptions related to national carbon grid intensity.

In addition, there is considerable concern that the current methodologies for building modelling can lead to decision making that prioritises the use of micro renewables to make up for poor fabric performance, often in scenarios where they would be largely ineffective. This is considered in further detail in *EPCs as Efficiency Targets* by the Passivhaus Trust and Good Homes Alliance. It is essential that intelligent modelling systems be developed in hand with improving building performance standards to ensure that onsite micro renewables and associated systems are assessed based on accurate whole life value in the context of an evolving national grid.

Embodied carbon associated with the manufacture, maintenance and end of life of micro renewables and associated systems has the potential to contribute significant proportions of embodied carbon to the whole life carbon analysis. As current assessment methods do not take consideration of embodied carbon, the whole life cost of these systems is therefore not, or very rarely, being measured when assessing alternative methods.

The project team in line with LETI and RIBA have adopted the principle that all energy demands, including regulated and

Action...

The design and incorporation of onsite micro renewables and low carbon technologies should be assessed based on whole life carbon and cost analysis.

This analysis should give realistic consideration to system life and maintenance, the daily and seasonal carbon intensity of the grid and the evolving long term carbon intensity profile of the grid.

unregulated energy, must be met by renewable sources. This means that gas and oil will not be used to heat homes and that all electricity used must be generated from renewable sources. The location of this generation must be informed by an accurate assessment of generation potential, the role of the national grid, smart technologies and storage opportunities, and the associated whole life embodied carbon associated with production, replacement and end of life of all proposed systems. Of particular consideration is the nature of the materials energy at both micro and macro scales, including photovoltaics and batteries, and ultimately nuclear power. Whilst there is a need to embrace these technologies, there remains significant environmental costs associated that render these imperfect, whether as landfill, mineral mining and by-products or nuclear waste.

The responsible approach, and that guided by the UK Green Building Council, is subsequently to reduce reliance on any form of energy through sustainable, sensible decision making invested in the home and the fabric. The decisions regarding fabric, form and orientation will be resolute throughout the life of the building - get it wrong and the costs associated with change will be far greater than investing in alternative technologies.

5.3. Carbon Offsetting

Offsetting is a way of capturing and storing CO2 that is equivalent to the CO2 emitted as a consequence of a development project. In our net-zero whole life carbon guidance we recommend that developers aim to offset to **below** Zero rather than to Zero. This is to allow a safety factor due to uncertainties

	Onsite	Offsite
Greenhouse Gas Removals	Build using timber (creating carbon store in home)	Woodland creation in Wales (verified through the Woodland Carbon Code
Renewable Energy	Install micro-renewables to generate more than consumption	Investment in renewable energy infrastructure

Fig 5.3.1 Potential opportunities for carbon offsetting delivered both onsite and offsite requiring capture codes.

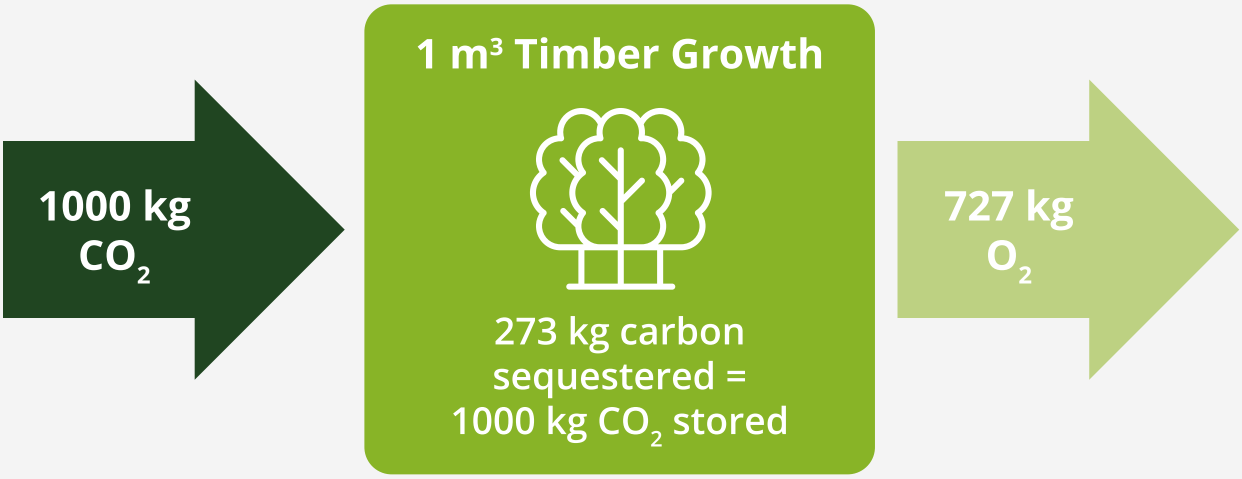


Fig 5.3.2 On average, a typical tree absorbs, through photosynthesis, the equivalent of 1 tonne of carbon dioxide for every cubic metre's growth, whilst producing the equivalent of 727 kg Oxygen.

associated with whole life carbon emission calculations in the future.

We recommend two approaches to offsetting:

- The creation of woodland – this represents a long term investment involving land acquisition (unless a joint initiative with a land-owner), tree planting and management of a woodland that can be certified by the Woodland Carbon Code. Specialist forest planners will support the development of a planting strategy using a mix of tree species that will create an accurate forecast of the amount of CO2 that will be captured over a 40+ year timescale. WoodKnowledge Wales have published *Capturing Carbon: Investing in woodlands to assist clients and developers navigate the issues around woodland creation*.
- Storing carbon - when we build with timber we are in essence creating a carbon store within a home. The amount of biogenic carbon stored in the timber can be calculated and included in the total offset of CO2 emissions. Currently the status of biogenic or sequestered carbon is uncertain in whole life carbon calculations however in the future this carbon storage could be included within the offset calculation or it could be potentially traded. If traded it would not be allowable as an offset within the embodied carbon calculation, ie double counted. Key to this area of development is the consideration of 'end of life' for carbon stored as biogenic carbon.

5.4. Completing the Carbon Calculation

The pillars of the framework subsequently generate a carbon calculation equation. The gross-offsetting requirement is calculated by adding the whole life embodied carbon emissions to the actual (following removal of the performance gap) operational carbon emissions of a housing development as modelled for a life of 6o years. This will represent the whole life carbon emissions for the development.

The net-offsetting requirement is calculated by taking the gross-offsetting requirement and deducting any biogenic carbon stored in the building. Structural timber and cellulose is the main source of this but thought should be given to all materials within the construction such as cladding or floor finishes.

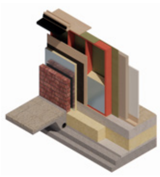
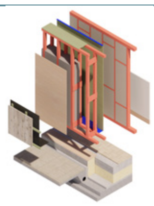
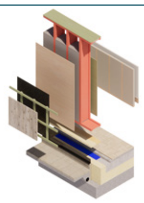
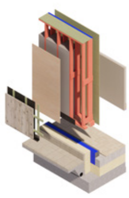
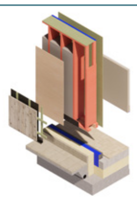
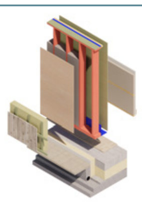
Net offsetting must then be translated into the mechanism(s) selected for offsetting following agreed and regulated accounting methods.

For woodland creation, the amount (in hectares) of new woodland that will be required is calculated by dividing the net offsetting requirement (Tonnes CO2e) by the forecasted CO2 capture of 1 hectare of woodland. We have estimated that 1 hectare of woodland planted to the UK Forestry Standard design will capture around **200 tonnes of CO2** over 40 years. This is a cautious estimate that falls between estimates provided by CONFOR (270 tonnes) and Forest Research (150 tonnes).

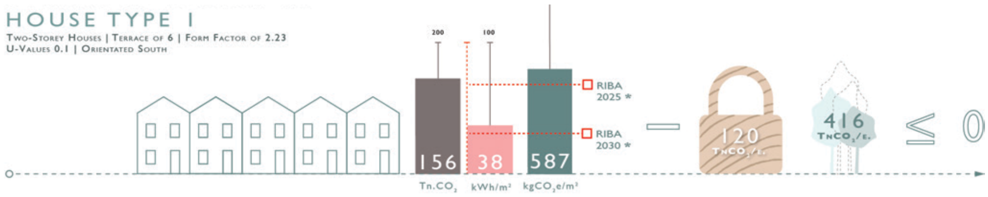
Figure 5.4.1 captures this complete calculation based on house type 1 meeting the embodied carbon and operational energy use intensity targets. This is calculated for alternative fabric proposals and scaled to a development of 100 2 bed 4 person houses for reference.

- A gross whole life carbon emission of 8536 tonnes of CO2 for the development, a 13% reduction over the benchmark fabric type.
- Carbon storage potential varies across the proposed fabric types but on average offers twice as much as the benchmark fabric.
- An average of 5400 tonnes of CO2 requires offsetting following carbon storage . This is approximately 65% of the offset requirement generated by the benchmark fabric.
- This represents a 27 hectare woodland developed at a cost of approximately £10,000 per hectare (with grant aid). By contrast the benchmark fabric would require an additional 14 hectares of woodland planting.
- If the housing development cost £15 million then the woodland establishment cost represents between 1.5% and 2% of development costs. Of course, the woodland remains a long-term asset of the client from which future revenues would be generated (contact WoodKnowledge Wales for further guidance).

Fig 5.4.1 Calculation of whole life carbon emissions associated with each fabric type and quantity of offset required via woodland planting

		BUILDING CARBON EMISSIONS				
		UP-FRONT CO2 Walls (kgCO2eqv/m2)	**UP-FRONT CO2** Building (kgCO2eqv/m2)	**WHOLE LIFE EC CO2** Building (kgCO2eqv/m2)	**TOTAL ENERGY USE INTENSITY** (kWh/m2)	**SPACE HEATING DEMAND** (kWh/m2)
Benchmark : Solid Stud With Polyurethane Foam		198.0	471.3	820.6	29.0	12.0
Fabric Type 01 : Larsen Truss		51.9	325.2	674.5	29.0	12.0
Fabric Type 02 : I Beam		48.3	321.5	670.8	29.0	12.0
Fabric Type 03 : Twin Wall 1 Intermittent Gussets		88.0	361.3	710.6	29.0	12.0
Fabric Type 04 : Twin Wall 2		70.5	343.8	693.1	29.0	12.0
Fabric Type 05 : Solid Stud		69.2	342.5	691.8	29.0	12.0

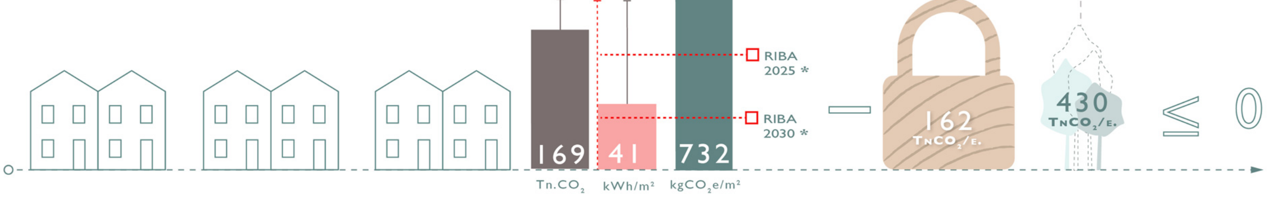
100 HOUSE DEVELOPMENT (60 Year Life)



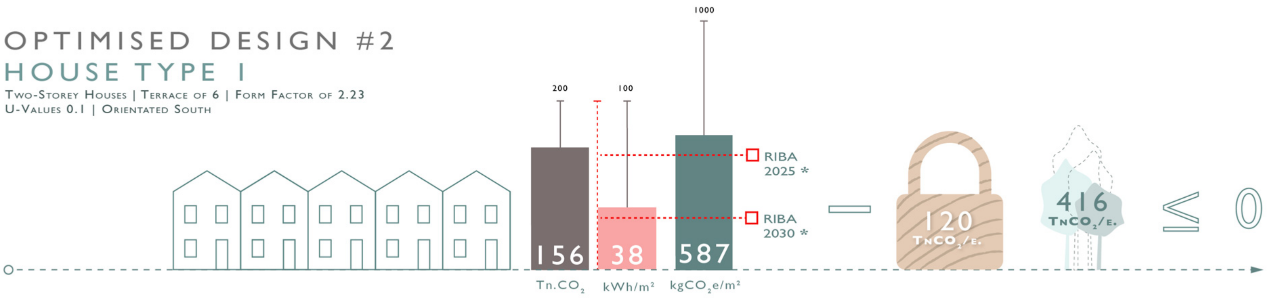
WHOLE LIFE CARBON			WHOLE LIFE CARBON				
UP-FRONT CO2 (Tonnes CO2)	WHOLE LIFE EC CO2 (Tonnes CO2)	OPERATION AL CO2 (Tonnes CO2)	OFFSET REQUIRED (Tonnes CO2)	GROSS REQUIRED +10% Safety (Tonnes CO2)	CO2 STORED (Tonnes CO2)	NET REQUIRED (Tonnes CO2)	WOODLAND 4 ZERO (Hectares of Planting)
3958.8	6892.6	1987.8	8880.4	9768.4	1531.7	8236.7	**41.2**
2731.8	5665.5	1987.8	7653.3	8418.7	2694.7	5724.0	**28.6**
2700.9	5634.7	1987.8	7622.5	8384.7	3524.8	4859.9	**24.3**
3034.8	5968.6	1987.8	7956.4	8752.0	3004.7	5747.3	**28.7**
2887.8	5821.6	1987.8	7809.4	8590.3	3231.8	5358.5	**26.8**
2877.2	5811.0	1987.8	8210.0	9031.0	2093.3	6937.7	**34.7**

▸ *Continued*

OPTIMISED DESIGN #1
HOUSE TYPE 1
3 x Two-Storey Houses | Semi-Detached | Form Factor of 3
U-Values 0.1 | Orientated South

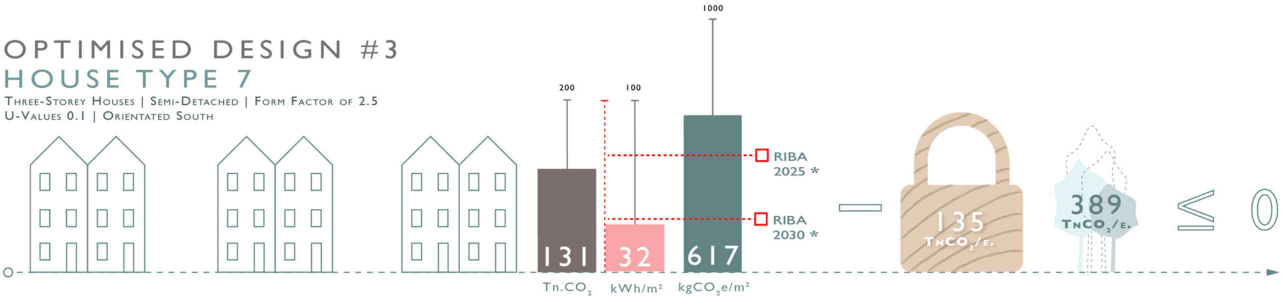


OPTIMISED DESIGN #2
HOUSE TYPE 1
Two-Storey Houses | Terrace of 6 | Form Factor of 2.23
U-Values 0.1 | Orientated South



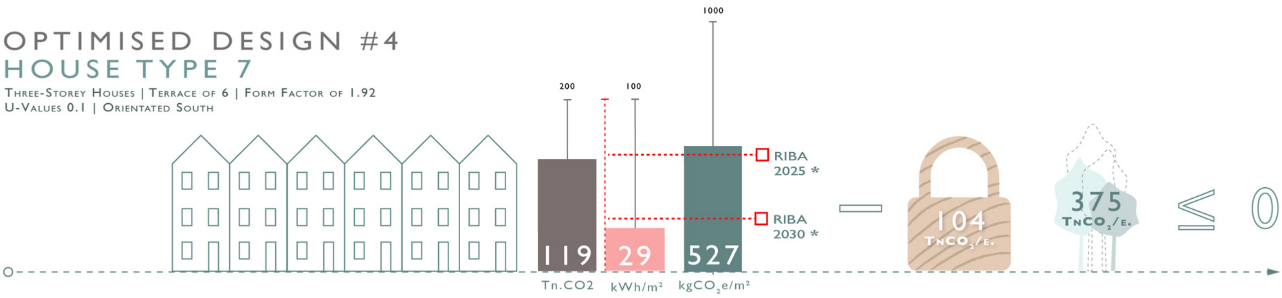
OPTIMISED DESIGN #3
HOUSE TYPE 7

Three-Storey Houses | Semi-Detached | Form Factor of 2.5
U-Values 0.1 | Orientated South



OPTIMISED DESIGN #4
HOUSE TYPE 7

Three-Storey Houses | Terrace of 6 | Form Factor of 1.92
U-Values 0.1 | Orientated South



ZERO CARBON
OPTIMISED DESIGNSOLUTIONS

06

PROCUREMENT, COST + DELIVERY

SECTION 6 SUMMARY :

At the forefront of the development of a Zero Carbon Timber Strategy is the consideration of cost and procurement. Delivering the radically ambitious improvements in performance proposed is not possible without similarly radical changes to established methods for procurement and cost analysis.

- Engagement with the client base and existing timber frame industries has demonstrated the potential and willingness to establish new working partnerships built on consistent demand and specification and the shared objective to act immediately to address a climate change emergency.
- The technical structure of Insurance Backed Warranty providers presents a risk to the route to market and a partnership approach represents an important vehicle to deliver technical approval, which may require prototype testing.
- Initial cost analysis demonstrates that the uplift in fabric cost is in the region of ... This is considered inevitable as the performance of the product, quantity and value of materials and quality of workmanship far exceeds the current benchmark product.
- This model however requires a fundamental shift in cost consideration, moving to a model that looks at whole life costs including offsetting, accounting for reduced operational costs delivered through the reduction of Space Heating Demand.

6.1. Timber Frame Procurement

There are a range of procurement routes currently being utilised in the delivery of timber frame homes for the social sector. Whilst representing a substantial and critical 'package' within the construction profile of a project, the timber frame is often a 3rd party package, outsourced by the appointed lead contractor via competitive tendering. At client tender stage, the procurement of this package is rarely dictated and is therefore down to each contractor to assess the balance between quality and cost. Through discussion with the manufacturing team of Welsh timber frame manufacturers, the following procurement routes have emerged as common and important to the sector -

- Competitive tendering as a principal contractor and direct supply manufacturer,
- Client nominated subcontractor,
- Competitive tendering as frame-only or frame and erection subcontractor,
- Direct appointment to a client / developed client,
- Direct supply to in-house developments.

Each procurement model presents a different profile in terms of the Cost vs Quality vs Time matrix.

Observation of recent Innovative Housing Project case studies have demonstrated the potential for dramatic improvements in building innovation and performance where ambitions are aligned and investment is made in shared learning. The programme has also highlighted the importance of individuals both from a knowledge and attitude perspective in the delivery of high performance / low carbon housing. In the absence of regulations, the trajectory towards zero carbon is being advanced by individuals and organisations adopting a personal commitment to this ambition, within all parts of the project team. In regards the IHP programme there is a great deal to be learnt regarding where commitments were challenged, sometimes to breaking point, but the frequent message heard from these projects is that the commitment of individuals is the key factor in delivering project ambitions. It is essential that organisational strategies, political will and regulations catch up to formalise this commitment, ensuring it becomes the new normal, reliant not on the will of individuals but on the contractual and legal obligations of the sector.

To deliver Net Zero Carbon housing we must look to address the current disconnected project delivery routes common particularly in the social housing sector. Projects see limited continuity between work stages, with responsibility for design, performance and quality often handing over at work stages, between consultants, contractors and subcontractors. This is particularly relevant regarding the current design / build procurement route whereby responsibility is frequently broken down across work stages.

This disconnected chain of responsibility manifests in a number of key areas which are likely to extend as specifications become more stringent and more focus is placed on demonstrating performance compliance.

Action...

In Zero Carbon Homes, Wood Knowledge Wales recommended :

Modernise procurement to reflect the changing nature of construction and the imperative to rapidly decarbonise.

An MMC approach needs a Modern Method of Procurement, one which creates sustained demand in home-grown timber and added value products. We believe that a Welsh timber procurement Initiative (through an alliance, consortium, framework or partnership) should be established to generate the demand commitment necessary to unlock investment in the Welsh timber construction supply chain. We know that the social housing sector alone is responsible for over £1 billion of direct investment in the Welsh economy and can be a powerful force for change.

Based on feedback from the timber frame industry, a key area of issue currently is in regards to airtightness. Timber frame manufacturers are often presented with responsibility for airtightness of the substructure and are frequently best placed to adopt responsibility for this critical element of performance. However when segregated into limited responsibility subcontractor packages, the continuity of airtight work processes and attention to detail will come under threat from all subsequent work packages. This presents a valid and challenging risk for timber frame manufacturers when having only limited control over the construction process. Similar concerns relate to the specification of materials, systems and products with the current industry frequently employing substitute products due to availability or cost. This can have often fully unintended consequences particularly as building performance becomes more sensitive to the performance of each element. This will come under further attention as the embodied carbon cost of all elements of the construction have to be accounted for.

As such, substitutions, approved products and performance specifications must be carefully managed with the assessment of equivalence given far more analysis than is currently common. Substitutions and deviations must inform the carbon accounting at all stages of the project. This can be extremely challenging where specifiers provide a limited or no service at all during construction stages.

Following engagement with the client base and the timber framing industries, it is undoubtedly the case that there is willingness and recognition of the value that a new working relationship can bring to delivery of zero carbon housing. The frequent message from the timber frame industry is the need for a **consistent, standardised performance specification establishing both a scale of demand and a consistency between tenders**. In parallel, the client base has frequently focused on quality and the lack of familiarity of the solutions being proposed generating a potential gap in confidence that they are getting what they pay for. This confidence is often hand in hand with a measurable perception that there is a performance gap between anticipated costs and actual in use performance. This is further exacerbated by the perceived complexity of mechanical and electrical systems leading to ineffective commissioning, use and maintenance.

Further work is required to examine the existing alternative working processes and procurement routes identified above and explore patterns of success in delivering high performance / low carbon projects. The role of principal contractors and the contractual relationship between timber frame manufacturers and principal contractors must be a focus of this analysis. In addition the role and responsibility of specialist consultants in the delivery of zero carbon solutions should be considered particularly in light of quality assurance processes and delivering continuity of knowledge, performance objectives and up to date performance modelling through the project.

6.2. Quality Assurance + Warranties

Unlike traditional onsite construction methods, the technical solutions proposed above represent construction products and building systems and as such require additional scrutiny in regards to Quality Assurance. There are a number of relevant paths that might apply to any proposed products -

- European Technical Assessment Guideline (ETAG) 007
- BM Trada Q-Mark for Building Systems.
- BM Trada Q_Mark for Engineered Wood Products

The BM TRADA Q-Mark Scheme is an independent third party product certification scheme that is recognised by NHBC and other such warranty providers. The Scheme takes into account both, the technical aspects of the product and also the Factory Production Control system that is documented and implemented by the Manufacturer. These elements are critical to demonstrate compliance to the Q-Mark Scheme and ensure consistency of product manufacture. Key areas of consideration that will be assessed include -

- Mechanical Resistance and Stability
- Safety in Case of Fire
- Hygiene, Health and the Environment
- Safety and Accessibility in Use
- Protection Against Noise
- Energy Economy and Heat Retention
- Sustainable Use of Natural Resources

The assessment process includes a review of all technical information including potentially test and calculation data followed by initial type testing to ensure the product meets the requirements of the relevant technical standard. Following approval under a Q-Mark, initial and annual audits will be undertaken to ensure a Factory Production Control System is implemented in accordance with the technical requirements.

The existing industry maintain and operate within a variety of quality assurance systems. The process of developing, implementing and maintaining these systems can be a significant burden for manufacturers particularly for small scale manufacturers.

This can often represent a barrier to innovation, particularly where work process and procedures have established certification and systems. Changing course and investing in innovation can be an expensive and high risk endeavour.

Insurance Backed Warranties

It is essential that any proposed building solution is capable of meeting the stringent evidentiary requirements of technical robustness required by an insurance backed warranty provider. Building warranties are required by primary funders and mortgage lenders as a form of guarantee regarding a building's compliance with Building Regulations and capability of fulfilling a life in excess of 60 years.

Action...

Establish a working group of timber frame manufacturers and specialist consultants to develop technical information, test data and prototypes as necessary to realise system technical approval by one or multiple insurance backed warranty providers.

Three key areas of development are required which may require specialist testing - Structural stability and robustness, performance in fire during construction and in use, and thermal performance. Other areas that may require some form of additional investigation include acoustics, assembly and quality assurance processes.

There are a range of warranty providers operating in the housing market with NHBC being the majority market leader. Other key providers include Premier Warranty and Built Offsite Property Assurance Scheme. NHBC and Premier Warranty are considered to cover the large majority of all homes built in the UK by major house builders, housing associations and local authorities.

Although slightly different between the providers, the warranty applies for a period of 10 years covering initially a period of builder backed warranty where defects that are not wear and tear or maintenance are resolved, followed by a further 8 years of cover protecting the owner (and lender) from damage to the home due to a failure to build in accordance with the accepted technical requirements and / or building regulations.

NHBC and Premier go beyond building regulations in presenting their own "Technical Standards". Regardless of construction method, all homes require compliance with the Technical Standards in order to achieve warranty cover. Where direct compliance with the Technical Standards is not possible, it is possible to achieve an approval by evidencing performance that is equivalent to the requirement. Both NHBC and Premier operate a 'System Approval' process whereby it is possible to introduce alternative construction methods and receive formal approval and certification of compliance.

Achieving Warranty compliance with one of the mainstream warranty providers presents a considerable challenge to innovative offsite construction solutions. Both main providers assess offsite systems against the same technical requirements as more traditional construction methods. They require confidence that any proposed innovation can ensure durability and deliver a 60+ year life. This is often extremely difficult for innovations to demonstrate and therefore systems often require a proportion of durability testing to support any technical proposal. This often goes hand in hand with recognised Quality Assurance processes such as BM Trada Q Mark.

Both product quality assurance and warranty demands represent a considerable challenge for any innovative product or system. Demonstrating compliance can prove to be extremely expensive both through testing and evidencing by calculation and production information. The typical method for system approval is the compilation of a detailed technical manual which is subsequently assessed for compliance against the warranty requirements. This process can be lengthy and somewhat indeterminate as there is no guarantee until the warranty provider is satisfied that all elements of the standards are suitably met.

The current evolving environment in regards fire regulations in construction and in use presents a further threat to any new construction approach. The project team recognise this challenge and propose that the most sensible path to a market ready advanced timber building solution or solutions is through open collaboration.

6.3. A Quality Assurance Method for Net Zero

In establishing an accepted Quality Assurance certification and insurance backed warranty the consideration of whole life carbon will have a limited reference. Although both assurances will consider the thermal robustness of proposed solutions, the proposed performance standards far exceed current minimum requirements and therefore it is assumed that these technical standards will give a very minimal assurance of construction quality. This is reflected in the continued demonstrable energy performance gap prevalent across the industry.

A quality assurance method is required to support and deliver the proposed net zero carbon aspirations and as such this is established as the fifth pillar of the Zero Carbon Framework**.**

Action…

In collaboration with experienced low carbon / Passivhaus contractors and commissioners, and the proposed client base and delivery partners develop a sector specific responsibility matrix and quality assurance methodology for the design and construction of net zero carbon homes.

This should identify and allocate key roles and responsibilities, set out a framework of activities aligned with each work stage including building performance modelling and calculation, in construction site inspections and recording, and building commissioning. This will align with and incorporate the core BPE techniques outlined in Wood Knowledge Wales' Building Performance Evaluation Guide and Toolpack.

An education programme is required to support the proposed guidance including toolbox talks, specialist designer training, zero carbon building commissioning and maintenance.

References have been made throughout this study to the performance gap and the need for robust and deliverable quality assurance in design, construction and use. The extent and impact of the performance gap on todays housing delivery is small by comparison to the impact that existing quality processes will have on our Zero Carbon aspirations. As building performance targets become more stringent the impact of missing targets presents considerable concern, not least in addressing the Climate Emergency. These impacts will manifest most likely first however as substantial and unexpected increases in fuel costs leading to fuel poverty.

To deliver high performance, low carbon buildings, Building Performance Evaluation methods and principles are critical to delivery. Wood Knowledge Wales have collaborated with Good Homes Alliance to create Building Performance Evaluation Guidance which should be embedded throughout the design, delivery and post occupancy stages of all social sector housing projects. The core BPE activities presented outline activities to be employed through each stage of project delivery and rather than requiring the commitment of individuals it promotes a consistent, repeatable and systematic approach to the day to day management and assessment of the project against its performance objectives.

Whilst this guidance sets out hugely valuable techniques to assist in the delivery of the operational performance targets of a project. In delivering net zero we must also develop techniques and methods to ensure embodied carbon objectives are also met. WoodKnowledge Wales have subsequently worked in collaboration with Construction LCA and the Alliance for Sustainable Building Products to develop Embodied Carbon Guidance. As discussed previously, embodied and whole life carbon analysis remains a niche specialism with limited application, particularly in the social housing sector. Of particular concern to the project team is the extent of variability of methods used for embodied carbon counting. The experience developed during the course of this study has demonstrated the potential to deviate, gloss over, manipulate or simply misinterpret when developing embodied carbon and whole life carbon calculations. It is essential that consistent and robust working methods continue to develop for this area of expertise.

Similarly to the broader picture of Building Performance Evaluation, the combination of these hugely valuable guidance documents needs to inform toolkits and education programmes for all parts of the supply chain. There are fantastic opportunities within this matrix of roles and responsibilities and it is essential that building professionals recognise the role they can play in both the design and delivery of zero carbon.

Action...

Working with the client base develop a portfolio of building information modelling combining a single or range of standardised timber based fabric solutions with a library of approved materials, products and systems and a pattern book of refined repeatable house typologies.

Pattern books or repeatable housing models are commonplace within the private and social housing sectors and offer realistic opportunities for economies of scale. These are often aligned with organisational 'standard specification' documents however through advanced building information modelling these objectives are taken further to generate a significantly resolved portfolio of building solutions with accompanying whole life carbon datasets.

This study has initially focused on social sector housing types. Although much of the learning will be applicable across sectors, the focus on this single sector along with a relatively small number of building typologies, namely house and low scale multi storey residential accommodation presents an opportunity to prepare models, tools and standardised design and technical solutions that can provide an immediate resource for the sector. Through the use of building information modelling it is feasible that a significant proportion of the necessary building performance data modelling, providing both operational and embodied carbon data, along with specific modelling such as thermal bridge analysis and overheating can be produced for standardised models. The sector frequently employs standardised typologies as previously examined and whilst this standardised approach will likely need adjustment to incorporate site specific data such as location, climate and orientation, there is potential to realise significant economies of scale whilst undertaking the necessary building performance evaluation. In addition a number of opportunities to develop dynamic modelling tools and / or pre-populated performance modelling using PHPP have emerged from the investigations undertaken within this study. These present opportunities to develop early stage quantified data information for developments with minimal data input, dramatically reducing the amount of project specific data entry required and allowing informed decisions to made about energy at early design stages.

It is notable that current standards for high performance / low carbon construction often maintain databases and libraries of data and learning, all displayed with an open transparency. This is in large part understandable, the achievement is often worthy of great pride. The sharing of building performance information, best practice ideas and innovations, procurement ideas provide a wide variety of useful and transferable knowledge to the wider market. It also provides a method of verification, benchmarking and testing of equivalence ensuring that practices develop a consistency particularly in measurement and recording which in turn can help with closing the performance gap. This is considered a hugely important and valuable element of the Zero Carbon framework.

Action...

Establish a Zero Carbon Building Performance Hub designed as a library of best practice, and a tool for verification and performance benchmarking.

Through an established and consistent format for measurement and recording the Hub would capture data including upfront embodied carbon, and energy consumption in use providing both a resource and learning database but also act as a compliance tool.

6.4. Cost

Cost has presented a key question throughout the course of the study. There are many facets to the cost equation associated with this consideration -

- At a site level, increased fabric thicknesses and floor areas due to additional plant, the potential need to manage orientation within a limited range, and the effect of overshadowing could reduce site densities on common typologies.
- At a fabric level, increased material cost and quantity, increased associated labour costs, and advanced innovation required

to achieve target performance levels will inevitably result in increased costs.

- In terms of systems, as previously discussed the proposed operational carbon targets are aligned with critical points in the cost profile of required mechanical and electrical systems, with improved performance at this level benefitting from cost reductions due to simplified and improved efficiency systems and reduction in infrastructure costs such as gas supplies.
- In terms of procurement, increased risk generated by strict performance targets, lack of familiarity and dependent on procurement methods and contractual obligations typically result in an inflation of costs.
- Over a whole life consideration, significantly reduced space heating demand dramatically reduces whole life operational costs.
- Getting to zero, although not part of the regulatory picture yet, to deliver the government's zero carbon commitments, statutory changes will occur resulting in changes to the current profile of project costs. With offsetting likely to become a key factor in getting to zero, the option of doing nothing or very little to improve building performance is likely to be weighted significantly by the cost of offsetting.
- Economies of scale represent an immensely valuable route to improving on the expected increased cost of development. Modern methods of construction in conjunction with greater standardisation of specifications, house types and professional services, along with an established consistent and stable demand, offer the greatest opportunity to realise economies of scale.

Presenting cost data based on fabric designs alone would be misleading. Costs need to be provided as a whole which includes for example, consideration of house typology and design, site accessibility and topography along with the other factors raised here. Data will subsequently be presented to analyse initial fabric proposals. Further work however is required to consider these factors as a whole life development cost study.

07

IN SUMMARY

The progression of this study has followed a meandering route and whilst presented as a summary report of progress to date this is considered a first stage requiring significant further work. The project sought to establish a net zero carbon solution for Wales, but in the course of development, 5 alternative proposals have been considered and remain viable requiring further focussed investigation. This should not be done in isolation, and whilst the project to date has consulted actively with all parts of the industry, the next phase of development must follow a multi pronged attack:

- with industry specialists to develop a route map to market in terms of certification, testing and warranty system approval including fire safety, thermal performance and quality assurance
- with the timber supply chain to technically resolve, prototype, test and apply new and evolved manufacturing and assembly proposals to develop one of more of the fabric proposals, including identifying supply chain opportunities and constraints, assessing build ability and advancement of offsite manufacturing opportunities, and identify development requirements for training and infrastructure
- With the client base and design professionals to develop design thinking, identify training and zero carbon design tools, and deliver beautiful zero carbon homes and spaces.
- With the funders to consider procurement and identify a pathway to developing a connected, robust and fair supply chain that can deliver zero carbon housing at scale to meet whole life cost and carbon objectives.
- To deliver these objectives will require collaboration at a scale that is not common in the construction industry. But the opportunity is huge.