# Embodied and Whole Life Carbon

## of Future Homes Standard Options Report

March 2025

## CONTENTS


1. *Introduction ........ 3*
2. *Findings in brief ........ 3*
3. *Definitions / glossary / references ........ 4*
4. *Building archetypes ........ 4*
5. *Outline specifications ........ 5*
6. *Calculation approach ........ 6*
7. *Upfront carbon comparison ........ 7*
8. *Whole life carbon comparison ........ 9*
9. *Improvement options ........ 10*
10. *Hub tool alignment ........ 14*
11. *Next steps ........ 18*

*Appendix A – Detail on Key assumptions and considerations ........ 19*

*Appendix B – Archetype macrovariables ........ 21*

*Appendix C – Detailed specifications ........ 22*

*Appendix D – Upfront Carbon Emissions per build-up functional unit. 28*


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# 1. INTRODUCTION

Since the publication of the Future Homes Standard (FHS) consultation in December 2023, developers have been working to identify likely specifications that will enable their house types to achieve Part L (operational carbon) requirements cost effectively and to be delivered at scale. The Hub's Ready for Zero report helped to inform government about some of the factors that may be important considerations ahead of this consultation, however specifically excluded embodied carbon from the Terms of Reference.

**What if homebuilders develop their house types to meet the FHS without ever thinking about embodied carbon?** This study aims to begin the conversation that mitigates that risk.

With embodied carbon now representing an increasingly large part of the carbon impact over a new home's life span, it is important for developers to be able to get a sense of the potential trade-offs between operational and embodied carbon for different options they may be considering.

**Objective:**

This study investigates the embodied and whole life carbon implications of building fabric and services specifications that developers are considering to meet the Future Homes Standard.

**It compares:**

- Upfront and whole life carbon for three example Future Homes Standard specifications and three dwelling archetypes, broken down by building element and by lifecycle stage.
- Outputs from the One Click LCA model with the Future Homes Carbon Assessment Tool for an example archetype.

# 2. FINDINGS IN BRIEF

There is no silver bullet when it comes to reducing embodied carbon of new homes. The study finds that, of the fabric specification options currently being considered by homebuilders to meet the operational carbon performance of the Future Homes Standard, **the upfront and whole life embodied carbon impacts are broadly similar.**

Whilst there are opportunities, considered here, to reduce embodied carbon based solely on design and construction-system, the limited scale of reductions identified indicates that **decarbonisation of construction products will need to play a significant role**.

With the aid of whole life carbon analysis tools, therefore, homebuilders must look both for design opportunities (at the early design stages) and to specify low-carbon products (at the detailed design and procurement stages) from manufacturers who are reducing carbon in the supply chain.

The Hub's Future Homes Carbon Assessment Tool, which estimates whole life carbon impacts based on a simplified elemental approach, was tested against a commercial tool, One Click LCA, for an example scenario.

The comparison showed **good alignment when it comes to fabric aspects, giving confidence that the Hub's tool could be an entry point for smaller developers** or those without the resource to do detailed modelling. It also highlighted that further work needs to be done to improve ability of the tool to reflect detailed Mechanical, Electrical and Plumbing (MEP) aspects, which did not align so well.

## 3. DEFINITIONS

**Building archetype:** Common house types chosen to represent a large proportion of the dwellings being built in the UK.

**FHS:** Future Homes Standard, i.e. proposed Part L 2025

**Macro-variables:** These are the high-level variables that feed into the 'elemental method' for estimating material quantities and impacts for each archetype. Macro-variables are listed in Appendix A.

**Outline specification:** The example product types and buildups defined by the Hub's working group as potential design options to meet the Future Homes Standard.

**RICS PS:** The RICS Professional Standard 2nd edition, 'Whole life carbon assessment (WLCA) for the built environment'

**Sequestration:** Biogenic carbon is captured from the atmosphere during growth of biogenic materials and stored for the life of the relevant building components, being released at end-of-life stages.

**Upfront carbon:** Embodied carbon emissions associated with materials and construction processes up to practical completion.

**Whole life carbon:** The total of all embodied and operational emissions over the whole life cycle of a building, including those associated with a building materials, construction, use, maintenance and end-of-life demolition and disposal.

**WLC Conventions:** The Future Homes Hub Whole Life Carbon Conventions for New Homes. This is a set of material and life cycle defaults and assumptions appropriate for WLC assessments for new homes in the UK.

## 4. BUILDING ARCHETYPES

The building archetypes chosen for this analysis are three of the more commonly constructed low-rise, single-family dwelling types among the working group members.

The archetypes are outlined Figure 1 and Table 1 below, and the further breakdown of macro-variables is provided in Appendix A.

Table 1 - Building archetype characteristics

| *End-terrace house* | *Mid-terrace house* | *Detached house* |
|---|---|---|
| 2-storey | 2-storey | 2-storey |
| 81m$^2$ | 81m$^2$ | 127m$^2$ |
| 2-bed | 2-bed | 4-bed |

Figure 1 - Building archetypes

# 5. OUTLINE SPECIFICATIONS

Three fabric and services specification options were defined through discussions with the working group members to represent likely options for meeting the FHS.

Option A: Masonry construction with 100mm cavity, mineral wool insulation, triple-glazed uPVC windows

Option B: Masonry construction with 150mm cavity, mineral wool insulation, double-glazed uPVC windows

Option C: Timber frame construction with 140mm studs, mineral wool insulation between the studs, 25mm PIR over-boarding, double-glazed uPVC windows

**Common specifications across options:**

Many of the elements are common across the different specification options as outlined in Table 2. The services approach is common with the capacity and sizing of the systems tailored to the archetype.

Table 2 - Common specifications across options

| Element | *Specification* |
|---|---|
| *Substructure* | Masonry, 100mm block, cavity to suit external wall |
| *Foundations* | 600mm strip foundations |
| *External wall facade* | Brick & mortar |
| *Upper floors* | Engineered timber joists, T&G chipboard |
| *Roof covering* | Concrete tiles |
| *Heating system* | Air Source Heat Pump 3.5 – 5kW |
| *Cylinder* | 150-200L |
| *Waste Water Heat Recovery* | Included |
| *PV* | 8-12 panels |

**Differing specifications across options:**

The specifications that differ across options are outlined in Table 3 and full details of all specifications can be found in Appendix B.

Table 3 - Differing specifications across options

| | Option A – Masonry, 100mm cavity, triple-glazing | Option B – Masonry, 150mm cavity, double-glazing | Option C – Timber frame, 140mm stud and over-boarding, double-glazing |
|---|---|---|---|
| External wall cavity and structure | Masonry, 100mm block, 100mm cavity, full fill | Masonry, 100mm block, 150mm cavity, full fill | Timber frame, 140mm stud plus 25mm over-boarding |
| Windows | Triple glazing, uPVC frame | Double glazing, uPVC frame | Double glazing, uPVC frame |
| Ground floor | Suspended beam and aircrete block | Suspended beam and insulation block | Suspended beam and insulation block |
| Lintels | Masonry, insulated or thermally broken steel lintel | Masonry, insulated or thermally broken steel lintel | External steel lintel + internal timber structure |
| Party walls | Aircrete block + mineral wool insulation | Aircrete block + mineral wool insulation | 89mm stud + mineral wool insulation |
| *Roof structure* | Pitched, trussed rafters, 450mm insulation at ceiling | Pitched, trussed rafters, 400mm insulation at ceiling | Pitched, trussed rafters, 400mm insulation at ceiling |

# 6. CALCULATION APPROACH

### Embodied carbon modelling

The embodied carbon modelling was carried out using the One Click LCA software, a widely used commercial software tool among housing developers for carrying out Whole Life Carbon Assessments (WLCAs).

Inputs:

- Geometry, elemental areas and other macro-variables were based on three building archetypes, previously used for FHH Ready for Zero report (2023).[1]
- Quantities for each elemental build-up were based on the specifications anticipated by developers.
- MEP quantities and materials were defined with the Hub to align with current SAP modelling conventions and likely configurations being considered by developers to meet the Future Homes Standard.

Assumptions:

- Default material and carbon impact data, transport, lifespan, wastage rates and end of life assumptions for each material were defined by the WLC Conventions for New Homes.
- The Reference Study Period (RSP) is 60 years.
- Material impacts for repair and replacement life cycle assume 50% decarbonisation in line with Hub Conventions RICS PS guidance.

### Operational carbon modelling

Operational energy demand for each dwelling archetype and design specification was modelled using SAP 10.2, the current version for Building Regulations Part L 2021 compliance.

Inputs:

- Geometry and elemental areas were based on the building archetypes.
- U-values for each elemental build-up are based on the specifications anticipated by developers.
- Thermal bridging psi values, airtightness and other fabric inputs were based on previous modelling done for the Hub's Part L 2021 guide and Ready for Zero report.
- MEP systems were defined to align with the size and occupancy of each building archetype, and likely configurations being considered by developers to meet the Future Homes Standard.

Assumptions:

- The FHS requirement for PV is as yet unknown. The amount of PV on each archetype was based on 40% ground floor area (8 panels for mid- and end-terrace, 12 panels for detached).
- The buildups (and therefore u-values) of roof and ground floor elements were tweaked slightly to give broadly similar outcomes in terms of overall fabric performance for each of the three specifications, as modelled in SAP10.2. This fed back into the embodied carbon modelling also.
- The electricity grid was assumed to decarbonise in line the National Grid's Future Energy 'Falling Short' scenario.

Please refer to Appendix A for more detail on the key assumptions and considerations.

[1] Download the Ready for Zero report from the Hub website.

# 7. UPFRONT CARBON COMPARISON

The upfront carbon comparison of each specification option across each house archetype is shown in Table 4.

Following RICS PS conventions, upfront carbon is reported excluding biogenic sequestration, which is reported separately in Table 5.

**Key insights:**

- Timber frame construction has ~3-5% lower upfront embodied carbon intensity than masonry construction for a similar thermal and energy performance across all archetypes.
- The choice of masonry specification (triple-glazing and 100mm cavity or double-glazing and 150mm cavity) does not make a significant difference to the upfront embodied carbon emissions. For example, detached and end-terrace <1% difference based on the external wall and window areas in these building archetypes.
- The *upfront carbon intensity per square metre* does vary across the archetypes. For example, upfront carbon intensity of end terrace is ~9-10% lower and mid-terrace ~17-18% lower than for the detached house.

The relative impact of the elemental components of the building are shown in Figure 2.

All elements that are common across each house type are shown in greyscale. The differences across the archetypes are due to the differences in the external and party wall structure and cavity (façade is common, structure and insulation differ), lowest floor construction (beams are common, aircrete or EPS block differ), and the windows (double or triple glazing).

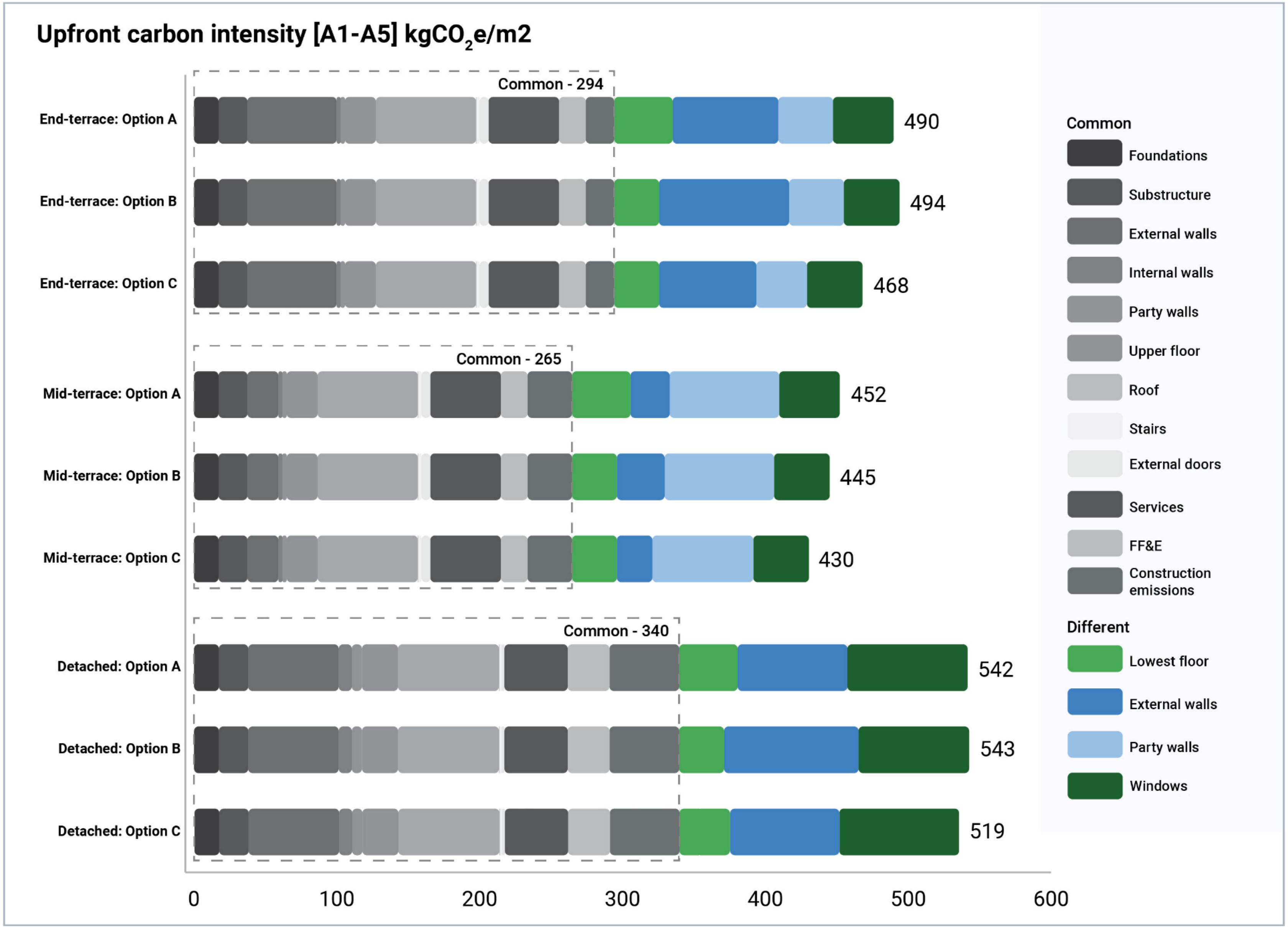
Table 4 - Upfront carbon intensity [A1-A5] $kgCO_2e/m^2$

| Upfront carbon intensity [A1-A5] $kgCO_2e/m^2$ | End-terrace | Mid-terrace | Detached |
|---|---|---|---|
| *Option A: Masonry, 100mm cavity, triple-glazing* | 490 | 452 | 542 |
| *Option B: Masonry, 150mm cavity, double-glazing* | 494 | 445 | 543 |
| *Option C: Timber frame, 140mm stud over-boarded, double-glazing* | 468 | 430 | 519 |

Table 5 – Sequestered biogenic carbon intensity [A1-A5] $kgCO_2e/m^2$

| Upfront carbon intensity [A1-A5] $kgCO_2e/m^2$ | End-terrace | Mid-terrace | Detached |
|---|---|---|---|
| *Option A: Masonry, 100mm cavity, triple-glazing* | -48 | -48 | -51 |
| *Option B: Masonry, 150mm cavity, double-glazing* | -48 | -48 | -51 |
| *Option C: Timber frame, 140mm stud over-boarded, double-glazing* | -135 | -115 | -121 |

Figure 2 - Upfront carbon comparison by archetype, specification, and building element



# 8. WHOLE LIFE CARBON COMPARISON

The whole life carbon comparison of each specification option across each house archetype is shown in Table 6.

Figure 3 breaks this down into the individual components of each life-cycle stage for the example of End-terrace, Option A.

**Key insights:**

- The timber frame construction has ~1-2% lower WLC intensity than masonry archetypes studied.
- For the building types and specifications studied, 73%-79% of WLC emissions are in the [A1-A5] stage highlighting the importance of understanding the materials, quantities, and manufacturing sector commitments to reduce the embodied carbon of materials.
- For an electric-only home, the [B6] emissions from regulated energy demand in the home make up only ~5% of the total WLC of the dwelling (without accounting for any PV generation to offset the grid electricity demand) over the 60-year study period.
- When PV generation is accounted for, the net operational emissions drop to ~1% of the total WLC.

*Whole life carbon is broken down by convention into different life cycle modules:*

*A1-A5* *Upfront carbon, including materials and construction.*

*B1-B5* *In use embodied carbon, including fugitive emissions, maintenance and replacement of components.*

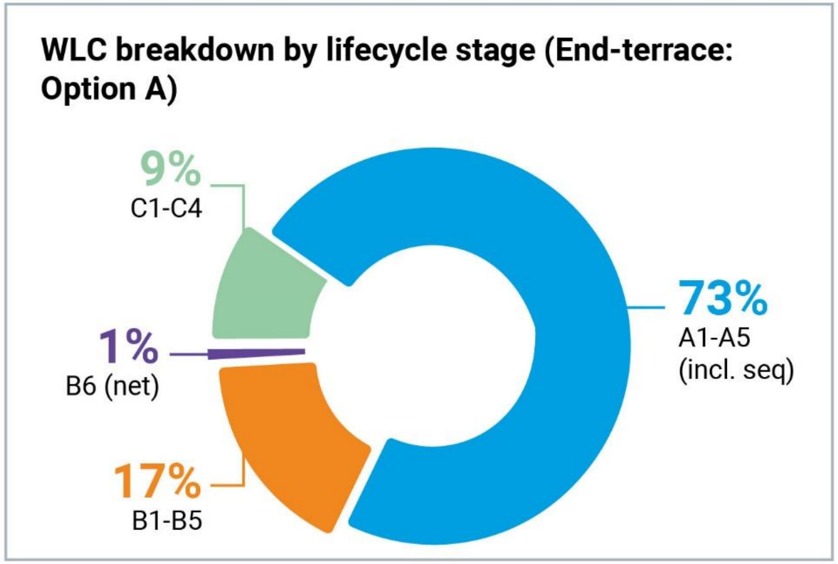
*B6* *In use operational carbon, including both regulated and unregulated energy consumption.*

*C1-C4* *End-of-life carbon, including deconstruction and disposal / recycling.*

Table 6 - Whole life carbon intensity [A1-C4] $kgCO_2e/m^2$

| WLC intensity [A1-C4] $kgCO_2e/m^2$ | End-terrace | Mid-terrace | Detached |
|---|---|---|---|
| *Option A: Masonry, 100mm cavity, triple-glazing* | 640 | 584 | 713 |
| *Option B: Masonry, 150mm cavity, double-glazing* | 642 | 577 | 711 |
| *Option C: Timber frame, 140mm stud over-boarded, double-glazing* | 628 | 571 | 696 |

Figure 3 – Whole life carbon breakdown by lifecycle stage



# 9. IMPROVEMENT OPTIONS

This section explores some simple, high-level design options to reduce embodied carbon of new homes.

Note that there are two main approaches to reducing embodied carbon:

1) Consider design opportunities (at the early design stages) to reduce the quantity of materials required or use alternative materials – this analysis is done using generic carbon data for materials.
2) Specify a low-carbon product (at the detailed design and procurement stages). If the product has a corresponding manufacturer- and product-specific EPD, the impact factor from the EPD will be used in place of the generic carbon data.

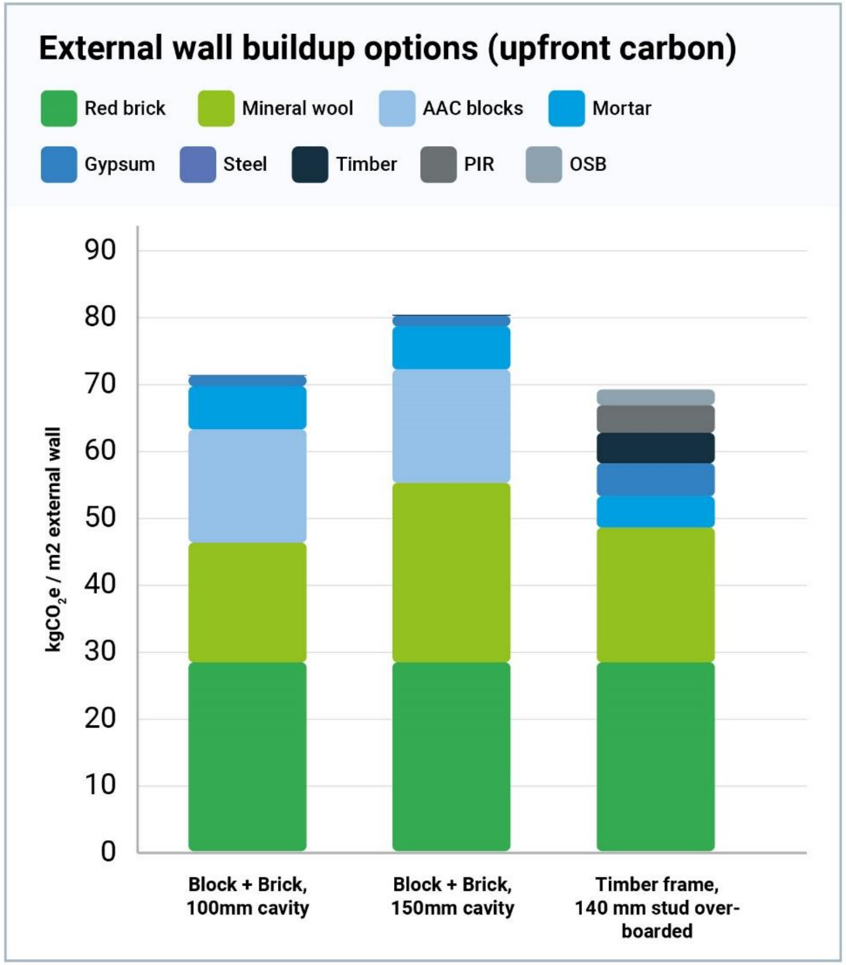
**This analysis looks at design options only and is based on generic carbon data.** Further work is required to understand the different product-specific options that may be available.

## 9.1 External wall comparison

The external wall (structure, insulation, and façade) makes up ~30-35% of the upfront embodied carbon of the detached and end-terraced dwelling archetypes, and ~12-14% of the mid-terrace dwelling archetype.

Figure 4 compares the three external wall build-ups studied on a per $m^2$ of external wall basis. This highlights the relative impact of the brick façade, the volume of insulation, the concrete block structure and other materials.

Figure 4 - External wall buildup options comparison (analysis based on generic material impact factors)



## 9.2 Windows comparison

The windows and external doors make up ~10-12% of the upfront embodied carbon of the end- and mid-terraced dwelling archetypes, and ~17-19% of the detached dwelling archetype.

Triple glazed PVC windows are approximately a 20% uplift in terms of intensity per m2 external façade area vs. double glazed windows, based on collective sector EPDs for uPVC windows. [2]

Again, specific manufacturer products may offer improved embodied carbon performance for similar operational energy performance (u-value and g-value).

## 9.3 Façade options

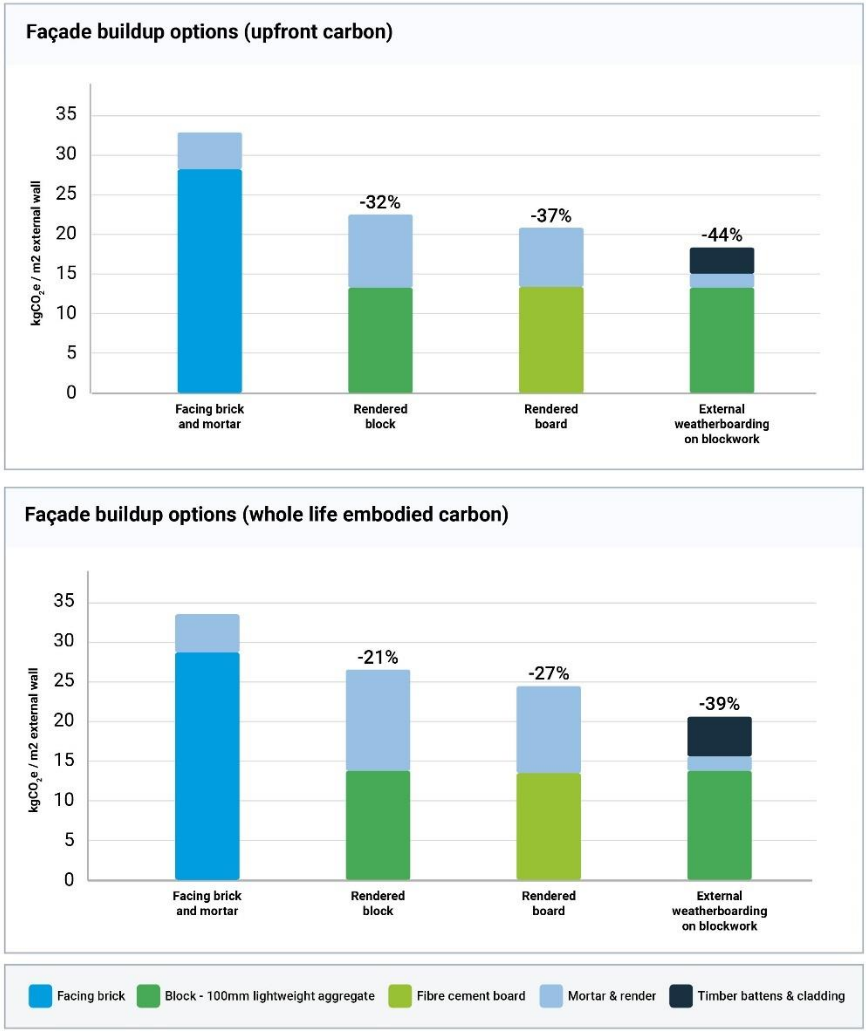
The standard façade of facing brick and mortar makes up ~14% of the upfront embodied carbon of the detached and end-terraced dwelling archetypes, and ~5% of the mid-terrace dwelling archetype.

Figure 5 compares different options for façades, indicating design opportunities to reduce embodied carbon emissions. The data labels show the % reductions in comparison with the facing brick and mortar façade.

Note that render and external weatherboarding are expected to be replaced after 30 years, which is reflected in the whole life carbon chart.

Note that brick manufacturers are working to reduce the embodied carbon of their products and, for comparison, manufacturer-specific low-carbon products currently available can achieve a similar embodied carbon reduction (~40%) compared to the performance of the collective sector-EPD for UK clay bricks.[3]

Figure 5 – Façade options comparison (analysis based on generic material impact factors)




[2] European PVC Window Profiles and related Building Products Association, 2022. See the Hub's [Default Materials and Assumptions] table, part of the Conventions for New Homes for the full list of generic impact data.

[3] Manufacturer-specific EPDs are available direct from manufacturers, or from tool or industry databases such as One Click LCA, 2050 Materials or the Built Environment Carbon Database.

## 9.4 Foundation considerations

Foundations, substructure and ground floor make up ~13-18% of the upfront carbon of the dwelling archetypes studied (based on a strip foundation being adequate[4]).

Ground conditions vary, and structural requirements may leave little scope for design options to reduce the embodied carbon impact.

If trench fill foundations are required, for example, increasing the depth of concrete from 225mm to 1500mm, that would require an additional 0.765 cubic metres of concrete per linear metre.

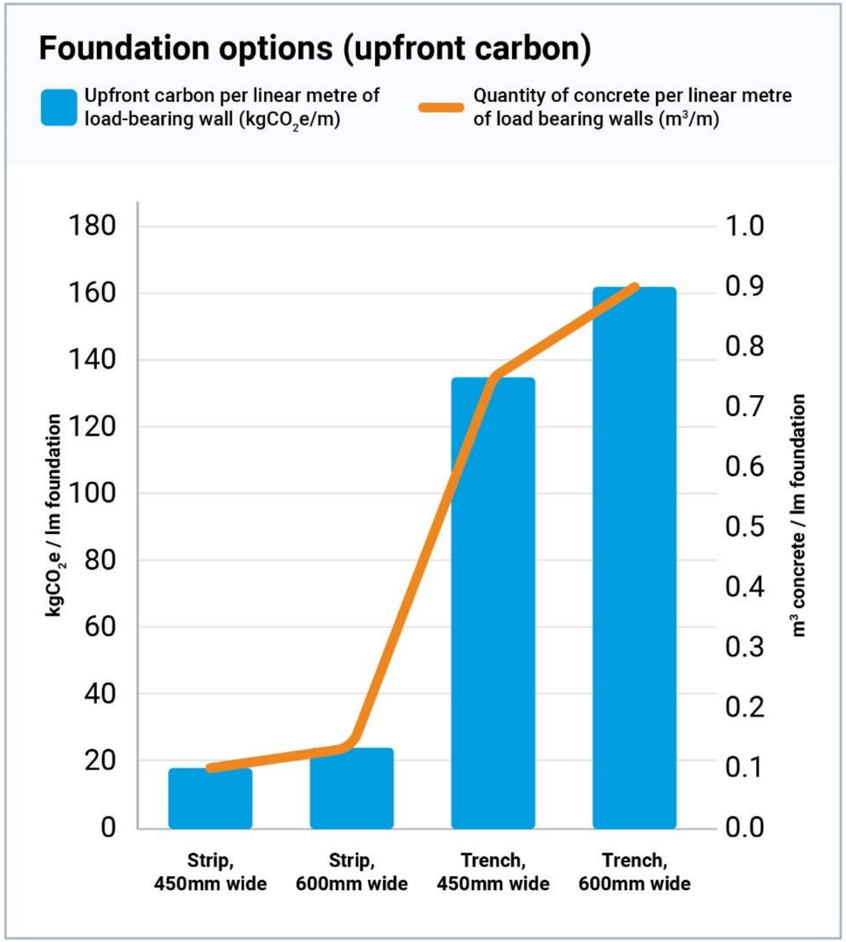
For the detached archetype the implication is an additional embodied carbon impact of approximately 103 $kgCO_2e/m^2$ or an uplift of around 20% on the whole dwelling impact.

One potential option would be to reduce foundation widths from 600mm to 450mm if external wall type allowed, which would reduce the amount of excavation and concrete required by 25% – an overall saving of 31 $kgCO_2e/m^2$ or 6% on the whole dwelling impact.

The upfront carbon is directly correlated to the quantity of concrete, as shown in Figure 6.

Other foundation designs and ground floor systems may offer even greater savings depending on the specific scenarios. Further work is required to identify typical quantities for other foundation types – and statistically how these scale with macro-variables such as floor area or length of load-bearing walls.

Figure 6 - Strip and trench foundations comparison (analysis based on generic material impact factors)




[4] All archetypes are assumed to have a 600mm foundation width of ready-mix concrete, based on feedback from developers that this is typical whatever the external wall thickness.

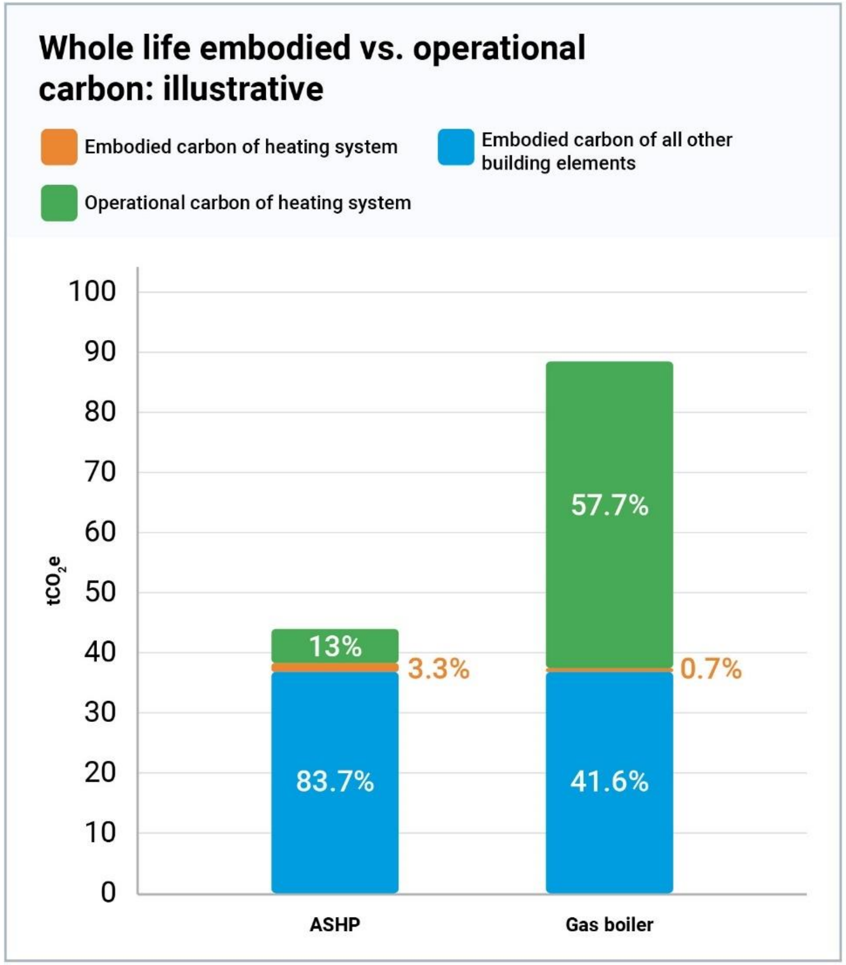
## 9.5 ASHP considerations

While moving away from a gas boiler will be required for FHS compliance – in most cases towards an Air Source Heat Pump (ASHP) – and hence is common to all the scenarios modelled here, it is worth noting that this change has the most significant impact of all compared to most new homes that have been built to date.

Figure 7 gives an illustrative example (not including PV in this case) of the whole life carbon benefit of an ASHP compared with a gas boiler over a 60-year period, accounting for the impact of refrigerant losses, material replacement cycles and the decarbonisation of the electricity grid and materials.

The chart shows the relative proportion of the home's WLC associated with both the embodied and operational carbon of the heating system.

Figure 7 – Whole life carbon for a home heated with ASHP vs. gas boiler comparison



# 10. HUB TOOL ALIGNMENT

The Hub introduced the **WLC Conventions for New Homes** and the first version of their **Future Homes Carbon Assessment Tool** in May 2024.[5]

This section discusses the alignment of the Hub tool's assessment of an example scenario (detached dwelling with 150mm cavity and double-glazing) with the One Click LCA outputs for the same archetype and specification.

It aims to answer two questions:

- How easy was it to apply the defaults and assumptions set out in the **WLC Conventions for New Homes** when using the One Click LCA commercial tool?
- How did the output from the tools compare?

## 10.1 One Click LCA inputs vs Hub tool inputs

The level of detail required for a full WLCA carried out in One Click LCA is vastly more than what is required for a WLCA carried out using the Hub's tool. The time and resources needed to use the Hub tool is very low if the macro-variables are readily available, which most developers should have to hand.

[5] Download both the Conventions and Tool from the Hub website.

## 10.2 Conventions & defaults

**Carbon data / EPDs:**

There were a number of materials where the carbon data source could not be matched in One Click LCA to the Hub tool's conventions, so an alternative EPD or generic source must be chosen in order to carry out comparable assessments.

Examples:

- Timber – softwood (treated), the Hub Conventions provide a figure for untreated timber with an additional carbon allowance added to account for the treatment. Could not be replicated in One Click LCA.
- Windows – uPVC frame, double glazing: This EPD was not available in One Click LCA's database, so an alternative EPD had to be chosen.

**Waste, transport, life span and end-of-life assumptions:**

Where the Hub conventions for wastage rates (concrete), transportation scenarios (timber) or component life spans (currently aligned) differ to the RICS PS defaults, these parameters must be updated individually for each line item within the One Click LCA model, which takes time.

The end-of-life proportions by waste route cannot be manually updated within the One Click LCA package, so any deviations in the Hub Conventions from the RICS PS defaults would not be able to be modelled. Currently EOL factors and proportions by waste route are aligned.

## 10.3 Post-processing required

There is some processing of the One Click LCA detailed results outputs required to make a like-for-like comparison against the Hub tool's charts to align the categories and aggregations.

**Component benchmarks:**

One Click LCA does not include the component benchmarks available within the Hub tool. To make comparison between the outputs, some post-processing of results was done in Excel to include the benchmarks for FF&E and construction emissions [A5.2 and C1].

**Whole life carbon uncertainty factor:**

Project specific information is required to input into One Click LCA in order to calculate the WLC Uncertainty Factor from within the software. Again, post-processing was required to apply an equivalent contingency factor.

**Operational and fugitive emissions:**

Operational and fugitive emissions are routinely calculated outside One Click LCA to ensure alignment with TM65 guidance, and application of the most conservative electricity grid decarbonisation scenario.

The Hub tool requires operational emissions to be calculated in SAP 10.2 and gives the option of decarbonised or no decarbonised outputs. Fugitive emissions are not entered separately, instead being built into the heating system benchmark.[6]

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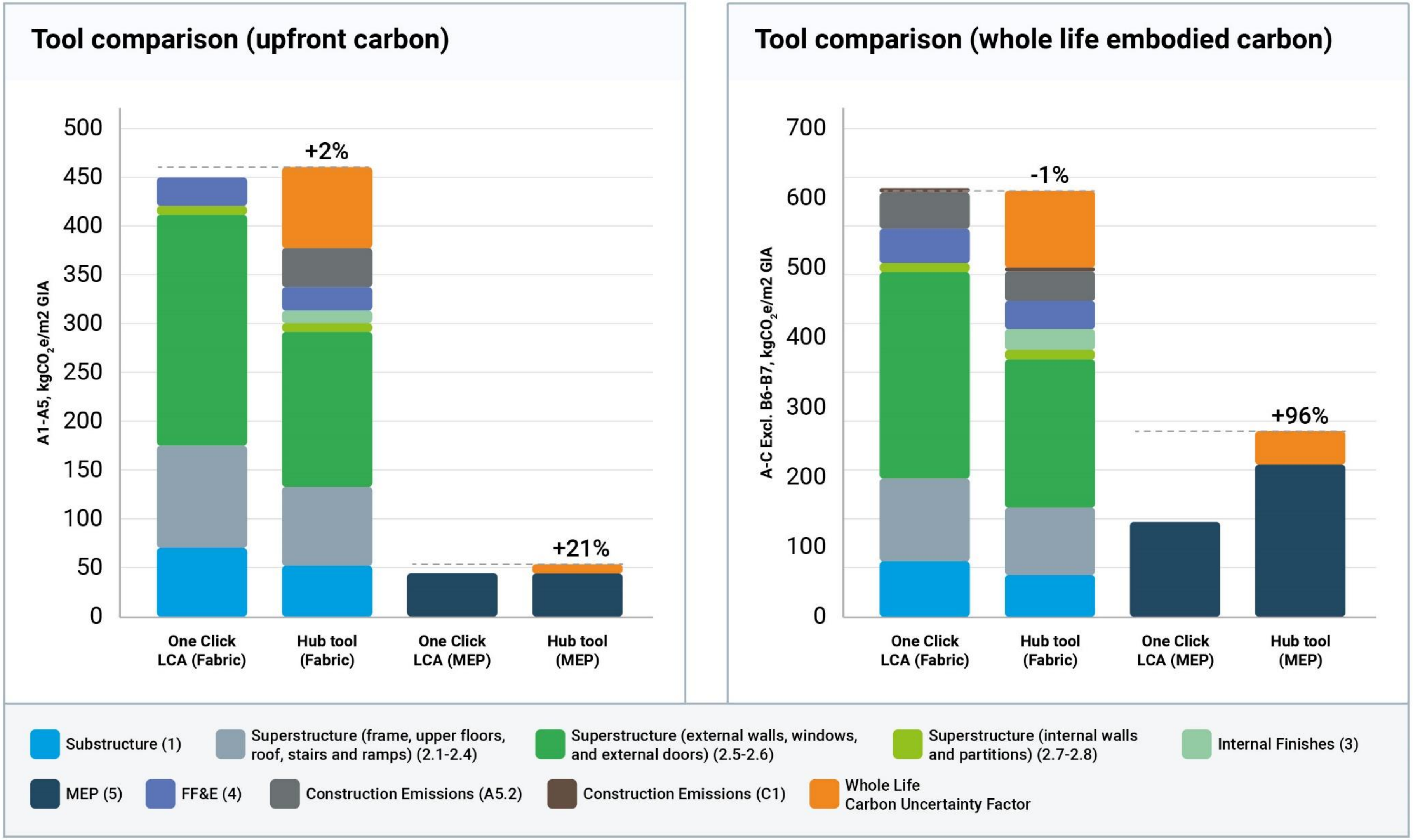
[6] Derived from TM65.1 Currently there is only one benchmark that represents an average for houses and one for flats – See [Appendix C of the WLC Conventions for New Homes](#).

## 10.4 Comparison of results

Looking at the overall comparison in figure 8, the two tools align very well when it comes to calculating the structure and fabric of the building, but less well when it comes to MEP services.

Figure 8 – Comparison between One Click LCA and Hub tool outputs, up front and whole life embodied carbon



**Comparison of upfront embodied carbon [A1-A5]:**

The Hub tool output for the upfront carbon of the detached masonry home with 150mm fully filled cavity and double-glazing is ~4% higher overall than the equivalent assessment carried out using One Click LCA.

Looking at the breakdown of fabric and services, the fabric is 2% higher, with the MEP is 21% higher.

**Comparison of whole life embodied carbon [A-C, excl. B6-7]:**

The Hub tool output for the whole life embodied carbon (all embodied carbon throughout the lifecycle but excluding operational carbon) is ~17% higher than the equivalent assessment carried out using One Click LCA.

However, looking at the breakdown of fabric and services, most of that error comes from the services. MEP is 96% higher, whilst all the fabric elements taken together are 1% lower.

The differences between the MEP benchmark used within the Hub tool and the scope and assumptions within One Click LCA needs further investigation if the accuracy of this element is to be relied upon. One aspect is the PV, which was additional in the One Click LCA assessment and cannot currently be accounted for within the Hub tool.

**Calculation notes:**

There are some differences in the allocation of internal finishes between the Hub tool outputs and the Hub elemental build-up details. For example, plasterboard is allocated to building elements 2.1 Frame, 2.2 Upper floors and roof, and 2.5 External envelope including roof finishes, and 2.7 Internal walls. Plasterboard could also commonly be allocated to 3.0 Internal finishes.

It is important to note that the uncertainty factor provided by the working group has been applied to each element in the One Click assessment but is added as a separate uplift when using the Hub tool.

In both the upfront and embodied carbon comparisons, the sub- and superstructure results are higher in the One Click outputs compared to the Hub tool outputs, partly due to the inclusion of the uncertainty factor within these figures but a further granular breakdown of the Hub tool outputs would be required to identify further the discrepancy here.

# 11. NEXT STEPS

Recommendations for next steps:

- Work with commercial tool providers to ensure that defaults and assumptions required to calculate the Conventions for New Homes are available and easy to access.
- Review further examples of homes calculated with commercial tools against output from the Hub tool, to gain confidence in the consistency of the outputs across different tools.
- When final details for FHS are announced by government, support users who are looking at different options by developing additional build-ups suitable for FHS compliance.
- Review and improve treatment of MEP services within the Hub tool, improving and /or providing several relevant benchmarks for different types or levels of servicing. This is particularly important if FHS strategies are to be properly reflected.
- Develop a post-processing tool to support comparison between users and outputs from different tools. Collect and compare examples of house types and projects for benchmarking.
- Further work to look at examples of how developers are actually specifying low carbon products within their developments, and what the potential is to improve the uptake.

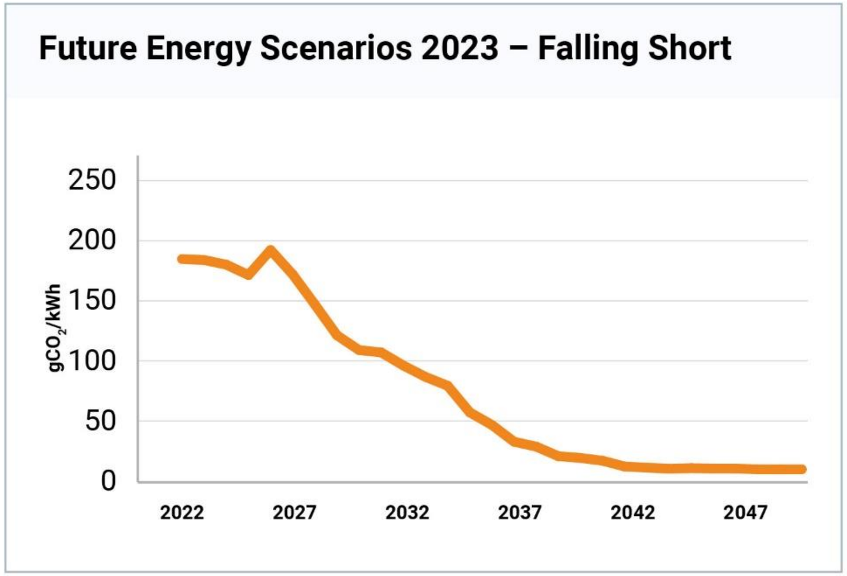
# APPENDIX A – DETAIL ON KEY ASSUMPTIONS AND CONSIDERATIONS

## Grid decarbonisation [B6]

The electricity grid is assumed to decarbonise in line with the most conservative scenario defined by the National Grid's Future Energy Scenario (2023) - 'Falling Short (excluding negative emissions from bioenergy and carbon capture)'[7].

The grid carbon intensity factor is assumed to remain static from the end of the FES projection in 2050 to the end of the RSP in 2084.

Figure A1 - FES falling short scenario




## Material decarbonisation [B4]

The whole life carbon results outlined in this report assume material decarbonisation for replacement materials in stages [B1-B5] during the 60-year reference study period of the home in alignment with RICS PS guidance.

## Fugitive refrigerant emissions [B1] & [C1]

Fugitive refrigerant emissions arise from the accidental leakage of refrigerants from air-source heat pumps. In the absence of measured and recorded leakage rates, fugitive emissions and their impact are estimated based on the type and size of system and the global warming potential (GWP) of the refrigerant, following CIBSE TM65 guidance.

Table A1 gives worked examples of the in use [B1] and end-of-life [C1] fugitive emissions for some Air Source Heat Pump (ASHP) systems commonly used by UK homebuilders.

For the assessments completed in this workstream we have assumed that the ASHP systems use R32 refrigerant which has a global warming potential (GWP) of 677. The impact of moving to a system utilising R290 with a GWP of 4 is significant, especially as the electricity grid decarbonises and the refrigerant losses make up an increasing proportion of the whole life carbon emissions.

Over the 60-year study period, emissions associated with refrigerant leakages make up ~5-7% of the WLC emissions of the archetypes and specifications studied.

[7] https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes

Table A1 – Fugitive emissions for example ASHP systems [B1] & [C1]

| EXAMPLE | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| CAPACITY | 5.7kW | 5kW | 6kW | 6.8 / 7.5kW |
| REFRIGERANT | R32 | R290 | R32 | R32 |
| RSP | 60 | 60 | 60 | 60 |
| GWP | 677 | 4 | 677 | 677 |
| CHARGE (KG) | 1.5 | 0.6 | 2.2 | 3.2 |
| ANNUAL LEAKAGE RATE[8] | 4% | 4% | 4% | 4% |
| REFRIGERANT EOL RECOVERY RATE[3] | 98% | 98% | 98% | 98% |
| B1 EMISSIONS OVER 60-YEARS | 2,437 | 6 | 3,575 | 5,199 |
| C1 EMISSIONS | 20 | 0 | 30 | 43 |
| TOTAL EMISSIONS (KGCO2E) | 2,458 | 6 | 3,604 | 5,243 |

*The global warming potential (GWP) of a refrigerant is a measure of how much heat a greenhouse gas traps in the atmosphere over a specific time-period, usually 100 years, compared to carbon dioxide ($CO_2$). GWP is expressed as a factor of $CO_2$, which has a GWP of 1.*

## Contingency & data quality uplift

In line with RICS PS, an overall uplift of 22% has been applied to all life cycle stages and modules to allow for contingency and data quality[9], as follows:

| | | |
|---|---|---|
| Contingency factor | 15% | Early design stage assumed |
| Carbon data uncertainty factor | 3% | Based on generic and representative data referenced by WLC Conventions for New Homes |
| Quantities uncertainty factor | 4% | Based on pre-defined buildups and benchmark information. |

[8] Table 4.4 CIBSE TM65 https://www.cibse.org/knowledge-research/knowledge-portal/embodied-carbon-in-building-services-a-calculation-methodology-tm65

[9] Note that after the modelling phase of this study, RICS guidance was updated to clarify that at early design stage a 15% overall factor should be applied for contingency, without any additional factors for data and quantities uncertainty.

# APPENDIX B – ARCHETYPE MACROVARIABLES

| *Global Constants* | *End-terrace* | *Mid-terrace* | *Detached* | *units* |
|---|---|---|---|---|
| *Number of Occupants* | 2.49 | 2.49 | 2.89 | Occupants |
| *Number of Storeys* | 2 | 2 | 2 | Storeys |
| *Floor-to-Floor Height* | 2.66 | 2.66 | 2.58 | m |
| *Gross Internal Floor Area (GIA)* | 81.34 | 81.34 | 127.40 | $m^2$ |
| *Demolished Gross Internal Floor Area (GIA)* | 0 | 0 | 0 | $m^2$ |
| *Total Floor Area (TFA)* | 81.34 | 81.34 | 127.40 | $m^2$ |
| *Total Ground Floor Area* | 40.67 | 40.67 | 63.79 | $m^2$ |
| *Total Length of Load-Bearing Walls (Ground Floor Only)* | 30.07 | 30.07 | 47.83 | m |
| *Total Length of Internal Load Bearing Walls* | 3.17 | 3.17 | 12.13 | m |
| *Total Length of Internal Stud Walls* | 6.16 | 6.16 | 31.80 | m |
| *Roof Area in pitch* | 58.47 | 58.47 | 114.96 | $m^2$ |
| *Roof Area in plan* | 47.90 | 47.90 | 75.60 | $m^2$ |
| *External Wall Area* | 127.22 | 44.23 | 202.00 | $m^2$ |
| *External Window Area* | 7.48 | 7.48 | 23.27 | $m^2$ |
| *Total Area of External Doors* | 4.30 | 4.30 | 2.15 | $m^2$ |
| *Total Area of Party Walls* | 41.50 | 82.99 | n/a | $m^2$ |
| *Total Length of Lintels* | 10.95 | 10.95 | 29.10 | m |
| *Number of Bathrooms (incl. En-Suites)* | 1 | 1 | 2 | Bathrooms |
| *Number of WCs* | 1 | 1 | 1 | WCs |
| *Number of Staircases and Stairwells* | 1 | 1 | 1 | Stair Cores |

# APPENDIX C – DETAILED SPECIFICATIONS

## Masonry, 100mm cavity, triple-glazing

| Building Element | Relevant Element Category | Build up name [U-value] | Build up description |
|---|---|---|---|
| Foundation, sub-surface, basement and retaining walls | Foundations | Strip, 600mm wide | Concrete |
| | Substructure | Masonry below DPC, 100mm cavity, low-rise houses | 305mm wide aircrete trench block + mortar. Outer leaf 100mm aircrete blockwork + mortar, with 102mm brickwork + mortar above ground. Inner leaf: 100mm aircrete blockwork + mortar. Cavity filled with insulation / lean mix below ground. Telescopic ventilator. |
| | Ground floors | Suspended beam and aircrete block [0.11] | 150mm EPS insulation top sheet, 75mm screed reinforced with A142 mesh, DPM (and or gas membrane if needed), Precast concrete T-beams 150mm deep, Aircrete block between beams |
| External walls and facade | External wall – structure, cavity, facade | Masonry, 100mm block 100mm cavity, full fill Facing brick [0.25] | 100mm aircrete blockwork + mortar, Plasterboard on 12.5mm dabs |
| | | | Insulation - mineral wool 100mm thick, Wall ties 225mm |
| | | | Facing brick + mortar |
| | Lintels | Masonry, insulated or thermally broken steel lintel | Insulated or thermally broken steel lintel |
| | Party walls | Masonry party wall, aircrete block + mineral wool insulation | 100mm aircrete blockwork + mortar, Insulation - mineral wool 100mm, Wall ties 225mm, Plasterboard 12.5mm on dabs |
| Floor slabs, ceilings, roofing decks, beams and roof | Upper floors | Engineered timber joists | 245mm engineered I-joists, 22mm T&G chipboard, 15mm plasterboard ceiling (Tape and joint finish) |
| | Roofs - external covering | Concrete tiles | Concrete tiles, Battens 38x25mm |
| | Pitched, trussed rafters, insulation at ceiling | Pitched, trussed rafters, insulation at ceiling [0.1] | Truss roof by specialist truss manufacturer, Counter battens 38x25m, 15mm plasterboard ceiling, Mineral wool loft insulation - to suit SAP – 450mm |
| Internal walls | Internal walls - Load bearing | Masonry, 100mm block, load bearing | 100mm aircrete blockwork + mortar, Plasterboard 12.5mm on dabs each side |

| | | | |
|---|---|---|---|
| | Internal walls - stud | Timber stud, 63mm stud, non-load bearing | 63mm timber studs, 25mm wool insulation to habitable rooms, 12.5mm plasterboard on each side |
| Windows and doors | External Doors | uPVC door, uPVC frame [Front door: 1.0 / Half-glazed door: 0.8] | uPVC door + frame, Sill 150mm |
| | Windows | Triple glazing, uPVC frame [0.8] | uPVC frame + triple glazed windowpane, Sill 150mm |
| Building systems and installations | ASHP | 3.5 - 5kW ASHP | 5kW heat pump, R32 |
| | Cylinder | 150-250L | |
| | WWHR | Yes | |
| | PV | 2.68 – 4.02 kWp (8-12 panels) | |

## Masonry, 150mm cavity, double-glazing

| Building Element | Relevant Element Category | Build up name [U-value] | Build up description |
|---|---|---|---|
| Foundation, sub-surface, basement and retaining walls | Foundations | Strip, 600mm wide | Concrete |
| | Substructure | Masonry below DPC, 150mm cavity, low-rise houses | 355mm wide aircrete trench block + mortar. Outer leaf 100mm aircrete blockwork + mortar, with 102mm brickwork + mortar above ground. Inner leaf: 100mm aircrete blockwork + mortar. Cavity filled with insulation / lean mix below ground. Telescopic ventilator. |
| | Ground floors | Suspended beam and aircrete block [0.11] | 150mm EPS insulation top sheet, 75mm screed reinforced with A142 mesh, DPM (and or gas membrane if needed), Precast concrete T-beams 150mm deep, Aircrete block between beams |
| External walls and facade | External wall – structure, cavity, facade | Masonry, 100mm block<br>150mm cavity, full fill<br>Facing brick<br>[0.19] | 100mm aircrete blockwork + mortar, Plasterboard on 12.5mm dabs<br>Insulation - mineral wool 150mm thick, Wall ties 275mm<br>Facing brick + mortar |
| | Lintels | Masonry, insulated or thermally broken steel lintel | Insulated or thermally broken steel lintel |
| | Party walls | Masonry party wall, aircrete block + mineral wool insulation | 100mm aircrete blockwork + mortar, Insulation - mineral wool 100mm, Wall ties 225mm, Plasterboard 12.5mm on dabs |
| Floor slabs, ceilings, roofing decks, beams and roof | Upper floors | Engineered timber joists | 245mm Engineered joists, 22mm T&G chipboard, 15mm plasterboard ceiling (Tape and joint finish) |
| | Roofs - external covering | Concrete tiles | Concrete tiles, Battens 38x25mm |
| | Pitched, trussed rafters, insulation at ceiling | Pitched, trussed rafters, insulation at ceiling [0.1] | Truss roof by specialist truss manufacturer, Counter battens 38x25m, 15mm plasterboard ceiling, Mineral wool loft insulation - to suit SAP – 450mm |
| Internal walls | Internal walls - Load bearing | Masonry, 100mm block, load bearing | 100mm aircrete blockwork + mortar, Plasterboard 12.5mm on dabs each side |

| | | | |
|---|---|---|---|
| | Internal walls - stud | Timber stud, 63mm stud, non-load bearing | 63mm timber studs, 25mm wool insulation to habitable rooms, 12.5mm plasterboard on each side |
| Windows and doors | External Doors | uPVC door, uPVC frame<br>[Front door: 1.0 / Half-glazed door: 0.8] | uPVC door + frame, Sill 150mm |
| | Windows | Double glazing, uPVC frame [0.13] | uPVC frame + double glazed windowpane, Sill 150mm |
| Building systems and installations | ASHP | 3.5 - 5kW ASHP | 5kW heat pump, R32 |
| | Cylinder | 150-250L | |
| | WWHR | Yes | |
| | PV | 2.68 – 4.02 kWp (8-12 panels) | |

## Timber frame, 140mm stud & over boarding, double-glazing

| Building Element | Relevant Element Category | Build up name [U-value] | Build up description |
|---|---|---|---|
| Foundation, sub-surface, basement and retaining walls | Foundations | Strip, 600mm wide | Concrete |
| | Substructure | Masonry below DPC, 150mm cavity, low-rise houses | 305mm wide aircrete trench block + mortar. Outer leaf 100mm aircrete blockwork + mortar, with 102mm brickwork + mortar above ground. Inner leaf: 100mm aircrete blockwork + mortar. Cavity filled with insulation / lean mix below ground. Telescopic ventilator. |
| | Ground floors | Suspended beam and insulation block [0.15] | 75mm EPS insulation top sheet, profiled insulation blocks between beams, 75mm screed reinforced with A142 mesh, DPM (and or gas membrane if needed), Precast concrete T-beams 150mm deep |
| External walls and facade | External wall – structure, cavity, facade | Timber frame, 140mm stud plus over boarding [0.17] | 9mm OSB, 140mm stud timber frame + mineral wool insulation, timber battens 50mm to service void, 25mm PIR over boarding, 14mm plasterboard, 3mm skim coat |
| | | | Facing brick + mortar |
| | Lintels | Timber frame, external steel lintel + internal timber structure | Galvanised steel, timber |
| | Party walls | Timber frame party wall, 89mm stud + mineral wool insulation | 89mm stud timber frame, mineral wool insulation, 9mm OSB, Timber frame party wall ties, Plasterboard 31.5mm |
| Floor slabs, ceilings, roofing decks, beams and roof | Upper floors | Engineered timber joists | 245mm Engineered joists, 22mm T&G chipboard, 15mm plasterboard ceiling (Tape and joint finish) |
| | Roofs - external covering | Concrete tiles | Concrete tiles, Battens 38x25mm |
| | Pitched, trussed rafters, insulation at ceiling | Pitched, trussed rafters, insulation at ceiling [0.11] | Truss roof by specialist truss manufacturer, Counter battens 38x25m, 15mm plasterboard ceiling, Mineral wool loft insulation - to suit SAP – 400mm |
| Internal walls | Internal walls - Load bearing | Timber, 89mm stud, load bearing | 89mm timber studs, 9mm OSB, 25mm wool insulation to habitable rooms, Plasterboard 12.5mm on each side |

| | | | |
|---|---|---|---|
| | Internal walls - stud | Timber stud, 63mm stud, non-load bearing | 63mm timber studs, 25mm wool insulation to habitable rooms, 12.5mm plasterboard on each side |
| Windows and doors | External Doors | uPVC door, uPVC frame<br>[Front door: 1.1 / Half-glazed door: 1.3] | uPVC door + frame, Sill 150mm |
| | Windows | Double glazing, uPVC frame [0.13] | uPVC frame + double glazed windowpane, Sill 150mm |
| Building systems and installations | ASHP | 3.5 - 5kW ASHP | 5kW heat pump, R32 |
| | Cylinder | 150-250L | |
| | WWHR | Yes | |
| | PV | 2.68 – 4.02 kWp (8-12 panels) | |

# APPENDIX D – UPFRONT CARBON EMISSIONS PER BUILD-UP FUNCTIONAL UNIT

Appendix D provides a further comparison between buildups, normalised by the appropriate functional unit (e.g. per m$^2$ of external wall).

| Hub build-up ID | RICS PS Categories - Granularity Levels 2 | Hub build-up name | Functional unit | A1-A5 kgCO2e / functional unit | U-value |
|---|---|---|---|---|---|
| 1.1 | 1.1 Foundations and piling | Strip, 450mm wide | per linear m - load-bearing walls | 30.3 | |
| 1.3 | 1.1 Foundations and piling | Strip, 600mm wide | per linear m - load-bearing walls | 37.9 | |
| 2.2 | 1.1 Foundations and piling | Masonry below DPC, 100mm cavity, low-rise houses | per linear m - load-bearing walls | 44.2 | |
| 3.3 | 1.2 Basement retaining walls and lowest slab | Suspended beam and aircrete block | per m2 - ground floor area | 69.2 | 0.11 |
| 3.6 | 1.2 Basement retaining walls and lowest slab | Suspended beam and insulation block | per m2 - ground floor area | 53.6 | 0.15 |
| 4.1 | 2.1 Frame | Masonry, 100mm block, load bearing | per linear m - internal walls (load) | 61.7 | |
| 5.1 | 2.7 Internal walls | Timber stud, 63mm stud, non-load bearing | per linear m - internal walls (non-load) | 30.0 | |
| 6.1 | 2.5 External envelope including roof finishes | Masonry, 100mm block | per m2 - external wall area | 19.5 | |
| 6.3 | 2.5 External envelope including roof finishes | Timber frame, 140mm stud | per m2 - external wall area | 34.8 | |
| 7.1 | 2.5 External envelope including roof finishes | 100mm cavity, full fill | per m2 - external wall area | 17.9 | |
| 7.3 | 2.5 External envelope including roof finishes | 150mm cavity, full fill | per m2 - external wall area | 26.9 | |
| 8.2 | 2.5 External envelope including roof finishes | Facing brick | per m2 - external wall area | 32.8 | |
| *Sub-total* | *2.5 External envelope including roof finishes* | *Masonry, 100mm cavity, facing brick* | *per m2 - external wall area* | *70.1* | *0.25* |
| *Sub-total* | *2.5 External envelope including roof finishes* | *Masonry, 150mm cavity, facing brick* | *per m2 - external wall area* | *79.1* | *0.19* |
| *Sub-total* | *2.5 External envelope including roof finishes* | *Timber frame, 140mm stud, facing brick* | *per m2 - external wall area* | *67.6* | *0.17* |
| 9.1 | 2.6 Windows and ext doors | uPVC door, uPVC frame | per m2 - external door opening | 98.0 | 0.8-1.3 |
| 10.1 | 2.2 Upper Floors and roof | Engineered timber joists | per m2 - upper floors | 13.2 | |
| 11.1 | 2.5 External envelope including roof finishes | Concrete interlocking tiles | per m2 - roof area in pitch | 15.9 | |
| 12.3 | 2.2 Upper Floors and roof | Pitched, trussed rafters, insulation at ceiling | per m2 - roof area in plan | 97.7 | 0.1 |
| 13.3 | 2.5 External envelope including roof finishes | Masonry, insulated or thermally broken steel lintel | per m - lintels | 16.2 | |
| 13.4 | 2.5 External envelope including roof finishes | Timber frame, external steel lintel + internal timber structure | per m - lintels | 10.4 | |
| 14.1 | 2.6 Windows and ext doors | Double glazing, uPVC frame | per m2 - window rough opening | 347.3 | 0.13 |
| 14.2 | 2.6 Windows and ext doors | Triple glazing, uPVC frame | per m2 - window rough opening | 377.8 | 0.8 |
| 15.1 | 2.1 Frame | Masonry party wall, aircrete block | per m2 - party wall area | 61.6 | |
| 15.4 | 2.1 Frame | Timber frame party wall | per m2 - party wall area | 56.8 | |