Building the Case for Net Zero:
Closing the gap towards net zero carbon new-build homes

Technical Report

OCTOBER 2022

Acknowledgements

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1. Introduction

1.1 OVERVIEW

This study aims to bring greater clarity to the ongoing debate surrounding net zero carbon new-build homes in the UK. In close collaboration with the partners of our Advancing Net Zero programme in 2021/22, UKGBC set out to investigate both the technical feasibility and cost implications of achieving different levels of operational energy and embodied carbon performance for four representative types of new-build homes.

This was undertaken with a view to identifying how quickly we might be able to achieve much higher levels of performance than those being achieved today – indeed, levels of performance that more closely resemble what is likely to be required for new-build homes to credibly claim to be net zero carbon. It follows on from a previous UKGBC study which illustrated how two new high-rise buildings – an office tower and residential block – could be designed to reach best practice performance targets and the effect this had on capital cost.

This study is based on an assumption that build rates of new homes will continue to increase to meet the governmental target of building 300,000 new-build homes a year by the mid-2020s, which validates the need to urgently close the gap between the performance of new-build homes today and the achievement of genuinely net zero carbon new-build homes. However, from a whole life carbon perspective, the first priority should always be to refurbish and retrofit existing homes where appropriate, and repurpose suitable existing buildings into residential ones, so as to drive down the need for new-build homes and thereby reduce upfront construction and embodied carbon of new-build development. This is an important consideration for sectoral modelling to determine the contribution that both new-build homes and existing homes can make to the overall carbon budget for the UK built environment sector. It should be noted that UKGBC has an extensive separate workstream on home retrofit for Government and industry to become involved in.

1.2 SUMMARY AND TECHNICAL REPORT

The Summary Report (16 pages) includes the headline findings and takeaways from the study and was launched alongside this Technical Report (36 pages) which includes the detailed modelling and further technical information. The Summary Report should, ideally, be read before the Technical Report to provide adequate context and framing.

To avoid duplication, the Summary Report includes the following sections which are not in this Technical Report:

- Introduction:
  - Purpose
  - Context
- First principles for a definition of net zero carbon new-build homes
- Key findings:
  - Operational energy
  - Embodied carbon
  - Cost

2. Project overview

2.1 SCOPE

This study takes a holistic approach to large-scale residential developments by assessing carbon impacts from the homes as well as the wider masterplan and site infrastructure. This report – on homes – has been published following an initial report outlining the masterplan. Both reports should be read in conjunction to paint a complete picture of how design changes for one might affect the other.

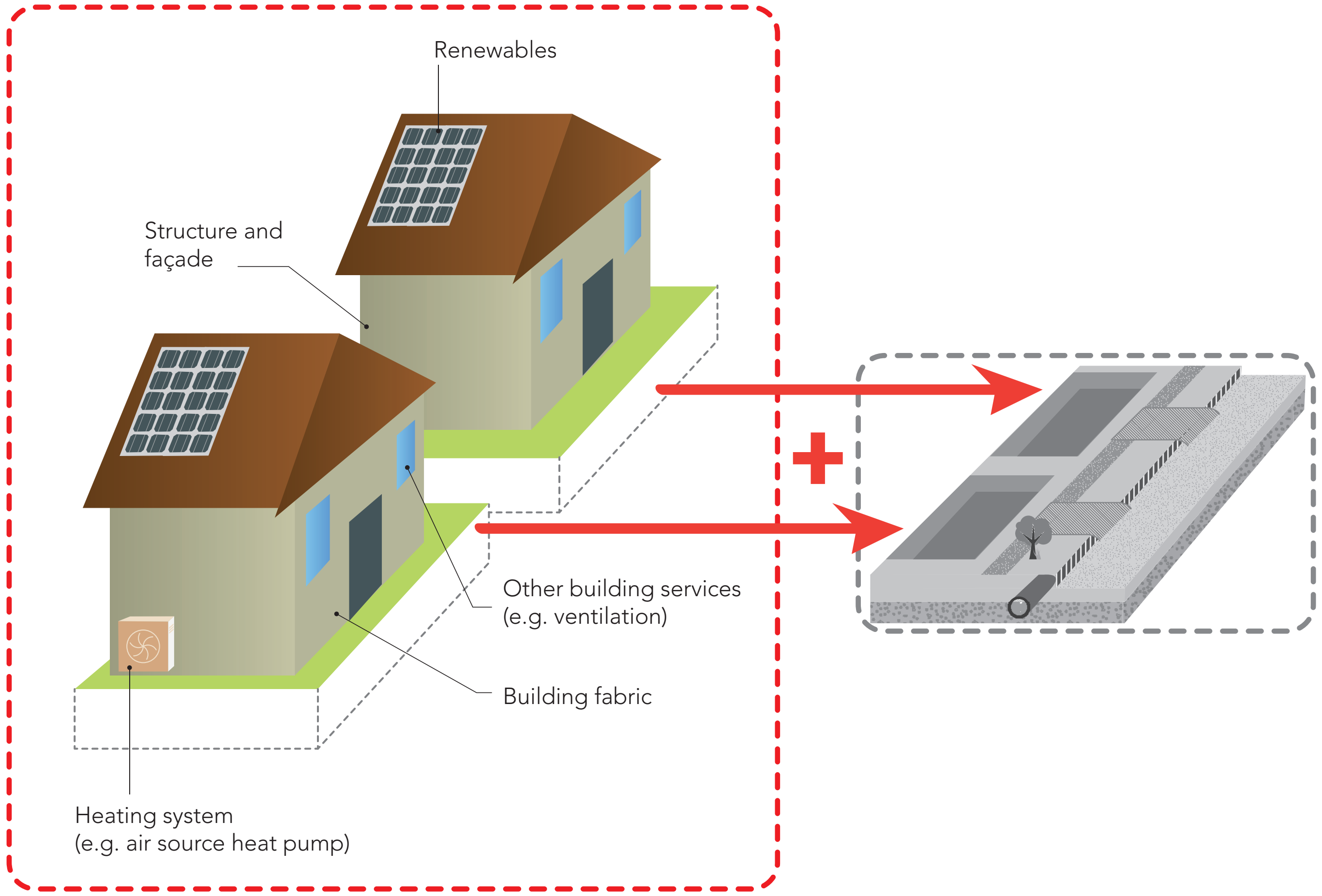
The focus for the analysis was closing the gap between the performance of new homes in design today and those that strive to achieve performance standards more akin to net zero carbon in future. Given that science-based decarbonisation levels have not yet been defined in absolute terms, it was decided that the appropriate targets to utilise for this particular feasibility study should be both currently in use by industry leaders, and a substantial improvement on standard levels of performance typically achieved by new-build homes in today's market. As a result, the project team defined two separate decarbonisation steps – one categorised as 'intermediate' and another as 'stretch' across both operational and embodied carbon for new-build homes. For the masterplan, however, given that there are no currently available performance targets, the focus was to reduce embodied carbon from construction works whilst considering other key urban design factors, such as transportation, nature, and water.

Neither component should be viewed in isolation as, typically, trade-offs will arise based on design decisions made for each. A clear example of this is the district heat network, which effectively increases the masterplan's embodied carbon whilst reducing the impact for homes. A high-level comparison of the scope from both reports is provided in Table 1.

Table 1: High-level comparison of scope between masterplan and homes

Homes	Masterplan
Operational energy • Building fabric • Building services • Heating system • Renewables • Embodied carbon **Structure and façade** • Material selection	**Embodied carbon:** • Roads • Hard surfaces (e.g., parking, squares) • Utilities (e.g., electrical, telecoms) **Infrastructure (e.g., drainage)** • Heat network • Urban design: • Nature and biodiversity • 'Blue/green' networks • Transportation • Housing density

Figure 1: This report focuses on homes (outlined in red) and both reports provide a complete picture of the carbon impacts from a large-scale residential development



2.2 TRUMPINGTON SOUTH

Trumpington South is a new development in South West Cambridgeshire, put forward by Grosvenor for the purposes of this study. The scheme was selected as it is considered representative of a typical urban extension, residential-led scheme going through the planning process. Subject to planning approval, the site could be delivering new homes by 2025. Trumpington South forms part of a wider promotion of land, additional to the consented Trumpington Meadows urban extension, sections of which are completed.

Trumpington South has a strong sustainability strategy, with a vision to help Cambridge Council achieve their ambition of zero carbon by 2050. The development proposal consists of 750+ new homes, a new primary school, a village centre and other mixed-use buildings. Connectivity and active transport were central to the planning and design proposals for the development, which wraps around the new guided busway and the Trumpington Park and Ride site, and links into the well-established cycleway network to the city centre. The scheme is also aiming to achieve a significant net biodiversity gain on the land which, as of 2023, will need to reach 10% for new developments to be granted planning permission under the recently adopted Environment Act 2021.

The study focuses on the carbon impacts of the homes and masterplan. As such, non-residential buildings have been excluded from the analysis and other holistic sustainability considerations have not been specifically measured, such as sequestration from increased nature provision, transport emissions in-use, and social value impacts.

Figure 2: Trumpington South illustrative masterplan

Figure 3: Photos from the completed Trumpington Meadows development (Photo credit: Terence O'Rourke)

3. Methodology

3.1 DESIGN SCENARIOS

The scope of the study covered four types of new-build homes which represent a range of typical new residential construction:

Type	No. of bedrooms	Size
Detached house	4	145m²
Semi-detached house	3	113m²
Terrace house	3	103m²
Apartment block	1&2	3-4 storey

Each typology has been modelled across three different design scenarios. The **baseline** scenario assumes that homes currently in design will perform roughly in alignment with Part L 2021 updates (introduced in June 2022). Voluntary performance targets have then been used covering both operational (regulated and unregulated energy) and embodied carbon emissions. Targets used have already been adopted by other industry bodies and represent both **intermediate** and **stretch** scenarios, as outlined in Table 2.

Table 2: Energy and embodied carbon performance targets for new-build homes

		Analysed in this feasibility case study			
		Business as usual	Intermediate targets	Stretch targets	Net zero carbon targets
		From RIBA 2030 Climate Challenge and LETI Climate Emergency Design Guide			TBC
Operational energy	Regulated	31% carbon reduction (Part L, 2021)	75-80% carbon reduction (Future Homes Standard, 2025)	100% carbon reduction (speculative target)	Currently under development via the UK Net Zero Carbon Buildings Standard initiative
	Regulated and unregulated[1]	120 kWh/m^2/year	60 kWh/m^2/year	35 kWh/m^2/year	
Embodied carbon	Upfront carbon emissions (construction only, module A)[2]	800 kgCO$_2$e/m^2	500 kgCO$_2$e/m^2	300 kgCO$_2$e/m^2	
	Embodied carbon emissions (whole life, modules A-C, excl B5 & B6)[3]	1200 kgCO$_2$e/m^2	800 kgCO$_2$e/m^2	625 kgCO$_2$e/m^2	

3.2 DESIGN CHANGES

A task group was charged with achieving the intermediate and stretch targets by progressively enhancing the baseline specification. This involved a consensus-led process to determine the most practical and feasible design changes that would be considered acceptable for the mass housebuilding market. Some of the key factors that drove the group's decision-making process included: capital cost (not operational cost), industry acceptance and risk.

All design changes are applied equally across all four types of homes, unless otherwise stated. As an example, where the U-values for windows was improved from the baseline to intermediate scenarios (from 1.4 to 1.1 U-value), the same improvement has been applied to the detached, semi-detached, terrace and apartment typologies. The only design change which uses a different approach is the heat delivery, where the intermediate scenario includes an option for either an on-plot air source heat pump or a district heat network – this is described in detail under the 'Building services' section of this report.

By upgrading the design of these homes, the study aims to illustrate the feasibility of achieving the targets, both in terms of potential design routes and the resulting impact on capital cost. It should be noted that the design options pursued in this study are not definitive and offer a single set of decisions that were determined by the task group – readers should apply this guidance as an evidence base only.

3.3 COST

The scope of the cost analysis has been limited to capital cost to ensure the results are as robust as possible, Please note, this modelling was undertaken in August 2021 and does not account for market price fluctuations or developments in technology and supply chain availability since then. The cost modelling demonstrates an estimated order of cost associated with the design changes modelled.

It is widely recognised that the cost to deliver low carbon homes will fall over time as the housing market adapts to delivering the more stringent requirements, including, for example, improvements in technology and growth in supply chain capacity. At present, however, it is still very difficult to quantify. The reduction in costs due to market forces must be considered alongside the findings in this report and other relevant studies.

In addition, other financial variables that have not formed part of this study would need to be considered when assessing the feasibility of a net zero carbon residential project. This includes lower risk from future regulatory changes, enhanced lending margins, increasing consumer demand, potential sales premium, potential reductions in utility costs for homeowners, etc.

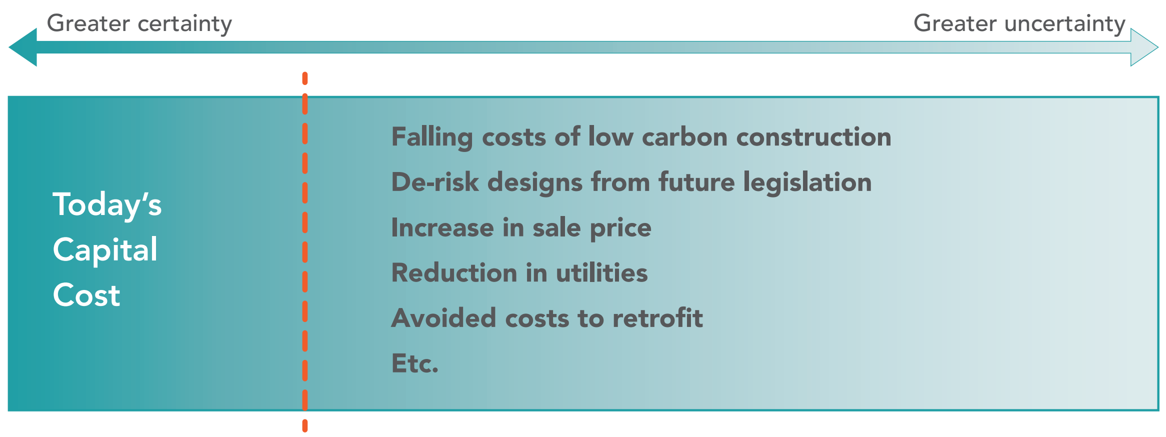
For those looking to future-proof homes currently in design, the findings are intended to raise awareness and stimulate forward planning to address the key challenges. From another perspective, the results provide evidence that, without faster and more effective regulation, credible standards of net zero carbon will not be achieved through voluntary industry practice alone

3.4 PROJECT CONTRIBUTORS

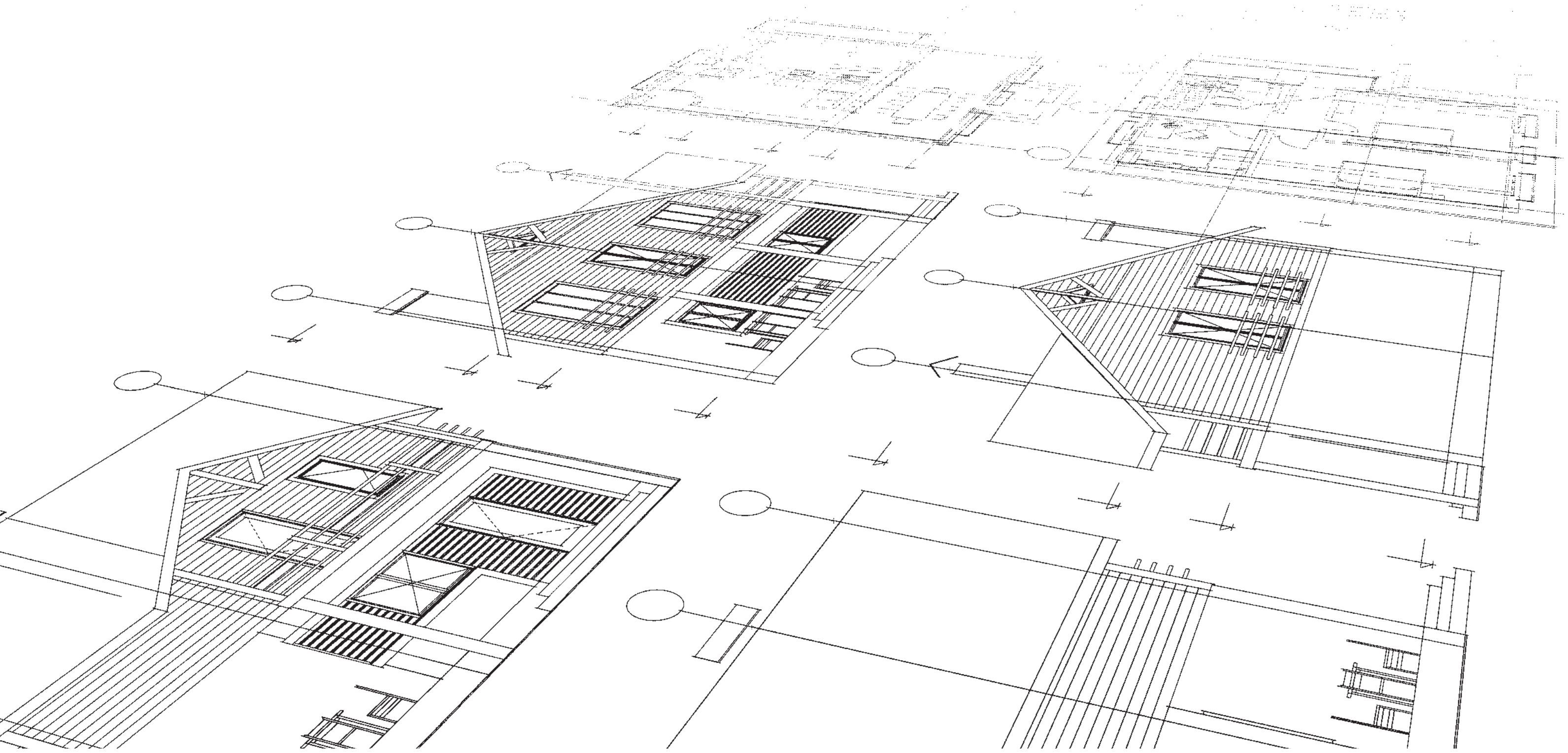
UKGBC convened individuals with experience working on the Trumpington South project to form the task group. The task group met regularly over a four-month period to develop the design scenarios, complete the carbon and cost modelling, and prepare findings for this report. We would like to offer a special thanks to all task group members, listed in Appendix A, for dedicating their time and expertise to this study.

UKGBC also sought to feed-in views from a wider set of stakeholders – including other designers, developers, housebuilders, financiers and policymakers – as part of a review group to help enhance the findings of the study. The review group, also listed in Appendix A, provided input at two key points during the development of the study, as well as reviewing the findings and final report.

Figure 4: The study focuses on capital cost today, which can be estimated more accurately than other variables which are covered in the Discussion section of the report



4. Design changes



This section provides an analysis of the changes made to the baseline design specification to reach the operational energy (4.1) and embodied carbon (4.2) targets, respectively, for both the intermediate and stretch scenarios. All design scenarios are assumed to build upon and retain the previous design unless otherwise stated.

4.1 OPERATIONAL ENERGY

4.1.1 Building fabric

	Unit	Baseline	Intermediate	Stretch
Windows	Type	Double	Double	Triple
	U-value	1.4	1.1	0.7
	G-value	0.44	0.6	0.6
External walls	U-value	0.21	0.17	0.13
Roof	U-value	0.19	0.12	0.1
Ground floor	U-value	0.2	0.14	0.1
Thermal bridging	Type	Default thermal bridges	Approved construction details	Passivhaus construction details
Air tightness	$m^3/(hm^2)$ @ 50 Pa	5	3	1

Please see Appendix B for detailed energy modelling inputs and Appendix C for a complete breakdown of results, for all four typologies.

Diminishing returns from improved U-values

As the U-value of building fabric elements improve, there is a diminishing return for their overall benefit in reducing energy demand. As an example, the task group originally modelled a wall U-value of 0.1 (instead of 0.13) for the stretch scenario and found that this high level of performance would require a larger wall cavity, increasing the overall wall thickness by 170mm (from 400mm to 570mm). This had knock-on effects, adding embodied carbon to homes and widening physical plot dimensions to fit the larger houses. Importantly, it also drastically increased the costs for wall construction. A U-value of 0.13 was settled on as it hit the 'sweet spot' between carbon benefit and cost feasibility. Careful consideration of U-values should always be undertaken to determine the most effective spend for fabric improvement measures.

The **BASELINE** design represents homes currently in design to meet Part L 2021. This includes double-glazed windows with typical opening sizes, default thermal bridges, and standard airtightness rates. It should be noted that the external walls, roof and floor U-values are slightly worse than Part L notional; however, they are all better than the limiting fabric parameters set out in Part L1A 2013.

The **INTERMEDIATE** design upgrades to best practice double-glazed windows with improved U-values, along with improvements to U-values for all other fabric elements. All U-values used in the modelling are inputs, rather than values specifically calculated or provided by a manufacturer, as it was assumed the homes would not target formal Passivhaus certification. The external walls switch from steel frame and concrete block to timber frame (for embodied carbon savings), allowing double the amount of insulation to fill the cavity space. SAP approved construction details for thermal bridging have been modelled, along with an airtightness rate of 3 (m^3/hm^2 @ 50 Pa), as this is considered achievable today with minimal cost difference.

For the **STRETCH** design, the fabric has been upgraded to meet Passivhaus standards (fabric only, not other building elements). This includes: a tightening of U-values to walls using glass wool insulation (0.031 W/mK) at 300mm thickness to maintain the same wall cavity; lower airtightness rates, requiring careful consideration of construction detail and quality assurance checks during construction; and a move to triple-glazed windows, requiring health and safety considerations during installation due to their additional weight.

4.1.2 Building services

	Baseline	Intermediate		Stretch
Ventilation	Natural ventilation (for houses) Mechanical extract ventilation (for apartments)	Mechanical extract ventilation (for all)		Mechanical ventilation with heat recovery (for all)
Heating	Gas boiler (on-plot)	Air source heat pump (on-plot)	Heat network (district-wide)	Air source heat pump (on-plot)
Renewables	2.2 kWp	3.2 kWp		4.4 kWp

Please note, the contribution from PV is excluded from the EUI results (in line with LETI guidance) to illustrate the improvements in energy efficiency and demand reduction, and only considered for the calculations to meet Building Regulations.

The **BASELINE** design assumes a gas boiler for homes being built today, however, this comes with strong caveats. Gas boilers are likely to be banned in new-build homes with the introduction of the Future Homes Standard from 2025 (and earlier in some Local Plans), and new buildings with on-site fossil fuel use would not meet UKGBC's definition for a net zero carbon building. Accordingly, any gas boilers installed today will need to undergo an expensive retrofit to low carbon alternatives before 2050.

Wastewater heat recovery is modelled with an efficiency of 42% (included across all scenarios), with no storage tank provided for hot water.

The **INTERMEDIATE** design adopts mechanical extract ventilation with intermittent extract to meet the increased air tightness requirements. The heating system is upgraded to a non-fossil fuel system, with two options modelled:

- **Air source heat pumps (4.5 kWp)** – provided on-plot with heating via radiators and hot water storage tanks (180 L)
- **District heat network** – provided within a centrally located energy centre, consisting of high temperature air source heat pumps and electric peak boilers within a centrally located energy centre, and no hot water storage tanks

Comparing the district heat network (SCOP of 2.75) and the on-plot air source heat pump (SCOP of 2.0), the results indicate an overall improvement in energy efficiency for the district heat network for houses (9% for detached, from 56 to 51 kWh/m^2/year) and a marginal decrease in efficiency for the apartments (-3%, from 62 to 64 kWh/m^2/year). This suggests that although minor improvements in energy efficiency can be achieved with a district heating system, it is worth comparing these operational carbon savings with the effects on embodied carbon and cost.

The district heat network was modelled for the purposes of comparison and borrows from successful European examples of low carbon, low-rise schemes. Further analysis would be required when adopting this system, including heat demand density and viability studies for a residential-led scheme (i.e., no non-residential buildings to balance peak loads, developer costs, and infrastructure outlay).

The **STRETCH** design also uses mechanical ventilation with heat recovery, with an assumed heat recovery efficiency of 84%. The air source heat pump is modelled again, however with the seasonal co-efficiency of performance (SCOP) improved from 2.0 to 3.0. The increase in efficiency was modelled on the basis of international studies which demonstrate that, as the market expertise for delivering air source heat pumps matures, higher levels of efficiency can be achieved, for example, through improved installation, commissioning, and system maintenance. Heating is provided via underfloor heating and a storage tank is provided for hot water.

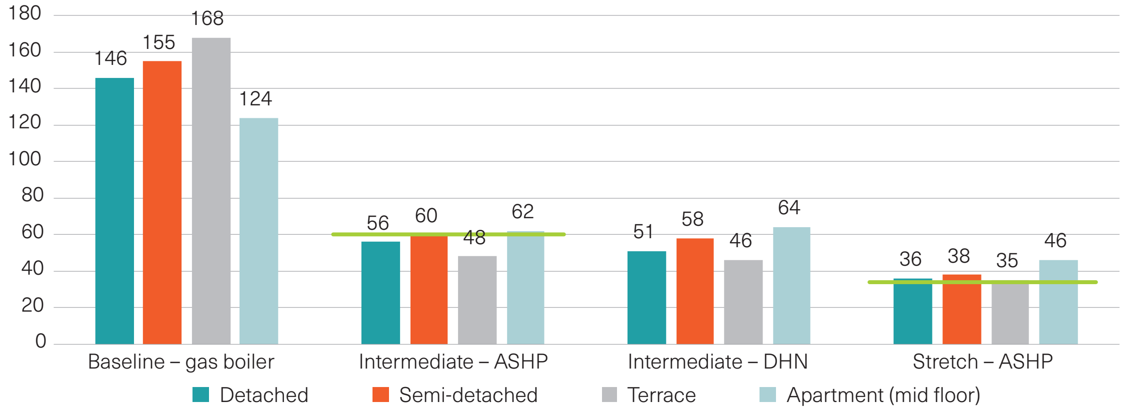
Other considerations

Given the drastically reduced heating demand – a 72% reduction between baseline and stretch scenarios for the detached house – electric radiators were considered as an alternative to an air source heat pump and underfloor heating. Given the relatively high hot water heating demand, however, this option was not considered feasible. Separately, air source heat pumps are modelled individually for all houses and apartments, however, efficiencies could be sought by using a communal network, especially for the apartment block and terraced houses.

The unregulated loads remain constant across all scenarios at around 17 kWh/m^2. These loads have not been reduced in this study (e.g., the increased use of personal tech and electric vehicle charging), due to this being outside of the designer's control. However, as unregulated loads become close to half of total energy use in the stretch scenarios, measures designed to reduce these loads (e.g., highly efficient white goods specifications) will become increasingly important.

4.1.3 Results

Figure 5: Regulated and unregulated energy results – total energy use intensity before renewables (kWh/m^2/year)



Key Green line indicates the target: Intermediate = 60; Stretch = 35 kWh/m^2/year
ASHP = air source heat pump
DHN = district heat network (only modelled for the intermediate scenario)

Conclusions

- Both the intermediate and stretch energy targets are achievable for this typology of new-build homes in design today, using existing technologies and design approaches
- The use of an air source heat pump, along with fabric performance improvements, future-proofs these homes, making it unlikely they will need to undergo expensive retrofit works in future to become 'net zero carbon' in operation

The results demonstrate that, based on available design practices and technologies, the stretch target is within reach for most typologies. However, this would require a significant shift from the a 'business as usual' approach to residential design – reflected in the baseline scenario. Reductions are in the order of 62-75% between the baseline and intermediate and stretch scenarios, respectively (i.e. from 146 to 56 and 36 kWh/m^2/year for the detached house). This represents significant savings in terms of energy and carbon.

The switch from gas boiler to air source heat pump – with the supporting improvements to building fabric performance – means these homes would avoid having to undergo further costly retrofit works in future, which in itself would save substantial embodied carbon savings later in the lifecycle of the homes. Marginal energy efficiency gains are achieved using the district heat network compared to individual air source heat pumps.

The terraced house performs best in the intermediate and stretch scenarios, likely due to the smaller building envelope and benefit of insulation from party walls. Although apartments consume the least energy (kWh) due to their generally smaller size, here they perform worst out of all four typologies due to the results being considered on an energy intensity per square metre basis (kWh/m^2). This illustrates the complexity of the subject, and suggests both Government and industry should consider bespoke targets for different types of new-build homes (e.g. low-rise versus high-rise).

'Net zero carbon' vs. 'net zero energy'

The key parameters for a net zero carbon building are defined in the Introduction section of this report, which includes the ability to procure renewable energy produced off-site. This is a key distinction from a net zero energy building, which requires that a building be self-sufficient and produce all the energy it consumes on-site. In practice, this can be quite challenging, especially for buildings with limited capacity for on-site renewables (e.g., a high-rise apartment block). The task group did consider additional upgrades to achieve a net zero energy home in operation. Preliminary modelling indicated that the ultra-low energy demand for the stretch design, combined with an increased provision of photovoltaics and solar thermal (sizing to be determined), and battery storage, could potentially enable the home to sit within net zero energy parameters.

Building Regulations

The modelling for the houses includes an amount of roof-mounted photovoltaic (PV) panels which increases across the three scenarios to keep in step with increasingly ambitious carbon reduction targets under Building Regulations. The contribution from PV has been excluded from the energy use intensity calculations (in line with LETI guidance) and only considered for the calculations to meet Building Regulations. The embodied carbon from the PV arrays have been included in the embodied carbon calculations for completeness.

SAP calculations were undertaken for the detached house to provide the estimated carbon savings from a Part L perspective (i.e., regulated energy only). This was used to determine the amount of PV required to meet the relevant targets, as shown in Table 3.

It should be noted that the PV amounts modelled are estimates only and would be subject to project-specific inputs, such as PV efficiency, orientation, location, etc.

These results indicate that as regulated energy reduces across the scenarios, the relative reduction in carbon (calculated in SAP) will increase. For example, the same 1.5 kWp of PV will deliver a three-fold reduction in carbon between the baseline and stretch scenarios (from 20% to 66%), based primarily on improvements to fabric. It should be reiterated that these calculations only consider regulated energy and not the total energy use of homes, as specified in the RIBA/LETI EUI targets.

Table 3: Varying amounts of PV and resulting carbon reduction across all three scenarios

	Carbon reduction		
Amount of PV (kWp)	**Baseline**	**Intermediate**	**Stretch**
1.5	20%	50%	66 %
2.2	32%	59%	75 %
3.2	-	71%	81 %
4.4	-	-	101 %
Target	31% (Part L, 2021)	75-80% (Future Homes Standard, 2025)	100% (speculative target, not in Building Regulations)

Part L vs. industry targets

UKGBC's Net Zero Whole Life Carbon Roadmap states that the building sector must 'shift away from the theoretical "notional building" approach and focus on how energy intensive buildings will be built in practice, alongside other key net zero enablers such as peak demand limits.' For the residential sector, this suggests moving away from Standard Assessment Procedure (SAP) calculations towards predictive energy modelling, which is what the industry targets used in this study are based on.

A comparison between the different approaches is provided below:

	Part L	Industry targets
Requirement	Legislative requirement – Building Regulations Part L	Voluntary – RIBA and LETI targets
Calculation	Standard Assessment Procedure (SAP)	Predictive energy modelling (Passive House Planning Package for this study)
Scope	Regulated energy only – defined as 'energy consumption resulting from the specification of controlled, fixed building services and fittings, including space heating and cooling, hot water, ventilation and lighting'.	Regulated and unregulated energy – unregulated energy is defined as 'the energy consumption of the home that is not "controlled", (i.e., energy consumption from aspects of the home on which Building Regulations do not impose a requirement)' which can make up over half a home's total energy use.
Methodology	A home of the same form and size but built to the minimum standards required by Part L 2013, is used as a basis to compare the new home design.	Detailed energy model using assumptions around occupancy, summer and winter temperature set points, unregulated loads etc., to reliably predict total energy use.
Contribution from renewables	Included in calculations.	Excluded from calculations to demonstrate improvements in building energy efficiency and demand reduction.

The focus of this study was to achieve the industry targets, which use an energy use intensity metric, however Standard Assessment Procedure (SAP) calculations were also undertaken to assess compliance with future targets under Building Regulations.

4.2 EMBODIED CARBON

4.2.1 Structure and façade

	Baseline	Intermediate	Stretch
Substructure	Concrete foundations Beam and block floor	As for baseline, but concrete foundations increase in size by 10% for point loads	Low carbon cement and concrete
Superstructure	Traditional masonry frame with structural steel beams Timber flooring and stairs (houses); concrete flooring and stairs (apartments)	Timber beams and frame Timber flooring and stairs (houses and apartments)	Timber beams and frame Timber flooring and stairs (houses and apartments) Low carbon products for PVC membranes, finishes, sanitaryware
Insulation	Expanded polystyrene insulation	Expanded polystyrene insulation	Glass wool insulation
Façade	Brick and natural stone cladding Steel entrance canopy	Brick cladding only Steel entrance canopy removed	1/3 brick cladding, 2/3 timber cladding

Please note, all figures quoted for comparison in the following section are for the detached house type, unless otherwise stated. Please see Appendix D for a complete breakdown of results for all four typologies.

Substructure

The **BASELINE** design represents standard construction practice using concrete foundations, and a beam and concrete block ground floor slab. The entire substructure makes up 18% of total upfront carbon (89 of 506 $kgCO_2e/m^2$ for the detached house type).

To accommodate the move from a steel to timber frame, the **INTERMEDIATE** design uses the same concrete foundations, however increased in size by 10%. Whilst the switch to a timber frame would result in a lighter superstructure, the increase in concrete foundation is required to account for a higher amount of point loads. The upfront carbon for the substructure actually increases by 12% from the baseline scenario (from 89 to 100 $kgCO_2e/m^2$ for the detached house type), despite the change to a timber frame. Further detailed design could help optimise the foundations to reduce the total amount of concrete required.

The **STRETCH** design uses the same concrete foundations as in the intermediate design, however with cement replacement to include 60% ground granulated blast-furnace slag[4] (GGBS) and calcium sulphate screed. This results in a significant carbon saving with the total substructure halving between the intermediate and stretch scenarios (from 100 to 48 $kgCO_2e/m^2$ for the detached house type). However, there are anticipated challenges in sourcing GGBS as the industry moves towards adopting it at scale, demonstrating the need for further R&D and innovation in product manufacturing.

Superstructure

The superstructure in the **BASELINE** design – comprising external walls, facade, internal walls, floors, windows and doors – is the highest contributor to upfront carbon at 58% (295 of 507 $kgCO_2e/m^2$ for the detached house type), representing a significant opportunity for carbon savings.

The baseline design uses a steel beam and concrete block frame; brick and natural stone cladding; timber interior walls, doors and roof; and PVC windows and membranes. The houses have timber floors and stairs, whereas the apartment has concrete floors and stairs.

The external walls in the **INTERMEDIATE** design undergo a switch from steel and concrete block to timber frame. The stone cladding from the façade is removed, leaving a full brick façade. These changes reduce embodied carbon by around 11% (from 295 to 265 $kgCO_2e/m^2$). In addition, for the apartment, the floors and stairs switch from concrete to timber.

Greater carbon savings were realised in the **STRETCH** design by replacing two-thirds of the brick façade with timber cladding. Brick was retained to the lower third of walls to maintain as it was considered typical of what houseowners would expect and also meet local design codes. However, in future, this market norm could be challenged with full timber cladding or other low carbon options (e.g., prefabricated panels). That said, it's important to note the significant barriers to switching for timber construction following the Grenfell enquiry – which is affecting the ability to obtain insurance get, guarantee customer confidence and indeed enter into the commercial agreements with contractors in the first place who now carry substantial liabilities and risks under the Building Safety Act.

Insulation switches from expanded polystyrene insulation panels to glass wool insulation, which has a lower carbon content and high thermal properties, and low carbon products are used in place of PVC membranes. Collectively, this reduces carbon by a further 30% from the intermediate scenario (from 265 to 186 $kgCO_2e/m^2$).

Other

The internal finishes, including plaster and paints, make up a relatively high contribution to embodied carbon – 5% to 6% of the baseline total for the detached house. Selecting low carbon alternatives reduced the embodied carbon of finishes by 20% between the baseline and stretch scenarios. A switch from PVC frame to timber frame windows would have reduce embodied carbon further but was not adopted by the task group owing to cost implications.

4.2.2 Heating system

Two **INTERMEDIATE** designs are assessed – one served by a local air source heat pump (ASHP) and another where the heating and hot water demands are met via a communal district heating network (DHN).

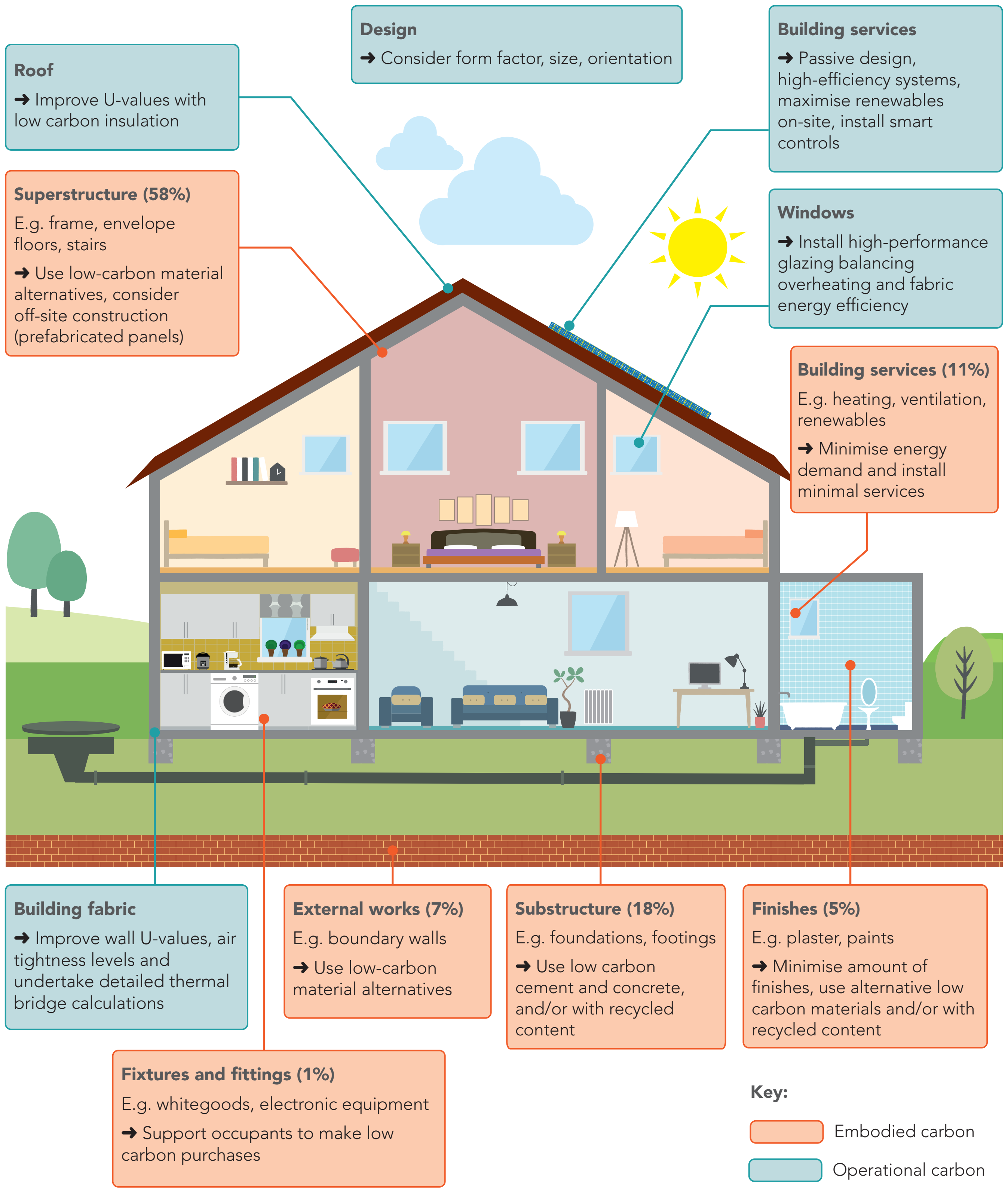
The masterplan report highlighted that the embodied carbon from the heat network is challenging to compare with other on-plot solutions, as the impact has effectively shifted from the homes analysis to the masterplan i.e. there will be a commensurate reduction in embodied carbon for homes due to the removal of on-plot heating systems.

For the designs implementing a heat network, to provide a comparative scenario, benchmark embodied carbon figures for heat network infrastructure, per square metre of floorspace, were taken from similar projects and applied to the house types of the intermediate design, in lieu of the local ASHP. The embodied carbon of a local heat interface unit is also included.

From an embodied carbon perspective, the difference between a home served by a local heating system and a community heat network was shown to be negligible (<1%) in the case of this analysis. However, due to the variability of heat network arrangements and designs, this may not reflect the reality of other prospective heat network implementations. It should also be noted that embodied carbon data and processes for building services are still emerging and these conclusions should therefore be considered with caution.

Figure 6: Example brick façades from Trumpington Meadows development

Figure 7: Summary of design interventions used to reduce operational carbon (in blue) and embodied carbon (in orange, with percentage contribution to total upfront carbon also shown)



4.2.3 Results

Figure 8: Upfront carbon results (module A; $kgCO_2e/m^2$)

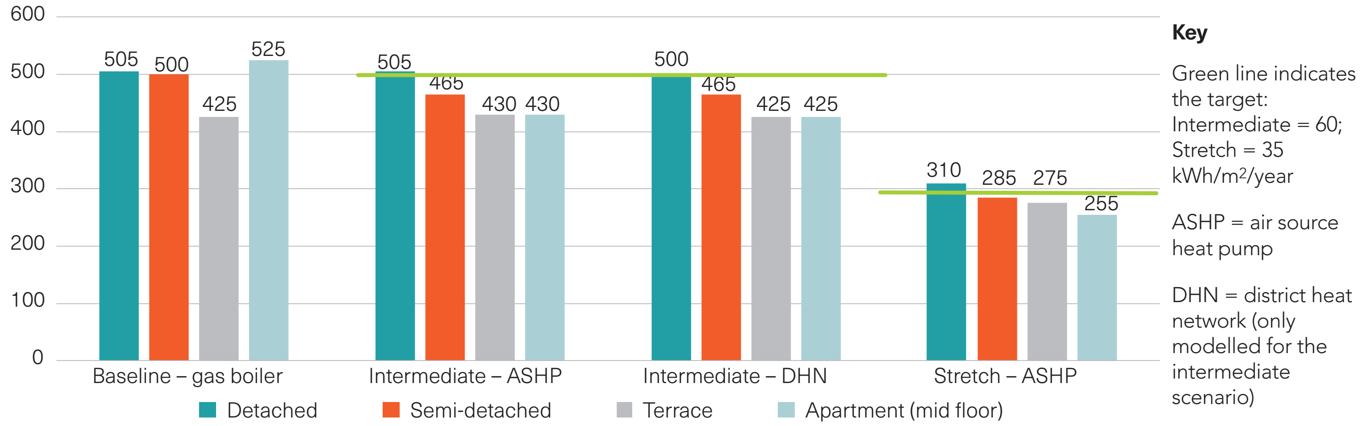
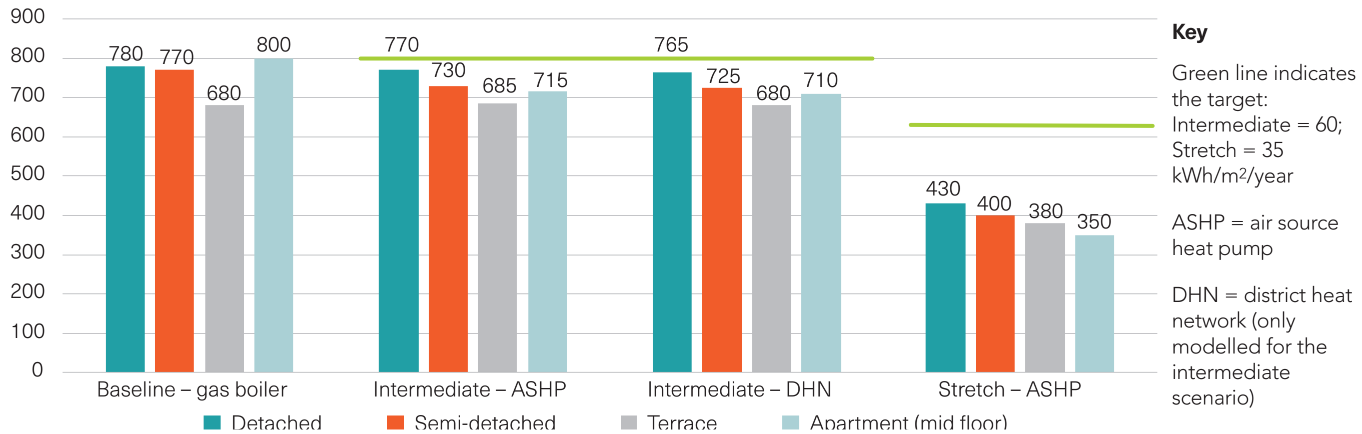


Figure 9: Embodied carbon results (modules A to C, excluding B6 & B7; $kgCO_2e/m^2$)



Conclusions

- Substantial reductions in embodied carbon can be delivered for new-build homes in design today, using existing products and design practices
- The difference in embodied carbon between a home served by a local heating system and a community heat network was shown to be negligible (<1%) in the case of this analysis
- More work is required to develop a consistent set of upfront construction and embodied carbon targets for different building typologies

All homes evaluated achieve both the intermediate and stretch upfront carbon and embodied carbon sets of targets (with the exception of the detached house for upfront carbon in the stretch scenario). This clearly demonstrates that substantial embodied carbon savings can be achieved by homes in design today, even without significant reductions in product manufacturing emissions, or robust supplies of reused or recycled materials. This also suggests that the derivation of embodied carbon targets may need to be revisited given, for example, that targets under the stretch scenario are easily achieved, which leaves room for strengthening ambition. Different embodied carbon targets tailored to different types of homes would also be beneficial.

Reducing emissions today presents the greatest benefit in mitigating the effects of climate change, and so reducing construction-related upfront carbon emissions should become a priority. Reductions in upfront carbon are primarily delivered by using alternative low carbon products, whilst maintaining much of the existing design. The terrace and apartment types have the lowest upfront carbon, largely given they share structural frames and foundations with other dwellings, with the apartment's upfront carbon intensity halving between the baseline and stretch scenarios (from 525 to 255 $kgCO_2e/m^2$).

5. Cost changes

As the previous section has shown, homes can be designed today to achieve ambitious energy and embodied carbon reduction targets. However, a better understanding of the effects on capital cost is necessary. This section provides estimates of the key cost changes from the baseline scenario to the intermediate and stretch scenarios.

5.1 METHODOLOGY

This section outlines the order of cost estimate to achieve the intermediate and stretch design targets for the houses and apartments. The cost changes are represented per building element on a cost per square metre basis (£/m²) to allow a direct comparison between the scenarios.

Please note, this modelling was undertaken in August 2021 and does not account for market price fluctuations or developments in technology and supply chain availability since then. The cost modelling demonstrates an estimated order of cost associated with the design changes modelled.

For the baseline scenario, detailed drawings were used as the basis of quantification and pricing. For the intermediate and stretch scenarios, costs are modelled on outline scope changes without detailed design information, and as such represent an order of magnitude estimate.

Costs are based on a blend of housebuilder and contractor data and are informed by the Arcadis benchmark database. Where possible, the supply chain has been engaged to provide cost data.

In some instances, accurate cost data has been difficult to obtain from the supply chain, which is representative of emerging technologies and a restricted supply chain. As such, assumptions have been made to give a cost uplift.

Costs were based on prices at the time of modelling (August 2021) and traditional methods of construction, and it is recognised that as the market matures, costs may decrease as efficiencies are realised. Furthermore, the introduction of government incentives and modern methods of construction may provide further cost reductions over time.

This report includes costs associated with on-plot heating systems, not the district heat network, which is included in the supporting Masterplan report. Facilitating works, overheads and profit, design fees, risk and out of the ordinary project specific costs (i.e., abnormals, such as, ground remediation, site specific constraints, pumping, ecology remediation) have been excluded.

Table 4: Key metrics and construction solutions proposed for each scenario

	Houses (Blended)			Apartments (Total Block)		
	Baseline	Intermediate	Stretch	Baseline	Intermediate	Stretch
GIA (m²)	120	120	120	1,017	1,017	1,017
NIA (m²)	120	120	120	745	745	745
NIA: GIA	100%	100%	100%	73%	73%	73%
No. of Units	1	1	1	12	12	12
Total Floors	3	3	3	4	4	4
Floor to Ceiling (m)	2.28	2.28	2.28	2.46	2.46	2.46

5.2 HOUSES

5.2.1 Overview

Although the study modelled three different house types (terrace, detached and semi-detached), the results below are based upon a blend. The table illustrates the cost uplift from the baseline to the intermediate and stretch scenarios for the design changes outlined in the Design Changes section of this report.

Table 5: Cost results for a typical blended house (represented per building element on a cost per metre square basis to allow direct comparison between the scenarios)

Blended houses	Baseline	Intermediate			Stretch		
	£/m²	£/m²	Variance £/m²	Change from baseline	£/m²	Variance £/m²	Change from baseline
1 Substructure	£149	£153	£5	3%	£163	£14	10%
2 Superstructure	£644	£682	£38	6%	£765	£121	19%
2.1 Frame	£58	£77	£19	32%	£77	£19	32%
2.2 Upper Floors	£46	£46	£0	0%	£48	£2	4%
2.3 Roof	£54	£62	£8	16%	£62	£8	16%
2.4 Stairs and Ramps	£5	£5	£0	0%	£5	£0	0%
2.5 External Walls	£276	£283	£7	3%	£352	£77	28%
2.6 Windows & External Doors	£67	£67	£0	0%	£77	£11	16%
2.7 Internal Walls & Partitions	£100	£103	£4	4%	£107	£7	7%
2.8 Internal Doors	£39	£39	£0	0%	£39	£0	0%
3 Internal Finishes	£145	£145	£0	0%	£152	£7	5%
4 Fittings, Furnishing & Equipment	£64	£64	£0	0%	£64	£0	0%
5 Services (incl PV)	£257	£313	£56	22%	£340	£83	32%
9 Preliminaries	£113	£122	£9	8%	£149	£35	31%
Total £/m²	**£1,371**	**£1,478**	**£107**	**8%**	**£1,634**	**£263**	**19%**

Table 6: Cost per unit for three house types

	Baseline	Intermediate		Stretch	
	Cost per Unit	Cost per Unit	Uplift from baseline	Cost per Unit	Uplift from baseline
Detached	£212,000	£226,000	6.6%	£251,000	18.4%
Terrace	£129,000	£141,000	9.3%	£155,000	20.2%
Semi-detached	£154,000	£167,000	8.4%	£184,000	19.5%

5.2.2 Key cost drivers

1 Substructure

Baseline	Intermediate	Stretch
£149	£153	£163

Note:

- Foundations increased for the intermediate and stretch scenarios to allow additional point loads imposed by a change to timber frame. Insulation thickness within the ground floor slab increased to 200mm.
- Stretch scenario has introduced recycled steel rebar, GGBS concrete, cellulose insulation, Enviroblock and calcium sulphate screed.

2.1, 2.2 and 2.4 Frame, Upper Floors & Stairs

Baseline	Intermediate	Stretch
£109	£128	£130

Note:

- Frame changed from traditional concrete block and steel lintel in the baseline to a timber frame solution for the intermediate and stretch scenarios.
- Upper floors are timber in all scenarios; with a recycled timber floor introduced in the stretch scenario.
- Internal timber stairs remain constant throughout all scenarios.

2.3 Roof

Baseline	Intermediate	Stretch
£54	£62	£62

Note:

- Timber flat roof in the baseline scenario amended to an increased insulation thickness of 350mm in the intermediate scenario.
- Insulation in the stretch scenario switched to glasswool with a laminated high density polyethylene membrane.

2.5-6 External Walls, Windows & External Doors

Baseline	Intermediate	Stretch
£343	£350	£429

Note:

- Baseline external wall build-up consists of a blockwork inner face, 100mm cavity with facing brick and stone banding.
- Intermediate scenario includes timber frame internal wall in lieu of blockwork, 200mm cavity with facing brick and stone banding.
- Stretch position includes timber frame internal wall in lieu of blockwork, 225mm glass wool insulation with a combination of facing brick and timber cladding. The stone banding has been omitted. The stretch scenario also includes additional cost to account for enhanced airtightness.
- Windows are PVC double-glazed for the baseline and intermediate scenarios, increasing to PVC triple-glazed for the stretch.
- The steel entrance canopy has been omitted from the intermediate and stretch scenarios.

2.7-8 Internal Partitions & Doors

Baseline	Intermediate	Stretch
£139	£142	£146

Note:

- Internal party walls between terrace and semi-detached houses change from blockwork to timber construction for intermediate and stretch, with increased insulation thickness. For the stretch scenario, the mineral wool insulation is replaced with glasswool.
- Internal non-load bearing stud partitions are the same for baseline and intermediate scenarios. At stretch, the insulation is replaced with glasswool, and the plasterboard is low carbon with increased thickness.
- No changes to internal doors across the scenarios.

3 Internal Finishes

Baseline	Intermediate	Stretch
£145	£145	£152

Note:

- Wall finishes remain constant between the baseline and intermediate scenarios. For the stretch scenario, paints with recycled content are specified.
- Floor finishes remain constant between the baseline, intermediate and stretch scenarios.
- Ceiling finishes remain constant between the baseline and intermediate scenarios. For the stretch scenario, there is an allowance for low carbon plasterboard with increased thickness, as well as clay plaster.

5 Services

Baseline	Intermediate	Stretch
£257	£313	£340

Note:

- Baseline consists of a gas boiler system with natural ventilation.
- Intermediate scenario includes mechanical extract ventilation and air source heat pump with oversized radiators.
- Stretch scenario allows for whole house mechanical ventilation with heat recovery, as well as the air source heat pump and wet underfloor heating.
- PV varies slightly across scenarios; however, this has a negligible impact on costs.

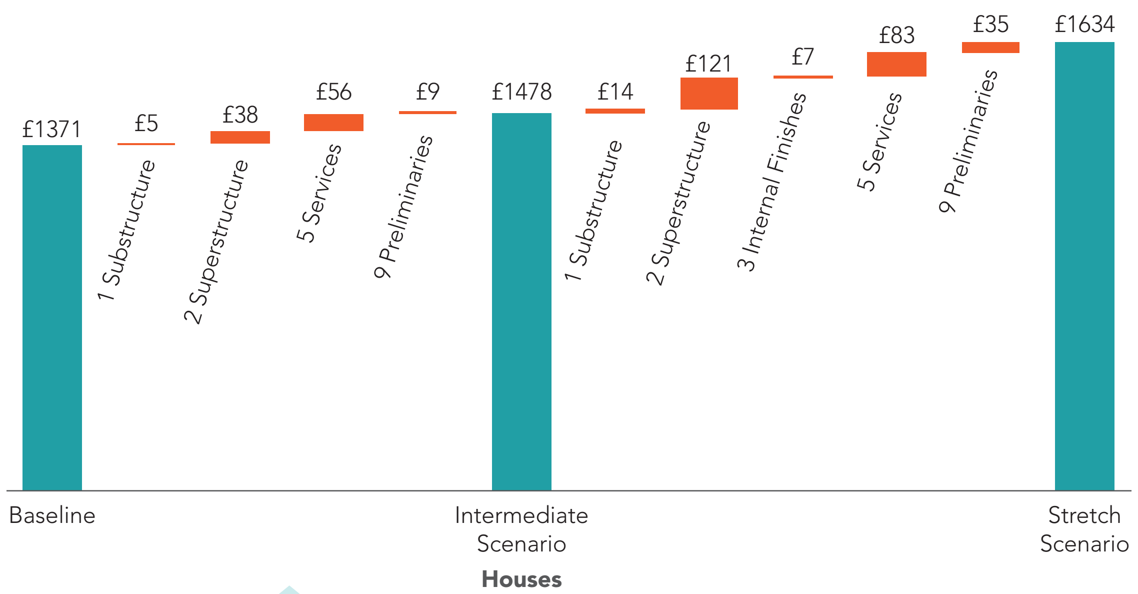
9 Preliminaries

Baseline	Intermediate	Stretch
£113	£122	£149

Note:

- Preliminaries percentage applied to the baseline and intermediate scenarios remained constant.
- Increase from 9-10% between the intermediate and stretch scenarios to account for additional preliminaries costs associated with achieving the required airtightness values enhanced quality assurance process on site.

Figure 10: Waterfall chart illustrating key cost drivers between the design scenarios for the blended houses



5.3 APARTMENTS

5.3.1 Overview

Table 7: Cost results for the mid-floor apartment (represented per building element on a cost per metre square basis to allow direct comparison between the scenarios)

Apartment	Baseline	Intermediate			Stretch		
	£/m²	£/m²	Variance £/m²	Change from baseline	£/m²	Variance £/m²	Change from baseline
1 Substructure	£121	£125	£4	3%	£136	£15	12%
2 Superstructure	£880	£921	£40	5%	£1,027	£146	17%
2.1 Frame	£57	£87	£30	53%	£87	£31	54%
2.2 Upper Floors	£81	£81	£0	0%	£130	£49	61%
2.3 Roof	£75	£83	£8	11%	£83	£8	11%
2.4 Stairs and Ramps	£29	£9	-£20	-69%	£9	-£20	-69%
2.5 External Walls	£322	£340	£18	5%	£385	£62	19%
2.6 Windows & External Doors	£101	£101	£0	0%	£112	£11	11%
2.7 Internal Walls & Partitions	£150	£155	£5	4%	£156	£6	4%
2.8 Internal Doors	£65	£65	£0	0%	£65	£0	0%
3 Internal Finishes	£131	£131	£0	0%	£143	£12	10%
4 Fittings, Furnishings & Equipment	£83	£83	£0	0%	£83	£0	0%
5 Services (incl PV)	£309	£380	£71	23%	£406	£97	31%
9 Preliminaries	£137	£148	£10	8%	£179	£42	31%
Total (£/m²)	**£1,661**	**£1,787**	**£126**	**8%**	**£1,974**	**£313**	**19%**

5.3.2 Key cost drivers

1 Substructure

Baseline	Intermediate	Stretch
£121	£125	£136

Notes:

- Foundations for the intermediate and stretch scenarios increased to allow additional point loads imposed by a change to timber frame. The insulation thickness within the ground floor slab has increased to 200mm.
- Stretch has introduced recycled steel rebar, GGBS concrete, cellulose insulation, Enviroblock and calcium sulphate screed in addition to the intermediate scenario.

2.1, 2.2 and 2.4 Frame, Upper Floors & Stairs

Baseline	Intermediate	Stretch
£167	£177	£226

Notes:

- Frame changed from traditional concrete block and steel lintel in the apartments to a timber frame solution for both the intermediate and stretch scenarios.
- Baseline upper floor construction is a pre-cast concrete plank floor slab, and the internal stairs are pre-cast concrete.
- For the intermediate scenario, the upper floor construction is timber joist construction, with timber stairs.
- The stretch scenario is timber floor joist construction with recycled raised access floor panels, and the internal stairs are timber.

2.3 Roof

Baseline	Intermediate	Stretch
£75	£83	£83

Notes:

- Timber flat roof in the baseline scenario is amended to an increased insulation thickness of 350mm in the intermediate scenario.
- For the stretch scenario, the insulation is changed to glasswool with a laminated high-density polyethylene membrane.

2.5-6 External Walls, Windows & External Doors

Baseline	Intermediate	Stretch
£423	£441	£497

Notes:

- The baseline external wall build-up consists of a blockwork inner face, 100mm cavity with facing brick and stone banding.
- The intermediate scenario includes timber frame internal wall in lieu of blockwork, 200mm cavity with facing brick.
- Stretch position includes timber frame internal wall in lieu of blockwork, 225mm glasswool insulation with a combination of facing brick and timber cladding. The stone banding has been omitted. The stretch scenario also includes additional cost to account for enhanced airtightness.
- Windows are PVC double-glazed for the baseline and intermediate scenarios, increasing to PVC triple-glazed for the stretch.
- The steel entrance canopy has been omitted from the intermediate and stretch scenarios.

2.7-8 Internal Partitions & Doors

Baseline	Intermediate	Stretch
£215	£220	£221

Notes:

- Internal load bearing party walls change from blockwork to timber construction for intermediate and stretch, with increased insulation thickness. For the stretch scenario, the mineral wool insulation is replaced with cellulose.
- Internal non-load bearing stud partitions are the same for baseline and intermediate scenarios save for additional pattresses within the intermediate for oversized radiators. At stretch, the insulation is replaced with cellulose, and the plasterboard is low carbon with increased thickness.
- No changes to internal doors through the scenarios.

3 Internal Finishes

Baseline	Intermediate	Stretch
£131	£131	£143

Notes:

- Wall finishes remain constant between the baseline and intermediate scenarios. For the stretch scenario, paint with recycled content is specified.
- Floor finishes remain constant through all scenarios.
- Ceiling finishes remain constant between the baseline and intermediate scenarios. For the stretch scenario, there is an allowance for low carbon plasterboard with increased thickness, as well as clay plaster.

5 Services

Baseline	Intermediate	Stretch
£309	£380	£406

Notes:

- The baseline is gas boiler system with local passive ventilation.
- The intermediate scenario includes mechanical extract ventilation and air source heat pump with oversized radiators.
- Stretch scenario allows for whole apartment mechanical ventilation with heat recovery, as well as air source heat pump and wet underfloor heating.

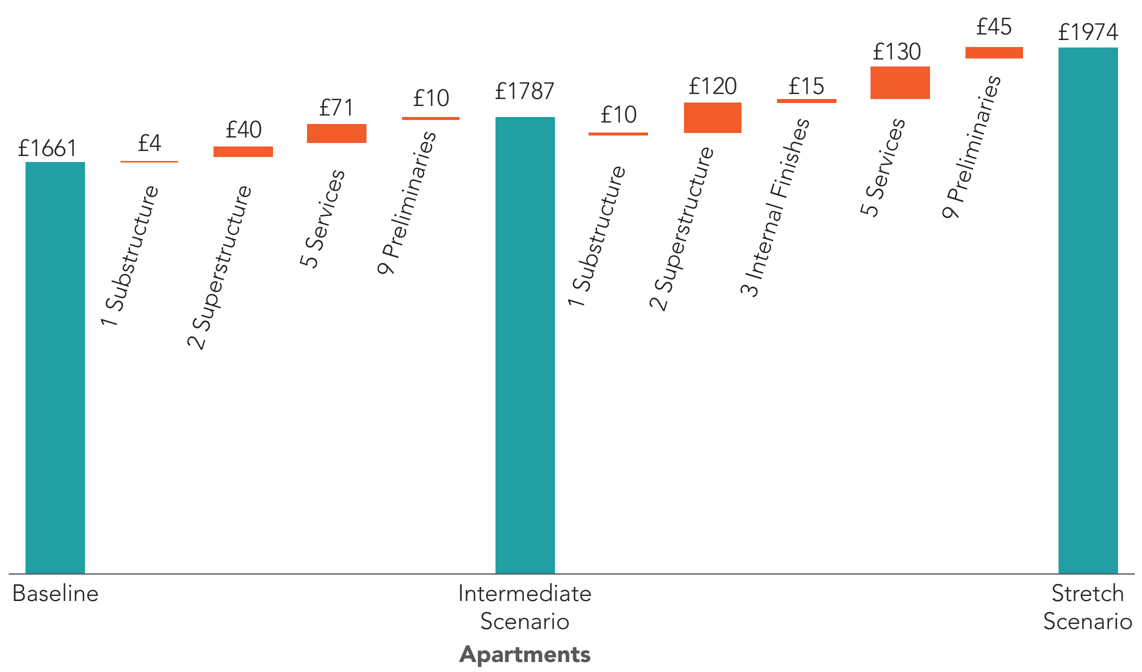
9 Preliminaries

Baseline	Intermediate	Stretch
£137	£148	£179

Notes:

- Preliminaries percentage applied to the baseline and intermediate scenarios remained constant.
- Increase from 9-10% between the intermediate and stretch scenarios to account for additional preliminaries costs associated with achieving the required airtightness values and enhanced quality assurance processes on site.

Figure 11: Waterfall chart illustrating key cost drivers between the design scenarios for the apartments



5.4 NOTES

5.4.1 Operational and embodied carbon split

The costs presented above are inclusive of design changes to achieve both the operational and embodied carbon improvements. An exercise was undertaken to roughly apportion the costs to achieve either the operational or embodied carbon targets, as per Table 8. The leading driver for any design change has been used to apportion costs and, where appropriate, estimated proportional values of specific elements have been applied.

These findings suggest that achieving operational energy targets (i.e., improving fabric and additional building systems) is currently more expensive than achieving the embodied carbon targets (i.e., dematerialisation or material switching). Please see Appendix E for a granular breakdown of how costs have been apportioned.

5.4.2 Other cost considerations

Throughout this exercise, the task group reviewed alternative solutions to meet and exceed the targets set out by current Part L, LETI, RIBA. For example, the use of ground source heat pumps (GSHP) was considered in lieu of air source heat pumps (ASHP), however this option was disregarded due to the uncertainty of ground conditions and the variables that impact the use of GSHPs. The use of a low carbon cellulose insulation to the external walls was also considered, however, achieving the required U-values would have resulted in an external wall cavity of 400mm, leading to a cost increase of circa £3,000 per dwelling in the stretch scenario.

5.4.3 Exclusions and other notes

Exclusions:

- Facilitating and enabling works
- Professional fees
- Costs for Passivhaus certification
- Disposal of contaminated material
- External works
- Solar thermal

Other notes:

- Detailed design has not been provided in the preparation of this estimate.
- Technologies are emerging and therefore, where appropriate, notional allowances have been applied for specific design changes.
- Costs are exclusive of main contractor overheads and profits.
- No allowance for VAT has been made.
- Costs consider current day prices (as of August 2021). No allowance has been made for significant spikes in material cost increases.

Table 8: Breakdown of cost uplifts according to operational energy and embodied carbon design changes for the houses

	Cost uplift from baseline	Intermediate targets		Stretch targets	
		Operational energy	Embodied carbon	Operational energy	Embodied carbon
Intermediate	8%	7%			
			1%		
Stretch	19%			14%	
					5%

6. Other Considerations

The scope of this study was initially intentionally focused in order to develop robust findings that would form part of an evidence base. Various discussion topics and wider considerations, however, were raised by the task group along the way. A summary of these have been captured below to stimulate discussion among relevant stakeholders and form the basis of future studies.

6.1 KEY DRIVERS FOR CHANGE

- Avoided cost of retrofit – Delivering near net zero carbon new-build homes from the mid-2020s would save the UK retrofitting an additional c. 9 million homes by 2050 and avoid consumer disruption, cost and embodied carbon.
- Operational energy savings – Energy reductions are in the order of 80% between baseline and stretch (exact monetary changes to occupiers would need to be modelled in a future study), and all-electric homes would reduce exposure to volatility from wholesale gas price increases (experienced recently in 2022).
- Improved occupier amenity – Low carbon homes are warmer, healthier, and more comfortable to live in due to high-quality design, including improved building fabric and smart building systems.
- Futureproof homes – Low carbon homes will avoid risks from upcoming regulation – including the Future Homes Standard, embodied carbon standards and MEES – and future climate risks – including flooding and overheating.
- Strengthen ESG credentials – Homebuilders demonstrate a leadership position by delivering significant energy and embodied carbon reductions in new-build homes, as per the NextGeneration benchmark, and reduce their scope 3 emissions by tackling embodied carbon.
- Falling capital costs – Over time, the cost to deliver low carbon homes are anticipated to fall as new and more efficient technologies emerge and through the potential introduction of Government subsidies.

6.2 OTHER DESIGN MEASURES TO CONSIDER

- Target unregulated loads – These are within the homeowner's control and, as such, have been modelled as constant for all scenarios in this study, however, could be addressed to reduce total energy use (e.g., through specification of highly efficient whitegoods).
- Bulk purchasing agreements – Agreements with the supply chain to achieve economies of scale and reductions from market prices (e.g., purchasing air source heat pumps for a large, 750-home scheme).
- Select materials that are reused, recycled, or can be reused at end-of-life – Prioritise circular economy principles, which can also be cheaper and maintain maximum utility over their lifetime.
- Prioritise home types – Deliver low carbon homes that are relatively easier and cheaper to deliver (e.g., increase proportion of terraces and apartments, in place of detached houses which are less efficient).

7. Glossary of Terms

Embodied carbon – Total greenhouse gas emissions and removals related to materials and construction processes throughout the whole lifecycle of a building, including construction, use, maintenance, repair, replacement, refurbishment, and end-of-life (modules A to C, excluding B5 & B6 from BS EN 15978).[5]

Net zero carbon – construction – When the amount of carbon emissions associated with a building's product and construction stages up to practical completion is zero or negative, through the use of offsets.[6]

Net zero carbon – operational energy – When the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly energy efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset.[7]

Regulated energy – Energy consumption resulting from the specification of controlled, fixed building services and fittings, including space heating and cooling, hot water, ventilation and lighting.[8]

Unregulated energy – Energy consumption of the home that is not 'controlled', i.e., energy consumption from aspects of the home on which Building Regulations do not impose a requirement, e.g., appliance energy use.[9]

Upfront carbon – Total greenhouse gas emissions related to materials and construction processes up to practical completion (module A from BS EN 15978).[10]

References

1 Royal Institute of British Architects (2021), 2030 Climate Challenge: https://www.architecture.com/about/policy/climate-action/2030-climate-challenge/sign-up, BAU = compliance approach; Intermediate = 2025 target; Stretch = 2030 target

2 London Energy Transformation Initiative (2020), Climate Emergency Design Guide: https://www.leti.london/cedg, BAU = Baseline; Intermediate = Best practice 2020; Stretch = Best practice 2030

3 Royal Institute of British Architects (2021), 2030 Climate Challenge: https://www.architecture.com/about/policy/climate-action/2030-climate-challenge/sign-up, BAU = compliance approach; Intermediate = 2025 target; Stretch = 2030 target

4 Cementitious Slag Makers Association (2021), Addition to Concrete: https://ukcsma.co.uk/ggbs-concrete/addition-to-concrete/

5 Whole Life Carbon Network (2021), Carbon Definitions for the Built Environment, Buildings and Infrastructure: https://www.leti.london/carbonalignment

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8 Building Research Establishment (2018), Home Quality Mark ONE Technical Manual England: https://www.homequalitymark.com/professionals/standard/

9 Building Research Establishment (2018), Home Quality Mark ONE Technical Manual England: https://www.homequalitymark.com/professionals/standard/

10 Whole Life Carbon Network (2021), Carbon Definitions for the Built Environment, Buildings and Infrastructure: https://www.leti.london/carbonalignment

Appendix A: Acknowledgements

TASK GROUP

UKGBC convened individuals with experience working on the Trumpington South project to form the task group. We would like to offer a special thanks to all task group members for dedicating their time and expertise to meet regularly over a four-month period to undertake the study's analysis. This included developing the design scenarios for both the homes and masterplan; completing the design, carbon, and cost modelling; and preparing findings for this report. UKGBC is grateful for their in-kind contribution to undertake this piece of work.

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Organisation	Role	Representatives
Arcadis	Costing	Richard Proctor, Elliot Taylor, Anthony Brown, David Day
Barratt Developments	Housebuilder	Oliver Novakovic, Danielle Michalska, Daniel Shea
Buro Happold	Sustainability	Mark Dowson, Josephine Benthall, Martha Dillon
Grosvenor Property UK	Developer	Andy Sharpe, Rupert Biggin
One Click LCA Ltd	Sustainability	Marios Tsikos
Terence O'Rourke	Architects and Masterplanner	Terry Williams, Dan Fairley, Richard Burton

REVIEW GROUP

UKGBC sought to feed-in views from a wider set of stakeholders – including other designers, developers, housebuilders, and financiers and policymakers – to help enhance the findings of the study. The review group provided input at two key points during the development of the study, as well as reviewing the findings and final report.

We would like to thank the organisations listed below:

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- GS8
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- Homes England
- HTA Design
- Hydrock
- Igloo
- Legal & General Capital
- Lendlease
- Lloyds Banking Group
- Ministry of Housing, Communities and Local Government (MHCLG)
- Modomo
- Nationwide
- NatWest Group
- Project Etopia
- PTE Architects
- Redrow
- Rockwool
- Telford Homes
- Thakeham

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Lead Partner:

Laudes Foundation

Corporate Partners:

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Appendix B: Detailed operational energy inputs

This schedule lists the inputs used to undertake the operational energy modelling within PHPP.

Green cells = all design changes are applied equally across all types of homes.
Orange cells = some variance in design changes, with notes on which homes are different.

			Baseline	Intermediate	Stretch
Fabric	Glazing	Window type	Double	Double / Triple	Triple
		Frame type	PVC	PVC	PVC
		Window U-value (Glass only)	1.4	1.1	0.7
		Window G-value (Glass only)	0.44	0.6	0.6
		Frame U-value	1.3	1	0.8
	Walls	External Wall U-value	0.21	0.17	0.1
		Party Wall U-value	0 (for three types, N/A for detached)	0.3 (for three types, N/A for detached)	0.17 (for three types, N/A for detached)
	Roof	Roof External U-value	0.19	0.12	0.1
		Roof Internal U-value	1 (apartment only)	1 (apartment only)	0.1 (apartment only)
	Ground floor	Ground floor U-value	0.2	0.14	0.1
		Party floor	0.15 (apartment only)	0.15 (apartment only)	0.12 (apartment only)
	Air tightness	$m^3/(hm^2)$	5	3	1
	Thermal Bridging		Default	ACDs	PCDs
Systems	Ventilation	Type	Natural ventilation (for three house types) Mechanical extract ventilation (apartment only)	Mechanical extract ventilation	Individual MVHR (84% heat recovery efficiency)
	Electricity* *Other unregulated loads are included using PHPP assumptions	Dishwasher present?	Cold water connection	Cold water connection	Cold water connection
		Dishwasher kWh/use	1.1	1.1	1.1
		Washing Machine	Cold water connection	Cold water connection	Cold water connection
		Washing Machine kWh/use	1.1	1.1	1.1
		Clothes drying	Condensation dryer	Condensation dryer	Condensation dryer
		Clothes dryer kWh/use	3.5	3.5	3.5
		Fridge (kWh/d)	0.78	0.78	0.78
		Freezer (kWh/d)	0.88	0.88	0.88
		Ceramic Cook Top (kWh/use)	0.22	0.22	0.22

			Baseline	Intermediate	Stretch
Systems	Space Heating	Length of distribution pipes (m)	60 (20 /floor)	60 (20 /floor)	60 (20 /floor)
		Nominal width of heat distribution pipes (mm)	15	15	15
		Insulation thickness on heat distribution pipes (mm)	25	25	25
		Thermal conductivity of insulation (W/(mK))	0.035	0.035	0.035
		Design forward flow temperature (°C)	55	45	30
	DHW	Wastewater heat recovery?	Yes	Yes	Yes
		Storage	No storage tank	DHW only	DHW only
		Inside or Outside thermal Envelope		Inside	Inside
	Heat Delivery	Primary heat generation type	Gas Boiler (0.95 efficiency)	Air source heat pump (for 100 home scheme) District heat network (for 750 home scheme)	Ground source heat pump
		Heat pump distribution system		Radiators (for 100 home scheme only)	Underfloor heating
		Efficiency	0.95	2	3.05
	Renewable Energy Generation	Renewable Energy Generation	PV	PV	Solar thermal and PV
		PV area (m^2)	9.6 (for three house types) 0 (for apartment)	9.6 (for three house types) 0 (for apartment)	9.6 (for three house types) 0 (for apartment)
		Solar Thermal Area (m^2)	0	0	4.5

Appendix C: Detailed operational energy results

BASELINE	Heating demand (kWh/m²)	Space heating consumption (kWh/m²)	Hot Water Consumption (kWh/m²)	Total Auxiliary (pumps and ventilation) (kWh/m²)	Lighting (kWh/m²)	Plug and cooking (kWh/m²)	Total generation (kWh/m²)	Total consumption (kWh/m²)
Detached	102	108	19	2	1	16	10	146
Semi-Detached	108	114	21	2	1	17	11	155
Terraced	118	124	22	3	1	18	12	168
Apartment	57	60	31	5	1	27	0	124

BASELINE	Regulated					Unregulated	
	Space heating ($kgCO_2/m^2$)	DHW ($kgCO_2/m^2$)	Auxiliary (pumps and ventilation) ($kgCO_2/m^2$)	Lighting ($kgCO_2/m^2$)	Regulated emissions ($kgCO_2/m^2$)	Plug and cooking ($kgCO_2/m^2$)	Total emissions ($kgCO_2/m^2$)
Detached	25.0	4.5	0.5	0.2	30	3.8	34
Semi-Detached	26.5	4.8	0.6	0.2	32	4.0	36
Terraced	28.9	5.1	0.6	0.2	35	4.2	39
Apartment	13.9	7.2	1.3	0.2	23	6.3	29
(Assumes all-electric systems and latest SAP10 carbon emissions factors)							

BASELINE	Regulated					Unregulated	
	Space heating ($kgCO_2/m^2$)	DHW ($kgCO_2/m^2$)	Auxiliary (pumps and ventilation) ($kgCO_2/m^2$)	Lighting ($kgCO_2/m^2$)	Regulated emissions ($kgCO_2/m^2$)	Plug and cooking ($kgCO_2/m^2$)	Total emissions ($kgCO_2/m^2$)
Detached	22.6	4.0	0.5	0.2	27.3	3.8	31
Semi-Detached	23.9	4.3	0.6	0.2	29.0	4.0	33
Terraced	26.1	4.6	0.6	0.2	31.5	4.2	36
Apartment	12.6	6.5	1.3	0.2	20.6	6.3	27
(Baseline gas boiler assumption)							

INTERMEDIATE	Heating demand (kWh/m²)	Space heating consumption (kWh/m²)	Hot Water Consumption (kWh/m²)	Total Auxiliary (pumps and ventilation) (kWh/m²)	Lighting (kWh/m²)	Plug and cooking (kWh/m²)	Total generation (kWh/m²)	Total Consumption (kWh/m²)
Detached	57	29	9	2	1	16	10	56
Semi-Detached	61	31	9	2	1	17	11	60
Terraced	34	17	10	2	1	18	12	48
Apartment	31	16	14	5	1	27	0	62

INTERMEDIATE - District Heating	Heating demand (kWh/m²)	Space heating consumption (kWh/m²)	Hot Water Consumption (kWh/m²)	Total Auxiliary (pumps and ventilation) (kWh/m²)	Lighting (kWh/m²)	Plug and cooking (kWh/m²)	Total generation (kWh/m²)	Total Consumption (kWh/m²)
Detached	68	25	8	2	1	16	10	51
Semi-Detached	73	27	11	2	1	17	11	58
Terraced	43	16	9	2	1	18	12	46
Apartment	49	18	13	5	1	27	6	64

STRETCH	Heating demand (kWh/m²)	Space heating consumption (kWh/m²)	Hot Water Consumption (kWh/m²)	Total Auxiliary (pumps and ventilation) (kWh/m²)	Lighting (kWh/m²)	Plug and cooking (kWh/m²)	Total generation (kWh/m²)	Total Consumption (kWh/m²)
Detached	32	11	6	2	1	16	5	36
Semi-Detached	34	11	6	3	1	17	6	38
Terraced	18	6	7	3	1	18	6	35
Apartment	8	3	9	6	1	27	0	46

Appendix D: Detailed embodied carbon results

Description	Target	Results ($kgCO_2e/m^2$)							
		A1-A5	B (excl B6/7)	B6/7	C	D	A Modules	A-C [Excl B6-7]	A-D (excl B6-7)
Detached	Baseline	506	234	0	38	-162	506	778	615
Semi-detached	Baseline	500	235	0	33	-172	500	768	596
Terrace	Baseline	426	223	0	30	-152	426	679	527
Apartment (mid floor)	Baseline	524	243	0	32	-124	524	799	675
Detached	Intermediate	494	218	0	46	-131	494	758	627
Semi-detached	Intermediate	458	220	0	41	-2222	458	720	-1502
Terrace	Intermediate	377	212	0	35	-121	377	623	502
Apartment (mid floor)	Intermediate	425	245	0	40	-118	425	710	592
Detached	Stretch	321	112	0	19	-72	321	451	379
Semi-detached	Stretch	300	104	0	18	-66	300	422	357
Terrace	Stretch	263	102	0	15	-54	263	379	325
Apartment (mid floor)	Stretch	263	79	0	15	-39	263	357	318

Description	Target	A1-A5 breakdown - excl external works					
		% Superstructure	% Substructure	% Services	% Finishes	% FFE	% External works
Detached	Baseline	58	18	11	5	1	7
Semi-detached	Baseline	59	16	11	6	1	7
Terrace	Baseline	52	19	14	6	1	9
Apartment (mid floor)	Baseline	66	15	9	4	1	7
Detached	Intermediate	53	20	13	5	1	7
Semi-detached	Intermediate	51	19	15	6	1	8
Terrace	Intermediate	44	20	18	7	1	10
Apartment (mid floor)	Intermediate	55	19	12	4	1	8
Detached	Stretch	46	14	21	7	1	12
Semi-detached	Stretch	44	15	21	6	1	12
Terrace	Stretch	40	13	25	7	1	14
Apartment (mid floor)	Stretch	42	17	21	6	1	14

Appendix E: Detailed cost results

	Detached			Terraced			Semi-detached		
Elemental cost (£/m^2)	Baseline	Inter.	Stretch	Baseline	Inter.	Stretch	Baseline	Inter.	Stretch
1. Substructure	168	173	184	145	149	158	127	131	139
2. Superstructure	738	775	875	513	548	615	643	684	767
2.1. Frame	91	107	107	40	60	60	34	54	54
2.2. Upper Floors	48	48	49	44	44	46	46	46	47
2.3. Roof	56	65	65	52	61	61	52	61	61
2.4. Stairs and Ramps	4	4	4	6	6	6	5	5	5
2.5. External Walls	367	377	458	133	134	188	288	297	366
2.6. Windows and External Doors	70	70	82	66	66	76	63	63	72
2.7. Internal Walls and Partitions	67	69	73	133	139	141	112	115	119
2.8. Internal Doors	36	36	36	38	38	38	43	43	43
3. Internal Finishes	151	151	158	136	136	143	144	144	151
4. Fittings, Furnishings & Equipment	54	54	54	75	75	75	66	66	66
5. Services	231	277	302	281	346	373	270	328	359
9. Preliminaries	121	129	157	103	113	136	112	122	148
Grand Total	**£1,463**	**£1,560**	**£1,732**	**£1,252**	**£1,368**	**£1,501**	**£1,362**	**£1,474**	**£1,630**

	Baseline	INTERMEDIATE						
		Intermediate (Total)		Embodied Uplift		Operational Uplift		
Blended houses	£/m²	£/m²	Variance £/m²	£/m²	Comments	£/m²	Comments
1 Substructure	£149	£153	£5	£2	Increased foundations for additional point loads for concrete frame.	£3	Increased insulation for enhanced U Values.
2 Superstructure	£644	£682	£38	£12	Details as below.	£26	Details as below.
2.1 Frame	£58	£77	£19	£19	Timber Frame.	£0	No change.
2.2 Upper Floors	£46	£46	£0	£0	No change.	£0	No change.
2.3 Roof	£54	£62	£8	£0	No change.	£8	Additional insulation.
2.4 Stairs and Ramps	£5	£5	£0	£0	No change.	£0	No change.
2.5 External Walls	£276	£283	£7	-£11	Omission of internal Blockwork, addition of timber frame (costs to be considered with 2.1 Frame). Omission of steel canopy.	£18	Additional insulation, enhanced external wall for larger cavity,
2.6 Windows & External Doors	£67	£67	£0	£0	No change.	£0	No change.
2.7 Internal Walls & Partitions	£100	£103	£4	£4	Timber partitions and walls.	£0	No change.
2.8 Internal Doors	£39	£39	£0	£0	No change.	£0	No change.
3 Internal Finishes	£145	£145	£0	£0	No change.	£0	No change.
4 Fittings, Furnishing & Equipment	£64	£64	£0	£0	No change.	£0	No change.
5 Services (incl PV)	£257	£313	£56	£0	No change.	£56	ASHP in lieu of Gas Boiler, MVHR, Oversized Rads, associated T&C, & additional PV.
9 Preliminaries	£113	£122	£9	£1	Proportionate increase in prelims.	£8	Proportionate increase in prelims.
Total £/m²	**£1,371**	**£1,478**	**£107**	**£15**		**£92**	
% Uplift from Baseline	*N/A*	*8%*		*1%*		*7%*	

	STRETCH					
	Stretch (Total)		Embodied Uplift		Operational Uplift	
Blended houses	£/m²	Variance £/m²	£/m²	Comments	£/m²	Comments
1 Substructure	£163	£14	£9	Increased foundations for additional point loads for concrete frame. Low carbon concrete, Enviroblock.	£6	Increased insulation for enhanced U Values.
2 Superstructure	£765	£121	£44	Details as below.	£77	Details as below.
2.1 Frame	£77	£19	£19	Timber Frame.	£0	No change.
2.2 Upper Floors	£48	£2	£2	Low carbon floor boards.	£0	No change.
2.3 Roof	£62	£8	£0	No change.	£8	Additional insulation.
2.4 Stairs and Ramps	£5	£0	£0	No change.	£0	No change.
2.5 External Walls	£352	£77	£17	Omission of internal blockwork, addition of timber frame. Omission of canopy. Timber cladding in lieu of Brickwork (top 2/3rds).	£60	Increased insulation for enhanced U Values, enhanced air-tightness.
2.6 Windows & External Doors	£77	£11	£0	No change.	£11	Triple glazing.
2.7 Internal Walls & Partitions	£107	£7	£7	Timber partitions and walls. Etex plasterboard.	£0	No change.
2.8 Internal Doors	£39	£0	£0	No change.	£0	No change.
3 Internal Finishes	£152	£7	£7	Low carbon paint and plaster	£0	No change.
4 Fittings, Furnishing & Equipment	£64	£0	£0	No change.	£0	No change.
5 Services (incl PV)	£340	£83	£0	No change.	£83	ASHP in lieu of Gas Boiler, MVHR, Underfloor Heating, associated T&C, additional PV.
9 Preliminaries	£149	£35	£8	Proportionate increase in prelims.	£27	Proportionate increase in prelims.
Total £/m²	**£1,634**	**£263**	**£68**		**£195**	
% Uplift from Baseline	*19%*		*5%*		*14%*	

This study explores the design and cost implications of delivering low carbon residential developments. We welcome input from any interested stakeholders on the content and potential future areas of study.

If you have any questions on this report or would like to provide feedback, please email **ANZ@ukgbc.org**

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