Building the Case for Net Zero:

A feasibility study into the design, delivery and cost of new net zero carbon buildings

SEPTEMBER 2020

Advancing Net Zero Programme Partners

Lead Partner:

Programme Partners:

The original idea for this study was developed by Hoare Lea and JLL, as Partners to UKGBC's Advancing Net Zero programme. The study would not have been possible without their support and contribution of significant team resources which UKGBC is grateful for.

Project supporters:

UKGBC would like to sincerely thank all design team participants, alongside all stakeholders involved for their feedback, assistance and contributions over the course of the project. The design teams included representatives from the following organisations:

- Alinea
- Bennetts Associates
- Cast
- Cundall
- EPR Architects
- Heyne Tillet Steel
- Hoare Lea
- JLL
- Robert Bird Group

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Foreword

Climate change is one of the greatest challenges of our time. We are already seeing a range of environmental changes around us: the increase in severity and frequency of extreme weather events, rising temperatures, flooding risks and impacts on human health. Global warming will impact biodiversity, agriculture, infrastructure, educational environments, living conditions and business productivity. The economic consequences of not controlling greenhouse gas emissions will be significant and impact us all.

The built environment sector, responsible for nearly half of global greenhouse gas emissions, remains relatively inefficient and is ripe for radical change.

There is an opportunity for built environment professionals to work together to reduce carbon in new buildings and existing stock. This report shows how designs for residential and workplace buildings can be influenced to improve resource efficiency, reduce running costs and get to net zero carbon. This should be the target for all new buildings by 2030.

The findings of the study show that the increased capital investment in net zero buildings needn't cost the earth. Failure to mitigate climate change will however, impacting everyone including those not living and working in the new buildings that are being constructed.

It's time we see net zero buildings as an opportunity to innovate, explore better building techniques and collaborate on a joint vision. We will face challenges. The supply chain needs to make and install materials and systems differently. We need to build skills and capacity. Buildings will look slightly different to how they do now, but not much. Using materials with lower embodied carbon may be unfamiliar to us but there are lessons and shared from successful design solutions. We also need to be better at measuring and monitoring building performance when buildings are handed over. Outcomes matter.

Ashley Bateson
Partner, Hoare Lea,
Advancing Net Zero
Programme Partner

Executive Summary

In late 2018, the IPCC issued a stark warning. It clearly established that achieving the ambitions of the Paris Climate Agreement and limiting warming to 1.5°C to avoid the most catastrophic impacts of climate change will require action at an unprecedented pace and scale.[1] The UK's target to reach net zero emissions by 2050 reinforces the imperative for businesses to assess their operating models in line with climate science. By better understanding the practical implications of achieving net zero carbon, businesses can be made more resilient to future operating conditions and pivot to embrace the upcoming change.

The World Green Building Council (WorldGBC) is catalysing the construction and property industry to lead the transition to a net zero carbon built environment through its Advancing Net Zero campaign. The campaign is calling for all buildings to be net zero carbon by 2050 and for all new buildings to be net zero in operation and to reduce embodied carbon by 40% by 2030.[2]

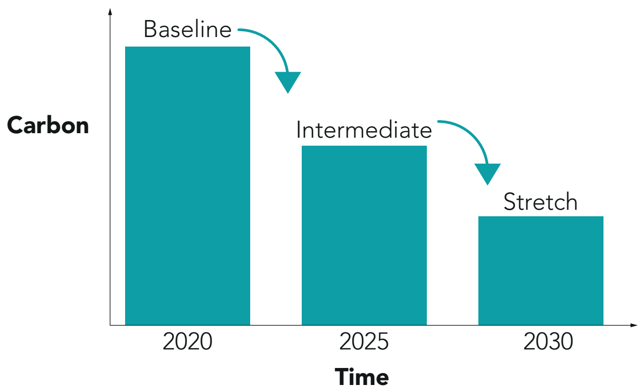
In the UK, the operation of buildings accounts for around 30% of emissions, mainly from heating, cooling and electricity use.[3] For new buildings, the embodied emissions from construction can account for up to half of the carbon impacts associated with the building over its lifecycle[4]. UKGBC's Advancing Net Zero programme is helping to drive the transition to net zero carbon buildings, including through its publication of the Net Zero Carbon Buildings Framework[5] in 2019.

In addition, a growing body of guidance is helping the buildings sector better understand the key requirements for new net zero buildings, such as performance targets developed by UKGBC,[6] LETI[7] and RIBA.[8] However, there is currently a limited understanding of the practical implications for designing and delivering these buildings including, critically, an evaluation of the cost impacts.

PURPOSE

This report presents the findings of a feasibility study that shines a light on the real-world implications for achieving new net zero buildings. It illustrates how new buildings can be designed to reach net zero performance targets and the effect this has on cost. The findings are intended to improve the collective understanding for the buildings sector and help build the case for new net zero buildings.

Figure 1: A representation of the step change in building performance required to meet future net zero targets and drastically reduce carbon



The report's findings are separated into two main sections:

1. Design changes

The study is based on two real-world projects that were in concept design stage at time of publishing – an office tower and a residential block. UKGBC convened the project teams for both schemes to iterate the existing designs – considered the 'baseline scenario' representing business as usual – to achieve two net zero design scenarios. In comparing these different design scenarios, the findings are intended to provide insight into some of the key changes required to the way buildings are currently designed and delivered.

The two net zero design scenarios were based on future net zero performance targets for embodied carbon and operational energy published by UKGBC, LETI and RIBA. An 'intermediate scenario' uses net zero targets for 2025 to represent buildings that are in, or will soon be in, design, and a 'stretch scenario' uses net zero targets for 2030 to represent design changes that may be seen as challenging today but will need to become the norm over the next decade.

The project teams' brief was to deliver the same building that had achieved planning approval (i.e. same overall volume, external massing, site conditions), with free reign to alter all other design parameters (e.g. structure, HVAC system, tenant requirements etc.) to achieve, or get as close to achieving, the net zero performance targets. Given this brief, some net zero targets have not been achieved as these would have required radical changes to the original building design.

2. Cost changes

In parallel, an analysis of the effect on cost across the design scenarios has been undertaken to estimate the changes required in the financing of new net zero buildings. The focus of this analysis has been on changes to capital cost and does not seek to make the value case for net zero buildings. The value case is significant when considering current market trends, such as investor pressure through the Task Force on Climate-related Financial Disclosure (TCFD), stranded asset risks, corporate ESG drivers, and increasing occupier interest in net zero. Future studies could explore this context further and the wider benefits of net zero buildings.

The cost uplift for the intermediate scenarios were calculated as 6.2% for office and 3.5% for residential compared to the baseline scenarios. This cost uplift can be considered feasible today given these costs will likely be offset by the value benefits, including increased rental premiums, lower tenancy void periods, lower offsetting costs, and lower operating/lifecycle costs.

However, the cost uplift for the stretch scenarios were more significant at 8-17% for office and 5.3% for residential. This is perhaps not surprising as the net zero targets for 2030 are substantially more demanding and the marketplace is not yet geared up to delivering them at scale. To overcome this, we need a long-term consistent regulatory trajectory that tightens standards over time so as to provide the certainty and level playing field required for the supply chain to innovate and costs to come down.

This report represents a step towards building the case for net zero buildings. It provides the facts and figures for two typical developments, whilst signalling broader structural changes required for the buildings sector. A supplementary publication will examine the market transformation in detail, and future studies could branch into other relevant areas, such as different building types, retrofit of existing buildings, and enabling green finance mechanisms.

Snapshot of findings

NET ZERO OFFICE

The baseline design is for a new 16 storey city office building – see "Project overviews" on page 13

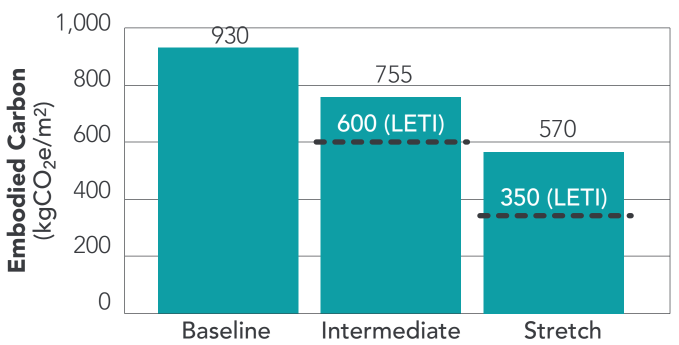
Key design changes for stretch scenario See pages 18-19

1. Replacement of steel and concrete in structure: Incorporating a fully timber structure along with the removal of a concrete basement helped reduce total upfront carbon by 39%, compared to the baseline. However, the larger-sized timber beams and columns did result in one floor being lost to maintain the same building height, which would impact the building's value.

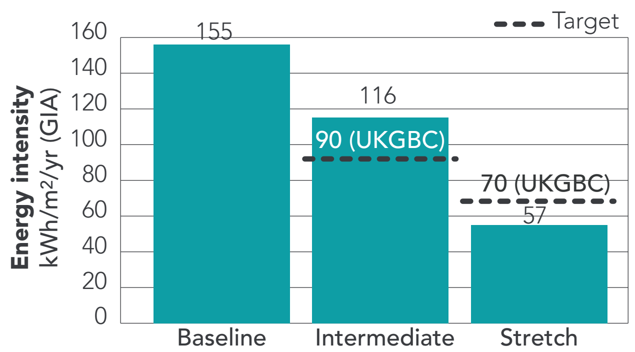
2. Introduction of mixed mode ventilation: Relaxing the internal comfort conditions helped to reduce heating and cooling loads by over half (compared to the baseline) and allowed the introduction of openable windows for passive cooling in the spring and autumn.

3. Dematerialisation of fitout and removal of server room: By simply not installing a suspended ceiling, a 14% saving in embodied carbon was made. Utilising offsite servers helped achieve a 78% decrease in IT energy usage, however shifting some energy use to a scope 3 emission.

Results See pages 20-27



Upfront embodied carbon*
(LCA module A; $kgCO_2e/m^2$)



Energy performance
(whole building; kWh/m^2 (GIA) / year)

Cost change (shell and core; £/m^2 GIA) See pages 40-46

£3,125

6.2% increase (£3,320)

8-17% increase (£3,370 to £3,660)

*Not including sequestration (capture of carbon in timber building materials)

NET ZERO RESIDENTIAL

The baseline design is for a new 18 storey city residential building – see "Project overviews" on page 13

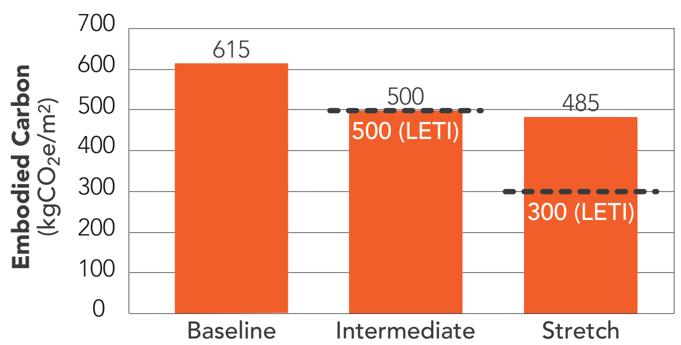
Key design changes for stretch scenario See pages 28-29

1. Replacement of concrete structure with timber frame: The use of a timber frame (beams, decking and columns) helped reduce total upfront carbon by 21%, compared to the baseline. However, given the increased depth of timber beams, two floors had to be removed to maintain the overall building height.

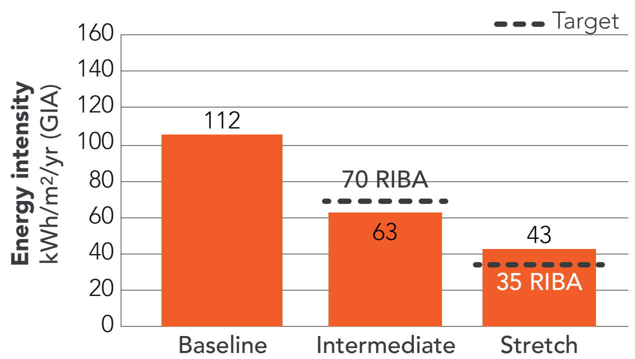
2. Reduction of glazing areas to reduce heat loss: The glazing ratio is reduced from 51% to 29% through reducing bedroom window sizes and removing bedroom balconies. This is in addition to incorporating triple glazing and reducing the wall u-value.

3. Replacement of gas boiler with air source heat pump: The switch to an air source heat pump significantly reduces operational energy demand. Approximately half of the final energy demand in the stretch scenario comes from unregulated loads.

Results See pages 30-37



Upfront embodied carbon*
(LCA module A; $kgCO_2e/m^2$)



Energy performance
(whole building; kWh/m^2 (GIA) / year)

Cost change (shell and core; £/m^2 GIA) See pages 47-51

£2,715

3.5% increase (£2,810)

5.3% increase (£2,860)

*Not including sequestration (capture of carbon in timber building materials)

Introduction

The past few years have seen a surge of interest in net zero carbon and how new buildings can be designed to achieve this outcome. A growing body of guidance is helping the buildings sector better understand the key requirements for new buildings, such as performance targets developed by LETI[7] and RIBA[8] and the net zero outcomes defined in UKGBC's net zero framework.[5] However, there is currently a limited understanding of the practical implications for designing and delivering these buildings including, critically, an evaluation of the cost impacts.

This report presents the findings of a feasibility study that shines a light on the real-world implications for achieving new net zero buildings. It provides an evidence base for designing net zero buildings and the cost of delivering them, whilst also beginning to outline the market transformation required for this to occur at scale. The findings should help to build confidence in the market that new net zero buildings are possible by removing significant unknown variables, such as cost uplift.

The UK's 2050 net zero carbon target, corporate ESG drivers, and increased occupier interest in net zero are just three reasons why developers and investors are becoming acutely aware of the need to deliver new net zero buildings. The recent publication of energy performance and embodied carbon targets for net zero carbon buildings have started to illustrate the increasing levels of building performance that will be expected in the future, representing a step change for the buildings sector. This report shows how theoretical net zero targets can practically be achieved by setting out the design changes required for two typical buildings.

By examining the design changes required to an office building and residential block – both in concept design stage at time of publishing – the findings provide a greater level of appreciation and insight into the fundamental changes required to the way buildings are currently designed and delivered. The study uses the building designs as a 'baseline' representing good practice today and iterates these designs to achieve two net zero scenarios. An 'intermediate' scenario uses net zero targets for 2025 to represent buildings that are in, or will soon be in, design, and a 'stretch' scenario uses net zero targets for 2030 to represent design changes that may be seen as challenging today but will need to become the norm over the next decade.

In parallel, an analysis of the cost impacts resulting from these design changes has been undertaken to estimate the changes required in the financing of new net zero buildings. The focus of the analysis has been on changes to capital cost, however future studies could examine changes across the life of net zero buildings to appreciate their increased value. This could include building on recent findings which show that sustainable buildings can result in increased rental value of 6-11% and lower void periods[9] which could potentially balance increases in capital costs.

Recognising that these changes will only be made possible within a supportive market, the report also begins to explore key themes for the buildings sector to address to mainstream new net zero buildings. Over the course of the study it became clear that structural changes will be required in the market, and so a supplementary publication is due to follow in the fall of 2020 which will delve deeper into these topics. In this way, a catalogue of future studies can be undertaken which continue to 'build the case' for net zero buildings, including examining other building types.

This report is a step on the path to achieving new net zero buildings, however the findings will require wide engagement across all stakeholders within the buildings sector, from designers and developers, to investors and occupiers. Critically, findings that breakdown technical hurdles and demonstrate the achievability of net zero buildings will help show the art of the possible. Given the significant opportunities to decarbonise the UK's buildings sector[3] and the pressing need for all new buildings to be net zero by 2030,[10] there is an urgency to take the findings from this study and use them to accelerate the delivery of new net zero buildings.

SCOPE AND METHODOLOGY

In April 2019, UKGBC published the Net Zero Carbon Buildings Framework which aimed to build industry consensus on a definition for net zero carbon buildings. It set out high-level principles for achieving net zero carbon for construction and for operational energy, with the noted intention that further detail and stricter requirements would be developed over time, including energy performance targets. For new buildings, the framework sets out how net zero carbon can be achieved for construction whilst designing for low energy to ensure net zero carbon for operational energy can be achieved when in use.

The scope and methodology of this feasibility study is aligned with that of the framework – to achieve net zero carbon in construction and follow the high-level principles for reducing operational carbon emissions. The high-level principles for new buildings are broadly: designing to reduce whole life carbon; designing for low energy use; installing on-site renewable energy (where possible); and offsetting all remaining carbon related to the building's construction stage (termed 'upfront carbon'). Once these steps have been completed, and following the verification of data, the building is deemed to achieve 'net zero carbon – construction'.

Figure 2: UKGBC's framework sets out two definitions for net zero carbon buildings that can be achieved today for construction and operational energy

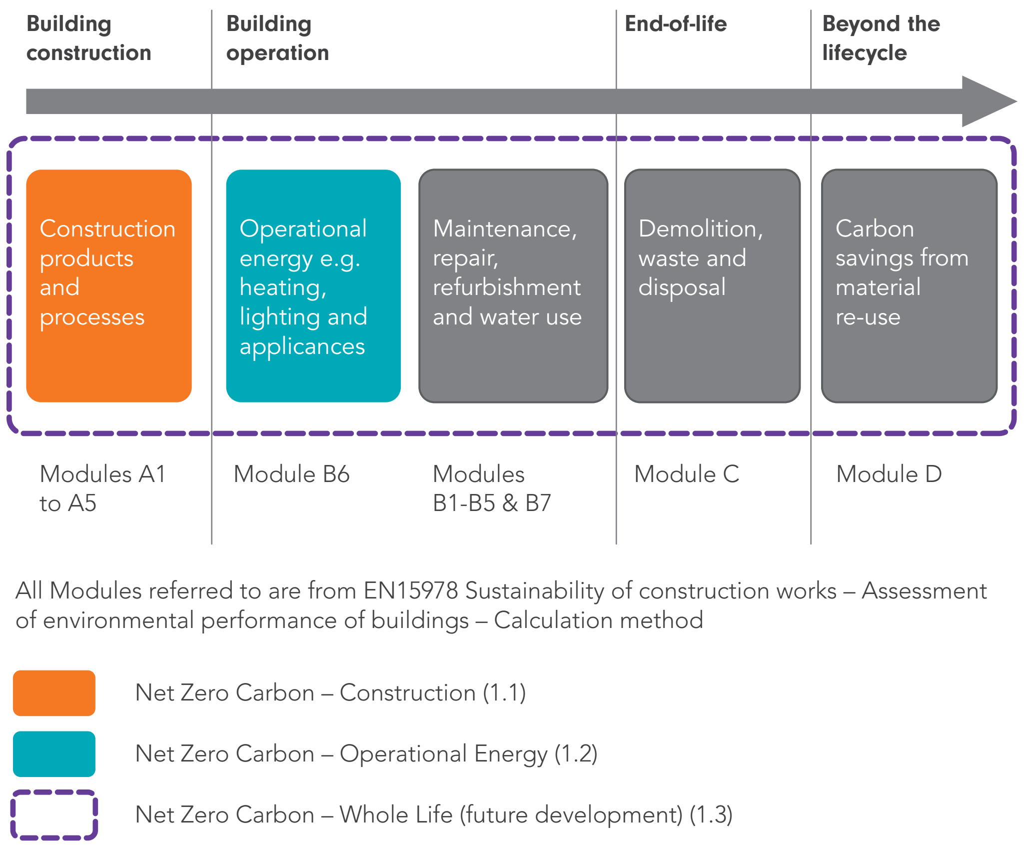


Figure 3: Steps to achieving a net zero carbon building

1. Establish Net Zero Carbon Scope*

1.1 Net zero carbon – **construction**

1.2 Net zero carbon – **operational energy**

2. Reduce Construction Impacts

2.1 A whole life carbon assessment should be undertaken and disclosed for all construction projects to drive carbon reductions

2.2 The embodied carbon impacts from the product and construction stages should be measured and offset at practical completion

3. Reduce Operational Energy Use

3.1 Reductions in energy demand and consumption should be prioritised over all other measures.

3.2 In-use energy consumption should be calculated and publicly disclosed on an annual basis.

4. Increase Renewable Energy Supply

4.1 On-site renewable energy source should be prioritised

4.2 Off-site renewables should demonstrate additionality

5. Offset Any Remaining Carbon

5.1 Any remaining carbon should be offset using a recognised offsetting framework

5.2 The amount of offsets used should be publicly disclosed

D New buildings and major refurbishments targeting net zero carbon for construction should be designed to achieve net zero carbon for operational energy by considering these principles.

* Please also note, a further scope for net zero whole life carbon (1.3) will be developed in the future.

The study is based on comparing different design scenarios for two new buildings – an office tower and a residential block. The design scenarios compare current business as usual levels of building performance (the baseline) with two sets of ambitious net zero designs. Developing these net zero design scenarios helps to illustrate potential design routes to achieving net zero targets, and the resulting cost impacts.

The net zero designs are based on targets for embodied carbon and operational carbon (emissions related to all regulated and unregulated energy use in the building) that have been developed by various industry bodies, including RIBA, LETI and UKGBC. By combining these targets across increasingly ambitious design scenarios, this study aims to illustrate their achievability when combined and the overall reduction on a building's whole life carbon.

Figure 4: Methodology for net zero feasibility study

1. Select representative buildings

The study examines two typical new development schemes: an office tower and residential block. The schemes were selected as representative of typical building types so that the study's findings can be broadly applied. The schemes have been anonymised for the purposes of this study but were in development at time of publishing.

2. Select design targets

The study involved iterating the existing design of each scheme to achieve increasingly ambitious design targets. The targets selected were drawn from work undertaken by RIBA, LETI and UKGBC covering embodied and operational carbon. Three scenarios were developed for each scheme: baseline, intermediate and stretch.

3. Develop design scenarios

The project teams involved in the real-world schemes led on the development of these design iterations, given their working knowledge of each project. Their brief was to deliver the same building that had achieved planning approval (e.g. same overall volume, external massing, site conditions, etc.), with free reign to alter all other design parameters (e.g. structure, HVAC system, tenant requirements, etc.).

4. Cost scenarios

The projects' cost consultants assessed the three different design scenarios to understand the capital cost impacts for each. For comparability, all scenarios achieve the same net zero carbon for construction outcome, so any costs for offsetting the remaining upfront carbon have also been applied.

5. Identify market implications

The project teams' findings were presented to an external team of consultants and advisors to assess the implications of taking the theoretical net zero building designs through to practical delivery. This discussion is intended to signal to the property and construction sector the key barriers and potential solutions for increasing the uptake of new net zero buildings, and a further report on these issues will be published later in 2020.

PROJECT TEAMS

UKGBC convened both project teams working on the real-world schemes to help develop the net zero design scenarios and would like to offer a special thanks to them for contributing their time and expertise to this study. It is only due to their voluntary efforts that this report has been made possible.

Office team

Bennetts Associates Architect	Peter Fisher
Alinea Cost consultant	Tom Atkinson, Matt Orford Review by JLL: Kenny Man, Emma Hoskyn
Landsec Developer	Nils Rage
Hoare Lea LCA, MEP	Ashley Bateson, Tom Spurrier, Will Belfield, Owen Boswell
Heyne Tillett Steel Structural engineer	Tom Watson, Will Johnson

Residential team

EPR Architects Architect	Alex Potter
Cast Cost consultant	Nick Jackson-Brown, Kojo Mensah Review by JLL: Kenny Man, Emma Hoskyn
Legal & General Developer	Stephen Murden
Hoare Lea LCA, MEP	Ashley Bateson, Greg Jones, Tom Wigg, Tom Brown LCA review by Cundall: Simon Wyatt
Robert Bird Group Structural engineer	Jessica Lovell, Freya Summersgill, Cormac Ennis, Camilla Cabria, Maria Pia Stasi, Simon Nicholas

Project supporters

The original idea for the study was developed by Hoare Lea and JLL, as Partners to UKGBC's Advancing Net Zero programme. UKGBC is grateful for their support and contribution of significant team resources to make this study a reality.

HOARE LEA JLL

PROJECT OVERVIEWS

The findings from this study are intended to be generally applicable across the industry. They should help to inform project teams on different design strategies to achieve net zero and to set budgets for new projects targeting net zero outcomes. They should not however take the place of proper planning and due diligence undertaken by clients and teams for specific projects. Both of the case studies analysed were selected on the basis that they were considered representative of common new developments, allowing the findings to be applied to other similar projects. Further consideration of the findings will always be required based on project-specific parameters including, for example, location, size, local planning rules, developer specification etc.

Office

The original design of the office scheme is for a new 16 storey building on an urban infill site. The developer's specification is for a BCO Grade A office, which is typical of a new city office building, and had strong environmental aims. The design is considered better performing compared to the market average and this is reflected in the figures provided in the cost analysis. The original design included some non-office space, however for the purposes of this study, these spaces have been excluded from the analysis.

Figure 5: Section through office development; the office tower is the focus of this study

Residential

The original design of the residential scheme is for a new 18 storey building on an urban site. Due to strict environmental planning requirements, the design is considered better performing compared to the market average and this is reflected in the figures provided in the cost analysis. The project plans to deliver 208 high-quality residential apartments, ranging from studio to three-bedroom units. The build-to-rent apartments and mixed-use nature of the project (including some retail and communal spaces) is considered typical of new high-rise apartment buildings. The focus of the study is the apartment design, so any commercial/retail spaces have been excluded from the analysis.

Figure 6: Artist's depiction of original residential design

NET ZERO TARGETS

UKGBC's net zero framework was developed to provide the buildings sector with clarity on the processes and outcomes required for achieving net zero carbon buildings. Complementary pieces of work, undertaken and published in RIBA's 2030 Climate Challenge,[8] LETI's Climate Emergency Design Guide[7] and UKGBC's Energy Performance Targets for Offices,[6] sought to provide clarity on the level of building performance required for buildings to claim to be net zero. These 'net zero targets' can be overlaid on UKGBC's framework to ensure any net zero building is highly efficient, uses only its 'fair share' of available resources and limits the reliance on offsets.

The approaches used to determine the targets have varied between these three organisations. This is mainly due to the inherently variable nature of the 'top-down' calculations (based on decarbonisation trajectories to reach the UK's 2050 net zero target), which consider a range of interdependent and economy-wide factors, such as, future renewable energy generation and decarbonisation of heat. The calculation of net zero targets is not an exact science but it does offer the buildings sector insights into the scale of reductions required to achieve a net zero carbon built environment.

This study aims to contribute to the growing bank of research on net zero buildings by examining what it will take to meet these published net zero targets. It does this by using the targets as performance requirements that both project's design teams were required to deliver against. In this way, the study highlights the key changes required to the way we design, deliver and operate buildings to achieve net zero buildings.

The targets selected are a blend from RIBA, LETI and UKGBC to create a comprehensive set of performance requirements that cover embodied and operational carbon, for both the office and residential building typologies. As these performance requirements become stricter over time, two net zero scenarios have been developed to align with a 2025 and 2030 time horizon. The different design scenarios and net zero targets used for this study are set out in Table 1.

Table 1: Design scenarios and net zero performance targets used in this study

		Baseline scenario	Intermediate scenario	Stretch scenario
Office	**Operational energy** (kWh/m^2 (GIA)/year)	225 (RIBA – business as usual)	90 (UKGBC – 2025 target)	70 (UKGBC – 2030 target)
Office	**Upfront embodied carbon** (LCA module A kgCO_2e/m^2)	1,000 (LETI – business as usual)	600 (LETI – 2020 target*)	350 (LETI – 2030 target)
Residential	**Operational energy** (kWh/m^2 (GIA)/year)	146 (RIBA – business as usual)	70 (RIBA – 2025 target)	35 (RIBA – 2030 target)
Residential	**Upfront embodied carbon** (LCA module A kgCO_2e/m^2)	800 (LETI – business as usual))	500 (LETI – 2020 target*)	300 (LETI – 2030 target)

*These targets are based on LETI's 'best practice 2020' target as there is no LETI target aligned with 2025.

GUIDE TO THIS REPORT

The findings in this report are presented across two main sections:

1. Design changes

This section begins with a comparison of whole life carbon results across the three design scenarios, including whether net zero targets were achieved and a summary of key design changes. The design changes are expanded on further within four subsections:

- Structure;
- Facade;
- Building systems; and
- Fitout design (for office), apartment design (for residential).

These subsections provide a narrative of how the building's design evolves from the 'baseline' to 'intermediate' and 'stretch' scenarios. All design scenarios are assumed to build upon and retain the previous design unless otherwise stated.

2. Cost changes

This section begins with a table summarising the overall cost changes between the three design scenarios, including a percentage change from the baseline scenario. The cost models have been developed using feasibility design documentation and as a result estimates or ranges have been used to demonstrate cost effects. Commentary further explaining the costs effects is provided on an elemental basis to provide greater insights.

Market transformation

Over the course of the study it became clear that, given the scale of changes required to achieve the changes needed in building design, the discussion about market implications and transformation deserved its own publication which will be released as a supplement to this report later in 2020. The report summary outlines the 10 key themes to signal what the future publication will address.

Specific topics within the design and cost narrative sections in the report that were identified as critical to support the uptake of new net zero buildings have been tagged with the icon on the left. In this way, readers are made aware of current approaches used in the study which may not be market norms, but which will need to be addressed to remove barriers for net zero buildings.

Section 1: Design Changes

This section provides an analysis of the upgrades made to the baseline design to achieve the higher levels of performance under the intermediate and stretch scenarios. An overview is provided, with subsections adding further detail by building element – structure, facade, building systems and interior design. All design scenarios are assumed to build upon and retain the previous design unless otherwise stated.

Net zero office

The baseline scenario for the office project represents a current standard practice office building. This building was modelled to meet the LETI embodied carbon targets for the three scenarios, as well as RIBA and UKGBC operational energy targets. The study's design team was instructed to attempt to meet these targets while keeping as close as possible to the project brief that had achieved planning approval (e.g. same overall volume, external massing, site conditions, etc.) as possible. The team had free reign to alter all other design parameters (e.g. structure, HVAC system, tenant requirements, etc.). The results below represent the design team's best attempt to meet the targets.

RESULTS

The following two tables provide a summary of results for the three design scenarios alongside a comparison with relevant net zero targets. A tick or cross has been applied depending on whether the target has been met.

Table 2: Embodied carbon (module A; $kgCO_2e/m^2$)

	Baseline	Intermediate	Stretch
Target (excluding sequestration)	1,000 (LETI – business as usual)	600 (LETI – 2020 target)	350 (LETI – 2030 target)
Achieved (excluding sequestration)	**930** ✓	**755** ✗	**570** ✗
Achieved (including sequestration)	N/A (no timber used)	**625** ✗	**305** ✓

Whilst LETI explicitly state that sequestration from timber is excluded from their embodied carbon targets, the results here show that the intermediate and stretch targets are difficult to achieve without either accounting for sequestration or significantly changing the baseline design.

Table 3: Operational energy (whole building; kWh/m^2 (GIA)/year)

	Baseline	Intermediate	Stretch
Target	**225** (RIBA – business as usual)	**90** (UKGBC – 2025 target)	**70** (UKGBC – 2030 target)
Achieved	**156** ✓	**115** ✗	**56** ✓

The intermediate scenario does not meet the target as more significant changes to the baseline design would have been required potentially impacting the project brief. The stretch scenario does meet the target, and the removal of the on-site server and reduction of IT loads helps to bring energy use within reach of UKGBC's 2050 net zero target of $55kWh/m^2$.

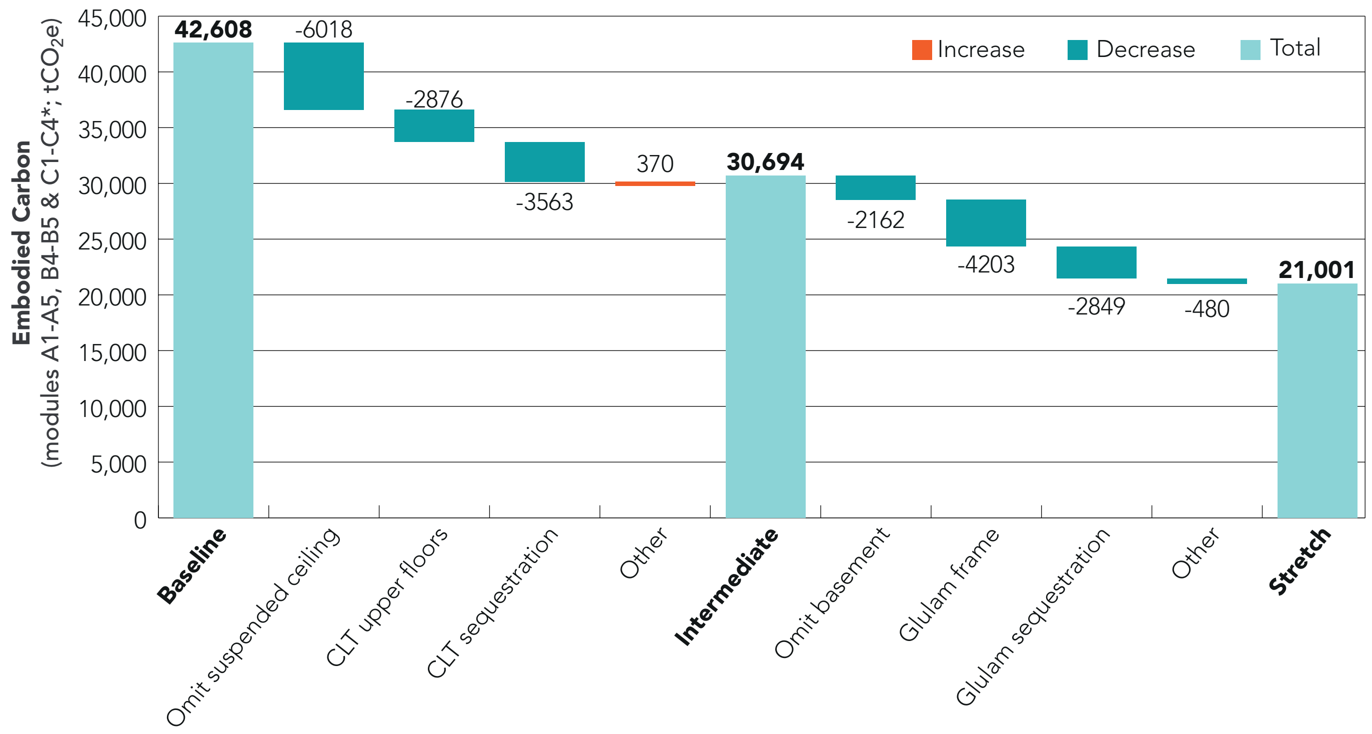
KEY DESIGN CHANGES TOWARDS NET ZERO

1. Replacement of steel and concrete in structure
Cement and steel are two of the most carbon intensive materials used in buildings, with steel making up around 7%[11] and concrete 7-9%[12] of global carbon emissions. The change from a conventional steel and concrete structure in the baseline design to a full timber structure (columns, beams and flooring) along with the removal of the concrete basement in the stretch design helped reduce total upfront carbon by 39%, compared to the baseline. However, to maintain the same building volume across all designs, one floor was lost due to the larger-sized timber columns and beams, which would affect the building's final value.

2. Introduction of mixed mode ventilation
City office buildings typically need to meet a standard level of specification (BCO Category A) which can often result in a blanket provision of heating/cooling and increased energy use intensity. The stretch design relaxes comfort conditions in the specification and introduces openable windows to enable passive cooling in the spring and autumn. The relaxation of comfort conditions down to 20°C in heating mode and up to 27°C in cooling mode helped to contribute to a 38-55% reduction in heating and cooling energy loads.

3. Dematerialisation of fitout and removal of server room
Offices delivered as shell and core can typically include a large degree of applied finishes which, at the discretion of tenants, can be removed during the fitout process. By not installing these finishes, embodied carbon savings can be made. An example is the 14% saving in embodied carbon in the intermediate design compared to the baseline design, simply by not installing a suspended ceiling due partly because of its regular need for replacement during the life of an office building. A similar approach to dematerialisation is to utilise offsite servers and reduce the level of on-floor IT and small power equipment,, which reduced the IT and server loads by 78% in the stretch design compared to the baseline design. As a result of the energy saving on-site, this energy would become a scope 3 emission.

Figure 7: Reductions in embodied carbon across the three design scenarios



* Please note, the lifecycle assessment was undertaken for all major building elements within a developer's base build scope. For this reason, the following modules were not included within the assessment: B1-B3, B6-B7. The operational energy strategy and results are provided in subsequent sections.

STRUCTURE

	Baseline	Intermediate	Stretch
Superstructure	Steel frame and composite floor	Steel frame and cross-laminated timber floor	Glulam frame and cross-laminated timber floor
Substructure	Concrete basement	Concrete basement	No basement

The **BASELINE** design represents the conventional design of high-rise office buildings using a steel framed superstructure with composite concrete floors on profiled metal decking. A double-height basement constructed from reinforced concrete was included in the design. Lateral stability to the structure is provided by reinforced shear walls at the stair and lift cores. Concrete and steel are carbon intensive materials and contribute a total of 49% (460 out of 930kgCO_2e/m^2) to upfront carbon in this design scenario.

The **INTERMEDIATE** design retains the steel superstructure, however replaces the composite concrete floors with cross-laminated timber (CLT) panels. The double height reinforced concrete basement and shear walls are retained. The use of CLT floors requires a larger structural floor build up, however provides several benefits that reduce the embodied carbon in the structure, including:

- Ability of CLT to span further lengths enables steel beam piece count and tonnage to be reduced;
- Approximately 20% reduction in structural dead load allows steel column tonnage to be reduced;
- Reduction in embodied carbon (kgCO_2e/m^2) of CLT compared with composite concrete floor;
- Inherent carbon sequestration of CLT.

The **STRETCH** design incorporates a full structural timber frame, with CLT floors supported on glue laminated timber (glulam) beams and columns. The reinforced concrete shear walls are replaced with a combination of internal and external glulam bracing. To achieve further carbon savings, the double height basement is removed, and the structure is founded on concrete pile caps and piles, with a suspended concrete slab forming the ground floor.

These measures reduce the upfront carbon of the structural elements in the stretch design by 64% compared to the intermediate design (from 357 to 129kgCO_2e/m^2). While there is relatively limited commercial value attached directly to a basement area, there may be other impacts which need to be considered for projects such as the re-location of services and amenities such as waste and cycle storage. For this project, mechanical plant could relatively easily be relocated to the roof space, with the compromise that PV panels could no longer be installed.

The use of a full structural timber frame required some concessions in the building design, including:

- Shorter spans achievable with glulam compared to steel, leading to additional structural columns;
- Increase in column size due to lower strength and stiffness of glulam, which along with the increased number of columns and larger core structure, resulted in a loss in floor space;
- Large services are not able to pass through the structure, requiring either increased ceiling build ups or a change in servicing strategy (although structural floor depth is reduced compared with the intermediate design).

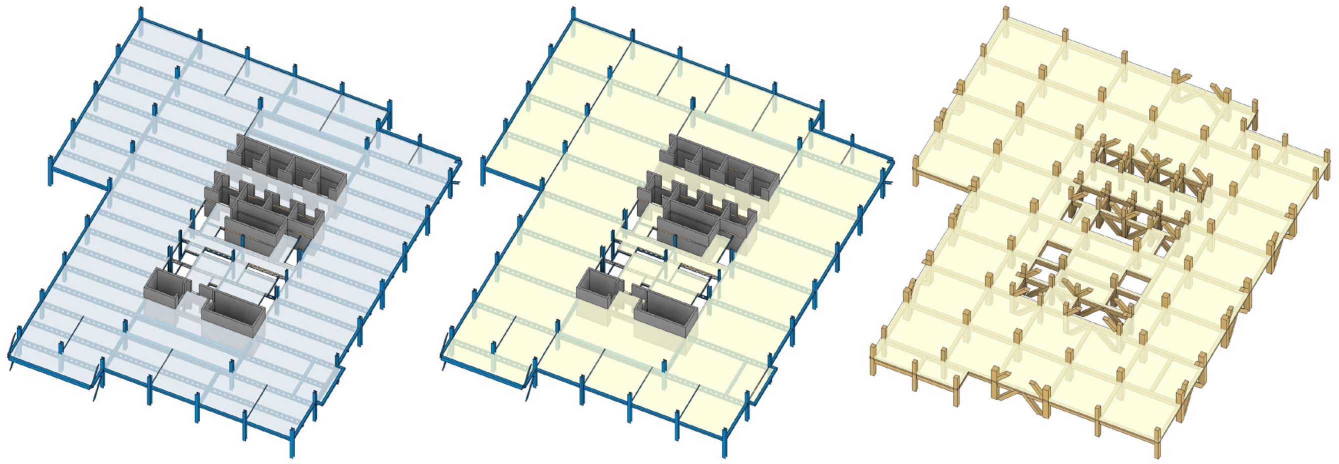
However, the change to a full structural timber frame allowed for several savings in embodied carbon, including:

- Removal of all steelwork (other than connection plates and fixings);
- Reduction in building weight leading to smaller foundations (in addition to the removal of the basement);
- Increase in carbon sequestration.

The fire risk for buildings with internally exposed timber is potentially greater than for a traditional steel and concrete frame. Specialist fire engineering input would be required, and it is likely that a specific burnout analysis would need to be undertaken to satisfy Building Control and building insurers.

Additionally, timber structures have a reduced density when compared with concrete. As such, additional noise and vibration treatment is likely to be required, which should be considered in the overall building design. Nevertheless, international examples show that timber commercial buildings can be constructed safely to comply with building regulations.

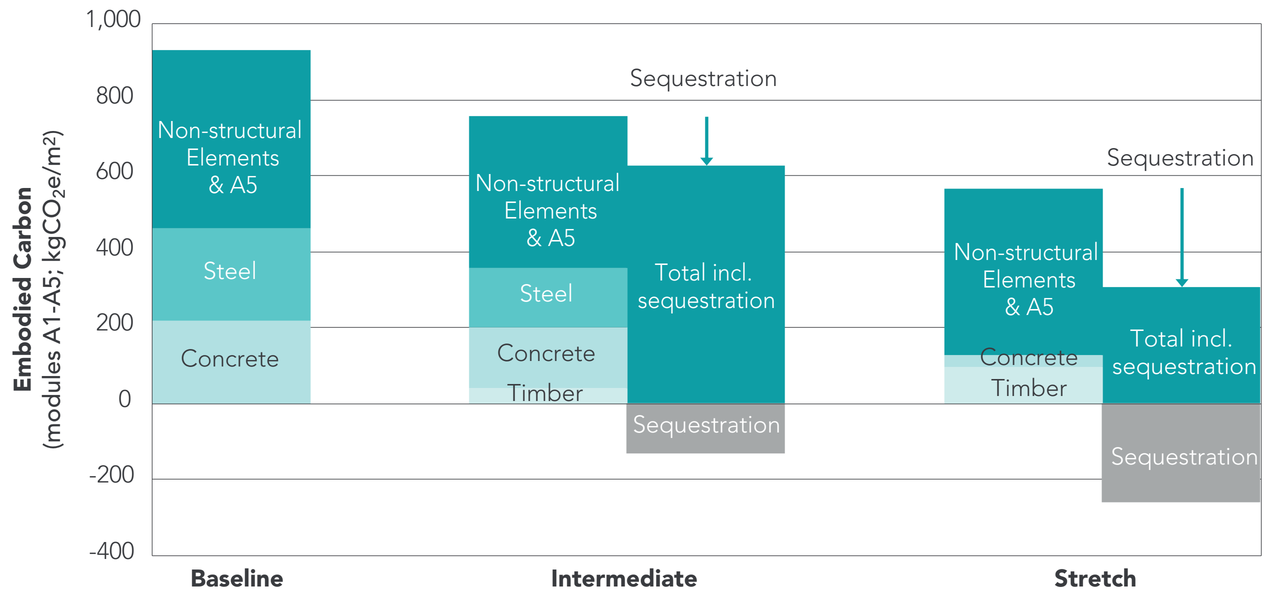
Figure 8: Typical upper floor plate for the baseline, intermediate and stretch designs



The LCA calculations for carbon sequestration in the timber structure have been made in line with the RICS Professional Statement (Section 3.4.1). This includes recognising the benefits of carbon sequestration in module A on the basis that end-of-life impacts are accounted for in module C, and that the timber originates from sustainable sources (certified by FSC, PEFC or equivalent). This takes a conservative approach to calculating carbon sequestration across a building's whole lifecycle given the unknown treatment of the timber structure at end-of-life.

For this study, an allowance has been made for the disassembly of the timber structure, and the anticipated end-of-life scenario is local re-use within the built environment. Within a net zero carbon built environment it will be crucial that landfill or incineration of timber products is avoided at end-of-life to avoid the re-release of the biogenic carbon (or worse, methane in the case of landfill), through application of circular economy principles. This discussion topic is due to be addressed in a supplementary report – please see "Market transformation" on page 58 for further information.

Figure 9: Chart showing the reduction in upfront carbon across all three scenarios based on changes to the structural design



FAÇADE

	Baseline	Intermediate	Stretch
Building fabric	Solid U-value of 0.2 Infiltration 5 m^3/hm^2@50Pa	Solid U-value of 0.2 Infiltration 3 m^3/hm^2@50Pa	Solid U-value of 0.15 Infiltration 1.5 m^3/hm^2@50Pa
External shading	None	Some external shading	Some external shading
Glazing ratio	80% glazed (floor to ceiling)	50-60% glazed average (south 40%, east/west 60%, north 80%)	40% glazed (all elevations)
Glazing	U-value of 1.4 G-Value of 0.32	U-value of 1.4 G-Value of 0.32	U-value of 1.2 G-Value of 0.28
Windows	Sealed	Sealed	Openable (to allow mixed mode ventilation)

The **BASELINE DESIGN** represents current standard practice in high-rise office buildings and assumes a conventional BCO-type specification. The structure is a steel frame and composite steel/concrete deck, with a floor-to-floor height of 3.6m, and the floorplates are column free. As is typical for such projects, it includes a basement that contains back-of-house (BOH) functions, as well as significant items of plant (machinery, equipment and appliances) with some also located at roof level.

The façade consists of floor-to-ceiling aluminium curtain walling, with a solar control coating and a glazing ratio of 80% to all elevations.

The **INTERMEDIATE DESIGN** switches the structure to a hybrid steel-frame and CLT deck. The deeper steel beams require a higher floor-to-floor height of 3.85m, which results in one less floor within broadly the same volume as the baseline design. The floorplates remain column free and the basement is retained.

The façade design more significantly incorporates orientation considerations, with lower glazing ratios of 60% to the east/west and 40% to the south. In addition, those elevations also have external shading to further reduce solar heat gains.

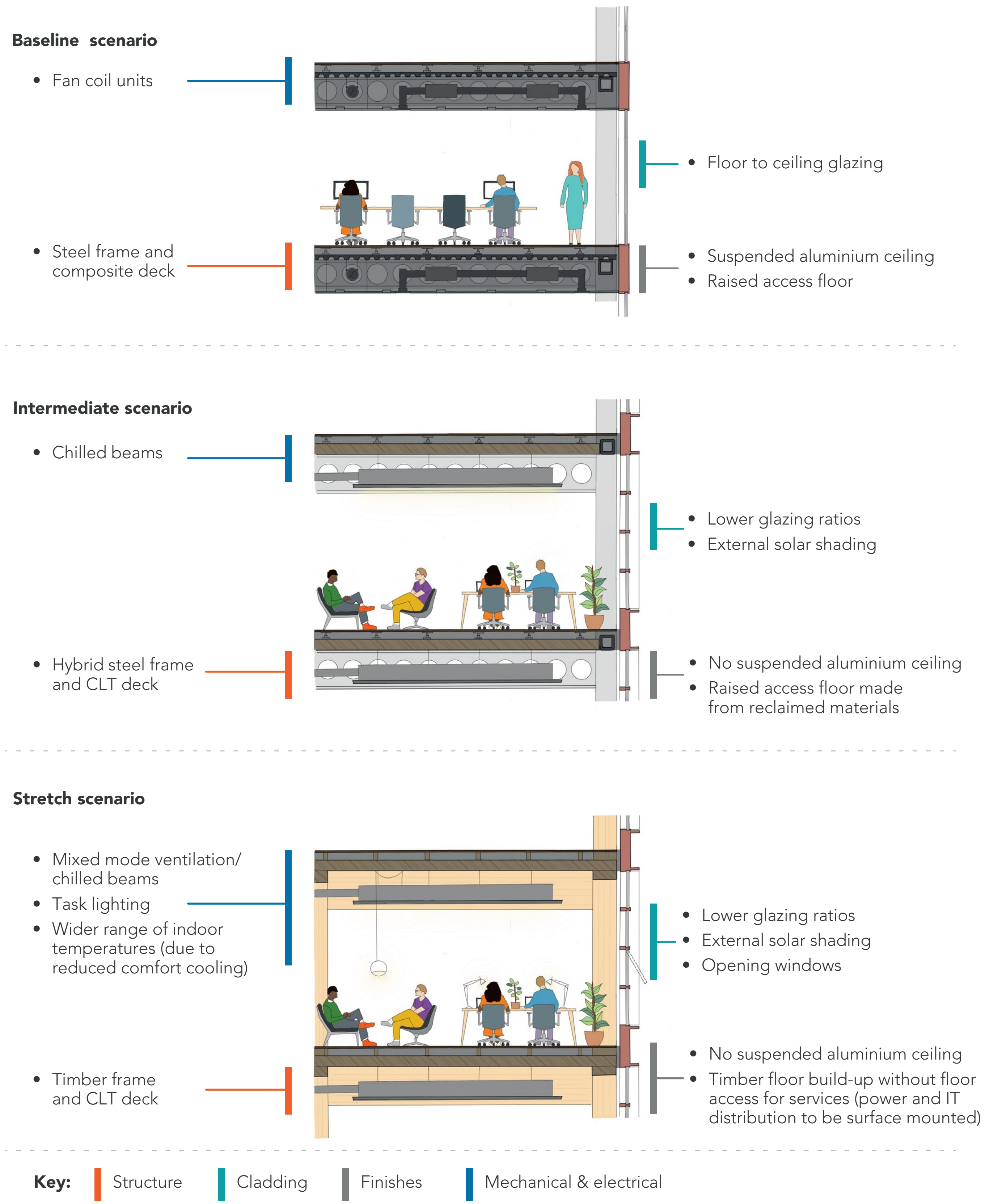
Appropriate glazing percentages and feasibility of facade openings will vary between buildings as they require consideration of local air quality and acoustic conditions, as well as the depth of floor plates. Approaches to facade design may also be influenced by site specific factors such as overshading from surrounding buildings in dense inner-city locations, and internal daylight levels from a health and wellbeing perspective.

The **STRETCH DESIGN** changes to a full timber structure, with glulam beams/columns and a CLT deck. The floor-to-floor height is the same as the intermediate version (3.85m), but the timber structure requires a central column within the floorplate. The columns are also larger in plan area than the steel versions.

The most significant change to the façade is the introduction of mixed-mode ventilation. This will enable free cooling in the spring and autumn, with the chilled beams used for cooling only in the warmest weather. The opening windows are assumed to be manual operated, but with indicators telling people when they are better kept closed. This has allowed the limit for comfort cooling to be lifted to 27°C. In addition, the glazing ratios are further reduced to 40% all around the building.

However, given the heat losses are predominantly from ventilation, the fabric U-values did not require increasing as much as originally assumed. As such, in order to not increase the embodied carbon significantly, the glazing remains double rather than triple.

Figure 10: Illustration of the upgraded facade and internal fitout spaces



BUILDING SYSTEMS

	Baseline	Intermediate	Stretch
Heating and cooling	Gas boiler Air cooled chiller	Air source heat pump	Air source heat pump
Ventilation system	Fan coil units	Active chilled beams	Active chilled beams
Ventilation strategy	Constant volume fresh air supply	Demand-controlled variable volume fresh air supply	Demand-controlled variable volume fresh air supply
Comfort conditions	22 to 24°C, with a +/- 2°C control band	22 to 24°C, with a +/- 2°C control band	20 to 27°C, with facade openings and mixed mode ventilation

The **BASELINE DESIGN** represents the conventional design approach to high-rise office buildings in recent years, with heating and domestic hot water provided by a gas boiler with an efficiency of 90%, and cooling provided by an electric chiller, with a seasonal efficiency of 4.5. Heating and cooling is delivered to the office floors via fan coil units, with constant volume fresh air provided by centralised air handling plant, with a heat recovery efficiency of 75% (included for all iterations). Internal design conditions for occupant comfort are 22°C for heating and 24°C for cooling, with a +/- 2°C control band.

The **INTERMEDIATE DESIGN** responds to grid decarbonisation and shifts thermal demands to an all-electric solution, utilising a (reversible) air source heat pump for heat generation, moving away from the combustion of fossil fuels on site and the associated carbon, nitrous oxide and particulate emissions. The heat pump also provides cooling, reducing the overall quantity of plant compared to the boiler and chiller scenario. Anticipated seasonal efficiencies are 3.5 for heating and 4.5 for cooling. Domestic hot water for core uses such as cycle showers is generated via the central heat pump plant, with on-floor hot water (i.e. kitchenettes) generated via point-of-use electric heating.

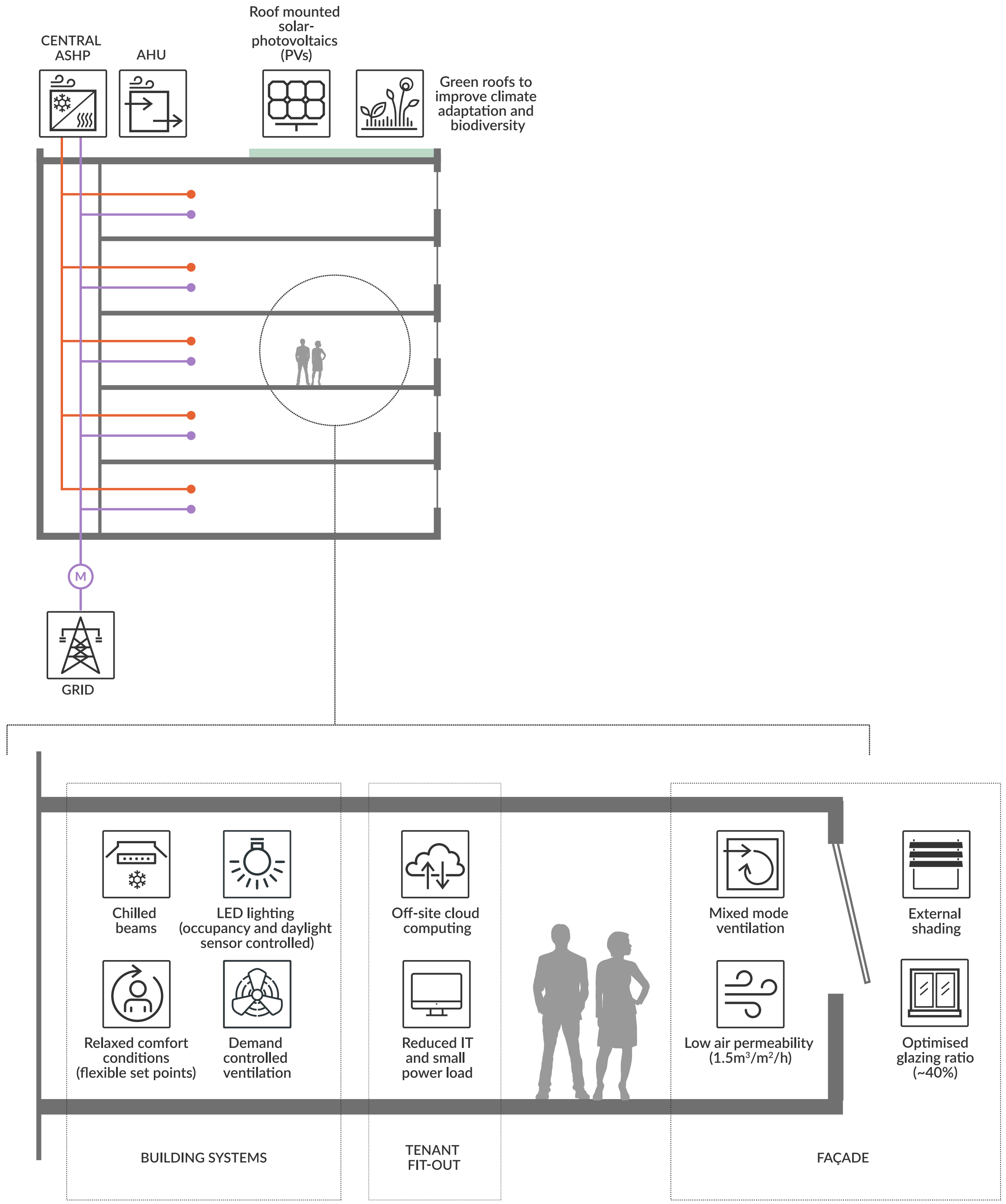
An active chilled beam solution is preferred to fan coil units, with demand controlled ventilation enabled, to allow fresh air provision to ramp back when CO_2 concentrations in the space allow. Office lighting is enhanced to represent best practice efficiencies whilst still delivering 400lux to the working plane and providing a holistic lighting design in conjunction with exposed soffits.

The fundamental change in the **STRETCH DESIGN** is the introduction of openings in the facade, which enables a mixed mode ventilation regime, with suitable controls linking the facade to the HVAC systems allowing them to be deactivated when external conditions allow (including the consideration of condensation risk). The reduction in glazing percentage on the facade assists in this regard by reducing solar gain and improving thermal comfort.

Internal comfort conditions within the stretch design are relaxed down to 20°C in heating mode, and up to 27°C in cooling mode to control the risk of overheating. Consideration was given to removing cooling altogether and adopting a free-running naturally ventilated design. Dynamic thermal analysis indicated that the stretch design could meet natural ventilation comfort standards based on current climate data, however its ability to provide comfort conditions decreased when considering future climate projections. The lack of thermal mass in the stretch design CLT slabs is another factor, and a degree of comfort cooling was therefore retained within the stretch design.

Office lighting total power density is limited to $4W/m^2$, through a combination of background and task lighting, reduced lux levels, and/or emerging technology such as power over ethernet.

Figure 11: Design schematic for net zero offices (including additional features not addressed within this study)



FITOUT DESIGN

	Baseline	Intermediate	Stretch
Specification	Aligned with BCO	Aligned with BCO	Not fully aligned with BCO
Occupancy	1 person per $8m^2$	1 person per $8m^2$	1 person per $10m^2$
Fresh air supply	16l/s/p (constant)	Up to 16l/s/p (demand controlled)	Up to 16l/s/p (demand controlled) and with mixed mode operation
Small power (installed)	$15W/m^2$	$12W/m^2$	$9W/m^2$
On-site server rooms	$10W/m^2$	$7.5W/m^2$	$0.5W/m^2$
Finishes	Suspended aluminium ceiling Raised access floor	Exposed ceiling Recycled raised access floor	Exposed ceiling Timber floor build-up

The **BASELINE DESIGN** represents a Class A office specification typical of new city office buildings, with the design brief meeting or exceeding the BCO Guide to Specification[13] in most instances. The building's operation is reasonably intense, with the base assumption that the entire building is fully occupied by tenants at a density of 1 person per $8m^2$, with fresh air supplied at a rate of 16l/s/p. Tenants small power is assumed to be $15W/m^2$ installed load. This represents the level of equipment installed by tenants, rather than the maximum allowance the building power and cooling systems can accommodate (i.e. the design brief) which would typically be higher, i.e. up to $25W/m^2$.

Occupancy schedules have been aligned with NABERS[14] modelling guidance, and represent standard office hours with minimal out-of-hours working. Outside normal hours, small power is assumed to operate at 25% of the installed capacity, with lighting operating at 5%. Tenant IT provision (server rooms with associated cooling) are included, equivalent to $10W/m^2$ power consumption across the office floors.

The finishes for the baseline design assumes a full suspended aluminium ceiling and a new raised access floor, which together contribute significantly to embodied carbon. It is also assumed that all the surfaces within the cores are dry-lined.

The **INTERMEDIATE DESIGN** varies from the baseline design in that the tenant installed small power is limited to $12W/m^2$, and tenant IT installation is limited to the equivalent of $7.5W/m^2$ across the floor-plates.

Additionally, there is no suspended ceiling, no dry-lining within the cores, and the raised access floors are recycled, all of which reduces the impact on embodied carbon. The increased floor-to-floor height, when combined with the omitted ceilings, results in a much greater perceived internal volume.

The **STRETCH DESIGN** makes fundamental changes to the fitout to significantly drive down tenant energy usage. Tenant energy use is a significant portion of total building energy, specifically IT server room operation. The stretch design adopts off-site cloud computing, with on-site server room usage limited to $0.5W/m^2$. This effectively shifts the associated energy and carbon emissions from buildings i.e. from scope 2 (direct energy usage) to scope 3 (supply/value chain).

It is recognised that to some degree this is simply moving energy usage form one building sector (offices) to another (data centres), however studies[15] have found that cloud-based operations are significantly more efficient than local server rooms, due to increased IT operational efficiency (aggregating resources and using less hardware to do more), IT equipment efficiency (using the most energy efficient hardware), and data centre infrastructure efficiency (dedicated buildings which are able to utilise advanced cooling technologies).

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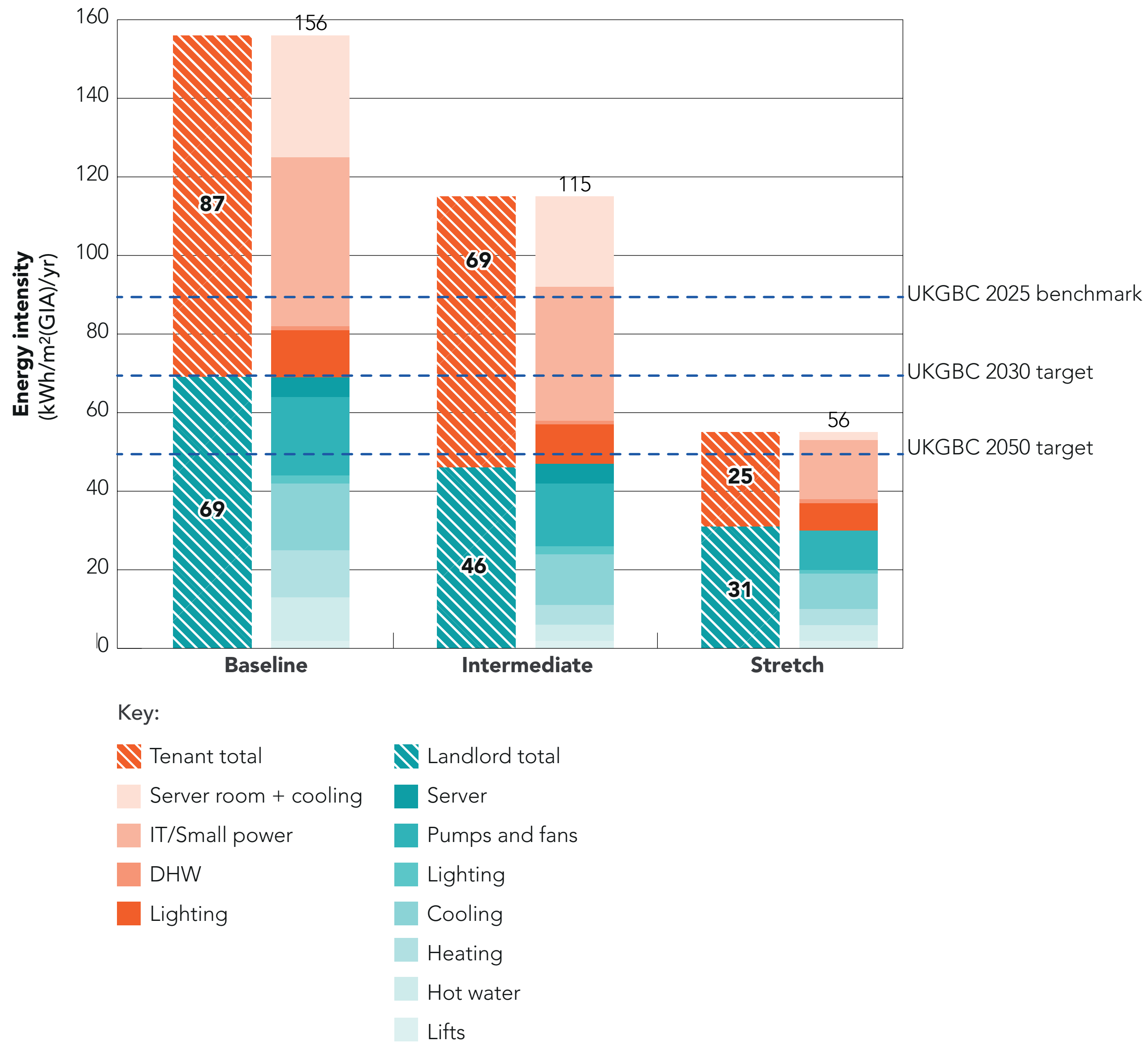
Office occupancy density is assumed to relax to 1 per $10m^2$ representing slightly less intense occupation than the baseline and intermediate design. Tenant on-floor small power is limited to $9W/m^2$, with out-of-hours usage reduced from 25% to 5%.

Like the intermediate design, most finishes have not been applied. The most significant change is moving from a recycled raised access floor to a simple floating timber build-up. The floor finish will endure much longer than a carpet, thereby reducing replacement rates in-use.

The shift from hardwired, onsite servers towards cloud computing and Wi-Fi will also mean that the much-reduced hardwiring will either be drawn through ducts or dropped from the soffit, as is already common in much of the rest of Europe.

Figure 12: Whole building energy use across three scenarios



Net zero residential

The baseline scenario for the residential project represents a current standard practice mid-rise development. This building was modelled to meet LETI embodied carbon targets for the three scenarios, as well as RIBA operational energy targets. As with the office team, the study's residential design team was instructed to attempt to meet these targets while keeping as close as possible to the project brief that had achieved planning approval (i.e. same overall volume, external massing, site conditions). The team had free reign to alter all other design parameters (e.g. structure, HVAC system, tenant requirements, etc.). The results below represent the design team's best attempt to meet the targets.

RESULTS

The following two tables provide a summary of results for the three design scenarios alongside a comparison with relevant net zero targets is provided. A tick or cross has been applied depending on whether the target has been met.

Table 4: Embodied carbon (module A; $kgCO_2e/m^2$)

	Baseline	Intermediate	Stretch
Target (excluding sequestration)	800 (LETI – business as usual)	500 (LETI – 2020 target)	300 (LETI – 2030 target)
Achieved (excluding sequestration)	**615** ✓	**500** ✓	**485** ✗
Achieved (including sequestration)	N/A (no timber used)	N/A (no timber used)	**315** ✗

These results show that the intermediate target is just achievable. It is however extremely challenging for the stretch target to be met, especially when sequestration from timber is not accounted for.

Table 5: Operational energy (whole building; kWh/m^2 (GIA)/year)

	Baseline	Intermediate	Stretch
Target	**146** (RIBA – business as usual)	**70** (RIBA – 2025 target)	**35** (RIBA – 2030 target)
Achieved	**112** ✓	**63** ✓	**43** ✗

The stretch scenario falls short of the RIBA target despite an 80% reduction in regulated loads ($74kWh/m^2$ in the baseline, $15kWh/m^2$ in the stretch design). The target can only be met with reductions in unregulated loads.

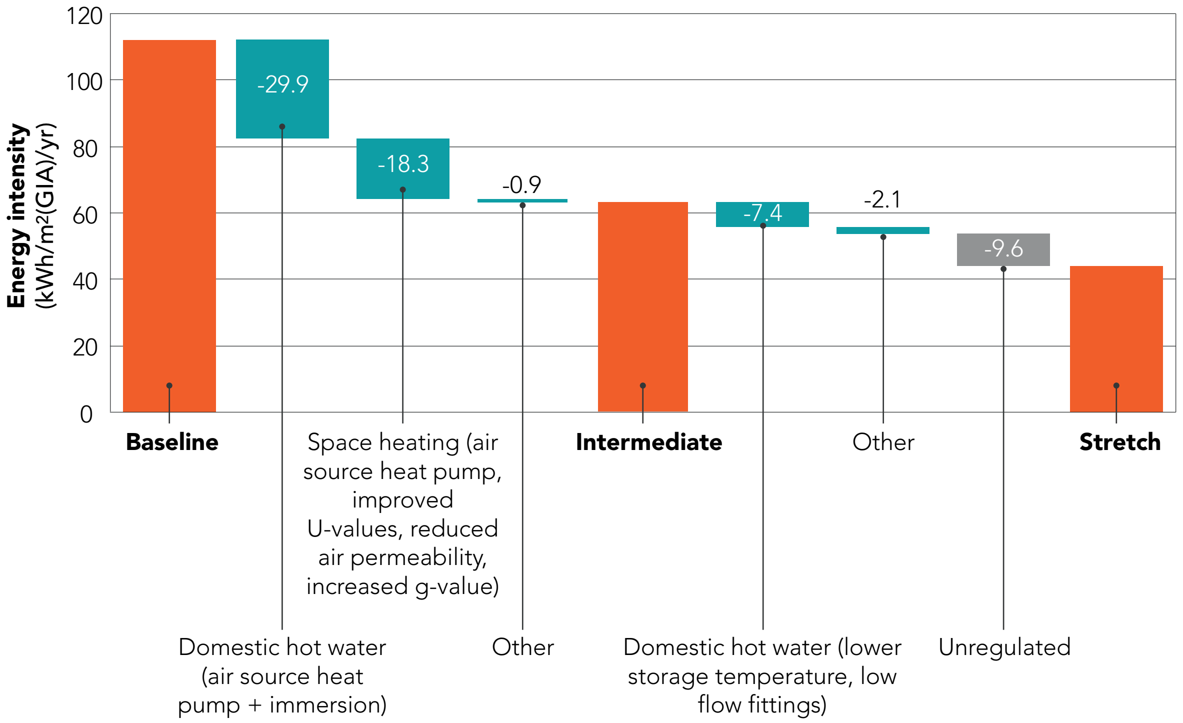
KEY DESIGN CHANGES TOWARDS NET ZERO

1. Replacement of concrete structure with timber frame
While low carbon concrete and post-tensioned concrete slabs helps to reduce embodied carbon from fully concrete structures, the use of a timber frame (beams, decking and columns) in the stretch scenario achieves the most significant upfront carbon reduction: a 74% reduction of the structural elements compared to the baseline design (from 273 to $70kgCO_2e/m^2$). However, given the increased structural zone required with the use of timber, two floors had to be removed to maintain the current building height which resulted in the loss of eight units, likely affecting the building's final value.

2. Reduction of glazing areas to reduce heat loss
Reducing heat loss when designing residential buildings is critical to tenant operational energy savings. In addition to incorporating triple glazing and reducing the wall u-value, the stretch design sees the glazing ratio reduced from 51% in the baseline and intermediate scenarios to 29% in the stretch scenario through reducing the bedrooms' window sizes and removing the balconies. Decreasing this ratio further could have negative quality of life impacts given potentially inadequate daylighting levels. While reducing the glazing ratio was necessary for achieving the stretch design targets, it is noted that this could be controversial in build to rent schemes where there may be greater dwell times in different rooms and thus increased daylighting requirements.

3. Replacement of gas boiler with air source heat pump
Most residential buildings today are equipped with a traditional gas boiler. The replacement of a gas boiler with an air source heat pump immediately achieves the intermediate design operational targets and contributes significantly to the energy savings in the stretch design. Given the increasing decarbonisation of the UK electricity grid, air source heat pumps are a relatively easy and cost-effective change that enable design teams to reduce a building's operational emissions with little lifestyle intrusion. Introducing additional energy recovery mechanisms help to further reduce regulated operational energy loads. Given the difficulty in achieving the 2030 operational target due to unregulated loads, regulation of minimum efficiency standards of domestic appliances, incentives for their adoption and strategies to encourage energy conscious behaviour would help facilitate the pathway to zero carbon homes.

Figure 13: Reductions in operational energy across the three design scenarios



STRUCTURE

	Baseline	Intermediate	Stretch
Superstructure	Reinforced concrete frame with flat slab construction Concrete core	Reinforced concrete frame with post tensioned (PT) flat slabs Concrete core	Full timber structure Concrete core
Substructure	Reinforced concrete frame basement Piled foundation	Reinforced concrete frame basement Piled foundation with pile tests	Reinforced concrete frame basement Piled foundation with pile tests
Concrete mix	Standard mix with some cement replacements	Low carbon concrete	Low carbon concrete

The **BASELINE DESIGN** represents the conventional design of mid-rise residential buildings using a using a concrete substructure and superstructure. There is a one storey basement with the structure supported by piled foundations. The concrete grade assumed to be used in the design is a typical London mix. This concrete mix has a high carbon impact and, along with rebar, contributes to 45% (273 out of 613kgCO_2e/m^2) of the upfront carbon in this scenario.

The **INTERMEDIATE DESIGN** retains a similar structure as the baseline design but replaces the standard concrete mix with low carbon cement alternatives. The volume of the slabs and piles decrease when using post tensioning, thereby reducing the overall amount of concrete needed and the associated embodied carbon.

For the piled foundations, the number of piles are reduced, in part due to a reduction in structural loads and more significantly due to the adoption of pile tests (preliminary and working). Pile tests provide confidence in the performance of the site-specific ground conditions and construction method, allowing the designer to assume a higher capacity per pile. Preliminary pile tests require an initial investment of time and cost, however, in this scenario pile tests alone resulted in a 14% reduction in concrete and spoil volumes.

With the benefits of pile tests, reduced structural loads and use of low carbon concrete, the embodied carbon for the concrete and rebar is reduced by by 46% (from 273 to 149kgCO_2e/m^2). Current tests have shown that low carbon concrete can be used in structural elements, however the use to date has largely been for piles. Over the next several years, ample testing and more project examples are likely to bring low carbon concrete alternatives into the mainstream.

The **STRETCH DESIGN** retains a concrete foundation and core, however the beams, decking and columns have been replaced with cross-laminated timber (CLT) and glulam. The use of timber achieves a 74% reduction in upfront carbon of the structural elements over the baseline scenario (from 273 to 70kgCO_2e/m^2 not including sequestration), however required further adaptation to the structural design.

The use of timber in the superstructure does come with several important caveats:

- The overall structural zone size is increased from 190mm to 520mm, with some local beams at 640mm, which requires the removal of two floors to maintain the current building height. This resulted in a loss of eight residential units (out of 209) which would directly impact the project's viability, unless a compromise pathway could be negotiated.
- Penetrations for services through beams are assumed to be a limited number of 150mm diameter penetrations, which would need to be reinforced and designed for fire. This has been excluded from the tonnages as they will require further design to validate and determine sizing.
- Columns will need to be encased in fireboard or similar to achieve the two-hour fire rating. This will have an associated increase in embodied carbon. Additionally, all connections are required to be fire-tested.
- The decking will need additional fire protection to achieve the two-hour fire rating. This could be achieved through the use of a fire board or similar in the floor build up above the decking. The fire board would also assist with damping any acoustic performance and resolve any vibration issues in the limited areas.

Whilst it would be possible to develop a cross-laminated timber wall panel structure that replaces the current glue laminated timber (glulam) columns and eliminates the concrete core, this was not considered viable for the 16 storey residential building height with current fire and safety regulations. This option would remove the need for a primary/secondary beam system, reducing floor tonnages, and also providing sufficient lateral stability to remove concrete in the cores.

While significant carbon savings were achieved, any use of timber is caveated with the expectation that safety of such structures has been firmly established and planning regulations are updated to allow for all timber structures.

The foundations have been reduced further in size for the stretch design, benefiting from an even lighter structure, low carbon concrete and assuming preliminary and working pile tests will be carried out.

Figure 14: Chart showing the reduction in upfront carbon across all three scenarios based on changes to the structural design

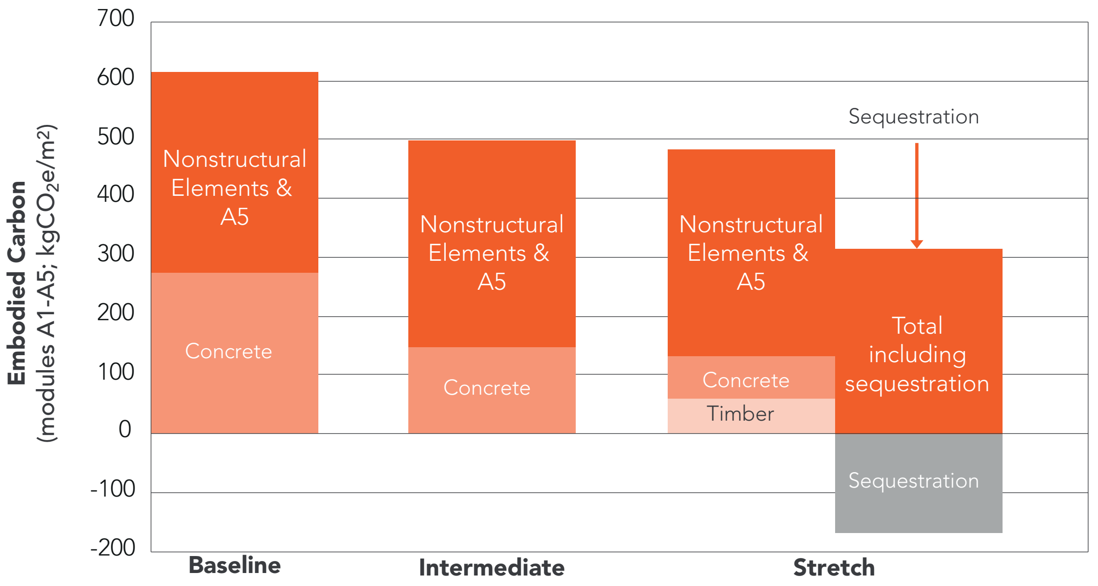
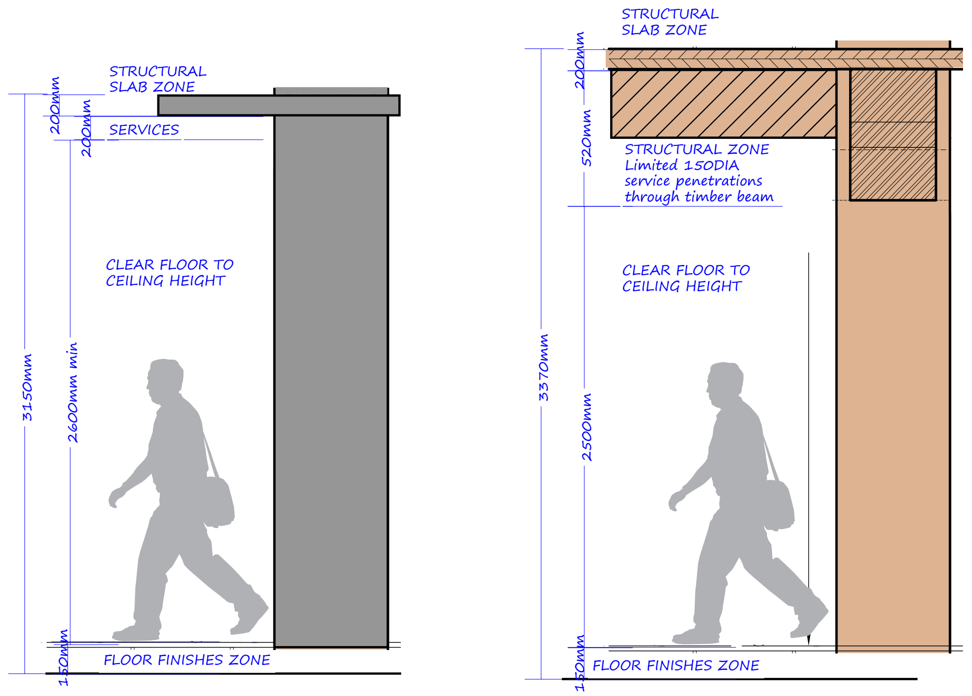


Figure 15: Section drawings for the baseline and stretch scenarios



FAÇADE

	Baseline	Intermediate	Stretch
Cladding	Full brick U-Value of 0.22 Infiltration 5m^3/hm^2@50Pa	Masonry wall construction U-Value of 0.15 (with insulation) Infiltration 2m^3/hm^2@50Pa	Masonry wall construction U-Value of 0.13 (with insulation) Infiltration 1m^3/hm^2@50Pa
Insulation	None	Roof: 150mm Wall: 50mm at slab edge Ground: 25mm	Roof: 150mm Wall: 50mm overall wall depth Ground: 25mm
Glazing ratio	51% glazed	51% glazed	29% glazed
Glazing	Double glazing U-value of 1.6 G-Value of 0.4	Triple glazing U-value of 1.1 G-Value of 0.5	Triple glazing U-value of 0.8 G-value of 0.6

The **BASELINE DESIGN** for the façade represents a standard mid-rise residential scheme as specified within the original project brief. The design decisions maximise the product value from an aesthetic, resident comfort and usability perspective. This results in large areas of double glazing that enable a significant quantity of bedrooms to have juliette balconies and each living room a bolt-on balcony.

Current standard practice allows the façade to be designed as a fully brick exterior. A rainscreen is used on a light steel frame with a 50mm clear cavity. The glazing and wall U-values achieve current Part L requirements.

The **INTERMEDIATE DESIGN** has a similar glazing ratio to the baseline scenario, however incorporates triple glazing into the wall envelope. To ensure insulation is improved and heat loss is reduced, a decision was made to move to traditional masonry construction. This results in a decrease in the U-value by allowing for a smaller wall cavity, thereby increasing the overall performance of the wall. Without this move to masonry construction, it would be difficult to achieve the required U-value over the whole wall without substantially impacting net saleable area.

The following design considerations were required:

- Installing insulation at the roof required an increase in the height of the building by 800mm and at ground required the addition of a 25mm insulation layer.
- Hand-laid brick was used as it is a robust and long-lasting material. The mortar was changed from a cement base to a lime base in order to increase the likelihood of reuse if the building were ever to be partially or wholly demolished.
- Powder coated aluminium panels were selected given these are recyclable, improving the carbon impacts of the building at end of life. However, the specification of aluminium should be carefully assessed given the range of product's embodied carbon dependent on where the aluminium is sourced.
- Whereas the baseline design decreases the glazing ratio and increases the G-value, the intermediate design retains the same glazing ratio but increases the G-value of the windows. This means that there is a greater risk of overheating without additional solar control measures, such as external shading or the inclusion of interstitial blinds in the windows. A positive impact on resident wellbeing, however, is the reduced acoustic transmission when using triple glazed windows which blocks out external noises such as traffic.

The **STRETCH DESIGN** reduces the glazing U-value to 0.8, further minimising heat loss. This is achieved through:

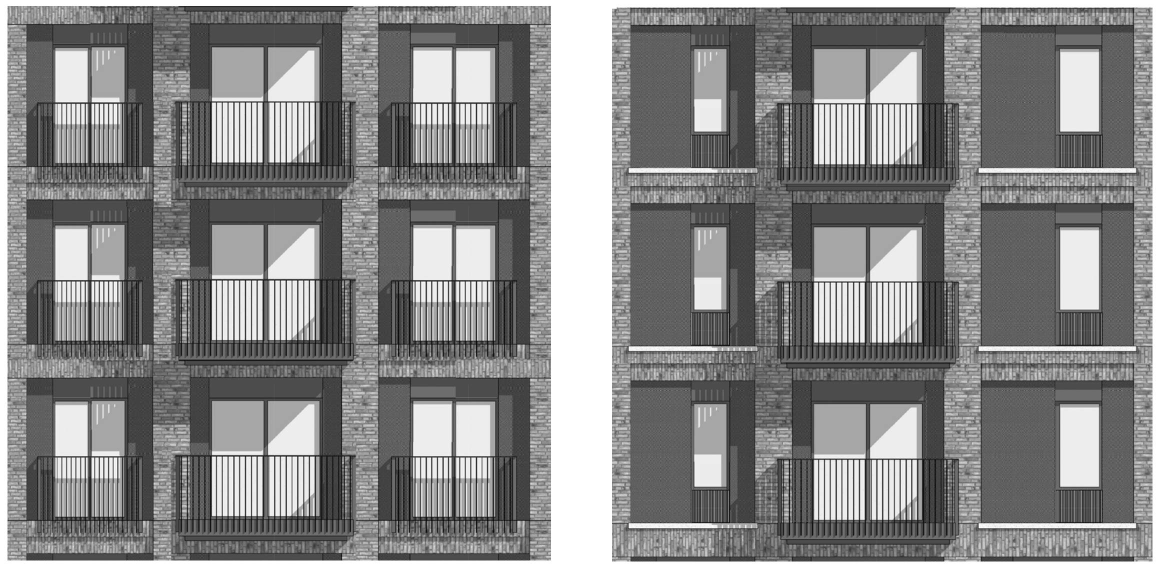
- Reducing the wall U-value to 0.13, compared to 0.15 in the intermediate scenarios.
- Reducing the glazing ratio to 29%. Designers are likely to be reluctant to decrease this further as it is important to keep adequate daylighting levels for quality of life. The living room has been protected from losing a significant amount of view outside as each living room maintains a minimum of one fully glazed double door. As a result of the reduced window size, juliette balconies are removed from all bedrooms.
- Increasing levels of insulation in the building fabric, which does create a reduction of 120m^2 net saleable area over the whole building. However, this was considered to be an appropriate design choice given the benefits of reducing operational energy requirements.

The reduction in glazing area can be considered a downside of the stretch scenario, as the glazing areas are less than current market expectations. However, with early analysis of daylight on projects it can be maintained to acceptable levels in high performance buildings.

With careful consideration of how windows are configured and positioned the compromise on daylight can be minimal. For example, horizontal windows, positioned in the centre of a room generally provide better daylight distribution than a vertical window of a similar area on the same wall.

In all cases overheating risk should be assessed and minimised. Solar shading may be appropriate to mitigate overheating risk and reduce tenant requirements for comfort cooling.

Figure 16: The original design included juliette balconies to most bedrooms (left), however this has been removed for the stretch design to reduce glazing areas (right)



BUILDING SYSTEMS

	Baseline	Intermediate	Stretch
Heating	Gas boiler Radiators	Air source heat pump with electric immersion heater for domestic hot water Radiators	Air source heat pump with suitable treatment to deal with legionella compliance Radiators
Ventilation	Mechanical ventilation with heat recovery	Mechanical ventilation with heat recovery	Mechanical ventilation with heat recovery
Other		Low flow water fittings	Low flow water fittings LED lighting improvements Reduced small power consumption through occupant selection of efficient electrical appliances

The **BASELINE DESIGN** uses a traditional gas boiler to produce low temperature hot water at 70°C with an efficiency of 95% for both space heating and domestic hot water. Mechanical ventilation with heat recovery (MVHR) with a heat recovery efficiency of 85% is included for all scenarios. This design represents a conventional approach given the majority of UK homes are still powered by gas boilers and new homes continue to be fitted with gas systems.

The **INTERMEDIATE DESIGN** utilises an air source heat pump (ASHP) in place of the gas boiler; the decarbonisation of the UK electricity grid means electric heating systems are, and will increasingly be, a lower carbon solution than fossil fuel alternatives. The air source heat pump generates low temperature hot water at 45°C. This is distributed to the dwellings for space heating and is typically uplifted to 60°C for domestic hot water by an electric immersion heater in the hot water cylinder.

This system is anticipated to result in an annual weighted efficiency of heat generation, or 'coefficient of performance' (CoP), of 3.22 for space heating and 2.06 for domestic hot water. These have been calculated using manufacturer's efficiency profiles, local weather data, and room side demands for heating and domestic hot water. Low flow water fixtures and fittings are also included, reducing domestic hot water demand.

Installing an ASHP instead of a gas boiler was an effective way to reduce carbon with limited cost, design, and occupant behaviour changes. The intermediate net zero targets were achieved with this change alone.

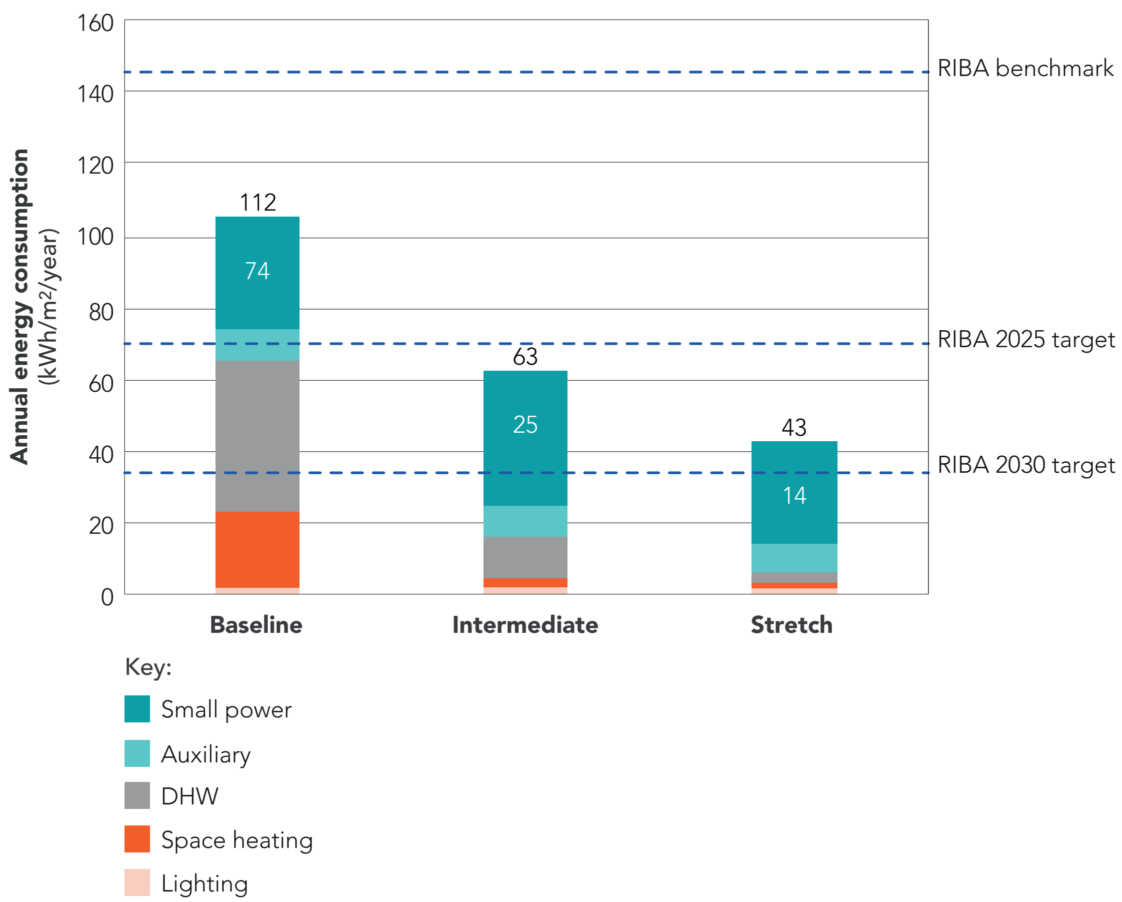
The **STRETCH DESIGN** includes the same ASHP as the intermediate design, introduces additional energy recovery technologies, and assumes improved lighting and appliance efficiencies. A chemical treatment method, such as a chlorine dioxide dosing system, is incorporated which allows the storage of domestic hot water at 45°C (negating the need for temperature-based legionella control). This greatly improves the overall generation efficiency; an annual efficiency (CoP) of 3.77 is anticipated for the domestic hot water system.

Whilst a chlorine dioxide system has been costed, other forms of legionella control enabling lower temperature domestic hot water, such as UV treatment or ionisation, as well as phase change storage, could be deployed. Note, that these systems have associated costs and maintenance requirements above and beyond a typical domestic hot water system which were not modelled in this study.

Improving the efficiency of generating domestic hot water by storing it at lower temperature is the primary gain in improving the regulated energy efficiency within the building systems. The improvements to building services and fabric lead to a 49kWh/m^2 reduction in regulated energy consumption for the intermediate scenario, with a further 10kWh/m^2 reduction for the stretch scenario. A total energy consumption, including residents' small power appliances, is anticipated to exceed the RIBA 2030 target, suggesting further strategies will be required to reduce regulated and unregulated energy consumption.

A ground source heat pump system could be considered as an alternative to air source heat pumps to further reduce energy consumption at sites with suitable ground conditions and space. Ground source heat pump systems should be appraised at an early stage in future housing projects so that an appropriate evaluation can be made for this low carbon technology.

Figure 17: Annual operational energy consumption per square meter of floor space



APARTMENT DESIGN

	Baseline	Intermediate	Stretch
Appliances	Occupier choice of whitegoods and appliances	Occupier choice of whitegoods and appliances	AAA- whitegoods and best appliances
Unregulated loads	38kWh/m²	38kWh/m²	29kWh/m²

The **BASELINE DESIGN** assumes occupiers choose their own white goods and appliances. This represents current market average levels of energy performance, and is unlikely to consist of many high-efficiency whitegoods or appliances factoring in affordability and other product considerations.

The **INTERMEDIATE DESIGN** assumes the same unregulated load demand.

The **STRETCH DESIGN** optimises the building fabric and building systems to achieve 15kWh/m² for all regulated energy uses. This involves exhausting nearly all interventions the building designer can make to achieve the RIBA 2030 overall target of 35kWh/m², leaving the balance in the hands of the occupier's unregulated loads.

Given the steady improvement in the energy efficiency of whitegoods and appliances, it was considered reasonable to assume that occupiers' unregulated loads can be reduced to 29kWh/m² for new buildings. This results in total energy use equalling 44kWh/m² with unregulated loads making up 65%, however, this still falls short of the RIBA 2030 target. This outcome could suggest that energy performance targets should be separated so that designers focus on the building energy uses that they have full control over (regulated energy) and allow other mechanisms (e.g. policy, efficiency ratings) to address what is out of their control (unregulated energy use).

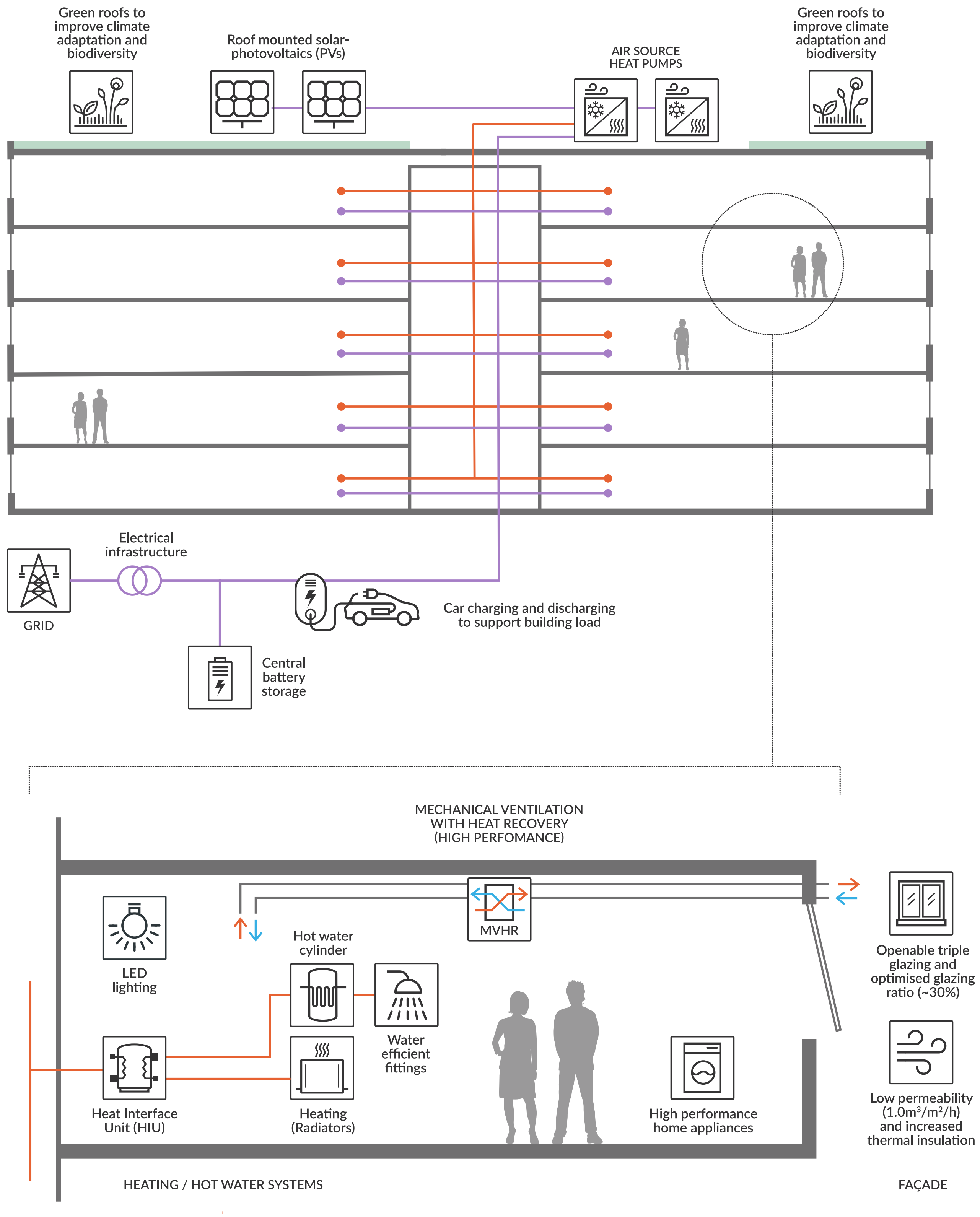
The designer's influence on unregulated loads in homes is particularly challenging as domestic equipment is not controlled by building regulations.

Consequently, residents are free to operate appliance in their home as they wish. Whilst design solutions can go a long way to providing the reductions in energy demand needed, ultimately the responsibility for reducing unregulated loads, such as white goods, kitchen equipment and TVs, will sit with the occupier. Build-to-rent developers can demonstrate best practice by installing very high efficiency appliances to keep consumer energy loads to a minimum.

From a policy perspective, regulation of minimum efficiency standards of domestic appliances, incentives for their adoption and strategies to encourage energy conscious behaviour would help facilitate the pathway to zero carbon homes. Smart meters and intelligent controls will also have a role in helping consumers to optimise the performance of electrical appliances. Such changes will be crucial in meeting future net zero building targets to address energy uses that fall outside of the building designer's control.

A more radical approach was considered for this study which was to remove access to individual whitegoods and instead rely on communal facilities, including washing and drying rooms. These communal facilities could have the highest efficiency whitegoods and eliminate large unregulated energy loads within apartments. Given the significant departure from current market practice and occupier preferences, this approach was not modelled.

Figure 18: Annual operational energy consumption per square meter of floor space.



Section 2: Cost changes

As this report has shown, buildings can be designed today to achieve future net zero targets. However, a better understanding of the associated cost is necessary to appreciate the changes required to the investment and financing of net zero buildings. This section provides estimates of the key cost changes from the baseline scenario to the intermediate and stretch scenarios, for both the office and residential projects.

Net zero office

OVERVIEW

The following section illustrates the effect on construction costs of embracing low carbon design and achieving ambitious net zero targets. The change in cost is broken down by building elements on a pounds per square metre basis to enable a direct comparison between the three design scenarios. The cost models have been developed using feasibility design documentation and therefore ranges have been utilised to demonstrate cost effects. Commentary explaining the rationale behind each range is provided below. These costs are representative of a market that is yet to fully embrace low carbon strategies, and this is reflected in the preliminary and on-costs.

Table 6: Design economics for three design scenarios

	Baseline	Intermediate	Stretch
Gross Internal Area (m²)	28,516	26,975	24,650
Net Internal Area (m²)	19,391	17,997	16,035
NIA:GIA overall efficiency	68%	67%	65%
Total floors (excl. roof)	17	16	15
Above ground floors (excl. roof)	16	15	15
Below ground floors	1	1	0
Slab to slab height (m)	3.60	3.87	3.85
Structural frame	Steel frame and composite floor	Steel frame and CLT floor	Glulam frame and CLT floor

The baseline design is benchmarked using a number of BCO compliant commercial buildings within central London. These projects are aligned in size however, represent a mid-high shell and core specification. A benchmark efficiency of 68% is achieved on the net to gross internal floor area.

In this study, it is assumed that the baseline design would benefit from an additional floor where slab to slab heights can be reduced due to the concrete and steel construction. The timber frame in the stretch design dictates greater slab to slab depths to enable services to pass under the CLT beams, rather than through them in a more conventional frame. The CLT beam depths are also deeper than steel beams.

The stretch design removes the basement and relocates plant to the upper floors whilst retaining the above ground building envelope (the same building height is maintained). Whilst this attracts a reduction in overall costs for the substructure, the loss of NIA is significant and reduces the building's overall area efficiency.

The reduction in total floors from 17 to 15 between the baseline and stretch scenarios has a compound impact on the commercial viability of the project. Capital costs have increased and the yield has decreased given total net internal area has reduced by 17%. Whilst out of scope of this study, future studies could examine other contributing factors to building value, including stranded asset risks, investor pressure through the Task Force on Climate-related Financial Disclosure (TCFD), and running costs. The latter could build on recent JLL findings showing that sustainable buildings can result in increased rental value of 6-11% and lower void periods, which could potentially balance increases in capital costs. "Even with a potential increase in construction costs, we estimate that the rental premium and yield compression could take a typical scheme from 15% profit on cost to over 20% profit on cost," from the JLL report.[9]

Additionally, the study did not consider whether a compromise pathway could be negotiated to improve the project's viability, for example, for an improved planning consent to increase building height, based on the net zero credentials of the development. In any case, the market will need to clearly examine the financial returns for full structural timber frame buildings to better understand the full implications. This discussion topic is due to be addressed in a supplementary report – please see "Section 3: Conclusion" on page 55 for further information.

Table 7: Cost change by building element (£/m² GIA) for office design scenarios

		Baseline	Intermediate		Stretch	
		£/m²	£/m²	% change from Baseline	£/m²	% change from Baseline
1.	Substructure	£325	£365	12%	£160 to 185	-44 to -50%
2.	Frame, upper floors & stairs	£450	£625	39%	£730 to 820	63 to 82%
3.	Roof	£75	£75	–	£75	–
4.	External walls, windows & doors	£495	£445	-10%	£495 to 550	0 to 11%
5.	Internal walls & doors	£95	£95	–	£95	2%
6.	Finishes & fittings	£235	£235	–	£235	1%
7.	Mechanical, electrical & plumbing (MEP)	£730	£745	2%	£745 to 820	2 to 12%
8.	Lifts	£110	£120	9%	£130 to 140	17 to 27%
9.	Preliminaries; overheads & profit; design & build risk	£610	£610	–	£700 to 775	15 to 27%
	Total Shell & Core	**£3,125**	**£3,320**	**6.2%**	**£3,370 to 3,660**	**8 to 17%**

It is important to note that costs are presented on a £/m² of GIA. Differences in the overall GIA will have a knock-on effect on the price per m² where some elements remain constant. For example, the external walls appear to have significantly increased in cost, and whilst some of this effect is the adoption of opening windows, a large proportion is attributed to costs being spread over a lower GIA following the removal of the basement.

KEY COST DRIVERS

	Baseline	Intermediate	Stretch
1. Substructure	£325	£365	£160 to 185

The concrete substructure for the baseline and intermediate designs remain the same. The costs, however, are lower for the baseline to remain consistent with the benchmarked analysis which are typically single storey, whereas the intermediate design is double height.

The removal of the basement in the stretch design omits costs for secant piling and basement excavation, generating a saving of £190/m² across the reduced GIA of 24,650m².

	Baseline	Intermediate	Stretch
2. Frame, upper floors & stairs	£450	£625	£730 to 820

The baseline design is based on a steel frame with concrete slabs on a metal deck, and a concrete core. The baseline is observed as the lowest cost of all three specifications at £450/m² which is expected; the market at the time of writing is well suited to respond to this specification and over time has increased the performance of the frame and gained efficiencies in construction methods and speed.

The intermediate design introduces CLT slabs in lieu of the concrete slabs on metal deck. This results in a cost increase of £175/m² to £625/m² which is because of CLT slabs being more expensive, and an overall loss of GIA.

In the stretch design, the frame and upper floors are entirely constructed from timber. A suitable range for adopting this design was considered to be £730-820/m². The quantum of timber has been calculated using a typical floorplate with marginal adjustments for ground and plant areas.

	Baseline	Intermediate	Stretch
3. Roof	£75	£75	£75

Whilst the roof slab is changed to CLT in the stretch design, no significant cost increase cost is expected between all three scenarios.

	Baseline	Intermediate	Stretch
4. External walls, windows & doors	£495	£445	£495 to 550

The baseline external walls benchmarked in this scenario typically have greater levels of articulation than the intermediate design. For this reason, the cost is slightly more expensive for the baseline design, allowing for a variety of performance and architectural specifications.

For the intermediate design, the external walls have been rationalised, reducing articulation and simplifying the number of cladding types. The simplification of the cladding accounts to a £50/m² reduction compared to the baseline design.

The stretch design takes the same façade as the intermediate design, however adds opening vents. The integration of these into the façade adds £80/m², which is partially driven by the reduction in GIA.

	Baseline	Intermediate	Stretch
5. Internal walls & doors	£95	£95	£95
6. Finishes & fittings	£235	£235	£235

Costs for these elements are subject to minor change and remain constant in this study.

	Baseline	Intermediate	Stretch
7. Mechanical, electrical & plumbing (MEP)	£730	£745	£745 to 820
8. Lifts	£110	£120	£130 to 140

The baseline MEP is for a high specification developer and therefore costs are considered higher than industry benchmarks. Numerous specification and scope enhancements were costed, such as:

- Supplementary cooling systems to MER, Transformer & UPS rooms
- On floor hydraulic separation of LTHW & CHW services
- Power system monitoring – PMS, PLC, EMS requirements
- Standby generation provision for tenants
- Inclusion of a passive/active network
- Inclusion of mobile phone enhancement
- Smart enablement

The baseline allows for this increased level of specification at £730/m² and lifts at £110/m².

The stretch design sees a £20/m² cost increase over the intermediate design. This is attributed to a fully automated temperature system, linked to window openings and the HVAC system

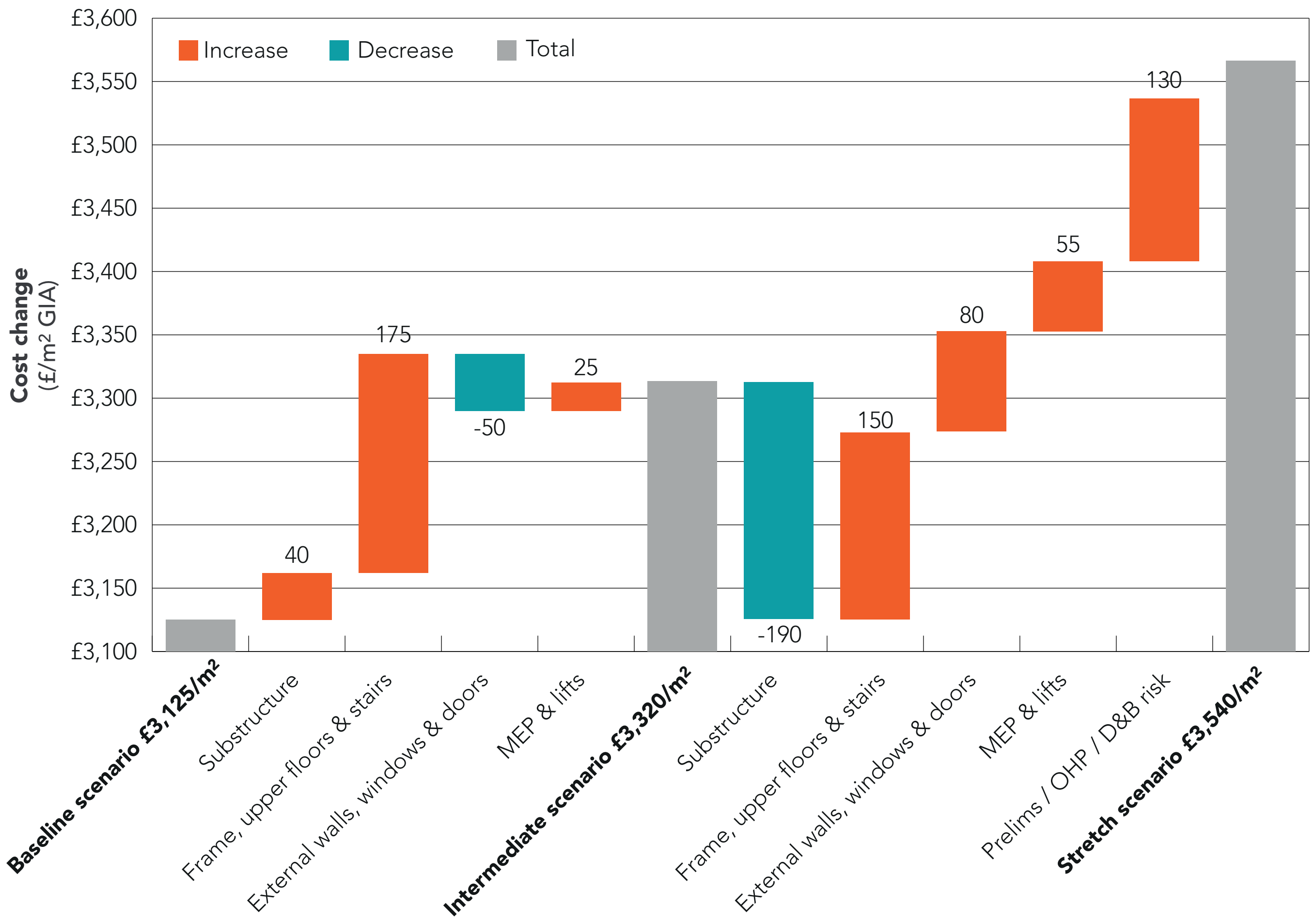
	Baseline	Intermediate	Stretch
9. Preliminaries; overheads & profit; design & build risk	£610	£610	£700 to 775

Industry benchmarks at the time of writing expect preliminaries to be between 14-15% of the construction cost of the project. Overheads and profit for new builds were observed at 5%, and design and build risk at a range of 2-3%.

The baseline and intermediate scenarios allow for industry benchmark percentages and therefore the majority of cost uplift is attributed to an increase in construction costs.

In the stretch design the anticipated level of preliminaries, overheads and profit, and risk are increased to reflect the current appetite in the market, lack of precedence and greater perceived risk relating to timber frames. In time, it is anticipated that these on-costs will become more competitive as the adoption of timber buildings becomes more commonplace.

Figure 19: Building element adjustments from baseline through to intermediate and stretch scenario



WHOLE LIFE COSTING

The scope of the main cost analysis for this study has been limited to changes in the buildings' capital cost, rather than whole life cost. This was considered reasonable given confident assumptions can be made for capital costs based on the feasibility stage design documentation, whereas these costs would have become less reliable when modelling across the life of the building. A whole life cost analysis, however, is beneficial in painting a fuller picture, allowing stakeholders to appreciate not only immediate cost changes, but also the influence design changes can have on cost throughout the life of a building.

Some examples of whole life cost changes for low carbon buildings include:

- Lower energy costs due to higher energy efficiency,
- Lower maintenance and replacement costs due to designing for durability,
- Higher rental premiums due to leading environmental attributes,
- Lower demolition costs due to designing for circularity,
- Lower offset cost due to efficient design and operation.

Whilst the previous section of this report provides the overall capital cost changes for the office design scenarios, a whole life costing analysis has been undertaken for a small selection of building design changes. This is intended to provide a sample of whole life cost findings which, ideally, should be undertaken as standard practice across the overall design of a building, similar to lifecycle carbon assessments.

The three building elements for which the whole life costing analysis has been undertaken is provided in Table 7 for both the baseline and stretch scenarios. A period of 30 years has been selected for the analysis as this is considered to be the point at which a major retrofit may be undertaken. The findings highlight the importance of assessing the feasibility of net zero buildings based on whole life cost, not only capital cost, and future studies could provide this analysis across the overall design of a net zero building.

Table 8: A limited whole life costing analysis was undertaken for three building elements

Baseline scenario	Stretch scenario	Cost change (over 30 years)
Gas boiler	Air source heat pump	Saving of 30-40%
Suspended ceiling	Exposed soffit	Saving of 50-60%
Raised access flooring	Solid timber flooring	Increase of 3.5%

Gas boiler vs. air source heat pump

The optimisation of the building's design between the baseline and stretch scenarios, combined with the change from gas boiler to air source heat pump, results in a 72% reduction in heating and co–ling loads – from 1,450,000kWh/yr to 410,000kWh/yr. This improved energy performance in-use results in a 30-40% cost saving over 30 years of operation. These calculations have been based on component lives derived from CIBSE Guide M and JLL's in-house benchmark data.

In addition to these cost savings, any costs to retrofit the building to meet future net zero legislation or market expectations should also be considered. This could include significant costs to remove any on-site fossil fuel use from gas boilers and replacement with either a hybrid (hydrogen/gas) system or air source heat pump. Designing new buildings that achieve net zero outcomes today would future-proof the building from future unknown costs such as these.

Suspended ceiling vs. exposed soffit

The fitout for the stretch scenario has been designed to reduce, or remove entirely, any excessive material finishes. This approach, also known as 'dematerialisation', helps to reduce embodied carbon from the building's construction and use (i.e. maintenance, repair, refurbishment, replacement) stages. The change from a standard suspended ceiling system to an exposed soffit with foil wrapped services not only helps to reduce embodied carbon but also results in a cost saving of 50-60% over a period of 30 years.

These calculations assume a rate of £85/m² for installing the suspended ceiling and £35/m² for foil wrapped services to the exposed soffit (to maintain aesthetics), with a 2% allowance for replacement every 5 years in both scenarios. Additional benefits of the exposed soffit include easy access to building systems and greater floor-to-ceiling heights, however further consideration would be required for the layout and provision of services without a ceiling void.

Raised access flooring vs. solid timber flooring

A similar dematerialisation approach that was applied to the ceiling has also been applied to the flooring. The change from raised access flooring with carpet tile to solid timber flooring saves the replacement of carpet tiles at the assumed rate of every 12 years, with commensurate reductions in embodied carbon. The calculations assume £60/m² for installing the raised access flooring with an allowance of 5% to be replaced every 20 years for planned and reactive maintenance churn; £30/m² for the carpet tiles, with a replacement life at every 12 years; and £120/m² for installing a timber floor cradle and batten system.

Unlike the cost savings for the exposed ceiling, the low carbon flooring option does result in a slight 3.5% cost increase over a period of 30 years. This points to the importance of accounting for multiple product and material life cycle costs as in some cases, cost increases will be balanced out by savings in other areas though this principle is subject to further project specific analysis. When considering solid timber flooring, one also cannot disregard the carbon savings from eliminating multiple carpet replacements and utilising wood instead.

Net zero residential

OVERVIEW

The following section illustrates the effect on construction costs of embracing low carbon design and achieving ambitious net zero targets. This has been done by modelling costs on a residential build-to-rent project in the south east with 209 units. The scheme is mixed-use with elements of retail, amenity, and workspace. The retail and workspace elements were discounted from the exercise to give a true reflection of the residential costs.

The change in cost is broken down by building elements on a pounds per square metre basis to enable a direct comparison between the three design scenarios. The cost models have been developed using feasibility design documentation and therefore values have been estimated and rounded. These costs are representative of a market that is yet to fully embrace low carbon strategies, and this is reflected in the preliminary and on-costs.

Table 9: Design economics for three design scenarios

	Baseline	Intermediate	Stretch
Gross Floor Area (m²)	18,216	18,216	17,536
Net Internal Area (m²)	12,117	12,117	11,513
NIA:GFA overall efficiency	67%	67%	66%
Total floors	18	18	16
Number of units	209	209	201
Structural frame	Reinforced concrete frame	Reinforced concrete frame, with post-tensioned slabs	Timber frame and CLT floors, with retained concrete cores

It is important to note that the stretch scenario has eight less residential units than the baseline and intermediate scenarios which would have a direct impact on the viability of the scheme. This is due to the requirements for the structural zone for this option increasing from 190mm to 640mm and the resulting two floors being lost to maintain the current building height. This has caused a reduction to the gross internal floor area and net internal area for this scenario.

Table 10: Cost change by building element (£/m² GIA) for residential design scenarios

		Baseline	Intermediate		Stretch	
		£/m²	£/m²	% change from baseline	£/m²	% change from baseline
0.	Demolition & enabling	£35	£35	-	£35	-
1.	Substructure	£130	£130	-	£125	-4%
	Shell & Core					
2.	Frame, upper floors & stairs	£250	£265	6%	£285	14%
3.	Roof	£85	£85	-	£90	6%
4.	External walls, windows & doors	£460	£510	11%	£475	3%
	Finishes					
5.	Internal walls & doors	£200	£200	-	£200	
6.	Finishes & fittings	£340	£340	-	£350	3%
7.	Mechanical, electrical & plumbing (MEP); lifts	£580	£590	2%	£625	8%
8.	External works	£60	£60	-	£65	8%
	Measured Works Total	£2,140	£2,215	3.5%	£2,255	5.4%
9.	Preliminaries; overheads & profit; design & build risk	£575	£595	3%	£605	5%
	Construction Total	£2,715	£2,810	3.5%	£2,860	5.3%

KEY COST DRIVERS

	Baseline	Intermediate	Stretch
1. Substructure	£130	£130	£125

Moving from the baseline design to the intermediate resulted in cost savings of (£3/m²) due to the reduction in weight moving to post-tension slabs, reinforcement reduced from 150kg/m³ to 85kg/m³. This saving was increased by a further £3/m² moving to the timber frame option in the stretch design.

The volume of concrete required for the piling reduced by 17% from the baseline to intermediate design, and a further 8% between the intermediate and stretch designs. For both the intermediate and stretch design a preliminary pile test and three working pile tests have been allowed for. For all three scenarios CFA piling was used.

An additional 25mm of excavation was allowed for to increase the thickness of the ground insulation by 25mm for the intermediate and stretch designs. This was reviewed and the cost impact was negligible.

	Baseline	Intermediate	Stretch
2. Frame, upper floors & stairs	£250	£265	£285

The baseline design cost is based on a traditional reinforced concrete (RC) frame with concrete cores. This is the most common type of construction for mid-rise residential buildings in the UK due to its efficiency, speed of construction and general familiarity of the UK supply chain with this method of construction.

The intermediate design moved to a post-tensioned (PT) concrete slab which resulted in a cost increase of £17/m², despite reductions in the volume of concrete and reinforcement required. PT slabs generally become more cost efficient than traditional RC frame on projects where large spans are required (over 6m), with a simple and repetitive floor plate shape.

The stretch design (timber frame and CLT) was the most expensive of the three scenarios. Cost data was notional given the limited amount of cost data available for medium to high rise timber residential buildings in the UK. Additional costs which are not required for the other two scenarios were also factored into these costs, including encasement of all columns in fire boarding to achieve a two hour fire rating, and similar within the floor build-up. Due to current Building Regulations and the requirement for non-combustible materials in the façade, further work and development will be required to better understand the risks with timber and CLT and thus make it more cost-effective for project delivery.

A key issue which also impacted the stretch design was the fact that the overall structural zone had to be increased from 190mm to 640mm when moving to a timber structure. This required the removal of two floors to maintain the current building height and has resulted in the loss of eight residential units, 680m² of gross internal floor area and 484m² of net saleable area.

	Baseline	Intermediate	Stretch
3. Roof	£85	£85	£90

150mm of roof insulation was added to the intermediate and stretch scenarios which resulted in a slight cost uplift.

	Baseline	Intermediate	Stretch
4. External walls, windows & doors	£460	£510	£475

The baseline design included a solid:glazing ratio of 51:49 and masonry wall construction (metsec inner skin) without insulation.

The intermediate design maintained the same solid:glazing ratio, however with a specification uplift to triple glazing, 250mm glass wool insulation and blockwork inner skin. Lime mortar was also introduced. This change in specification increased costs by £50/m^2.

The stretch design increased the solid:glazing ratio to 71:29 (whilst maintaining triple glazing). This reduction in the proportion of glazing brought costs down by £32/m^2 and brought the capital value broadly in line with the baseline design. It is to be noted that in this final scenario the amount of light entering the apartments is reduced and may have a knock on effect on their desirability.

The insulation is increased to 300mm in the stretch design and, importantly, this results in 120m^2 of net internal area being lost throughout the building, due to the increased wall thickness build-up.

	Baseline	Intermediate	Stretch
6. Finishes & fittings	£340	£340	£350

Changes for costs for these elements were kept constant in this study and any movements are due to changes in GIA/NIA. For the stretch design, additional costs were included for the introduction of fireboard to the floor build-up to achieve a two-hour fire rating.

	Baseline	Intermediate	Stretch
7. Mechanical, electrical & plumbing (MEP); lifts	£580	£590	£625

The major change from the baseline design is the addition of air source heat pumps (ASHP) to provide heat in lieu of a gas boiler system. This cost has been based on analysis explored by the cost consultant on the current scheme's design development. The provision of gas on-site has been removed, as well as specific equipment for gas boilers only, such as flues. It has been assumed that the structure can accommodate the ASHP at roof level.

The LED improvements included for the stretch design are assumed not to demonstrate a cost uplift i.e. reflect similar progress in the market as has been seen over the last decade.

Wastewater heat recovery systems (WWHRS) has also been included in the stretch design. This would require a system on each shower/bath drain and the costing has been based on one unit per apartment using the Showersave system.

The addition of the chlorine dioxide (ClO2) system for domestic hot water (DHW) to allow lower water temperatures and therefore much higher water generation efficiencies from the heat pump provides an uplift in cost. This would necessitate an electric zip tap (or similar) to the kitchen sink of each apartment to provide higher temperature water. The costing has been based on one unit per apartment.

The stretch design sees a £35/m² increase in cost over the intermediate design, attributable to the items highlighted above.

Value engineering options would be explored on all design scenarios and costs could be reduced via MMC options, such as bathroom pods and prefabricated MEP systems, although has not been explored in this study.

	Baseline	Intermediate	Stretch
9. Preliminaries; overheads & profit; design & build risk	£575	£595	£605

Preliminaries have been benchmarked at 15.5% in line with current tender returns received for similar residential projects; overheads and profit have been allowed at 5.5%; design and build risk has been benchmarked at 5% on shell and core works, and 3% on fitout rates. All three scenarios make use of these rates.

In the stretch design, it would be anticipated that for timber framed buildings the preliminaries costs may be slightly lower, however due to the perceived risks around timber at present it was deemed prudent to maintain the same level of on costs as the baseline and intermediate scenarios. In the future, as timber is more widely adopted and the risks are better understood, this should in turn make pricing more competitive.

Carbon offsetting

In line with the scope and methodology of this study, all three design scenarios were intended to meet UKGBC's definition of 'net zero carbon – construction'. This involves calculating the total upfront embodied carbon for each scenario and offsetting this in full to achieve a net zero carbon balance at practical completion. Each design scenario has placed different levels of emphasis on reducing the building's whole life carbon, so this final step helps to provide comparability across all three scenarios for achieving a net zero carbon outcome.

There is a growing recognition among leading developers that the embodied carbon from construction can account for a large portion of their scope 3 emissions, and voluntary reporting initiatives such as TCFD and SBT are increasingly encouraging businesses to measure and mitigate these impacts[16]. Concurrently, leading city authorities such as London and Greater Manchester are beginning to require embodied carbon assessments of new developments through planning, in the expectation that targets or offsetting requirements will be required in the future. These corporate and policy drivers mean that there are likely to be growing pressures on developers to mitigate and offset embodied carbon impacts in the coming years.

A UKGBC Task Group has been convened to develop guidance further detailing best practice in this area, including the potential inclusion of an explicit carbon price for use in conjunction with the hierarchy in UKGBC's net zero framework.[17] This guidance has a targeted publication date of spring 2021 so the methodology and pricing outlined for carbon offsetting within this report may be superseded once the updated guidance is released.

Setting a carbon price

There are a range of reference carbon prices utilised or proposed within the industry[18]. These can be implicit, such as the voluntary carbon offset market, or explicit, such as the £95/tCO_2 for the new London Plan (currently only for regulated emissions)[19]. Explicit prices typically focus on a specific range of emissions, most often scope 1 and 2, which is reflected in their pricing. As a result, there is limited existing guidance on what might be considered an appropriate carbon offset strategy for embodied carbon. A range of offset prices were therefore reviewed to inform this study:

Table 11: Carbon price examples

	Source	Average Carbon Price (/tCO_2)	Comments
Implicit	International voluntary market, e.g. Gold Standard	£2.40[20]	Range of project types including renewable energy, fuel switching, waste disposal, etc.
Implicit	UK Woodland Carbon Code – Pending Issuance Units (PIUs)	£7 – 20[21]	PIUs are based on predicted sequestration and therefore cannot be used to report against UK-based emissions until verified. Reasonable level of assurance of actual carbon sequestration is not available until Year 15 onwards. A Woodland Carbon Unit (WCU) is a tonne of CO_2 that has been verified to be sequestered but given the current UK market only a small number of verified WCUs have been sold. Consequently, an average price range cannot yet be determined.
Explicit	World Bank; High-Level Commission on Carbon Prices (2017)	US $40 – $80[22]	The Commission concluded that the explicit carbon price level consistent with achieving the Paris temperature target is at least US $40–80/t$CO_2$ by 2020.

The World Bank outlines the minimum carbon price range to be consistent with the Paris Agreement in 2020 as £32 – £64/tCO_2 (US $40-$80/tCO_2), therefore a conservative value of £64 is proposed for this analysis.

Note that the carbon price levied can be used to purchase carbon units from the voluntary carbon offset market or WCUs. Any PIUs bought must be matched with the equivalent amount of accredited carbon units to report against any embodied carbon emissions or to use in claims of net zero emissions.

OFFSET COSTS

Using the offset price of £64/tCO_2, the additional capital cost for offsetting to achieve net zero carbon – construction for all three scenarios is provided in the tables below.

Table 12: Office breakdown of costs to achieve net zero carbon – construction for all three scenarios

	Baseline	Intermediate		Stretch	
		Excluding sequestration	Including sequestration	Excluding sequestration	Including sequestration
Total upfront carbon (module A; tCO_2e)	25,125	20,419	16,857	14,036	7,625
Price of offset unit (£/tCO_2)	£64				
Price to offset total carbon for construction (£)	£1,608,000	£1,307,000	£1,079,000	£898,000	£488,000
Offset price (£/tCO_2e/m² GIA)	£59.61	£48.45	£40.00	£36.43	£19.80

Table 13: Residential breakdown of costs to achieve net zero carbon – construction for all three scenarios

	Baseline	Intermediate*	Stretch	
			Excluding sequestration	Including sequestration
Total upfront carbon (module A; tCO_2e)	13,538	11,009	10,347	6,750
Price of offset unit (£/tCO_2)	£64			
Price to offset total carbon for construction (£)	£866,500	£704,600	£662,200	£432,200
(£/tCO_2e/m² GIA)	£39.25	£31.91	£30.95	£20.20

* Unlike the intermediate scenario for the office design, the intermediate scenario for the residential design does not include a timber structure, so sequestration is not considered.

These results demonstrate the importance of including offset payments within the capital cost appraisal for new buildings. Developers and investors that account for offsetting help to future-proof the business case for new buildings where offsetting could become a requirement, for example, through planning or market expectations. A current example, is the requirement to offset regulated emissions in the new London Plan, which is due to be extended to major non-residential developments.[19]

This analysis demonstrates that higher performing, lower carbon buildings will have to pay less for offset payments. Whilst these buildings will require an overall initial increase in capital cost compared to the baseline, this can help to reduce the true cost of a building, including its environmental impact and cost to achieve net zero. Carbon prices will only increase over the next decade and this will impact the absolute values.

Section 3: Conclusion

Net zero buildings will play an important role in the UK's goal to decarbonise by 2050. Whilst there has been a proliferation of guidance which set out the key requirements for net zero carbon buildings, the practical design and cost implications have yet to be fully explored. This report begins to shine a light on the design and cost changes required for buildings to achieve net zero performance targets and helps to reduce some of the currently unknown variables.

Summary of findings

This study has shown that building to net zero does result in a cost uplift but, nonetheless, there is a strong case for these designs given shifting market demands and future requirements to meet operational and embodied carbon targets. Cost increases of 6.2% for the office tower and 3.5% for the residential block under the intermediate scenarios can be considered feasible today. While the capital costs may be higher, this is likely to correspond with an increase in the value of the buildings, higher rental premiums, lower tenancy void periods, potentially lower life cycle costs, and more. From a tenant's perspective, there can be reputational benefits, positive health and wellbeing impacts, lower operational costs, and other benefits. Given these targets will be necessary to meet net zero goals in the future, a strong argument can be made for attempting to meet the intermediate targets as soon as possible.

The cost increases of 8-17% for the office tower and 5.3% for the residential block may be considered unfeasible today without widespread market transformation and adequate consideration of the value proposition of net zero buildings. The unavoidable loss of floor area and corresponding loss of sellable NIA under the two stretch scenarios is acknowledged as a negative impact on the building's value. This could also be partially offset by an increase in rental premiums and decreased void periods, as well as avoiding the risk that the building will become a stranded asset in future. While there was only limited analysis conducted on the life cycle costing of some components in the office tower, accounting for life cycle savings shows promise in increasing the value of net zero buildings. A similar analysis could be conducted for residential buildings in the future.

Whilst all of the scenarios achieved significant reductions across both carbon and energy, some of the specific targets were not met due to limitations of the study (e.g. adhering to the project briefs), limitations of the building design (e.g. building orientation and massing), slower uptake of low carbon materials in the UK, and more. Some additional potential implications of these findings could include: needing to allow greater deviations and flexibility from project briefs to improve project viability; more research into achieving the targets, particularly for embodied carbon; occupant lifestyle changes; exploration of regulatory and policy changes needed, such as for unregulated loads in residential buildings; and more.

The industry will likely need to transform over the next few years to be better able to deliver net zero buildings. It is expected the supply chain will adapt over the next few years to better provide the skills and materials needed for net zero buildings, decreasing the construction costs and project times. Innovative technologies will continue to make it easier to achieve targets.

In this way, this report is the first step towards 'building the case for net zero buildings'. It provides the facts and figures for two typical developments, whilst signalling broader structural changes required for the buildings sector. A supplementary publication will examine the market transformation in detail (see below), and future studies could branch into other relevant areas, such as different building types, retrofit of existing buildings, and enabling green finance mechanisms.

MARKET TRANSFORMATION

Achieving new net zero buildings at scale will require the buildings sector to re-imagine the current design and delivery process. Wider collaboration and buy-in from stakeholders across the value chain will be needed to ensure net zero carbon outcomes are embedded throughout all stages of a building's lifecycle.

As this report has shown, the transition to a net zero built environment is becoming achievable with effective design changes and adequate investment. However, a better understanding of current market conditions is necessary to appreciate the challenges and opportunities to enable a rapid transition to new net zero buildings.

Over the course of this study, a series of topics requiring further industry research and discussion to enable this shift were identified. These were developed in collaboration with JLL where views have been fed-in from a cross-section of teams – including development, planning, construction, letting and management – to gain important market insights throughout critical stages of a building's lifecycle.

It became clear throughout the project that these topics are just as important to address for the net zero transition as the design and cost implications outlined in this report. As such, a supplementary publication has been planned which will focus on market transformation which will delve deeper into each of the below themes, with publication due later in 2020. The next page has a non-exhaustive list of themes from the series of topics identified thus far.

Figure 20: 10 key themes to enable net zero buildings

1. Set the net zero carbon vision
Clients need to show leadership and set the ambition for net zero carbon buildings. By working towards an ambitious outcome, all stakeholders are inspired to step up to the challenge.

2. Effectively communicate the net zero carbon vision
The vision should be marketed in a positive way to emphasise the whole life benefits of to all stakeholders, including end-users. Market recognition of net zero carbon buildings, using certification or other recognised schemes, can help realise value. General upskilling across the value chain – including local authorities, design teams, construction workforce, end-users (tenants, residents) – can help improve the holistic understanding and benefits of net zero buildings. Often terminology can become 'jargon' and lead to disengagement.

3. Adopt an evidence-based approach to net zero design
It is critical to understand the carbon impact of design decisions to make informed decisions about net zero buildings. The use of modelling and cost assessments, as conducted in this study, are beneficial but this will differ based on project specifications and locations.

4. Improve end-user perception of net zero buildings
Net zero buildings should be considered high-performing across other dimensions, not just environmental aspects, e.g. amenity, health and wellbeing, aesthetics. They should not be seen as compromising other building qualities.

5. Rethink financing of net zero carbon projects
It is critical to unlock financing opportunities early in the project to guarantee their development. This would include both green finance options (e.g. preferential borrowing rates for green developments) and approaches to carbon offsetting.

6. Increase design innovation at scale
Innovation across all aspects of building design and construction is needed to deliver net zero carbon buildings at scale. This needs to be supported by a favourable regulatory environment that favours a climate first approach to design and construction. Rapid innovation and accelerated uptake is also key to reducing cost.

7. Transform the supply chain to build capacity and capability
Designers will need skills in energy efficient design and specification of low carbon materials; constructors and product suppliers will need skills in the installation of low carbon materials and technologies; all stakeholders will need to embrace the circular economy.

8. Change project timescales
The design and construction of the project should be focused on the net zero carbon outcome, taking care not to 'value engineer' and compromise the vision. A soft landings approach should be used, including adequate time programmed in throughout construction and into aftercare.

9. Post occupancy is as important as the design stage
Comprehensive testing and commissioning will be necessary to achieve the intended outcome. Careful handover, user-training and post-occupancy evaluation should be implemented. Regulators and end-users should be taken on the journey, so they are comfortable with the result and how to use the building as it was designed.

10. Building management should maintain the net zero carbon vision
Appropriate building management and maintenance routines should be in place, to ensure the performance is optimised, including low carbon repairs and refurbishment. Occupants should fully understand how to get the best outcomes for the building to sustain efficient operation and comfort.

Next steps

Whilst the focus of this report has been on two specific building types, it starts to shed light on the approaches that will be needed for the design, construction and delivery for all net zero carbon buildings. UKGBC considers this report to potentially be the first in a catalogue of studies that 'build the case for net zero'. In line with this, two planned future publications are:

- **Market transformation for net zero carbon buildings**
  This report is intended to expand on the 10 key themes outlined above to stimulate discussion about the ways that the supply chain, building owners and tenants will need to adjust their activities and behaviours to enable net zero carbon buildings. This report is due to be published later in 2020.

- **Large-scale housing case study**
  The delivery of large-scale housing developments that meet net zero carbon standards presents another set of challenges. A future study could apply the same methodology used in this report to understand the design and cost implications for this type of development. UKGBC is eager to explore options for further analysis on other building types, and invites members to contribute their suggestions.

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QUESTIONS & FEEDBACK

This study aims to explore design and cost implications of building to net zero. We welcome input from any interested stakeholders on the content and potential future iterations.

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

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