Assessing the trajectory for net-zero buildings for the Oxfordshire Cotswolds Garden Village

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1 Executive Summary

The purpose of this report is to clarify and assess the implications associated with meeting zero carbon for new buildings at the Oxfordshire Cotswolds Garden Village. This has been reviewed across varying levels of carbon emissions reductions and includes capital and running cost analysis. A number of key performance indicators (KPIs) are proposed to support the zero carbon trajectory target. This document is intended to aid the development of the Area Action Plan (AAP).

1.1 Zero Carbon is recommended

Four carbon scenarios were investigated for new buildings, results have been extrapolated to include the entire Garden Village site, results are summarised aside, for details see Appendix 3. In this report the industry consensus definition for zero carbon has been used developed by LETI, see section 4.1.

It is recommended that scenario 4, zero carbon, be pursued as this is the only scenario that achieves the level of energy efficiency required to meet climate change targets. It also aligns with the aspirations of the Council and local communities. If any other scenario is chosen, it is likely that developments will need to undergo energy refurbishments before 2050, this has been estimated to cost up to around £80 million.

1.1.1 Key performance indicators

Section 1.3 outlines the Key Performance Indicators (KPIs) that are recommended for the Area Action Plan in order to meet the requirements of zero carbon for new buildings.

1.1.2 Capital cost

It is important to note that the Future Homes standard is due to be implemented by 2025, which is roughly in-line with the commencement of Phase 1 of the Garden Village development. The exact requirements of the standard are yet to be defined but could range from scenario 3 - 80% reductions on-site with no gas connection to scenario 4 - true zero carbon.

Compared to scenario 3, scenario 4 is estimated to have an increase in capital cost of 3-4%. This increase represents significantly improved building fabric and systems performance and a 10% decrease in running costs.

1.1.3 Reduced risk

Clarity on the performance requirements to meet zero carbon in the AAP will reduce the risk and provide certainty for the developer. It will ensure a clear understanding of the long term energy and carbon strategy for the Garden Village.

Scenario 4. Zero Carbon

3,400	35%	5-7%	✓
Tonnes CO_2 saved annually	Reduction in running costs	Increase in capital cost	Zero carbon

£80 million	100%
Saved as retrofit does not need to take place	Of energy generated on-site

Scenario 3. 80% onsite + no gas

2,400	-25% to 23%	1-4%	✗
Tonnes CO_2 saved annually	Reduction in running costs	Increase in capital cost	Zero carbon

Scenario 2. 35% onsite

500 to 2,100	-32% to 25%	-1% to 6%	✗
Tonnes CO_2 saved annually	Reduction in running costs	Increase in capital cost	Zero carbon

Scenario 1. Building Regulations

0 TCO_2	0%	0%	✗
Saved annually	Reduction in running costs	Increase in capital cost	Zero carbon

Figure 1.1.1: Summary of results for the Cotswolds Garden village

1.2 Summary of Analysis

Cost and carbon modelling was carried out in support of this report. A summary of the analysis is shown for a typical new build mid-terraced house aside.

1.2.1 Part L methodology is not fit for purpose

The results have shown that the current Building Regulations energy modelling methodology (SAP), together with the indicator *'Carbon emission reductions, compared to the notional building'* disguises the performance of a building. Percentage carbon reduction is not a useful indicator to understand the future energy performance of the building and whether the development is aligned with meeting zero carbon. Figure 1.2.1 shows the results for a terrace house, see section 5 for the results for an office, school and a medium rise apartment building.

1.2.2 Energy related recommendations

We recommend introducing the following to set the New Garden Village on the right path towards net zero carbon.

1. **Introduce Energy Use Intensity (EUI) requirements**: the use of EUIs would provide an absolute metric in kWh/m²/yr. EUI is independent from carbon and can be easily verified by the building/home owner/tenant after completion.

2. **Request predictive energy use modelling**: We recommend requiring estimates of the building's future energy use. This could be done with Passivhaus Planning Package (PHPP) for domestic buildings and/or other tools consistent with the CIBSE TM54 methodology for non-domestic buildings.

3. **Consider regulated and unregulated energy**: unregulated energy needs to be assessed in addition to regulated energy if net zero operational carbon building is the destination.

4. **Include planning conditions to address the performance gap**: Use outline and detailed conditions to require more energy modelling and quality checks after planning, particularly during detailed design and construction to help to reduce the performance gap.

The cases are placed in each scenario based on their % carbon emission reduction from the notional building using SAP modelling for scenario 1-3, and their predicted EUI for scenario 4.

The predicted modelling results show the predicted EUI and Carbon emissions for each case. For more details on the definition of EUI see Section 1.5.

				SAP modelling	Predicted modelling using PHPP		Cost modelling	
Scenario	Case	Fabric	System	CO_2 % reduction from notional building	EUI kWh/m² (no PV)	$kgCO_2/m^2$	Capital cost increase %	Running cost increase
1	1.1	Business as usual	Gas Boiler	3	98	14	0.0	£0
2	2.1	Business as usual	Gas Boiler+ PV	47	98	12	3.6	£0
	2.2	Ultra-low energy	Gas Boiler	37	64	9	6.1	-£362
	2.3	Ultra-low energy	Direct Electric	43	57	4	2.9	-£12
	2.4	Good practice	Direct Electric + PV	35	78	5	-1.4	£349
3	3.1	Good practice	Heat pump 1	77	43	3	3.0	-£267
	3.2	Business as usual	Heat pump 2	79	41	3	2.2	-£296
	3.3	Good practice	Direct Electric + PV	77	78	4	-0.2	£349
4	4.1	Good practice	Heat pump 2 + PV	n/a	33	0	5.4	-£370
	4.2	Ultra-low energy	Heat pump 1+ PV	n/a	31	0	7.4	-£411

Figure 1.2.1: Summary of results for the Terrace house

The results above, for the Terrace house, show that while different cases in each scenario look like they are achieving similar carbon emission reductions, using SAP modelling, the predicted modelling shows a wider spread in performance. For example, in scenario 2, the cases have a range of 35-47% carbon emission reductions, but using the predicted modelling results case 2.1 will generate three times the amount of carbon emissions than case 2.3.

1.3 Key performance indicators

This study has developed recommended key performance indicators (KPIs) to be included in the Area Action Plan (AAP). The KPIs are outlined opposite.

1.3.1 Implementation

Compliance with KPIs should be demonstrated across outline and detailed planning submissions, with further consideration at the following stages of a detailed application:

- Planning submission
- Pre-commencement (if the information differs from the planning submission)
- Pre-occupation
- Post-completion for the first five years

Further information has been included in Section 7 – Implementation.

1.3.2 Running cost

If the targets set out opposite are met and a construction quality is assured, then the running costs will be reduced in line with energy consumption and therefore do not need a separate KPI. However, if the KPIs are diluted then it is important that a running cost KPI is developed, as energy reductions are not guaranteed.

1.3.3 Passivhaus

Passivhaus certification would be an optional route to achieving the fabric and energy efficiency KPIs. Passivhaus could be pursued as a requirement in the AAP to improve quality assurance and reduce the technical policy review burden on the Council.

1.3.4 Feedback loop

Post-occupancy energy monitoring should be carried out every year for the first five years of use of each building to understand the energy consumption of the development in-use. The results should be stored centrally and shared between developers, design teams and contractors on-site. It is important that lessons are learned within and across each phase of development.

Fabric

< 15 kWh/m².yr *of space heating demand for both residential and non-residential developments.*

Demonstrated using predicted energy modelling.

Energy Efficiency

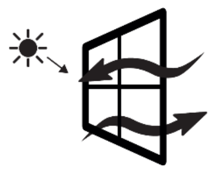
Meeting EUI targets *demonstrated using predicted energy modelling. See table below for targets.*

Fossil fuel free

Fossil fuels, *such as oil and natural gas* ***shall not be used*** *to provide space heating, hot water or used for cooking in both residential and non-residential developments.*

Zero operational carbon balance

100% *of the energy consumption required by buildings on-site shall be generated using on-site renewables, for example through solar PV.*

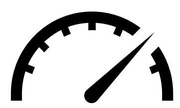


Overheating

Modeling shall be undertaken to show compliance with ***TM 59 for residential and TM 52 for non-residential.***

Embodied Carbon

<500 kg CO_2/m² *Upfront embodied carbon emissions for residential and non-residential developments. (Building Life Cycle Stages A1-A5). Includes Substructure, Superstructure, MEP, Facade & Internal Finishes. Full lifecycle modelling is encouraged.*



Measurement and verification

Meter, monitor and report on energy consumption and renewable energy generation post-completion for the first 5 years for residential and non-residential developments.

EUI targets

Architypes	EUI (kWh/m².yr)	Architypes	EUI (kWh/m².yr)
Homes	35	**Community space (e.g. health care)**	100
Offices	55	**Sports + Leisure**	80
Research Lab (specialist office)	55-240*	**Primary and secondary school**	65
Retail	80		

***** For some typologies, for example specialist offices such as research labs, that could have varying requirements for ventilation and process loads, it is difficult to set an EUI target without knowing further building specific details. It is suggested that these are developed and agreed with the Council as part of pre-application discussions.

1.4 Zero Carbon Summary

Zero carbon is possible
It is also important to realise that reaching net zero operational carbon on new buildings is technically possible. This is assuming that an exemplar level of energy efficiency is achieved, that a low carbon heating system is used and that solar PVs are maximised on roofs. This report uses the LETI definition for operational zero carbon – see section 4 for more details.

Indicative design requirements which are likely to comply with the KPIs are shown opposite. It is important to note that these are not mandatory to satisfy the KPIs, but should be considered holistically rather than individually.

	Zero Carbon home	***Zero Carbon office***
Key Performance Indicators (KPI)	**Indicative design requirements to comply with KPIs**	**Indicative design requirements to comply with KPIs**
Space heating demand [b] **< 15 kWh/m²/yr (TFA)**	1. Efficient form factor: < 0.8-1.2 2. Proportion of windows: 10-25% 3. External wall U-value < 0.13 W/m².K 4. Floor U-value < 0.10 W/m².K 5. Ground floor U-value < 0.10 W/m².K 6. Thermal bridge free junctions 7. Triple-glazed windows 8. Airtightness < 1 m³/h/m² at 50 Pa	1. Efficient form factor: < 1-2 2. Proportion of windows: 25-40% 3. External wall U-value < 0.13 W/m².K 4. Floor U-value < 0.10 W/m².K 5. Ground floor U-value < 0.10 W/m².K 6. Thermal bridge free junctions 7. Triple-glazed windows 8. Airtightness < 1 m³/h/m² at 50 Pa
EUI Target **Residential < 35 kWh/m²** **Office < 55 kWh/m²**	9. MVHR within 2m of external wall 10. WWHR (Waste Water Heat Recovery System) in each unit 11. Heating system analysis required 12. 100 litres of hot water storage per unit	9. 90% efficiency MVHR 10. Central AHU 1.2-1.5 W/l/s 11. A/C set points 20-26 °C 12. Demand Control Ventilation 13. Mixed mode Ventilation 14. Lighting power density 4.5 w/m² NIA 15. Out of hour lighting power density 0.5 w/m² NIA 16. Tenant power density 8 w/m² NIA 17. ICT loads 0.5 w/m² NIA 18. Small power out of hours density 2 w/m² NIA 19. Heating system analysis required
Fossil fuel free	13. No gas supply	20. No gas supply
Upfront Embodied Carbon target < 500 kg CO₂/m²	14. Embodied Carbon modeling undertaken	21. Embodied Carbon modeling undertaken
Overheating	15. Potential external shading to south and west facing windows to mitigate overheating	22. Potential external shading to south and west facing windows to mitigate overheating
Measurement and verification	16. Adequate sub-metering from key energy uses and renewables, electric vehicles, heating fuel consumption 17. Post-occupancy energy monitoring with comparison to predictions 18. Reporting of energy data 5 years post-completion	23. Adequate sub-metering from key energy uses and renewables, separate landlord and tenant energy use meters 24. Post-occupancy energy monitoring with comparison to predictions 25. Reporting of energy data 5 years post-completion
Zero operational carbon balance	18. Roof areas covered in PV panels	19. Roof areas covered in PV panels

Figure 1.4.1: Zero carbon summary

1.5 Energy Use Intensity

In order for there to be zero carbon emissions associated with a building, over the course of the year a net zero operational balance must be met. For ultra-low energy detached and terraced housing that have a large roof area relative to floor area and a low energy intensity, 100% of their annual energy consumption can be met through on-site renewables, typically solar PV on the roof of the buildings. For buildings that are more energy intensive and where roof area is limited and sites are constrained, investment may have to be made in off-site renewables, see Figure 1.5.1. In the case of the Cotswolds Garden Village site, the potential exists for all renewable energy to be generated on-site.

It is important that all new buildings in the UK become net zero carbon in operation, and as the UK has a limited renewable energy resource, in order to achieve a net zero carbon operational balance across the UK, an energy budget must be set, such that there is enough renewable energy UK wide, for all buildings to achieve zero carbon.

Energy budgets are often called EUI targets – the energy use intensity is measured in $kWh/m^2.yr$. For fossil fuel free buildings, the EUI is measured in-use through the incoming electricity meter. This is a simple metric that can be predicted at the design stage using software such as PHPP or CIBSE TM54.

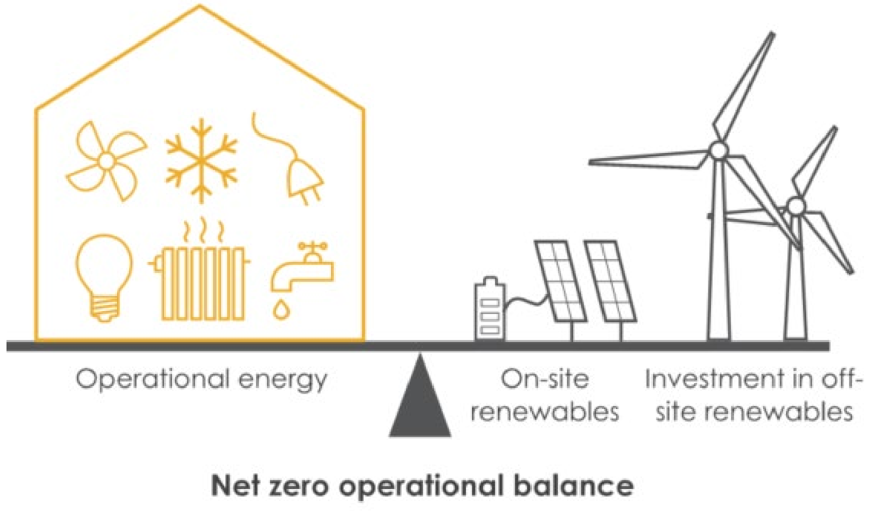


Figure 1.5.1: Net zero operational balance

Source: LETI Climate Emergency Design Guide

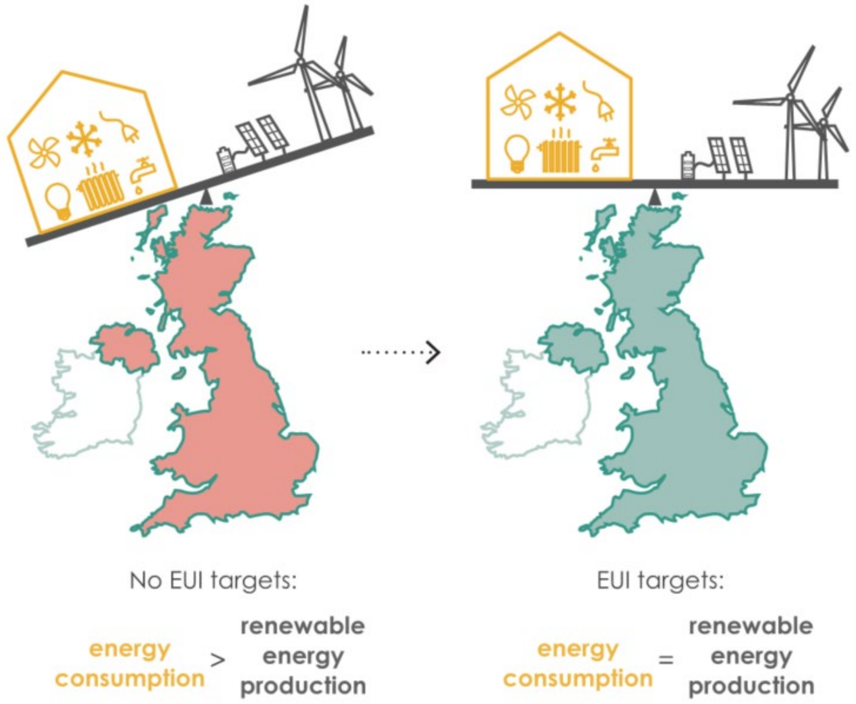


Figure 1.5.2: Why EUI targets are required for zero carbon at a national level

Source: LETI Climate Emergency Design Guide

1.5.1 Setting the targets

The targets in this report are based on the targets from the LETI Climate Emergency Design Guide for the homes, office and school, as well as RIBA 2030 challenge. The other targets have been set based on work by the Dutch Green Building Council and previous project experience.

1.5.2 It does not include renewable energy generation

The EUI target does not include renewable generation, as the renewable energy generation must make up the other side of the operational zero carbon balance. This means that if two buildings are built identically, but one has a roof filled with PV panels and the other does not, they will both have the same EUI.

1.5.3 It includes energy related to district heating

If the building uses a district heating network then the energy consumption associated with the heat received must be included in the EUI of the building (included losses in the network).

1.5.4 Specialist office EUI

For some typologies, for example specialist offices such as research labs, that could have varying requirements for ventilation and process loads, it is difficult to set an EUI target without knowing further building specific details. It is suggested that these are developed and agreed with the Council as part of pre-application discussions.

Architypes	Assumed floor area in Garden Village GIA (m^2)	EUI ($kWh/m^2.yr$)	Source
Homes	165,000	**35**	Net Zero Operational Carbon definition[1], RIBA 2030 Challenge
Offices	40,000	**55**	Net Zero Operational Carbon definition[1] RIBA 2030 Challenge
Research Lab (specialist office)	40,000	**55-240[2]**	Net Zero Operational Carbon definition[1] and project team experience
Retail	1,500	**80**	from Dutch GBC
Community space (e.g. health care)	800	**100**	from Dutch GBC
Sports + Leisure	2,000	**80**	Interpolation
Primary and secondary school	3,563	**65**	Net Zero Operational Carbon definition[1] RIBA 2030 Challenge

Figure 1.5.3: EUI for typologies in the Garden Village

1 The Net Zero Operational Carbon Definition was developed by the London Energy Transformation Initiative (LETI) and the UK Green Building Council (UKGBC) and the Better Building Partnership (BBP). It is also supported by the Good Homes Alliance (GHA), the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE).

2 See section 1.5.4 aside

2 Introduction

West Oxfordshire District Council (WODC) is developing an Area Action Plan (AAP), which once adopted will form part of the statutory development plan alongside the West Oxfordshire Local Plan 2031. The AAP promises exemplary and innovative design as an expectation of development. Included within this Plan is a commitment to look at the potential for zero carbon. There is also strong local support from members of the Energy Plan working group, and from local communities within the village of Eynsham for a target of net-zero development and for a carbon positive energy strategy which embeds on-site renewable energy infrastructure within its proposals.

This report assesses the viability for achieving zero carbon with respect to the new buildings that will be developed on the Garden Village Site.

2.1 WODC - Declaring a climate and ecological emergency

A climate and ecological emergency was declared by the Council in June 2019. There is a commitment to developing a Climate Change Strategy for West Oxfordshire and a Carbon Action Plan in 2020 as a pathway to becoming a carbon-neutral Council by 2030.

The Garden Village will be a phased development likely to start onsite in 2024/25 and be completed by 2035, as such it is important that this development is aligned with the zero carbon ambitions of the council.

2.2 The Garden Village site

The garden village site (c. 215 ha) is located to the north of the A40 near Eynsham. It is predominantly undeveloped and greenfield in nature. The majority of the site is currently made up of agricultural fields and open countryside.

The site is allocated for development as a new garden village of about 2,200 new homes together with business space in the form of a new science park (c. 80,000m^2), as well as a park and ride and other supporting services and facilities such as schools, community space (e.g. health care) and retail.

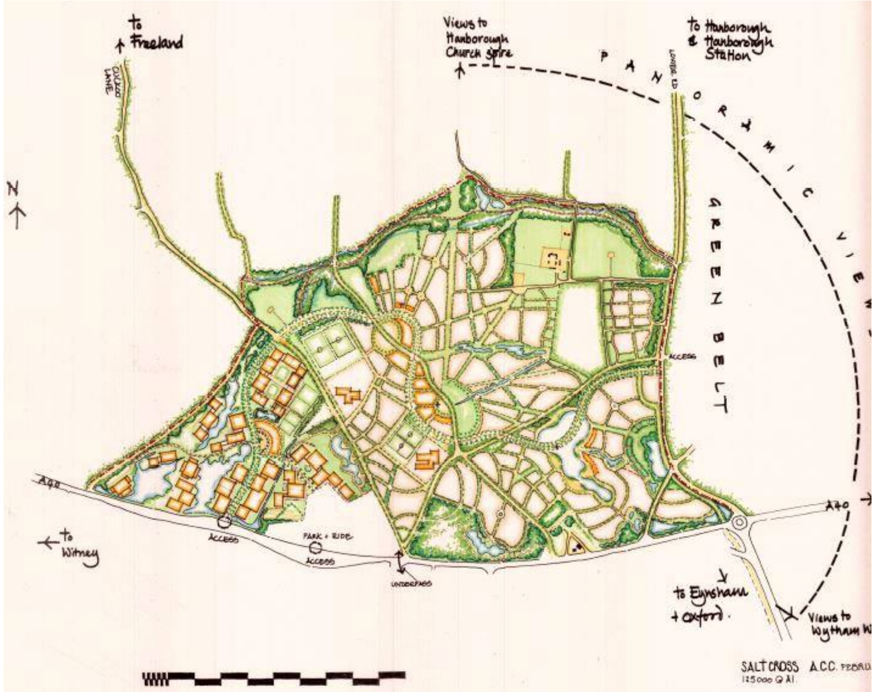


Figure 2.2.1: Indicative layout of the Garden Village development

2.3 Carbon scenarios

A high-level assessment has been undertaken into four carbon scenarios as outlined below:

1. Building Regulations compliance (current).

2. A minimum 35% on-site reduction in CO2 emissions over Building Regulations compliance (current) with carbon offset

3. 75-80% carbon emission reductions with fossil fuel free heating and hot water

4. Net-zero buildings

2.3.1 Future homes standard

The Future Homes Standard, to be implemented by 2025, will introduce a requirement for all new homes to use low carbon heating and achieve world-leading standards of energy efficiency. The specific details of this standard is not yet fully defined, although it is stated that it will mean 75-80% carbon emission reductions with fossil fuel free heating and hot water and the use of waste water heat recovery for showers. Fabric performance may be such that space heating demand is in the range of 15-20kwh/m^2 although this is not specified in detail and will in part depend on the levels of airtightness, approach to ventilation and compliance methods (eg SAP) adopted.

Scenario 3 of our modelling represents a version of the Future Homes Standard in that it achieves a 75-80% reduction in regulated carbon emissions using the current Building Regs methodology with SAP 10.1 carbon factors and fossil fuel free heating. It does not necessarily achieve a space heating demand level of 15-20 kWh/m^2 although some of the compliant models (i.e. with ultra-low energy) do achieve this standard.

Scenario 4, represents a zero carbon standard and is aligned with achieving 15-20 kwh/m^2 space heating demand using predicted modelling and exemplary level of energy efficiency as well as the industry definition of zero carbon developed by LETI. (See section 4). In some respects this scenario is consistent with the requirement for 'world-leading standards of energy efficiency' but may, or may not, be a more stringent standard than the Future Homes Standard depending on the development of the policy.

2.3.2 Analysis

Analysis has been carried out to understand the following for each carbon scenario:

- Building fabric and specification.
- A description of potential decentralised, heat network solutions.
- Low- and zero-carbon energy technologies.
- An assessment of development cost for the purposes of understanding financial viability.
- Predicted, annual running cost of energy to occupants.

2.3.3 Transitionary measures for retrofit to achieve net zero buildings

This has been dealt with separately, in section 5.6.

3 Defining the problem

3.1 Building Regulations methodology

Building Regulations calculation methodology (NCM) is a modelling methodology used to show compliance with Part L of the Building Regulations, as well as planning stage compliance (% carbon emissions reduction) and to generate Energy Performance Certificates. The results of the assessment are not intended to predict the energy performance of buildings, however EPC ratings are still the basis of defining 'good' in the building industry. Similar to a green rating on electrical appliances, EPC ratings are meant to be used to show the energy efficiency of buildings. Figure 3.1.1 shows that there is little correlation between EPC rating and the energy consumption of homes. The next few sections outline the problem with the Building Regulations calculation methodology and why it cannot be used when assessing ultra low energy or zero carbon buildings.

3.2 Issues with Part L methodology

Part L Building Regulations modelling must be undertaken using the National Calculation Methodology (NCM). For residential buildings SAP modelling is undertaken and for non-residential buildings SBEM modelling is undertaken. The NCM methodology was not developed in order to predict energy use and thus can't be used to calculate energy consumption, (cannot be used to predict the EUI target). Figure 3.2.1 shows the difference between energy consumption from Part L modelling and predicted modelling software such as PHPP and TM54. In addition, Part L modelling underestimates heating demand in both residential and non-residential buildings, this means that the benefits of a higher performing fabric is not properly rewarded in Part L modelling. [1]

3.3 Issues with this relative metric

The Part L Building Regulations methodology compares the regulated carbon emissions from the 'actual' building to a 'notional building'. Various issues with this are outlined below:

- **Form factor**: Part L does not incentivise efficient form factor as the notional building has the same form as the actual building, see figure 3.3.1.
- **Carbon**: using a carbon metric can be misleading, see section 3.4 for more details.
- **Verification**: Percentage carbon emissions metric is not an indicator that can be verified in-use.
- **Zero Carbon:** 100% carbon emission reductions do not mean that the building will meet net zero operational carbon.

[1] For further studies see CIBSE TM54-Evaluation of energy performance at design stage and London Borough of Islington Energy Evidence Base 2017 by Etude

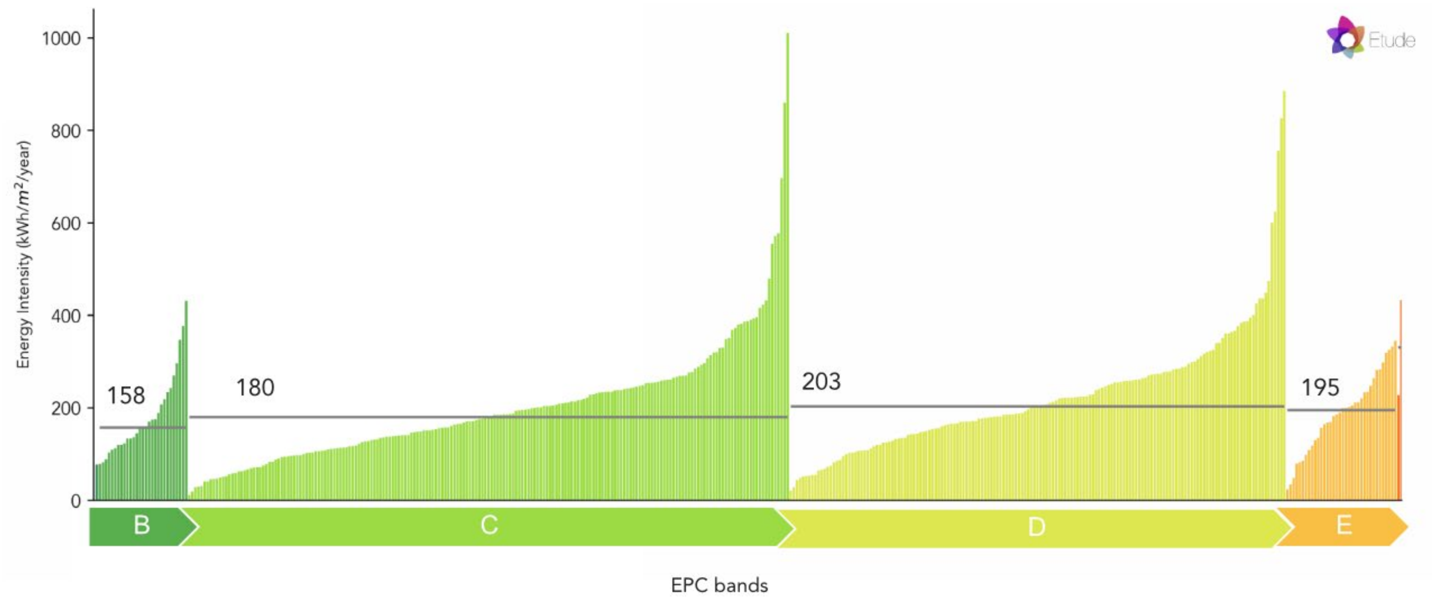


Figure 3.1.1: A comparison of the EPC's energy efficiency rating with metered energy consumption of 420 homes shows a huge variance within the energy consumed within each rating band. There is little correlation between EPC rating and the energy consumption of homes. This is problematic, as the construction industry has been focusing on improving the EPC ratings of buildings, rather than focusing on actually reducing the energy consumption of buildings.

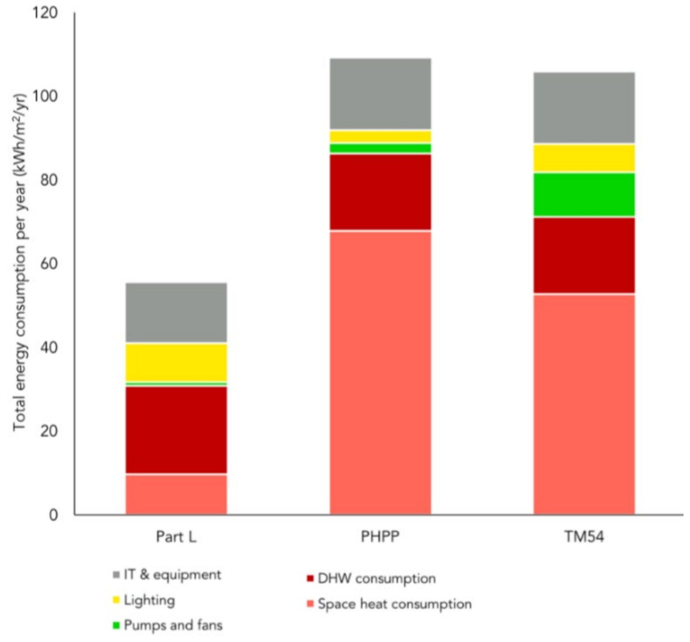


Figure 3.2.1: The modelled energy consumption of a school using Part L (SBEM), PHPP and TM54 (Source: London Borough of Islington Energy Evidence Base 2017 by Etude)

Figure 3.3.1: The percentage carbon emission reductions does not vary between the above designs, even though the third design has nearly half the heat loss than the first design. This is an example of why the relative metric does not incentivise low energy design

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3.4 Carbon Factors

A carbon factor represents the amount of carbon associated with 1 kWh of gas or electricity that a building consumes. The carbon emissions associated with generating electricity have reduced over the last 40 years, and they are predicted to further reduce over the next 30 years, see Figure 3.4.1. The carbon emissions associated with gas have remained relatively constant.

The carbon factors that are used in Building Regulations are seriously out of date, this is problematic as this affects which heating and hot water systems that appear to reduce carbon. It is important that the carbon factors in modelling calculations are updated to be as close to the average carbon factor of the grid, such that the modelling methodology incentivises the systems that are most likely to reduce carbon emissions.

This has meant that some Local Authorities have implemented a different set of carbon factors that are more in line with current carbon factors of the grid today. In London SAP 10.0 carbon factors are used in planning applications. It is proposed that in the 2020 building regulations update SAP 10.1 carbon factors are used.

For example for a home with ultra-low energy fabric that has a heat pump 40% carbon emission reductions are achieved using Building Regulations carbon factors, this increases to 83% carbon emission reductions using SAP 10.1 carbon factors, for both scenarios the home is using the same amount of energy.

3.5 Does a 100% improvement over Part L mean Net Zero Carbon?

If a home has ultra-low energy fabric and a standard heat pump as well as PV panels on the roof it can achieve over 100% carbon emission reductions using SAP. But SAP only includes regulated carbon emissions (emissions from heating, hot water, lighting, pumps and fans).

Figure 3.5.1 show that once unregulated energy (TV, computer, washing machines, fridges etc) is included, the house would still actually emit approximately 6 $kgCO_2/m^2/yr$. Therefore, a 100% improvement over Part L is not equivalent to Net Zero Operational Carbon. The example shown is for a residential building, but the same issue still exists for non-residential. Moreover many studies show that there is a significant performance gap between SAP and in use energy and carbon emissions. [2]

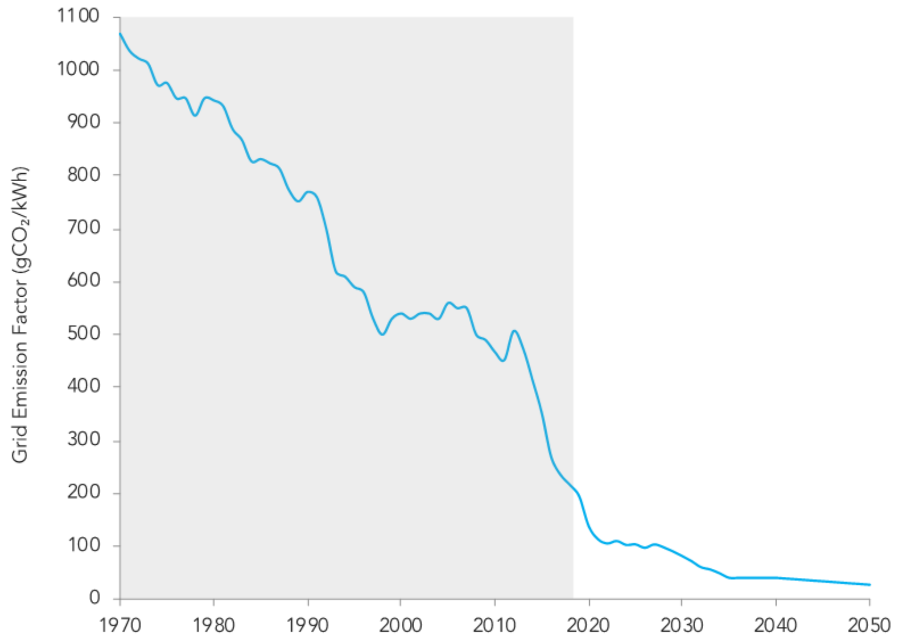


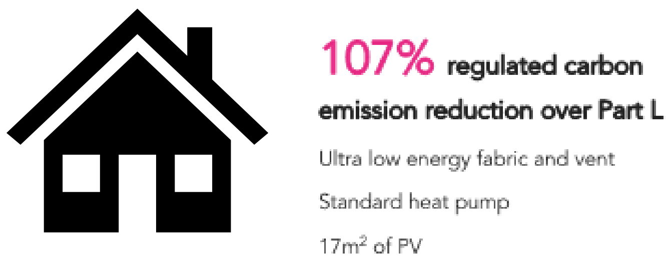
Figure 3.4.1: Carbon factors of the UK electricity grid

Gas Boiler		Building Regs	SAP 10	Sap 10.1	Lifetime	EUI kWh/m²
		Carbon Emission reductions				
Fabric & Ventilation	Business as usual	3%	10%	12%	14%	90
Fabric & Ventilation	Ultra low Energy	30%	37%	40%	42%	55

Figure 3.4.2: Carbon emission reductions at various carbon factors – a terraced house with a gas boiler

Heat Pump		Building Regs	SAP 10	Sap 10.1	Lifetime	EUI kWh/m²
		Carbon Emission Reductions				
Fabric & Ventilation	Business as usual	18%	59%	75%	88%	56
Fabric & Ventilation	Ultra low Energy	40%	70%	83%	90%	33

Figure 3.4.3: Carbon emission reductions at various carbon factors – a terraced house with a heat pump



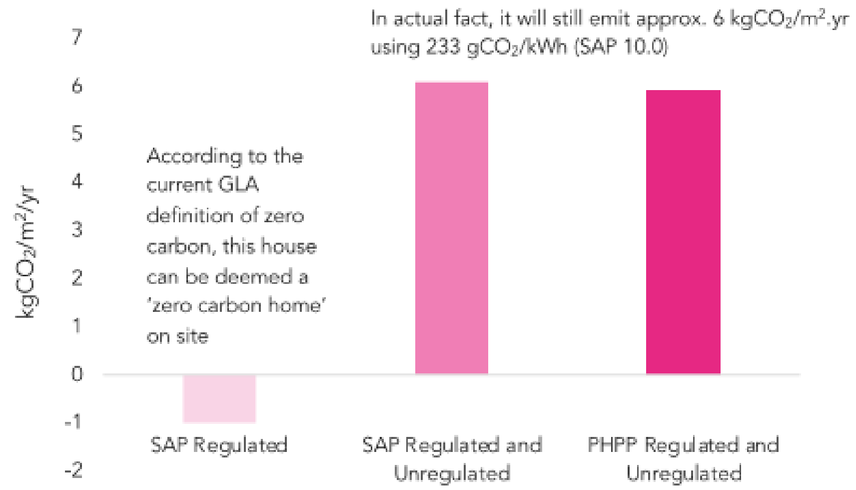


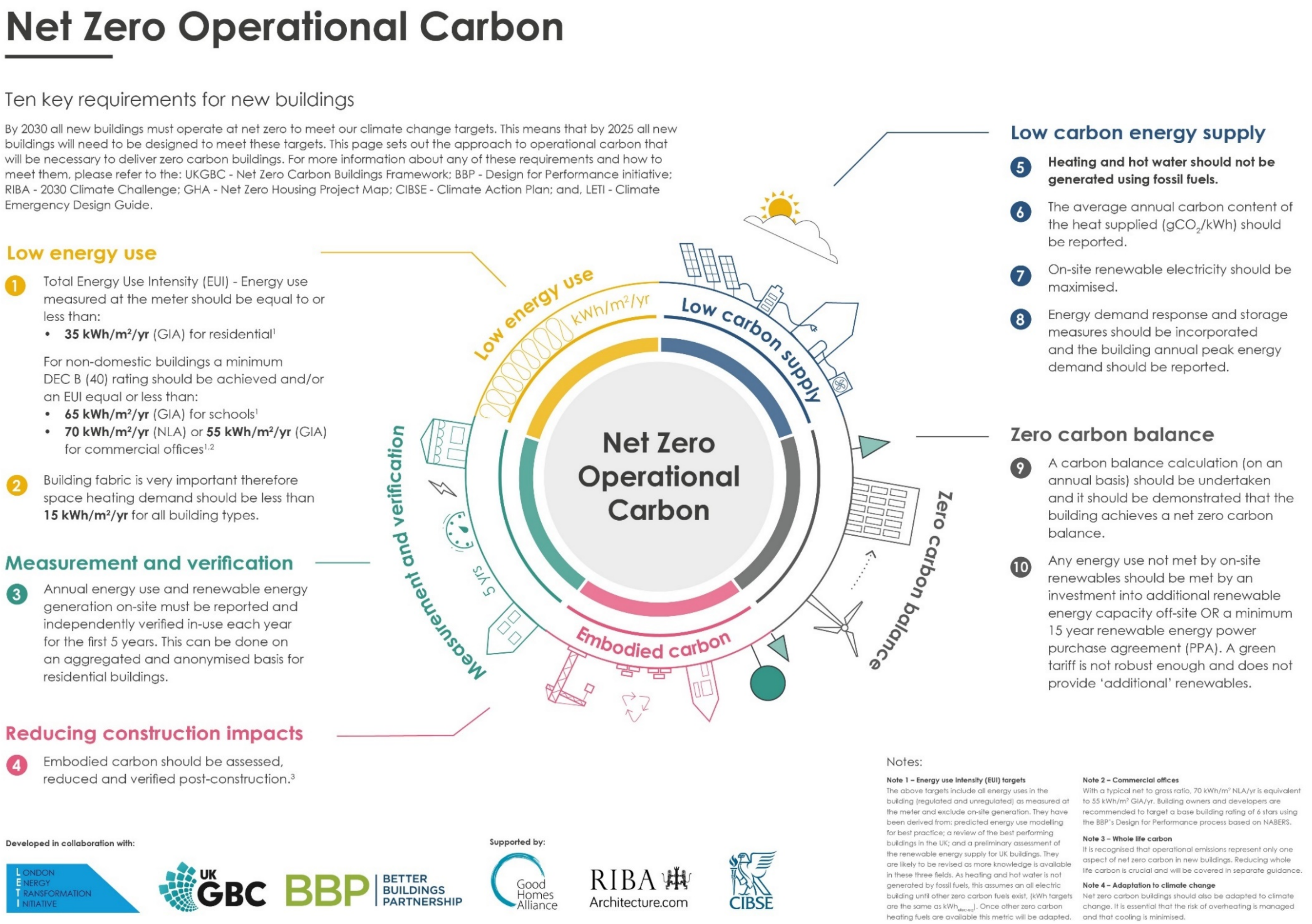
Figure 3.5.1: Carbon emission reductions at various carbon factors – a home with a heat pump

[2] For further studies see CIBSE TM54-Evaluation of energy performance at design stage and London Borough of Islington Energy Evidence Base 2017 by Etude

4 Net Zero Carbon Definition

4.1 Industry consensus

In 2019 the built environment industry came together and achieved consensus on the definition of net zero operational carbon. It was developed by the London Energy Transformation Initiative (LETI) and the UK Green Building Council (UKGBC) and the Better Building Partnership (BBP). It is also supported by the Good Homes Alliance (GHA), the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE).



Net Zero Operational Carbon

Ten key requirements for new buildings

By 2030 all new buildings must operate at net zero to meet our climate change targets. This means that by 2025 all new buildings will need to be designed to meet these targets. This page sets out the approach to operational carbon that will be necessary to deliver zero carbon buildings. For more information about any of these requirements and how to meet them, please refer to the: UKGBC - Net Zero Carbon Buildings Framework; BBP - Design for Performance initiative; RIBA - 2030 Climate Challenge; GHA - Net Zero Housing Project Map; CIBSE - Climate Action Plan; and, LETI - Climate Emergency Design Guide.

Low energy use

1. Total Energy Use Intensity (EUI) - Energy use measured at the meter should be equal to or less than:
   - **35 kWh/m²/yr** (GIA) for residential[1]

   For non-domestic buildings a minimum DEC B (40) rating should be achieved and/or an EUI equal or less than:
   - **65 kWh/m²/yr** (GIA) for schools[1]
   - **70 kWh/m²/yr** (NLA) or **55 kWh/m²/yr** (GIA) for commercial offices[1,2]
2. Building fabric is very important therefore space heating demand should be less than **15 kWh/m²/yr** for all building types.

Measurement and verification

3. Annual energy use and renewable energy generation on-site must be reported and independently verified in-use each year for the first 5 years. This can be done on an aggregated and anonymised basis for residential buildings.

Reducing construction impacts

4. Embodied carbon should be assessed, reduced and verified post-construction.[3]

Low carbon energy supply

5. **Heating and hot water should not be generated using fossil fuels.**
6. The average annual carbon content of the heat supplied (gCO_2/kWh) should be reported.
7. On-site renewable electricity should be maximised.
8. Energy demand response and storage measures should be incorporated and the building annual peak energy demand should be reported.

Zero carbon balance

9. A carbon balance calculation (on an annual basis) should be undertaken and it should be demonstrated that the building achieves a net zero carbon balance.
10. Any energy use not met by on-site renewables should be met by an investment into additional renewable energy capacity off-site OR a minimum 15 year renewable energy power purchase agreement (PPA). A green tariff is not robust enough and does not provide 'additional' renewables.

Notes:

Note 1 – Energy use intensity (EUI) targets
The above targets include all energy uses in the building (regulated and unregulated) as measured at the meter and exclude on-site generation. They have been derived from: predicted energy use modelling for best practice; a review of the best performing buildings in the UK; and a preliminary assessment of the renewable energy supply for UK buildings. They are likely to be revised as more knowledge is available in these three fields. As heating and hot water is not generated by fossil fuels, this assumes an all electric building until other zero carbon fuels exist, (kWh targets are the same as $kWh_{elec-eq}$). Once other zero carbon heating fuels are available this metric will be adapted.

Note 2 – Commercial offices
With a typical net to gross ratio, 70 kWh/m² NLA/yr is equivalent to 55 kWh/m² GIA/yr. Building owners and developers are recommended to target a base building rating of 6 stars using the BBP's Design for Performance process based on NABERS.

Note 3 – Whole life carbon
It is recognised that operational emissions represent only one aspect of net zero carbon in new buildings. Reducing whole life carbon is crucial and will be covered in separate guidance.

Note 4 – Adaptation to climate change
Net zero carbon buildings should also be adapted to climate change. It is essential that the risk of overheating is managed and that cooling is minimised.

Developed in collaboration with: LETI, UKGBC, BBP Better Buildings Partnership

Supported by: Good Homes Alliance, RIBA Architecture.com, CIBSE

Figure 4.1.1: Net Zero Operational Carbon one pager- Source www.leti.london

4.2 Net zero in this report

In this report when the term zero carbon is mentioned, it is short hand for net zero operational carbon, in line with the LETI definition aside. It does not include carbon emissions associated with embodied carbon.

4.3 Showing that net zero operational carbon is met at planning stage

In order to understand if a building meets zero carbon at planning stage and throughout the design phases predictive modelling must be undertaken. For residential this can be through Passivhaus planning package (PHPP) and for non-residential this can be through PHPP, CIBSE TM54 or Design for Performance NABERS type modelling[3].

[3] http://www.betterbuildingspartnership.co.uk/node/360

5 Analysis

5.1 Methodology

The purpose of the analysis is to understand the cost and carbon implications of requiring different levels of carbon emission reductions under the following scenarios:

1. Building Regulations
2. 35% on-site reductions (based on Building Regulations) with carbon offset
3. 75-80% carbon emission reductions with fossil fuel heating and hot water
4. Net zero operational carbon

5.1.1 Establishing Fabric and system performance for each carbon scenario

In order to understand the cost and carbon implications of new build developments requiring different levels of carbon emission reductions, modelling using Building Regulations methodology was carried out for a mid-terrace house, a medium rise apartment, and school and an office.

Carbon emission reductions are based on a variety of factors, including fabric performance, systems for generating heating and hot water, efficiency of lighting and ventilation systems and whether Solar PV is installed. This means that there is a variety of ways that developments can achieve the performance levels of the different carbon scenarios.

For each typology, 12 different cases, with varying fabric performance and systems were modelled, each with a different fabric and systems option outlined in Figure 5.1.1. In addition, various amounts of Solar PV were added where required.

The calculations were carried out with a variety of carbon factors, see Figure 5.1.3.

The results of the Building Regulation compliant models were used to place the 'cases' into the relevant carbon emission scenarios, based on the carbon emission reductions that are achieved at the various carbon factors, see Figure 5.1.2 that outlines requirements for each scenario.

Figure 5.1.2 outlines how the cases are placed in the 4 scenarios for the terrace house typology.

Fabric	System
Business as usual	Gas Boiler
Good practice	Direct Electric/ VRF
Ultra-low energy	Heat pump 1
	Heat pump 2

Figure 5.1.1: Fabric and systems 'cases' modelled

The table above shows the levels of fabric and systems that were modelled.

Scenario	Case	Fabric	System	CO_2 % reduction from notional building	EUI kWh/m^2 (no PV)
1	1.1	Business as usual	Gas Boiler	3	0
2	2.1	Business as usual	Gas Boiler + PV	47	0
	2.2	Ultra-low energy	Gas Boiler	37	0
	2.3	Ultra-low energy	Direct Electric	43	0
	2.4	Good practice	Direct Electric + PV	35	0
3	3.1	Good practice	Heat pump 1	77	0
	3.2	Business as usual	Heat pump 2	79	0
	3.3	Good practice	Direct Electric + PV	77	0
4	4.1	Good practice	Heat pump 2	n/a	37
	4.2	Ultra-low energy	Heat pump 1	n/a	35

Figure 5.1.2: Showing the grouping of the cases in the scenarios for the terrace house

The table above shows how the 'cases' modelled have been placed into each scenario. For scenario 1-3, this is based on the carbon emissions reductions achieved through the Part L modelling. For scenario 4 this is based on the EUI that is achieved with the predicted modelling.

	Scenarios	Scenario requirements	Carbon Factors	Offsets
1	Building Regs	Building Regulations 2016 are met using NCM methodology (SAP for residential and SBEM for non-residential).	Current Building regulations carbon factor 0.519 kg CO_2/kWh (Electricity) 0.216 kg CO_2/kWh (Gas)	Not included
2	35% onsite	35-50% carbon emission reductions are achieved compared to a notional building with a gas boiler using NCM methodology (SAP for residential and SBEM for non-residential).	SAP 10.0 carbon factor 0.233 kg CO_2/kWh (Electricity) 0.21 kg CO_2/kWh (Gas)	Remaining regulated Carbon emissions for 30 years at £95/CO_2 tonne/yr
3	80% onsite+ No gas	75-80% carbon emission reductions are achieved compared to a notional building with a gas boiler using NCM methodology. Fossil fuel free heating and hot water. (SAP for residential and SBEM for non-residential).	SAP 10.1 carbon factor 0.136 kg CO_2/kWh (Electricity) 0.21 kg CO_2/kWh (Gas)	Remaining regulated Carbon emissions for 30 years at £95/CO_2 tonne/yr
4	Net zero operational carbon	The net zero carbon EUI in kwh/m^2 target is met. See Section 1.5 for more information. This is based on predicted modelling.	n/a	n/a –Net zero operational carbon met onsite

Figure 5.1.3: Requirements for each carbon scenario

5.1.2 Predicted modelling

The cases were then modelled using predicted modelling software to understand how they are likely to perform in-operation.

While the cases remain placed in the carbon scenario due to their performance in the Building Regulation calculations, the results shown in the following pages are largely based on results from predicted energy models, using PHPP.

Figure 5.1.4 explains how the performance of the packages are being measured both in terms of energy and carbon performance and cost uplift.

5.1.3 Building fabric and systems

Full details of the fabric and system assumptions are shown in Appendix 1, an extract is shown in Figure 5.1.5-5.1.6 for the terrace house.

The predicted EUI, as explained in section 1.5, based on modelling that predicts energy consumption using the Passivhaus planning package (PHPP). This excludes subtracting any generation from PV panels.

The estimated increase in running cost from the Building Regulations scenario based on the energy consumption from the predicted modelling

2. 35% onsite

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
2.1	Business as usual	Gas Boiler+ PV	98	12	3.6	£0
2.2	Ultra-low energy	Gas Boiler	64	9	6.1	-£362
2.3	Ultra-low energy	Direct Electric	57	4	2.9	-£12
2.4	Good practice	Direct Electric+ PV	78	5	-1.4	£349

The estimated average annual operational carbon emissions over the period 2020-2050 based on BEIS projections. These carbon emissions are based on the energy consumption from the predicted modelling and includes regulated and unregulated energy consumption

The estimated increase in capital cost from the Building Regulations scenario based on the energy consumption from the predicted modelling

Figure 5.1.4: An example of the results for scenario 2 for the Terrace house

	Fabric and Ventilation		
	Business as usual	Good practice	Ultra-low energy
Floor U-value (W/m2.K)	0.12	0.10	0.08
Wall U-value (W/m2.K)	0.18	0.15	0.13
Roof U-value (W/m2.K)	0.14	0.12	0.10
Window U-value (W/m2.K)	1.40	1.2	0.8
Thermal bridge performance (y-value)	0.08	0.06	0.04
Ventilation	Good quality MVHR Long ducts to outside	High quality MVHR Long ducts to outside	High quality MVHR Short ducts to outside
Ventilation system heat recovery efficiency	85%	90%	90%
Ventilation SFP	0.8 W/l/s (SAP) 1.75 W/l/s (PHPP)	0.7 W/l/s (SAP) 1.25 W/l/s (PHPP)	0.6 W/l/s (SAP) 0.85 W/l/s (PHPP)
Airtightness (m³/hr.m² @50Pa)	<3	<3	<1

Figure 5.1.5: An example of the Fabric and ventilation assumptions in the terrace house

	Systems			
	Gas boiler	Direct Electric	Heat pump 1	Heat pump 2
Heat source	Individual gas boiler	Direct electric panel radiator providing heating	Individual heat pump serving residential unit	Individual heat pump serving residential unit
Heating system	LTHW radiators fed by gas boiler	Direct electric panel radiators	LTHW radiators fed by heat pump	LTHW radiators fed by heat pump
Hot water system	180L hot water store in residential unit	80L hot water store with an immersion heater	180L hot water store	180L hot water store WWHR for the showers
Heating and hot water seasonal efficiency	89.5%	100%	270% space heating 210% water heating	330% space heating 280% water heating

Figure 5.1.6: An example of the systems assumptions in the terrace house

5.1.4 Capital cost analysis

The uplift costs associated with each specification option were estimated based on Currie & Brown's cost datasets for energy efficiency and low carbon technologies which incorporate information from market prices obtained, specific market testing and first principles cost planning by specialist quantity surveyors. The costs are based on Q3 2019 prices and reflect an Oxfordshire / West Midlands cost base.

Costs were developed for each affected element to identify the variance in price between a baseline specification and various alternatives with enhanced energy efficiency and / or use of low carbon heat. The baseline specification was taken to be building to current regulatory standards (i.e. Part L 2013) via a 'business as usual' specification and using a gas boiler.

Uplift costs are based on defined changes in:

•fabric standards (ie external walls, floors and roofs and windows)
•performance (ie airtightness, thermal bridging)
•ventilation strategy (ie use and efficiency of mechanical ventilation and heat recovery systems)
•heating and hot water generation, storage and distribution

Costs are based on exactly the same design and do not include the cost reductions and efficiencies achievable from a low energy design process (e.g. improved form factor and glazing positioning). Highly efficient form factors could potentially achieve the same energy standards with less stringent u values and at lower cost (especially if the external envelope to internal area is smaller).

Those elements that are not materially affected by the energy efficiency / low carbon technology options, eg substructure, roof coverings, kitchen and bathrooms, etc, were not costed in detail.

It should be remembered that construction costs vary from project to project for a wide range of reasons based on the effectiveness of the supply chain, site practices, design and site specific conditions. The costs used here reflect a reasonably efficient supply chain and a medium sized developer.

5.1.5 Running cost analysis

The costs of running each building were estimated based on the future costs of their predicted energy consumption. Energy prices are based on the annualised domestic or commerical energy prices over 60 years based on projections produced by BEIS for policy appraisal. These equate to rates of £0.19 and 0.14 per kWh for domestic and commerical electricity and £0.05 and £0.04 per kWh for domestic and commerical gas supply.

Other elements of running costs eg maintenance and replacement of services were were not considered. Although these might have some impact on the total running costs between options these are expected to be relatively small in the context of individual systems within residential dwellings, perhaps with the exception of direct electric systems where maintenance and replacement costs are expected to be lower than those for 'wet' heating systems. The longer term costs of plant replacement are highly uncertain as in, for example, 2040 it is highly unlikely that natural gas boilers will be widely available (or even permitted) for installation into home and the costs and performance of electric based heating systems are likely to have advanced significantly.

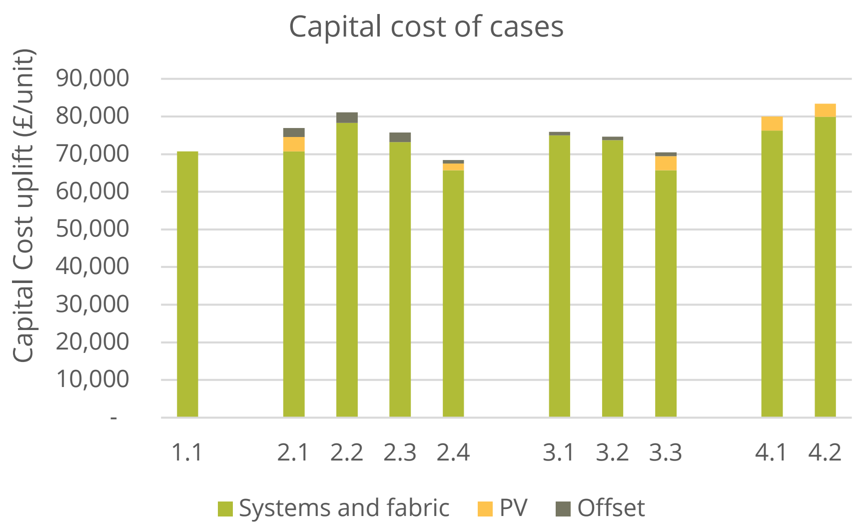


Figure 5.1.7: An example of the capital costs for the Terrace house

5.1.6 Graphic representation in analysis

In section 5.2-5.5 the capital cost differences are shown for the different cases. The capital costs include fabric, systems, offsets if relevant and the installation of PV panels. As an example figure 5.1.7 shows the capital costs for the terrace house, excluding the base cost (cost of everything else). As it is quite hard to see the difference in costs, a close up version like figure 5.1.8 will be shown in section 5.2-5.5.

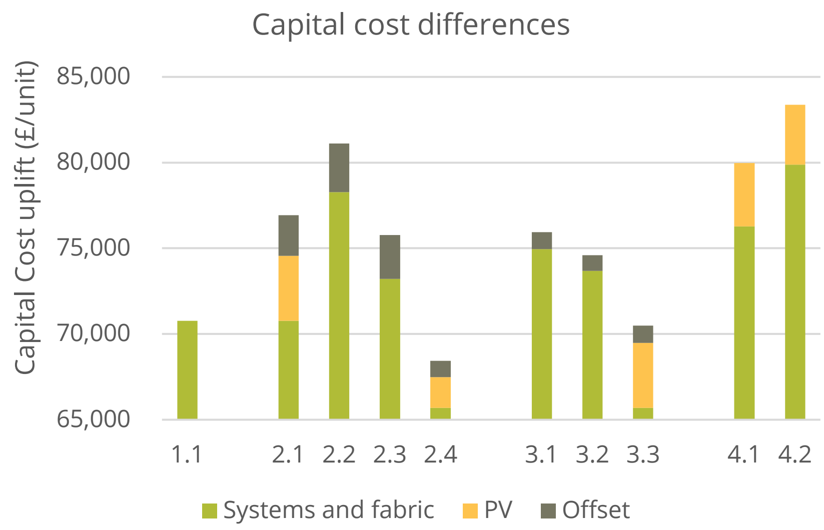


Figure 5.1.8: An example of the capital costs differences for the Terrace house

5.2 Terrace House

Modelling was carried out for a mid-terrace house of 95m^2 for 12 different cases, with varying fabric performance and systems. The results of the SAP assessments were used to categories the cases into the 4 carbon scenarios. Relevant cases are shown in Figure 5.2.1-5.2.4. This analysis helps to understand the energy performance, carbon emissions capital cost increase and impacts on running costs of developments that meet the requirements of the development scenarios. There is a great variety of ways that the carbon levels can be met, especially with scenario 2 - 35% onsite.

5.2.1 Building Regulations

Business as usual fabric with a gas boiler meets Building Regulations, this is used as the comparator for the other cases modelled.

5.2.2 35% onsite

With terrace housing a large area of Solar PV can be installed per floor area of the development, this means that 35% carbon emission reductions can be met by just adding Solar PV to the case with 'business as usual' fabric and a gas boiler.

For the options in this scenario there is a wide range of energy consumption at the meter - with a difference of 41kWh/m^2 from highest to lowest. Most options are higher in capital cost and lower in running cost, apart from scenario 2.4, due to the fact that heating and hot water are provided by direct electricity. This case has lower capital costs but significantly higher running cost than the Building Regulations comparator.

5.2.3 80% onsite + no Gas

Carbon scenario 3.3 can be achieved through adding a little more Solar PV to scenario 2.4, this is the lowest cost way to achieve 80% on-site, but it has significantly increased running costs. Another way of achieving this scenario is by having a heat pump, this costs 2-3% more in capital costs but has cheaper running costs than the comparator.

5.2.4 Operational net zero carbon

Both cases meet the 35kWh/m^2 and achieve zero carbon, either through better performing fabric or a better performing heat pump.

5.2.5 Building fabric and systems

For details of the building fabric and the systems go to Appendix 1.

Scenario 1. Building Regs

	Fabric	System	EUI kWh/m^2 (no PV)	$kgCO_2$ /m^2	Capital cost increase %	Running cost increase
1.1	Business as usual	Gas Boiler	98	14	0.0	£0

Figure 5.2.1: Scenario 1: Building Regs

Scenario 2. 35% onsite

	Fabric	System	EUI kWh/m^2 (no PV)	$kgCO_2$ /m^2	Capital cost increase %	Running cost increase
2.1	Business as usual	Gas Boiler + PV	98	12	3.6	£0
2.2	Ultra-low energy	Gas Boiler	64	9	6.1	-£362
2.3	Ultra-low energy	Direct Electric	57	4	2.9	-£12
2.4	Good practice	Direct Electric+ PV	78	5	-1.4	£349

Figure 5.2.2: Scenario 2: 35% Onsite

Scenario 3. 80% onsite + no gas

	Fabric	System	EUI kWh/m^2 (no PV)	$kgCO_2$ /m^2	Capital cost increase %	Running cost increase
3.1	Good practice	Heat pump 1	43	3	3.0	-£267
3.2	Business as usual	Heat pump 2	41	3	2.2	-£296
3.3	Good practice	Direct Electric+ PV	78	4	-0.2	£349

Figure 5.2.3: Scenario 3: 80% Onsite + no gas

Scenario 4. Net zero operational carbon

	Fabric	System	EUI kWh/m^2 (no PV)	$kgCO_2$ /m^2	Capital cost increase %	Running cost increase
4.1	Good practice	Heat pump 2+PV	33	0	5.4	-£370
4.2	Ultra-low energy	Heat pump 1+PV	31	0	7.4	-£411

Figure 5.2.4: Scenario 4: Net Zero Operational Carbon

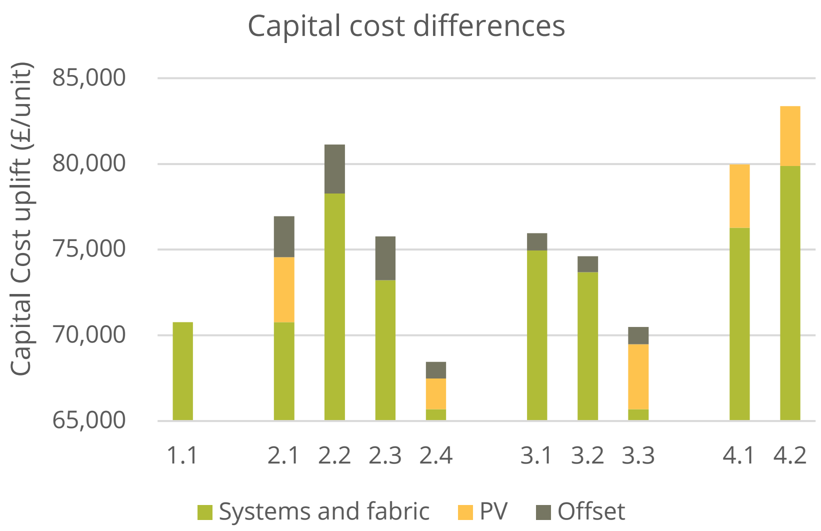


Figure 5.2.5 Difference in Capital Cost/ unit

$kgCO_2$ /m^2	Running cost increase	EUI kWh/m^2 (no PV)	Capital cost increase %
4+	£150+	50+	<0%
2-4	£50-£150	42-50	0-2%
0-2	£0-£50	35-42	2-4%
0	<£0	<35	5%

Figure 5.2.6: Key

5.3 Medium-rise apartment building

Modelling was carried out for a 5 story medium rise apartment building of 3,000m² for 12 different cases, with varying fabric performance and systems. The results of the SBEM assessments were used to categorise the cases into the 4 carbon scenarios. Relevant cases are shown in Figure 5.3.1-5.3.4. This analysis helps to understand the energy performance, carbon emissions capital cost increase and impacts on running costs of developments that meet the requirements of the development scenarios. There is a great variety of ways that the carbon levels can be met, especially with scenario 2: 35% onsite.

5.3.1 Building Regulations

Business as usual fabric with a gas boiler meets Building Regulations, 1.1 is used as the comparator for the other cases modelled.

5.3.2 Building fabric and systems

For details of the building fabric and the systems go to Appendix 1.

Scenario 1. Building Regs

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
1.1	Business as usual	Gas Boiler	63.2	10.2	0%	£0
1.2	Business as usual	Heat pump 1	41.7	2.9	2%	£185

Figure 5.3.1: Scenario 1: Building Regs

Scenario 2. 35% onsite

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
2.1	Ultra-low energy	Gas Boiler+PV	47.8	6.5	4.7	-£60
2.2	Good practice	Heat pump 1	38	2.7	4.0	£130
2.3	Business as usual	Heat pump 2	32.6	2.3	3.9	£49
2.4	Good practice	Gas Boiler+PV	55.6	8.0	3.2	-£30
2.5	Business as usual	Direct Electric+PV	59	3.4	-1.0	£443

Figure 5.3.2: Scenario 2: 35% Onsite

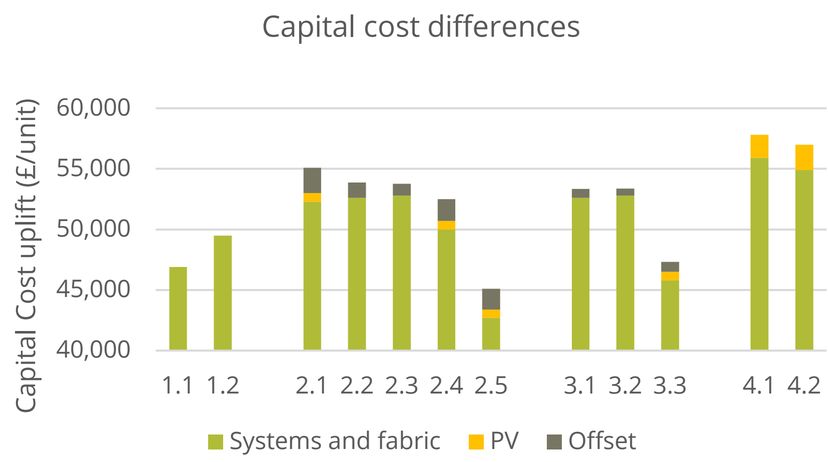


Figure 5.3.5 Difference in Capital Cost/ unit

Scenario 3. 80% + no gas

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
3.1	Good practice	Heat pump 1	38	2.7	3.7	£130
3.2	Business as usual	Heat pump 2	33	2.3	3.7	£49
3.3	Good practice	Direct Electric+PV	51	2.8	0.2	£327

Figure 5.3.3: Scenario 3: 80% Onsite + no gas

Scenario 4. Net zero operational carbon

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
4.1	Good practice	Heat pump 2+PV	30.5	0	6.2	£18
4.2	Ultra-low energy	Heat pump 1+PV	35	0	5.7	£70

Figure 5.3.4: Scenario 4: Net Zero Operational Carbon

$kgCO_2$ /m²	Running cost increase	EUI kWh/m² (no PV)	Capital cost increase %
4+	£150+	50+	<0%
2-4	£50-£150	42-50	0-2%
0-2	£0-£50	35-42	2-4%
0	<£0	<35	5%

Figure 5.3.6: Key

5.4 Office

Modelling was carried out for a 3-story office of 4,000m^2 for 12 different cases, with varying fabric performance and systems. The results of the SBEM assessments were used to categorise the cases into the 4 carbon scenarios. Relevant cases are shown in Figure 5.4.1-5.4.4. This analysis helps to understand the energy performance, carbon emissions capital cost increase and impacts on running costs of developments that meet the requirements of the development scenarios. There is a variety of ways that the carbon levels can be met, especially with scenario 2: 35% onsite and scenario 3: 80% onsite +no gas.

5.4.1 Building Regulations

Business as usual fabric with a gas boiler meets Building Regulations, this is used as the comparator for the other cases modelled.

5.4.2 35% onsite

In order to meet 35% onsite for an office, either the fabric needs to be upgraded, in combination with the installation of PV or the systems need to be upgraded in combination with the installation of PV.

5.4.3 Operational net zero carbon

Only one case meets the 55kWh/m^2 target and achieves zero carbon, however 2 further cases are close to meeting the EUI target and thus have been shown in scenario 4.

5.4.4 Building fabric and systems

For details of the building fabric and the systems go to Appendix 1.

Scenario 1. Building Regs

	Fabric	System	EUI kWh/m^2 (no PV)	kgCO$_2$ /m^2	Capital cost increase %	Running cost increase
1.1	Business as usual	Gas Boiler	140	12.9	0%	0%

Figure 5.4.1: Scenario 1: Building Regs

Scenario 2. 35% onsite

	Fabric	System	EUI kWh/m^2 (no PV)	kgCO$_2$ /m^2	Capital cost increase %	Running cost increase
2.1	Good practice	Heat pump 2	105	7.4	5.5	-14%
2.2	Good practice	Gas Boiler+PV	130	10.7	3.2	-4%
2.3	Business as usual	VRF+PV	120	7.8	-1.3	-1%
2.4	Business as usual	Heat pump 1+PV	110	7.1	1.2	-10%

Figure 5.4.2: Scenario 2: 35% Onsite

Scenario 3. 80% onsite + no gas

	Fabric	System	EUI kWh/m^2 (no PV)	kgCO$_2$ /m^2	Capital cost increase %	Running cost increase
3.1	Ultra-low energy	VRF+PV	105	6.2	3.1	-14%
3.2	Ultra-low energy	Heat pump 1+PV	110	6.6	4.4	-10%
3.3	Ultra-low energy	Heat pump 2+PV	90	5.2	5.9	-26%
3.4	Good practice	Heat pump 2+PV	105	6.2	5.5	-14%

Figure 5.4.3: Scenario 3: 80% Onsite +no gas

Scenario 4. Net zero operational carbon

	Fabric	System	EUI kWh/m^2 (no PV)	kgCO$_2$ /m^2	Capital cost increase %	Running cost increase
4.1	Ultra-low energy	VRF+PV*	60	0	4.0	-51%
4.2	Ultra-low energy	Heat pump 2+PV*	55	0	7.0	-55%
4.3	Good practice	Heat pump 2+PV*	70	0	6.8	-43%

* Includes out-of-hours lighting and small power turn down, very low ICT loads, natural vent in summer demand control ventilation and relaxation of set points.

Figure 5.4.4: Scenario 4: Net Zero Operational Carbon

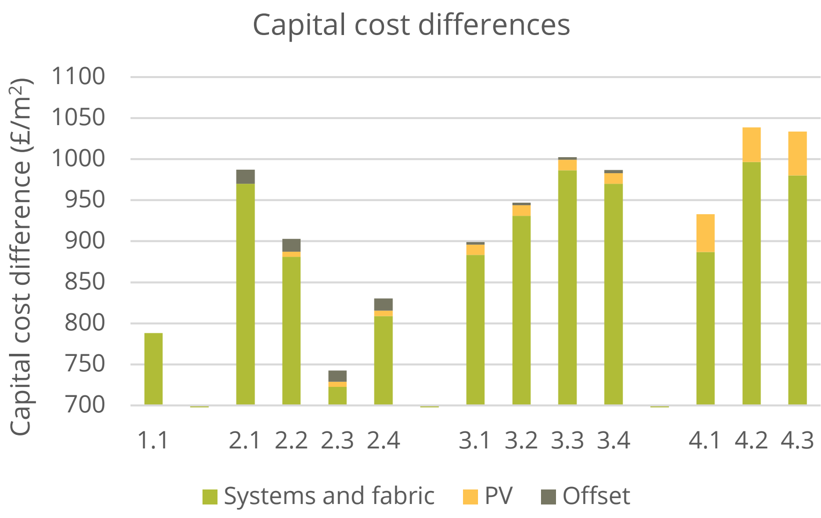


Figure 5.4.5 Difference in Capital Cost/m^2

CO$_2$/m^2	Running cost increase	kWh/m^2 (no PV)	Capital cost increase %
8+	10%	100+	<0%
4-8	5-10%	75-100	0-2%
0-4	0-5%	55-75	2-4%
0	<0%	<55	5%

Figure 5.4.6: Key

ELEMENTA Currie & Brown Etude Levitt Bernstein People.Design

5.5 School

Modelling was carried out for 3 storey school of 6,000m² for 12 different cases, with varying fabric performance and systems. The results of the SBEM assessments were used to categories the cases into the 4 carbon scenarios. Relevant cases are shown in Figure 5.5.1-5.5.3. This analysis helps to understand the energy performance, carbon emissions capital cost increase and impacts on running costs of developments that meet the requirements of the development scenarios. There is a great variety of ways that the carbon levels can be met, especially with scenario 2: 35% onsite.

5.5.1 Building Regulations

Business as usual fabric with a gas boiler meets Building Regulations, this is used as the comparator for the other cases modelled.

5.5.2 35% onsite

Due to the Part L SBEM methodology, and the way that heating energy consumption is greatly underestimated, this means that the benefits of high performing fabric are not seen in the results, this mean that a lot of the cases fall in scenario 2. There is a wide variety of EUI results with a difference of 54 kWh/m2 from highest to lowest.

5.5.3 80% onsite + no gas

As mentioned above due to the fact that the Part L methodology underestimates heating energy consumption, ultra-low energy fabric, with Heat pump 2 and PV panels on the roof only achieves 65% carbon emission reductions using SAP 10.1, hence none of the cases meet the requirements of scenario 3.

5.5.4 Operational net zero carbon

Three cases meet the 65 kWh/m² target and achieves zero carbon.

5.5.5 Building fabric and systems

For details of the building fabric and the systems go to Appendix 1.

Scenario 1. Building Regs

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
1.1	Business as usual	Gas Boiler	123	17.2	0%	0%

Figure 5.5.1: Scenario 1: Building Regs

Scenario 2. 35% onsite

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
2.1	Business as usual	Gas Boiler+PV	123	16.5	0.9	0%
2.2	Business as usual	Direct Electric+PV	119	16.5	-1.0	63%
2.3	Good practice	Gas Boiler+PV	89	10.9	3.1	-22%
2.4	Good practice	Direct Electric+PV	86	5.2	1.6	18%
2.5	Good practice	Heat pump 1+PV	74	4.4	3.5	2%
2.6	Good practice	Heat pump 2+PV	69	4.1	5.0	-5%

Figure 5.5.2: Scenario 2: 35% Onsite

Scenario 4. Net zero operational carbon

	Fabric	System	EUI kWh/m² (no PV)	$kgCO_2$ /m²	Capital cost increase %	Running cost increase
3.1	Ultra-low energy	Direct Electric+PV	61	0	3.9	-16%
3.2	Ultra-low energy	Heat pump 1+PV	56	0	5.0	-23%
3.3	Ultra-low energy	Heat pump 2+PV	54	0	5.3	-26%

Figure 5.5.3: Scenario 4: Net Zero Operational Carbon

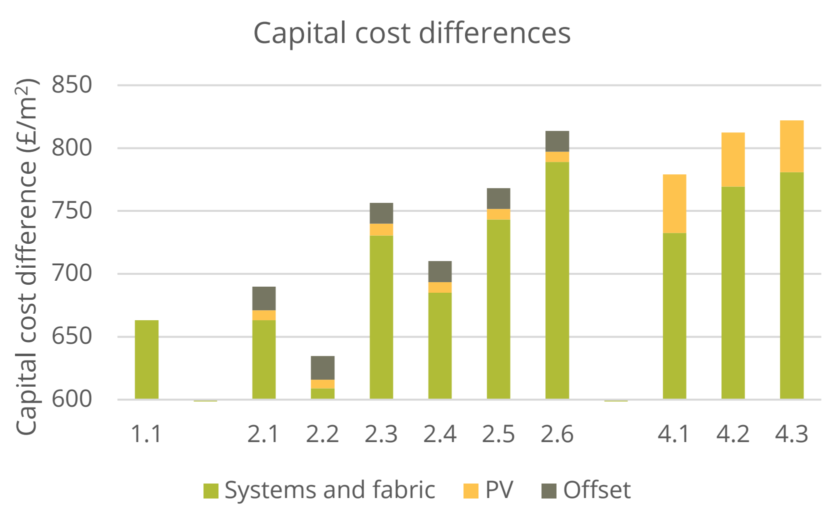


Figure 5.5.4 Difference in Capital Cost/ unit

$kgCO_2$ /m²	Running cost increase	EUI kWh/m² (no PV)	Capital cost increase %
8+	10%	100+	<0%
4-8	5-10%	80-100	0-2%
0-4	0-5%	65-80	2-4%
0	<0%	<65	5%

Figure 5.5.5: Key

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5.6 Transitionary Retrofit measures to get to Zero Carbon

It is far more cost effective and simpler to achieve high performance and carbon standards in new build development than via retrofit and, particularly in the case of fabric energy efficiency it is likely to be prohibitively expensive from both a financial and embodied carbon perspective to attempt to upgrade from a 'business as usual' standard to an ultra-low energy standard. Further, the financial benefits from so doing would be small relative to the retrofit costs because the base building, although less efficient than it could be, is not so poor that the energy savings would be significant in purely financial terms.

Figure 5.6.1, is drawn from Currie & Brown's work for the Committee on Climate Change[4]. This analysis illustrates (for a semi-detached house, albeit the same principles apply to all domestic buildings) that the costs of achieving a specific standard during new build are around a fifth of those required to achieve this standard during retrofit. Even the relatively simple change associated with switching from a gas boiler to an air source heat pump could cost nearly £10,000 if undertaken as a retrofit measure compared to around £2,000 if it formed part of the new build specification.

Although figure 5.6.1 shows the cost of improving on a home built to the Part L notional specification and with gas, the same order of costs are likely to be incurred wherever a package of whole house fabric and services upgrades are required. This is because most of the cost is associated with undertaking the work and making good all the associated finishes rather and differential insulation thicknesses would have a very limited impact on the overall costs. This can be seen in the very small variation in costs associated with retrofits to space heating standards between 25 and 15 kWh/m^2.

If the homes in the Oxfordshire Cotswolds Garden Village were built to a standard that would necessitate a fabric and heating system retrofit to achieve zero carbon, then uplift costs for retrofitting c.2,200 homes could be in the order of £50 million depending on build mix.

The energy savings associated with moving from a business as usual to ultra-low energy state are in the order of 10-15 kWh/m^2 per year (assuming a heat pump is used for heat supply) or approximately £160-£240 per year for an 85m^2 house. These savings (and associated comfort benefits) are material in the context of a new build cost impact of under £5,000 but are very small in comparison to a retrofit cost of around £25,000.

Leaving aside the high costs and relatively small financial savings of retrofit works to improve fabric performance there is also the question of how these works would be delivered in practice. In the absence of any form of compulsion it is difficult to see how households could be effectively incentivised to undergo retrofit works in large numbers as even if access to low / zero cost finance were available, the savings would not justify the expenditure and the levels of disruption, risk and general inconvenience would be high.

Even if homes were retrofitted within, say, 10 years their lifetime carbon emission would still be several times higher[4] than they would otherwise be if these measures had been adopted from the outset.

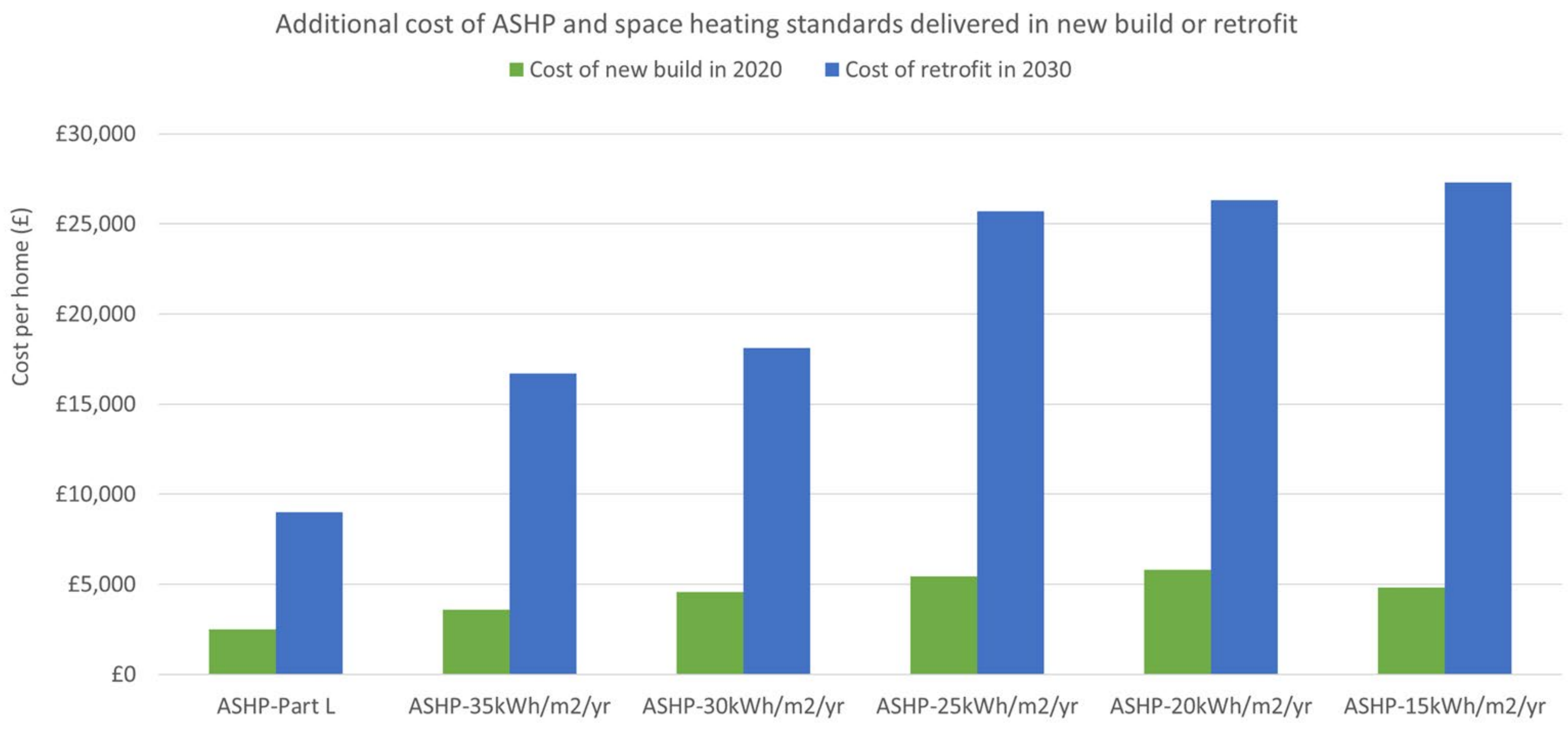

Figure 5.6.1 Cost of new build and retrofit in 2020 for homes

5.7 Commercial developments

For commercial development the costs of retrofit has been estimated based on upgrades to walls, windows and roofs. It is estimated that this will cost £30 million for the indicative 93,000m^2 of commercial area in the Garden Village that has been assumed for the purposes of this report.

5.8 Estimate uplift in cost

If the Oxfordshire Cotswolds Garden Village were built only to current regulatory standards, or in fact to any standard that would necessitate a fabric and heating system retrofit, then uplift costs for retrofitting c.2,200 homes and 93,000m^2 of commercial area could be in the order of £80 million depending on build mix.

[3] Committee on Climate Change, 2019. The Costs and Benefits of Tighter Standards for New Buildings.

6 Onsite Renewables

6.1 Introduction

Photovoltaic panels that generate electricity are likely to be the most appropriate form of renewable energy generation at the garden village. This section summarises the Photovoltaics Panel (PV) requirements for the development to achieve net zero operational carbon balance and generate a total amount of energy onsite equal to the net total energy consumed annually.

6.2 EUI

The Energy Use Intensity (EUI) of a development is measured in kWh/m^2.yr. For fossil fuel free buildings, the EUI is measured in-use using the incoming electricity meter. This is a simple metric that can be predicted at the design stage using software such as PHPP (Passivhaus planning package). EUI target does not include renewable generation, as the renewable energy generation must make up the other side of the operational zero carbon balance. This means that if two buildings are built identically, but one has a roof filled with PV panels and the other does not, they will both have the same EUI. For more information on EUI targets see section 1.5.

6.3 Energy Balance

Figure 6.1.1 shows how much electricity each typology consumes, and how much energy can be generated on the roof of each typology, given the assumptions outlined in figure 6.1.3. (This assumes that all office and lab space has an EUI of 55 kwh/m^2.yr,).
This shows that between 70%-100% of the electricity consumed by the buildings can be generated on the roof of the buildings, depending on the orientation and massing of the roofs.

If not all of the required PV panels can be accommodated by the roofs,

the remainder of the energy required will need to be supplied via other means, such as PV installed on empty fields or on top of car parking canopies. These solutions could still be arranged within the boundaries of the Garden Village development.

The analysis shows that some phases, that include typologies such as the offices and research labs are unlikely to be able to meet operational net zero carbon with the roof available to that typology. This may mean that some phases will need to overprovide renewable energy to compensate for others which cannot provide enough.

To give an understanding of context, figure 6.1.2 shows the area of PV required on a map of the Garden Village site.

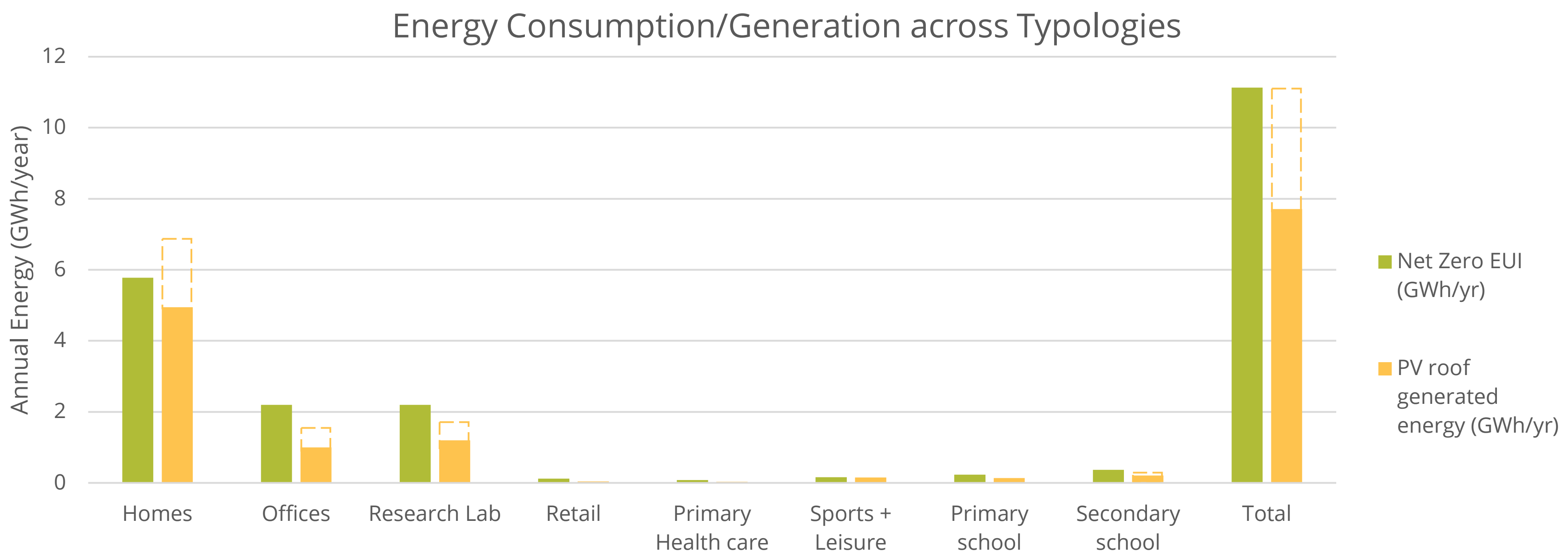

Figure 6.1.1 Energy consumption/generation across the Garden Village typologies

This figure illustrates the energy consumption for each typology in the garden village (the green bar), based on the assumption that the EUI targets outlined in section 1.5 are met. The yellow bar shows the amount of energy that could be generated by roof mounted PV, a range is shown as this depends on how much of the roof areas utilised for PV and the orientation of the roofs. (The range is from 70-100% of the roof area is used for PV panels (with a utilisation ratio of 0.7)

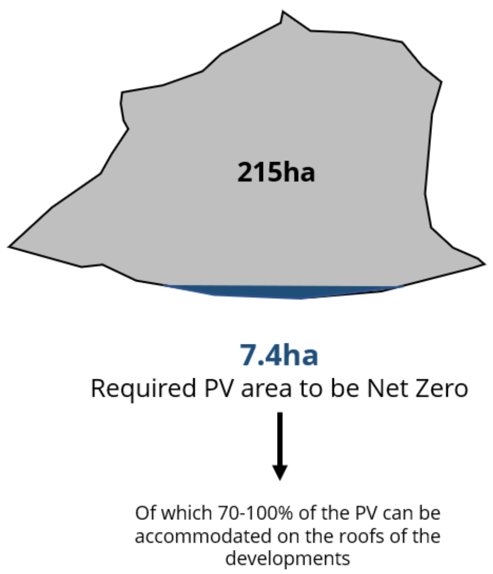

Figure 6.1.2 Area of PV required onsite to achieve net zero operational carbon

	GIA (m2)	Storeys	EUI (kWh/m2-yr)
Homes	165,000	2.5	35
Offices	40,000	3	55
Research	40,000	2.5	55
Retail	1,500	3	80
Community space (e.g. health care)	800	2	100
Sports + Leisure	2,000	1	80
Primary school	3,563	2	65
Secondary school	5,600	2	65

Figure 6.1.3 Assumptions used in analysis

7 Implementation

7.1 Phasing

Housing development is expected to begin at the New Garden Village in 2024/25 and run through to 2034/35. Therefore, there is no time to delay the adoption of net zero operational carbon.

The Future Homes Standard is due to come into force in 2025 and *"it is expected that an average home built to it will have 75-80% less carbon emissions than one built to current energy efficiency requirements (Approved Document L 2013)."*

Currently MHCLG expect this will be achieved *"through very high fabric standards and a low carbon heating system. This means a new home built to the Future Homes Standard might have a heat pump, triple glazing and standards for walls, floors and roofs that significantly limit heat loss."*

While we are awaiting details and further consultation of the 2025 Future Homes Standard, it is clear that the intention is for new homes to be designed as far as possible to meet zero operational carbon.

It is therefore prudent to work to a version of zero operational carbon that futureproofs the design of all homes across the phasing of the New Garden Village.

This should also be extended to the non-domestic buildings on-site for which Building Regulations is due for consultation.

Meeting zero carbon in design and operation on Phase 1 should be used as a testbed for all subsequent phasing, with lessons learned from dwelling to dwelling and phase to phase. This will ensure the intentions are delivered.

7.2 Recommendations for the Area Action Plan

The AAP promises exemplary and innovative design as an expectation of development. Included within this Plan is a commitment to look at the potential for zero carbon.

From members of the Energy Plan working group, and from local communities within the village of Eynsham, there is also strong support for a target of net-zero development and for a carbon positive energy strategy which embeds on-site renewable energy infrastructure within its proposals.

From review of the AAP we recommend including broad but strong policy wording regarding achieving net zero operational carbon. This is alluded to under 11.19 and 11.20 of the supporting wording of Chapter 11 – Climate change and resilience (AAP – Preferred Options Paper July 2019). However, this would benefit from being strengthened in the Core Objectives.

Core Objective GV37 states: "*To adopt an ambitious approach towards low and zero carbon energy - maximising opportunities to draw energy from decentralised, renewable or low carbon energy supply systems.* "

We would encourage this objective or an additional objective to also require a significant reduction in energy demand of buildings through the specification of ultra-low energy fabric and ventilation. We suggest the KPIs set out in this report should be used in the AAP.

7.3 Implementing the KPIs

We have specifically set indicators in order to meet zero operational carbon rather than hard targets. This is because in the majority of cases the KPI will be achievable. However, there may be some exceptions which mean the indicators are exceeded or cannot be met for individual buildings. It is therefore important that the indicators are used to determine whether the Garden Village as a whole will meet net zero operational carbon.

The KPIs set out in the report can be implemented as follows:

Fabric

<15 kWh/m²/yr of space heating demand. Demonstrated using predicted energy modelling.

This is the primary metric to ensure the building is energy efficient through high efficiency fabric and ventilation.

To ensure best practice - require predictive energy modelling (e.g. using PHPP or CIBSE TM45 or equivalent) with the intention to meet the target space heating demand. Modelling should be carried out: as part of the detailed planning submission, be reconfirmed pre-commencement, validated pre-occupation and monitored post-completion.

Energy efficiency

Meeting Energy budgets (also called EUI targets) Demonstrated using predicted energy modelling. Targets are shown below:

- *Residential <35 kwh/m².yr*
- *Office <55 kwh/m².yr*
- *Research labs <55-240 kwh/m².yr**
- *Retail <80 kwh/m².yr*
- *Community space (e.g. health care) <100 kwh/m².yr*
- *Sports and Leisure <80 kwh/m².yr*
- *School <65 kwh/m².yr*

**See section 1.5 for details*

The EUI ensures overall energy efficiency of the building and is a measurable metric that can be used in design and operation. It excludes renewable energy contribution.

As with the fabric KPI, to ensure best practice, predictive energy modelling (e.g. using PHPP or CIBSE TM45 or equivalent) should be carried out with the intention to meet the target EUIs. Modelling should be carried out: as part of the detailed planning submission, be reconfirmed pre-commencement, validated pre-occupation and monitored post-completion.

Fossil fuel free

Fossil fuels, such as oil and natural gas shall not be used to provide space heating, hot water or used for cooking.

A building or development cannot be zero carbon without eliminating the use of fossil fuels.

Require demonstration of the heating strategy as part of an energy statement at outline and detailed application which should show that the development is fossil fuel free.

Zero operational carbon balance

100% of the energy consumption required by buildings on-site shall be generated using on-site renewables, for example through Solar PV.

To meet net operational zero carbon the amount of energy required on-site should be balanced by installing on-site renewables to supply the equivalent amount of energy across the course of a year.

Require an energy statement as part of the planning submission that demonstrates the quantum of proposed renewable energy for the whole site (outline planning) and each phase (detailed planning) this should be shown in kWh/yr. This may mean some phases will need to overprovide renewable energy to compensate for others which cannot provide enough. The amount of renewables should be enough to allow the site to achieve net zero operational carbon as a whole. The planning statement should state the total kWh/yr of energy consumption of the buildings on the site and the total kWh/yr of energy generation by renewables to show that the balance is met. An explanation should be given as to how these figures have been calculated.

Renewable energy contribution calculations should be carried out as part of the outline and detailed planning submissions, be reconfirmed pre-commencement, validated pre-occupation and monitored post-completion.

Overheating

Modelling shall be undertaken to show compliance with TM 59 for residential and TM 52 for non-residential.

Where the energy efficiency of a building is improved and as the climate changes there is a greater risk of overheating in buildings.

Overheating should be avoided though good design and mechanical cooling should only be included as a last resort.

At outline planning stage overheating should be mitigated through appropriate orientation and massing. A statement on the likely strategies that could be implemented at detailed planning stage should be covered.

At detailed planning stage the applicant should submit overheating calculations in line with the latest CIBSE TM59 or TM52 guidance, demonstrating that the homes are not expected to overheat. Mitigation measures should be included where possible to prevent overheating in future climate scenarios. This may include the flexibility of designs to have future measures installed at a later date.

Design for the mitigation of overheating should be demonstrated as part of the outline planning submission. Overheating calculations should be carried out as part of the detailed planning submission and reconfirmed pre-commencement.

Embodied carbon

< 500 kg CO_2/m^2 Upfront embodied carbon emissions (Building Life Cycle Stages A1-A5). Includes Substructure, Superstructure, MEP, Facade & Internal Finishes. Full lifecycle modelling is encouraged.

As the operational carbon of a building reduces the embodied carbon becomes a greater portion of the overall emissions. Therefore, it is important to measure and reduce embodied carbon where possible.

Require a report as part of the planning submission that demonstrates the calculation of the expected upfront embodied carbon of buildings. Attempt to reduce embodied carbon to meet the embodied carbon KPI.

Embodied carbon calculations should be carried out: as part of the outline and detailed planning submission, be reconfirmed pre-commencement, and validated pre-occupation.

Measurement and verification

Meter, monitor and report on energy consumption and renewable energy generation post-completion for the first 5 years.

It is important that where buildings are designed to be net zero operational carbon that they also perform to this standard when complete.

Applicants should confirm the metering, monitoring and reporting strategy as part of the detailed planning application. There should be a commitment to monitor consumption and report on it anonymously for the first 5 years following handover of the building.

7.4 Introducing planning conditions

To support the objectives of the AAP, WODC have the option to set specific planning conditions to reinforce the requirements.

We suggest this could be implemented at Outline Planning submission and at the Detailed Planning submission of each phase.

Outline Planning Conditions

Any condition set at outline stage should be stretching, holistic and also be able to stand the test of time. Example wording could include:

Demonstrate the whole site can achieve net zero operational carbon on-site through ultra-low energy fabric specification, low carbon technologies and on-site renewable energy generation.

Each phase of the development will be required to contribute to the whole site achieving zero carbon, therefore, some phases may need to contribute more renewable energy to counterbalance those phases which are unable to generate enough.

Commit to meeting the most up-to-date version of the key performance indicators. Demonstrate how each phase of the development will achieve the KPIs through an energy statement as part of the detailed planning application submission.

Detailed Planning Conditions

It is expected that the detailed planning conditions may morph over time, based on changing regulation and advances in construction and technology. The key performance indicators should be periodically reviewed to reflect this.

Pre-commencement *– Submit details to demonstrate the site achieves net zero operational carbon. Demonstrate the key performance indicators as detailed in the AAP will be achieved for all building types.*

Pre-occupation*– prior to handover update and submit information demonstrating the key performance indicators have been achieved.*

Post completion *– carry out energy monitoring of all energy uses per building/tenant/dwelling for 5 years. Disclose anonymised metered energy data to the Council to indicate in-use performance. Share lessons learnt and energy data with the design team, contractor and developers of the other phases of the Garden Village.*

7.5 Mechanism for change

It is acknowledged that the KPIs may need to change over time, with new calculation methods, low and zero carbon technologies or new construction practices. Therefore, provision should be made in the AAP and site planning conditions to allow for this.

7.6 Design review panel

Many local authorities use design review panels to peer review the incoming planning submissions. This provides a level of confidence in the design and the quality of a scheme, including its sustainability credentials. We would recommend that a mixed panel of designers, engineers and sustainability specialists are formed to assist in peer reviewing the development. This will assist in ensuring that the zero carbon requirements set are likely to be achieved.

Appendix

8 AP 1 - Modelling

8.1 Fabric Assumptions

The fabric and ventilation assumptions in the modelling are shown aside.

		Fabric and ventilation		
		Business as usual	**Good practice**	**Ultra-low energy**
Terrace and mid-rise residential	**Average floor U-value (W/m2.K)**	0.12	0.10	0.08
	Average wall U-value (W/m2.K)	0.18	0.15	0.13
	Average roof U-value (W/m2.K)	0.14	0.12	0.10
	Average window U-value (W/m2.K)	1.40	1.2	0.8
	Thermal bridge performance (y-value)	0.08	0.06	0.04
	Ventilation	Good quality MVHR Long ducts to outside	High quality MVHR Long ducts to outside	High quality MVHR Short ducts to outside
	Ventilation system heat recovery efficiency	85%	90%	90%
	Ventilation SFP	0.8 W/l/s (SAP) 1.75 W/l/s (PHPP)	0.7 W/l/s (SAP) 1.25 W/l/s (PHPP)	0.6 W/l/s (SAP) 0.85 W/l/s (PHPP)
	Airtightness ($m^3/hr.m^2$ @50Pa)	<3	<3	<1
School	**Average floor U-value (W/m2.K)**	0.15	0.12	0.09
	Average wall U-value (W/m2.K)	0.20	0.18	0.13
	Average roof U-value (W/m2.K)	0.15	0.13	0.11
	Average window U-value (W/m2.K)	1.40	1.2	0.8
	Thermal bridge performance (losses)	5%	3%	1%
	Ventilation	Fan assisted ventilation	Good quality MVHR	High quality MVHR
	Ventilation system heat recovery efficiency	0%	70%	90%
	Ventilation SFP	0.5 W/l/s	1.6 W/l/s	1.2 W/l/s
	Airtightness ($m^3/hr.m^2$ @50Pa)	<5	<3	<1
Office	**Average floor U-value (W/m2.K)**	0.15	0.12	0.09
	Average wall U-value (W/m2.K)	0.25	0.18	0.13
	Average roof U-value (W/m2.K)	0.15	0.13	0.10
	Average window U-value (W/m2.K)	1.60	1.4	0.8
	Thermal bridge performance (losses)	5%	3%	1%
	Ventilation	Standard quality AHU	Good quality AHU	High quality MVHR
	Ventilation system heat recovery efficiency	75%	80%	90%
	Ventilation SFP	1.8 W/l/s	1.6 W/l/s	1.2 W/l/s
	Airtightness ($m^3/hr.m^2$ @50Pa)	<5	<3	<1

Figure 8.1.1 Fabric assumptions

8.2 Systems Assumption

8.2.1 Residential

The system assumptions used in the modelling are shown aside.

		Systems			
		Gas boiler	**Direct electric/VRF**	**Heat pump 1**	**Heat pump 2**
Terrace House	**Heat source**	Individual gas boiler	Direct electric panel radiator providing heating	Individual heat pump serving residential unit	Individual heat pump serving residential unit
	Heating system	LTHW radiators fed by gas boiler	Direct electric panel radiators	LTHW radiators fed by heat pump	LTHW radiators fed by heat pump
	Hot water system	180L hot water store in residential unit	80L hot water store with an immersion heater	180L hot water store	180L hot water store WWHR for the showers
	Heating and hot water seasonal efficiency	89.5%	100%	270% space heating 210% water heating Blended efficiencies for SAP models 1/2/3: 253% /245%/235%	330% space heating 280% water heating Blended efficiencies for SAP models 1/2/3: 317%/311%/303%
Medium rise residential	**Heat source**	Communal gas boiler serving a communal heating system with flow and return temperature 70◦C /50◦C	Direct electric panel radiator providing heating	Air source heat pumps serving a communal heating system with flow and return temperature 65◦C /50◦C and communal thermal stores	An ambient loop fed by communal ground loops or sources of secondary heat Small individual heat pumps (water-source) in each residential unit
	Heating system	LTHW radiators fed by HIU	Direct electric panel radiators	LTHW radiators fed by HIU	LTHW radiators fed by HIU
	Hot water system	HIU provides instantaneous hot water	An 80L hot water store with an immersion heater in each residential unit	HIU provides instantaneous hot water	An 80L hot water store. Waste water heat recovery for the showers in each residential unit
	Heating and hot water seasonal efficiency	93%	100%	190% space heating 210% water heating Blended efficiencies for SAP models 1/2/3: 204% /201% / 200%	330% space heating 280% water heating Blended efficiencies for SAP models 1/2/3: 304% / 300% /293%

Figure 8.2.1 Residential system assumptions

8.2.2 Non-residential

The system assumptions used in the modelling are shown aside.

		Systems			
		Gas boiler	**Direct electric/VRF**	**Heat pump 1**	**Heat pump 2**
Office	**Heat source**	Gas boiler serving a heating system with flow and return temperature 70○C /50○C	VRF	Heat pumps serving a heating system with flow and return temperature 65○C /50○C	Heat pumps serving a heating system with low flow and return temperature 45○C /40○C fed from ambient loop or ground source array
	Heating system	LTHW Fan Coil Unit fed by gas boiler	Fan Coil Unit fed by VRF	LTHW Fan Coil Unit fed by Reversible chiller/heat pump	LTHW Fan Coil Unit fed by Reversible chiller/heat pump
	Hot water system	Direct electric hot water to toilets A 400L hot water store for the showers fed by gas boiler	Direct electric hot water to toilets and electric showers	Direct electric hot water to toilets a 400L hot water store for the showers fed by the heat pump	Direct electric hot water to toilets a 400L hot water store for the showers fed by the heat pump
	Heating and hot water seasonal efficiency	95%	350% for heating 100% for hot water	220%	450% for heating 300% for hot water (top up 2nd stage heat pump)
School	**Heat source**	Gas boiler serving a heating system with flow and return temperature 70°C /50°C	Direct electric panel radiator providing heating	Air source heat pumps serving a heating system with flow and return temperature 65°C /50°C	Ground source heat pumps serving a heating system with low flow and return temperature 45°C /40°C fed from a ground source array
	Heating system	LTHW radiators fed by gas boiler	Direct electric panel radiators	LTHW radiators fed by heat pump	LTHW radiators fed by heat pump
	Hot water system	A 1,000L hot water store	Direct electric point-of-use hot water to bathrooms	Direct electric point-of-use hot water to bathrooms	Direct electric point-of-use hot water to bathrooms
	Heating and hot water seasonal efficiency	93%	100%	190% space heating 100% water heating	330% space heating 100% water heating

Figure 8.2.2 Non-residential system assumptions

9 AP 2 – Further Guidance

9.1 District heating losses

Heating and hot water systems can be delivered through site wide district heating systems, communal heating systems per block/ phase or individual heating systems per dwelling/building. There are heat losses associated with transporting hot water through pipework. Figure 9.1.1 shows these losses in district communal and individual hating systems and different temperatures, for a residential development at 3 different heat loads, existing buildings, business as usual new build and Ultra low energy buildings.

In the case of the Cotswolds Garden Village, zero carbon can be achieved with an ultra-efficient building fabric, a low carbon heating system and on-site renewable energy generation. The low carbon heating system could be an individual heating system such as a heat pump per building or a district system. If a district solution is preferred it is recommended that an ambient district solution is implemented as this reduces heat losses through the pipework.

9.2 Heat pump COP's

The efficiency of a heat pump is called a Coefficient of Performance (CoP) and it represents how many times better a system is at delivering heat than using direct electricity.

A heat pump has a better efficiency when the heat source is at a higher temperature. For example, an air source heat pump, that uses the atmosphere as a heat source is more efficient in summer when the temperature outside is warmer than in winter.

The heating season for ultra-low energy homes is much shorter than homes built to Building Regulations, as ultra-low energy homes have a much higher performing fabric. This means that they only need to be heated in deep winter, where the outside temperatures are very low. This means that if you had the same heat pump that is providing space heating to a home built to Building Regulations and a ultra-low energy home, the CoP of the heat pump in the ultra-low energy home would be worse. For this reason, it is important to calculate project specific CoP's when carrying out design stage energy calculations.

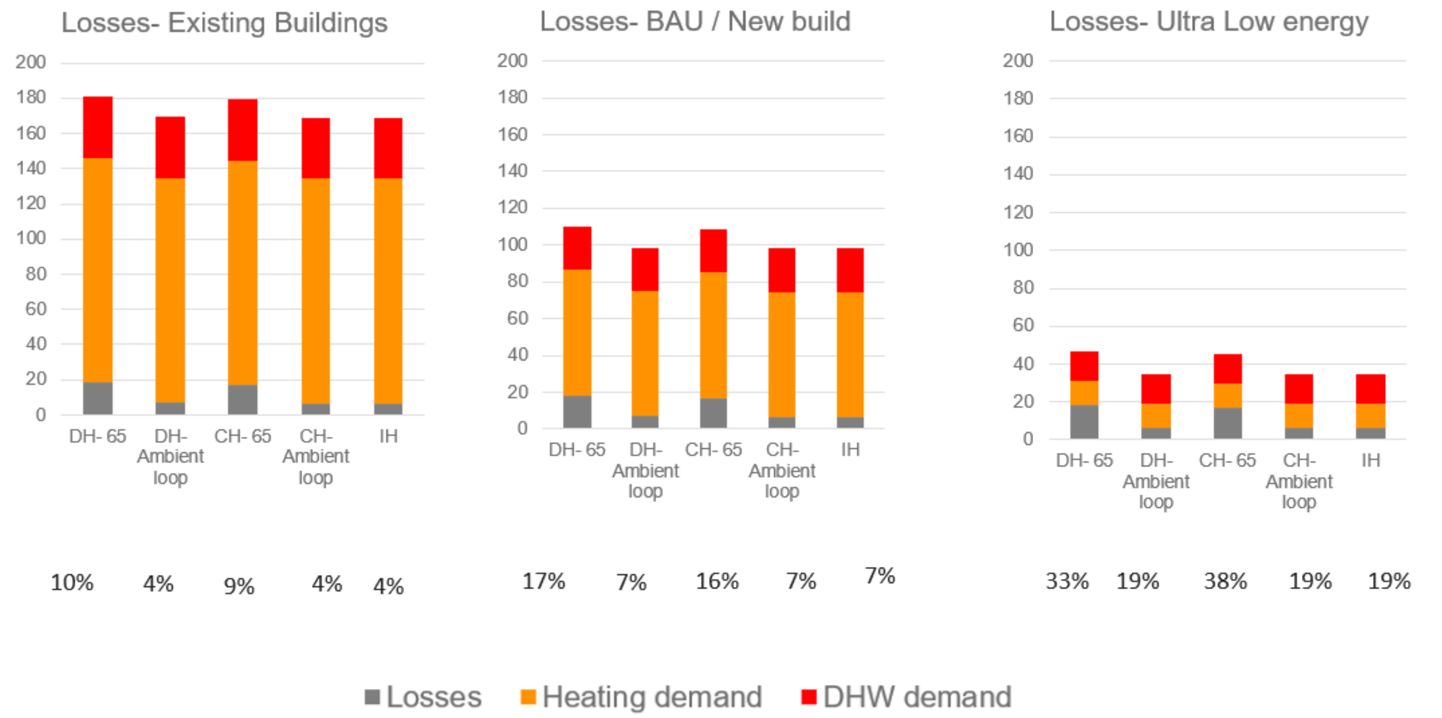

Figure 9.1.1: Losses in district, communal and individual heating systems

The figure above shows that heating systems at a higher temperature have more heat losses. The figure also shows that losses remain constant no matter what the load, this means that they represent a higher proportion of the overall demand on the systems with a low load (an ultra-low energy development.

For existing development if a district heating systems is installed that operated at 65°C, then 10% of the heat generated by the heating plant is associated with losses in the system whereas for a new ultra-low energy development this increases to 33%.

System type	Description
DH-65	District heating at 65°C flow temperature
DH-Ambient loop	District heating at ambient temperature
Ch-65	District heating at 65°C flow temperature
DH-Ambient loop	District heating at ambient temperature
IH	Individual heating system

Figure 9.1.2: Key

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10 AP 3 – Summary Calculations

The numbers shown figure 1.11 in the executive summary are a summary of the calculations in the report, based on the modelling undertaken and extrapolation to further typologies that were not explicitly modelled. This appendix shows details on how the figures were calculated.

Percentage increase in capital cost

	GIA (m^2)	Scenario 1	Scenario 2		Scenario 3		Scenario 4	
			Best	Worst	Best	Worst	Best	Worst
Homes -Terrace type	132,000	0	-1.4	6.1	-0.2	3	5.4	7.4
Homes- Medium rise type	33,000	0	-1.0	4.7	0.2	3.7	5.7	6.2
Offices	40,000	0	-1.3	5.5	3.1	5.9	4.0	7.0
Research	40,000	0	-1.3	5.5	3.1	5.9	4.0	7.0
Retail	1,500	0	-1.3	5.5	3.1	5.9	4.0	7.0
Community space	800	0	-1.3	5.5	3.1	5.9	4.0	7.0
Sports + Leisure	2,000	0	-1.3	5.5	3.1	5.9	4.0	7.0
Primary school	3,563	0	-1.0	5.0	n/a	n/a	3.9	5.0
Secondary school	5,600	0	-1.0	5.0	n/a	n/a	3.9	5.0
Area weighted average		**0**	**-1.3**	**5.7**	**1.0**	**4.1**	**4.9**	**7.0**

Figure 10.1.1: Percentage increase in capital cost

Percentage uplift in running cost (%)

	GIA (m^2)	Scenario 1	Scenario 2		Scenario 3		Scenario 4
			Best	Worst	Best	Worst	
Homes -Terrace type	132,000	0	-35	34	-29	34	-38
Homes- Medium rise type	33,000	0	-14	100	11	74	10
Offices	40,000	0	-14	-2	-26	-9	-50
Research	40,000	0	-14	-2	-26	-9	-50
Retail	1,500	0	-14	-2	-26	-9	-50
Community space	800	0	-14	-2	-26	-9	-50
Sports + Leisure	2,000	0	-14	-2	-26	-9	-50
Primary school	3,563	0	-21	61	n/a	n/a	-22
Secondary school	5,600	0	-21	61	n/a	n/a	-22
Area weighted average		**0**	**-25.0**	**31.6**	**-22.7**	**24.8**	**-35.2**

Figure 10.1.2: Percentage uplift in running cost (%)

The table to the right shows the details of how the carbon emission reductions were calculated.

Carbon emissions $kgCO_2/m^2/yr$							
	GIA (m^2)	Scenario 1	Scenario 2		Scenario 3		Scenario 4
			Best	Worst	Best	Worst	
Homes -Terrace type	132,000	13.7	4.0	11.8	2.9	3.6	0.0
Homes- Medium rise type	33,000	10.2	2.3	8.0	2.3	2.8	0.0
Offices	40,000	12.9	7.1	10.7	5.2	6.2	0.0
Research	40,000	12.9	7.1	10.7	5.2	6.2	0.0
Retail	1,500	12.9	7.1	10.7	5.2	6.2	0.0
Community space	800	12.9	4.1	16.5	5.2	6.2	0.0
Sports + Leisure	2,000	12.9	7.1	10.7	5.2	6.2	0.0
Primary school	3,563	17.2	4.1	16.5	5.2	6.2	0.0
Secondary school	5,600	17.2	4.1	16.5	5.2	6.2	0.0

Figure 10.1.3: Carbon emissions $kgCO_2/m^2$

Site wide carbon emissions saved TCO_2/yr							
	GIA (m^2)	Scenario 1	Scenario 2		Scenario 3		Scenario 4
			Best	Worst	Best	Worst	
Homes -Terrace type	132,000	0	1,273	250	1,421	1,334	1,803
Homes- Medium rise type	33,000	0	262	74	262	244	337
Offices	40,000	0	232	90	311	269	517
Research	40,000	0	232	90	311	269	517
Retail	1,500	0	9	3	12	10	19
Community space	800	0	7	-3	6	5	10
Sports + Leisure	2,000	0	12	4	16	13	26
Primary school	3,563	0	47	3	43	39	61
Secondary school	5,600	0	73	4	68	62	96
Total			**2,146**	**514**	**2,448**	**2,245**	**3,388**

Figure 10.1.4: Carbon emissions saved TCO_2/yr