South Oxfordshire and Vale of White Horse Joint Local Plan: Net Zero Carbon Study

Task 3 – Feasibility Study: Energy modelling

12 December 2023

Bioregional

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Executive summary

This document presents the technical evidence supporting the development of net zero carbon buildings policies within a new Joint Local Plan (JLP) for the districts of South Oxfordshire and Vale of White Horse, with a focus on energy modelling for policy recommendations. The analysis considers eight archetypal buildings, four domestic and four non-domestic, to establish baselines and specifications for achieving proposed policy targets. The policy targets, informed by emerging policies from other areas in the UK, underwent rigorous testing to ensure that they are both technically and economically feasible. The study evaluates space heating demand, energy use intensity, photovoltaic sizing, net zero operational energy, and embodied carbon: providing insights for policy relevance and architectural design impact.

This assessment selected eight typical archetype buildings (four residential + four non-residential).

To each of the 8 archetypes, a range of different construction specification variants were applied to test performance against the emerging JLP targets for energy use, renewable energy and embodied carbon. All specification variants are made up of products, techniques and materials widely available today. The variants are, in order of ascending ambition:

- New build - Meeting Part L 2021 (current building regulations)
- New build - Meeting Part L 2025 (Future Homes (Buildings) Standard)
- New build - Meeting optimal energy targets for 'net zero' buildings set by industry
- New build - Meeting industry targets for reduced embodied carbon (optimal or moderate) at the same time as meeting optimal energy targets.
- Existing buildings – retrofit towards climate-aligned industry targets on energy/carbon.

This was done reciprocally with a cost assessment to avoid relying on unrealistic specification.

1.1 Key findings

1. Space Heating Demand

- Current building regulations and the Future Homes (Buildings) Standard (FH(B)S) do not deliver on the proposed policy targets for space heating demand, in the 8 archetypes modelled.
- The 'Net zero operational energy' and 'reduced embodied carbon' variants do meet the proposed targets in the 8 archetypes, demonstrating technical feasibility.
- Retrofits outperform current and emerging building regulations.

2. Energy Use Intensity (EUI)

- The policy proposes EUI targets that will create zero or near zero carbon buildings. The EUI priorities a reduction in building energy over the production of energy on site.
- Current building regulations do not meet the proposed EUI policy targets across the 8 archetypes and correspondingly none achieve zero carbon.
- The 'Zero operational energy' variants comfortably meet the policy targets in the modelled archetypes.
- 'Retrofit' specifications for the archetypes are within advisory best practice EUI targets developed by LETI (the proposed policies do not seek these).
- Unregulated energy becomes a proportionally significant share of total EUI, in the 'zero carbon' variants.
- Some non-domestic uses may exceed policy targets due to high unregulated loads.

3. Photovoltaic Sizing

- A minimum photovoltaic target of 120 kWhr/m^2/yr (projected building footprint) is proposed in cases where it is not achievable to match PV to 100% of energy use.
- Only the office archetype falls short of 'net zero' with this specified photovoltaic target.

4. Net Zero Operational Energy

- Some non-domestic archetypes, notably the office, struggle to achieve net zero operational energy due to limited roof space for PV in proportion to floor space.
- Retail and warehouse archetypes that have high unregulated loads may face challenges in meeting policy targets.
- Primary schools are better positioned to achieve net zero due to large roof space.

5. Embodied Carbon

- Embodied carbon increases across archetypes from 'Part L 2021' variant to 'Net Zero Operational Energy' due to more insulation and equipment, but the 'reduced embodied carbon' variants bring this back down to a reasonable level while meeting energy targets.
- Retrofits demonstrate the lowest embodied carbon.
- Homes can achieve LETI A comfortably, while non-domestic archetypes can currently achieve LETI B.

6. Design Constraints

- Architectural form affects space heating demand (SHD) and EUI performance.
- Policy should incentivise efficient building forms via fixed targets for EUI and SHD.
- Reduced embodied carbon can be achieved while also allowing for flexibility in material cladding choice.
- Rooftop design is influenced by PV supply needs.
- Overall, policy targets influence architectural design without unduly restricting options.

7. Retrofit

- Retrofitting existing buildings reduces embodied carbon compared to new construction.
- Retrofit standard airtightness target outperforms FH(B)S.
- Space heating demand reduction in retrofits contributes to achieving Net Zero Carbon.
- Non-domestic archetypes are generally easier to retrofit than domestic archetypes.

1.2 Conclusion

This comprehensive analysis provides a robust technical foundation for the proposed Joint Local Plan. It demonstrates the feasibility of achieving policy targets, identifies challenges in certain archetypes and uses, and emphasises the importance of a balanced approach to achieve energy efficiency and sustainability goals. The findings inform policy recommendations and highlight the need for ongoing monitoring and adaptation as technology and industry practices evolve. The separate 'Task 4' report confirms costs of achieving these targets, for viability testing.

Glossary of terms and acronyms

BREDEM	Buildings Research Establishment Domestic Energy Model. A methodology for estimate calculations of the energy use and fuel requirements of a home based on its characteristics. BREDEM is the basis for SAP (see in this glossary), but BREDEM retains more flexibility by allowing the user to tailor some assumptions made in the calculations to better reflect the project.
Biobased	A biobased material is one that has been grown by a plant rather than extracted from a mineral or petrochemical resource. This includes timber, hemp, jute, straw etc
Building fabric or envelope	All the external surfaces of the building including wall, floors, roofs, windows and doors.
Carbon, or carbon emissions	Short for 'carbon dioxide' but can also include several other gases with a climate-changing effect, which are emitted to the atmosphere from human activities.
Carbon budget	Amount of greenhouse gas that can be emitted by an individual, organisation or geographic area. Usually set to reflect a 'fair share' of the global amount that can be emitted before reaching a level of atmospheric carbon that causes severely harmful climate change.
Carbon intensity/ carbon factors	A measure of how much carbon was emitted to produce and distribute each kWh of grid energy at a certain point in time. For electricity, this has been falling as coal-fired power stations have been phased out over years. It also varies on an hourly basis: at times of high renewable energy generation, the carbon intensity is lower than at points where gas-fired electricity dominates the generation mix.
CLT	Cross-laminated timber. An engineered wood product made of solid wood glued together in layers with the wood grain perpendicular to the previous layer. This gives the product excellent strength, making it more suitable for structural use.
CO_2	Carbon dioxide. Often shortened to 'carbon'.
CO_2e	Carbon dioxide equivalent. The sum of a mixture of gases, in terms of their climate-changing impact in a 100-year period expressed as the amount of CO_2 that would have the same effect. Often shortened to 'carbon'.
Embodied carbon	Carbon that was emitted during the production, transport and assembly of a building, infrastructure, vehicle or other product, before the product is in use. As opposed to 'operational carbon' which is emitted due to energy use when operating the building / infrastructure / vehicle / other product.
EUI	Energy use intensity, a measure of how much energy a building uses per square metre of floor. Expressed in kilowatt-hours per square metre of floor space per year.
Form Factor	The ratio of useful floor area to building envelope. A block of flats has a good form factor and a bungalow a poor form factor
FH(B)S	Future Homes (Buildings) Standard. The version of national building regulations Part L (which regulates energy and carbon) that will be in place from 2025. *Homes* is used for domestic and *building* for non-domestic.
GHG	Greenhouse gas (CO_2 and several other gases: methane, nitrogen dioxide, and fluorinated refrigerant gases). Often collectively referred to as 'carbon'.
JLP	Joint Local Plan.
kWh	Kilowatt-Hour, a unit of energy
kWp	Kilowatt Peak. This is used for the peak power of a PV panel. It states the highest power output of the panel in optimum conditions.
LETI	Low Energy Transformation Initiative. A coalition of over 1,000 UK built environment professionals working together to set standards and guidelines for this sector to combat the climate crisis.
cMEV	Centralised mechanical extraction.
dMEV	Decentralised mechanical extraction. Typically, fans in kitchens and bathrooms.
MVHR	Mechanical Ventilation with Heat Recovery
Notional Building	In building regulations, the *notional building* refers to a hypothetical building designed to meet the fabric efficiency standards specified in the regulations. It is

	based upon the proposed design and used as reference point for compliance.
Operational Energy / Net Zero Operational Energy	Operational energy is energy used to operate the building. Separate from 'embodied energy' or 'embodied carbon' (see separate definition in this glossary). 'Net zero operational energy' is when a building in operation uses no more energy than it generates on site, over the course of the year. Achieved via a combination of excellent energy efficiency and on-site renewable energy generation.
Part L	Building regulations section that sets basic legal requirements regarding buildings' energy and CO_2.
Performance gap	The 'energy performance gap' is the difference between the amount of energy a building is predicted to use during design, versus the actual amount of energy it uses. The gap is due to poor prediction methodologies, errors in construction, and unexpected building user behaviour.
PV	Photovoltaics: solar panels that generate electricity.
PVC	Polyvinyl chloride. A kind of plastic, commonly used for doors, windows and floors.
PHPP	Passivhaus Planning Package – a tool to accurately calculate a building's energy use. It is used to design buildings that seek Passivhaus certification but can be used without pursuing certification.
Regulated energy or carbon	Carbon emissions associated with energy uses that are 'regulated' by building regulations Part L. This covers permanent energy uses in the building, (space heating, space cooling, hot water, fixed lighting, ventilation, fans and pumps).
Value Engineering	A process of identifying and evaluating alternative solutions to deliver a given outcome (e.g. carbon emissions) to see if it offers greater value for money.
VRF	Variable Refrigerant Flow (VRF) is a heating, ventilation, and air conditioning technology that efficiently controls the amount of refrigerant flowing to different indoor units in a building. Instead of using a single, constant flow of refrigerant, VRF systems can adjust the flow to meet the specific heating or cooling requirements of individual zones or rooms.
SAP	Standard Assessment Procedure – the national calculation method for residential buildings' energy and carbon, used to satisfy building regulations Part L. SAP is based on BREDEM model, but with fixed assumptions and thus less flexibility.
SBEM	Simplified Buildings Energy Model – the national calculation method for non-residential buildings' energy and carbon, used to satisfy building regulations Part L.
Sequestration	Removal and storage of carbon dioxide (or other GHGs) so that it cannot perform its harmful climate-changing role in the atmosphere. Currently only achieved by trees, plants and soil. May be achieved by technologies in future.
SHD	Space heat demand – the amount of energy needed to heat a building to a comfortable temperature. Expressed in kilowatt-hours per square metre of floor space per year.
TER	Target Emission Rate – a limit set by Part L of building regulations on CO_2 emissions per square metre of floor, from regulated energy use in the building.
TPER	Target Primary Energy Rate – a limit set by Part L of building regulations on 'primary energy' use per square metre of floor. Unlike metered energy, 'primary energy' considers energy lost to conversion inefficiencies during power generation and distribution.
TFEE	Target Fabric Energy Efficiency – a limit on space heat energy demand per square metre of floor, set by Part L of building regulations. Based only on fabric performance; not affected by building services like heating system, lighting, ventilation.
TM54	A method to accurately calculate buildings' energy use. Devised by Chartered Institution of Building Services Engineers (CIBSE).
Unregulated energy or unregulated carbon	Carbon associated with energy use in a building or development, but which is not covered by building regulations Part L. Includes plug-in appliances, lifts, escalators, external lighting, and any other use not covered by Part L.

Contents

1 Introduction

1.1.1 This document covers the technical evidence base for the development of net zero carbon buildings policies within a new Joint Local Plan (JLP) for the districts of South Oxfordshire and Vale of White Horse.[1] This document focuses explicitly on energy modelling used to develop the policy recommendations. The information laid out in this document has been conducted in parallel and in conversation with the separate cost uplift assessment (Task 4), which quantifies the exact cost impacts of the various policy targets (so that these can be fed into the separate viability assessment for the JLP). The Scoping Report and carbon reduction, with policy recommendations (Tasks 1 and 2) should be read in conjunction with this document. The scoping report contains the policy context, definitions, and targets. The longer definitions are not included here to prevent repetition; however, succinct explanations are given for key terms and the glossary is included for ease of reference. A technical appendix is also included for those wanting additional detail on the methodology and modelling.

1.1.2 The wider context is important to note as other local authorities (Central Lincolnshire, Greater Cambridgeshire, Bath and Northeast Somerset, Cornwall, and others) have already prepared equivalent local plans, with respective evidence bases. Therefore, this report whilst specific for South Oxfordshire and Vale of White Horse, builds upon a growing evidence base[2].

[1] This study and its findings were accurate prior to the release of the Written Ministerial Statement entitled 'Planning - Local Energy Efficiency Standards Update' dated 13 December 2023. The Councils will be reviewing their approach to Net Zero Carbon Buildings in light of the Written Ministerial Statement.

[2] In particular we credit and acknowledge Etude for this work and collaborative approach.

2 Methodology and definitions

2.1 Archetype methodology

2.1.1 The evidence base comprises eight archetypal buildings—four domestic and four non-domestic—representative of those submitted for planning permission and endorsed in current and emerging local plans. These archetypes reasonably reflect the buildings governed by the proposed Joint Local Plan policy. Additional policy wording is outlined for unmodeled archetypes, detailed in the following section.

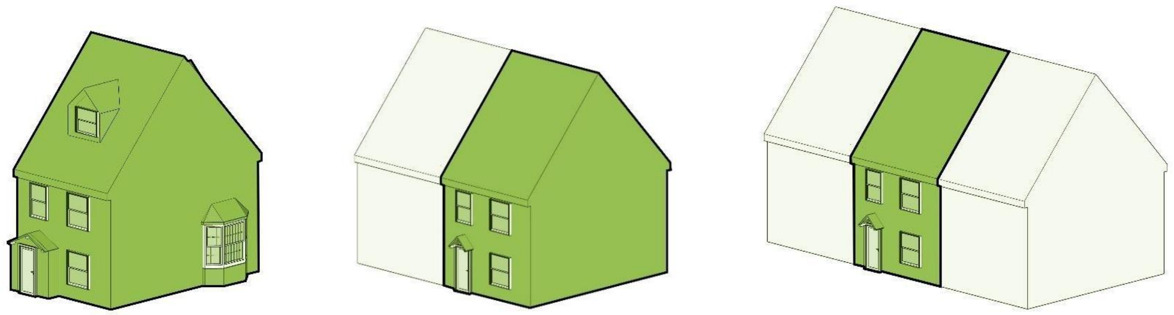


Figure 1. Archetypes A, B, C – Detached, Semi-detached, Terrace

2.2 Domestic archetypes

2.2.1 The houses are typical of those put forward for new build residential developments of low to medium density. Archetypes A, B and C are variants of the same house type – A is detached, B is semi-detached, and C is terraced. The three-bedroom five-person detached archetype is more complex with dormers, bay window, internal porch and accommodation over three floors. The two-bedroom three-person semi-detached is the same but over two storeys and less complex with no dormers or bay windows. The terrace is identical to the semi-detached but with a gable wall converted to a party wall. The flats (archetype D) are medium to low-rise as the major urban areas are not of high density. It includes a retail unit beneath as an indication of policy supported mixed-use developments. This also allows for integration with the retail archetype.

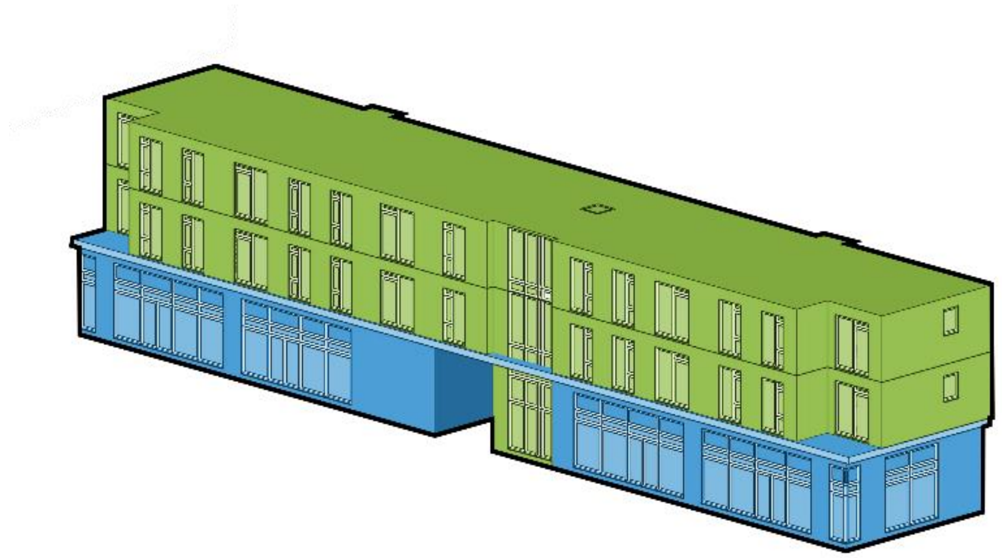


Figure 2. Archetype D – Medium rise flats

2.3 Non-domestic archetypes

1 – Retail

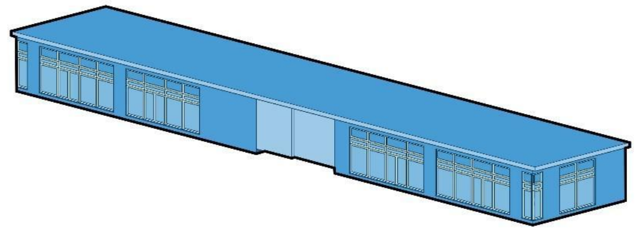


Figure 3. Archetype 1 – Retail unit

2.3.1 The selected retail unit represents a typical convenience grocery store in a medium density residential proposal. It is shown as both a free-standing single-storey unit and integrated beneath a flat to assess how architectural design may impact energy performance that can feasibly be required in policy.

2 – Primary school

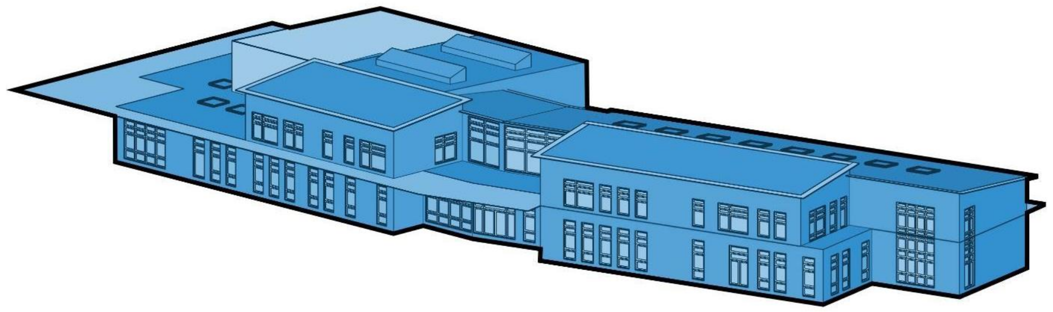


Figure 4. Archetype 2 - Primary school

2.3.2 A two-form primary school was selected as aa common educational building proposed for the districts. A two-storey version was chosen over single storey as it aligns with typical density.

3 – Offices

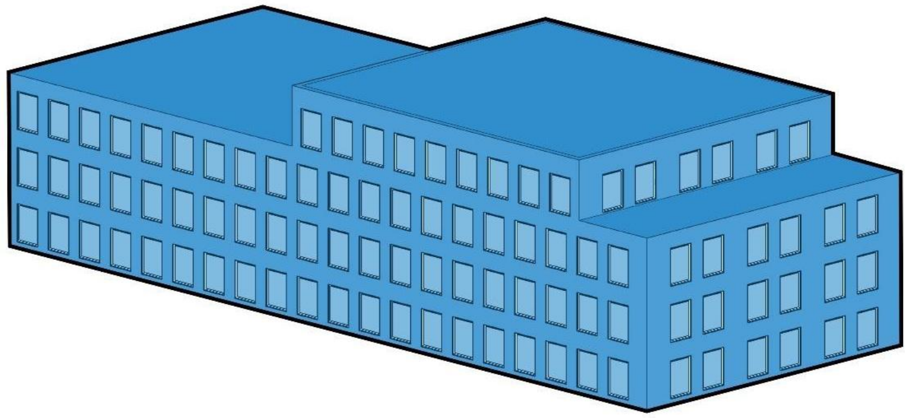


Figure 5. Archetype 3 - Offices

2.3.3 A simple office building was selected which has three and a half storeys. It is the tallest of the archetypes but still typical of those brought forward. It is not dissimilar to the research and development facilities common in the area. There is a higher demand for offices than research buildings so a standard office use was modelled.

4 - Warehousing

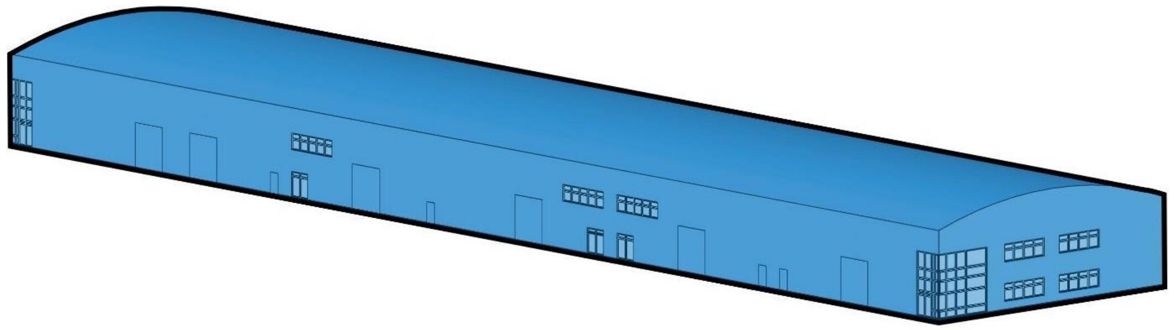


Figure 6. Archetype 4 - Warehouse

2.3.4 Warehouses are by floor area, the biggest area of non-domestic existing stock in the districts, and with the significant rise of online shopping post the COVID-19 pandemic, more warehousing could come forward. Because the building is effectively an industrial shed, it can serve multiple purposes. The warehouse has one of the lowest energy footprints as it is primarily used for storage with limited office space. To illustrate the other end of the energy-use spectrum, a power-hungry data centre was also modelled.

2.4 Archetype modelling

2.4.1 The energy and carbon of each archetype is modelled at several levels of performance: from current and emerging regulation; to various zero operational and embodied carbon specifications. The rationale of the archetypes selected is provided in the technical appendices.

2.4.2 Some of the archetypes were manipulated spatially to test the effect of being detached or part of a larger building or terrace. This allowed the effects of differing architectural/spatial design on the energy performance. Two of the non-domestic archetypes we tested for have different commercial purposes to understand the effect on the energy use[3]. These archetype variants are described in the technical appendix to ensure clarity on the main policy proposals.

2.5 Operational net zero energy

2.5.1 To achieve net zero energy, the supply of on-site energy must match the operational energy demand of the building. Operational energy is what is required for the building to work as intended, keeping occupants comfortable e.g., warm spaces, warm water, fresh air, well lit, and enough power for the use of the building.

2.5.2 This study uses Passivhaus predictive modelling software PHPP[4] to calculate the operational energy. The Passivhaus methodology has been used and outputs adapted[5] for compatibility with UK standards. We use the emerging conventions developed by LETI (Low Energy Transformation Initiative) and energy use intensity (EUI), described below, to measure how much operational energy is used.

2.5.3 Figure 7 graphically shows the energy balance. The total energy demand of the building needs to be equal to the amount of zero-carbon energy supplied to the buildings over the period of a year. This is either on the site or on the building, and typically this is provided by photovoltaic panels[6]. If on-site solutions are not possible then an off-site solution may be required – please see the Scoping Document for more information. If a building uses more energy than produced on site, then it cannot be considered to have net zero operational energy. As shown in the results section, all the archetypes modelled to current and emerging building regulations do not achieve this definition of zero operational energy. This is because the buildings use more energy over one year than is produced by the solar panels on the building's roof.

2.5.4 To convert between *net zero energy* and *net zero carbon* each kilowatt hour used by the building needs to be multiplied by the carbon content of the energy source used. Gas, for example, has a lower carbon content of coal. The carbon content of electricity can vary greatly. If coming from a solar panel on the roof the carbon content is zero. If it is coming from the grid it can range between 90g to 500g per kilowatt hour[7].

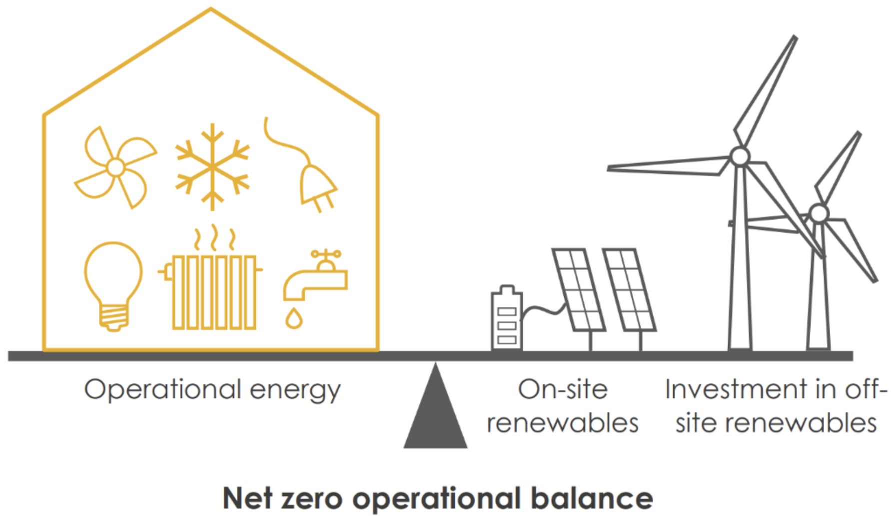


Figure 7. Diagram of LETI net zero operational balance

Energy Use Intensity (EUI)

2.5.5 This is the total energy consumption of the whole building, measured in kWh/m^2/year (of floor space). Energy Use Intensity (EUI) takes account of regulated and unregulated energy. This is important because the scope of Part L of building regulations does not include unregulated energy, meaning any policy based on Part L cannot result in a truly net zero building. It is an extremely important metric because helps stop the use of inefficient heating systems (like gas boilers or 'direct electric') in buildings designed to meet the requirements of net-zero energy policy.

Regulated and unregulated energy

2.5.6 *Regulated* energy loads are anything that is installed during the construction of the building, such as heating, ventilation, fixed lighting. *Unregulated*, is anything plugged into the building by the user post completion (as shown in diagram below). In a non-domestic building, this will include the equipment required for the buildings purpose such as: machinery, fridges, research equipment, servers, office equipment, commercial kitchens and smart boards. In current building regulations, these unregulated energy demands are excluded from calculations. As demonstrated in the results of this study, some unregulated loads can have a significant impact in achieving a true net zero operational carbon.

[3] For example, a shoe shop needs less energy than a convenience grocery store with multiple fridges and freezers.
[4] The Passivhaus Planning Package.
[5] Credit to Delta Q for their plug-in in converting from PHPP to emerging UK metrics.
[6] Other forms such as wind or hydro are possible but often not feasible particularly in urban and sub urban settings.
[7] Where the study shows a carbon value it is calculated by multiplying the kilowatt hours by the carbon content in SAP 10.

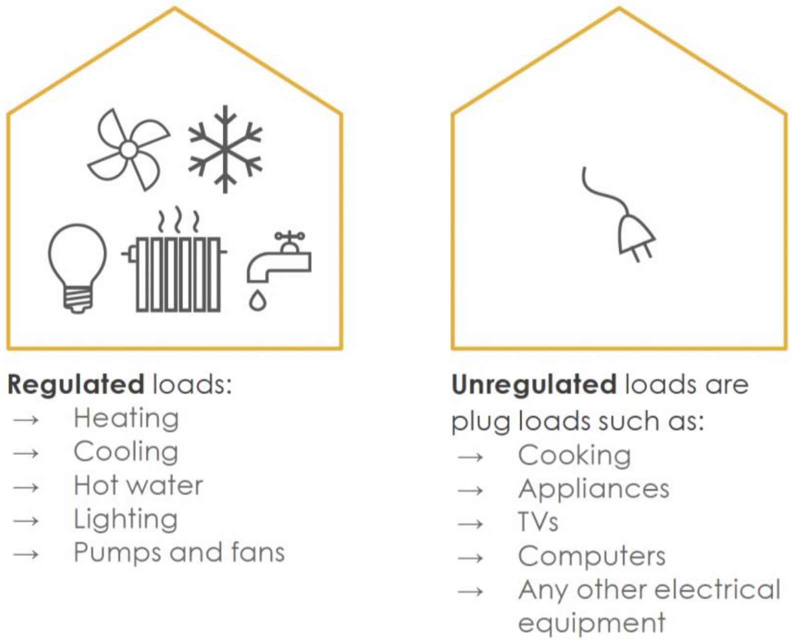


Figure 8. Diagram from [LETI Climate Emergency Design Guide]

Space Heating Demand

2.5.7 Space heating demand simply represents the thermal energy efficiency of a building, which is primarily controlled by insulation properties of external and internal building elements, air tightness and thermal bridging. Unlike EUI, space heating demand does not consider the type or efficiency of the heat technology of the building; rather the space heat demand metric is a measure of how many units of heat (kWhrs/m^2/yr) are required to provide sufficient comfort levels for occupants of the building. Whatever technology is used, whether this is a heat pump or gas boiler, will not change the space heating demand value as it is solely based on the fabric efficiency[8] of the building.

2.6 Embodied Carbon

2.6.1 Embodied Carbon is the associated carbon from construction, maintaining, and disposing of a building at the end of life. It can also consider the carbon stored by materials such as timber – that is carbon locked into a natural material as it grows and then stored in the building. Detailed models also consider the post-demolition reuse of materials as part of a circular economy. At present, this is unregulated and therefore not covered by building regulations Part L or similar. During construction a typical home may produce around 70 tonnes of embodied carbon, and a school or office many thousands of tonnes, even if there is zero operational energy. This represents a major challenge for a holistic net-zero policy, as even if operational energy is addressed, embodied carbon emissions remain.

[8] Existing Part L uses Fabric Energy Efficiency FEE as an equivalent term.

2.6.2 This study uses the Low Energy Transformation Initiative (LETI) approach[9] to setting targets for embodied carbon, because of its policy relevance and focus on upfront carbon in the construction phase. This relates directly to what is being proposed by the applicant at the planning stage (that is, all works up to completion and handover of the building). Figure 9 below shows LETI's pathway to net zero by combining both the operational and embodied carbon of buildings. Whole life carbon is not included in the policy recommendations; however, a brief analysis is included in the technical appendix.

2.7 Retrofit

2.7.1 Retrofit refers to works to an existing home or building that are designed to reduce its energy use, while making it warmer and more comfortable for the people who live there. To achieve this, retrofit works will make existing homes more energy efficient. For example, making them better insulated, or improving the indoor air quality. The study includes an exploration of retrofit and its benefits for embodied carbon and challenges to operational carbon. Existing buildings caused a certain amount of embodied carbon emissions when they were built; keeping them in use makes the most efficient use of that 'investment' for as long as possible. It is therefore highly beneficial to retain them rather than demolish and rebuild. Conversely existing buildings tend to perform poorly for operational energy because many of them are not very energy efficient.

2.8 Compatibility of net-zero ambitions with building regulations

2.8.1 The below table gives a summary of terms and units used in current building regulations and how they related to this study and policy proposals. They are loosely interchangeable but slightly different in calculation. The former being SAP and the latter generally PHPP.

Unit (m^2 here refers to floor space)	Building regulations	LETI & the emerging local plan
kWh/m^2/yr	N/A	EUI/Delivered Energy (Energy Use Intensity)
kWh/m^2/yr	Primary Energy Rate (regulated energy only)	Total Energy Demand (regulated and unregulated)
kWh/m^2/yr	FEE (Fabric Energy Efficiency)	SHD (Space Heating Demand)
kgCO_2/m^2/yr	D/TER (Dwelling / Target Emissions Rate) – regulated only	Operational CO_2 – regulated and unregulated
kgCO_2/m^2	N/A	Embodied CO_2

Table of this studies metrics compared with building regulations.

[9] LETI Embodied Carbon Primer

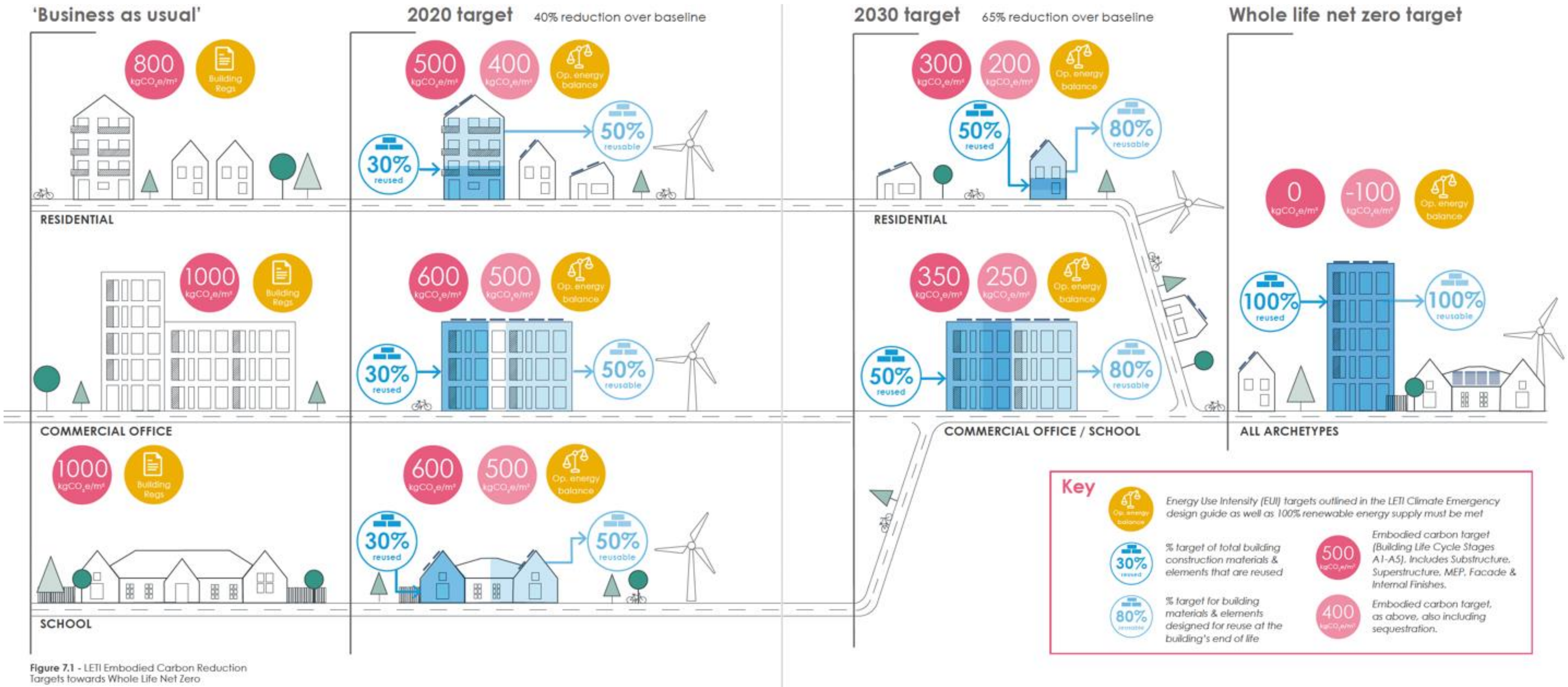


Figure 9. Targets from LETI Embodied Carbon Primer

Limitations of building regulations

2.8.2 Part L of Building Regulations building regulations, is the current national standard of regulating energy use. Its purpose is for the conservation of fuel and power, and it uses a methodology called the Standard Assessment Procedure (SAP) to calculate a building's energy performance. The aim of this study is not an in-depth review of Part L, instead it explains, as previous information bases have, that compliance with Part L will not result in a zero-carbon building (and in fact the Part L SAP method on its own is not capable of assessing whether a building is truly net zero carbon). It is worth noting that Part L of building regulations is due for update. This update is known as the Future Homes (Building) Standard[10], and it aims to ensure that new homes built from 2025 will produce 75-80% less carbon emissions than homes built under the current Building Regulations. As detailed below, the Future Homes (Building) Standard is also modelled in the study and is also shown not to achieve zero carbon buildings.

2.9 Modelling of policy recommendations

2.9.1 The key policies to test for feasibility are:

- Space heading demand (SHD) targets
- Energy Use Intensity targets (EUI) targets
- Delivering Net zero energy
- Reduced embodied carbon targets

2.10 Baselines

2.10.1 This study uses two baselines: the current building regulations Part L 2021; and the proposed Future Homes (Building) Standard. They are summarised in Figure 10 alongside historical targets (note: Figure 10 denotes Part L 2013 as 'current' because it is taken from a document written before Part L 2021 was implemented). Although building regulations Part L 2021 will certainly be superseded before the adoption of the Joint Local Plan, which is the focus of this study, it is still used as a baseline because the Future Homes (Building) Standard (Part L 2025) is only in indicative form. The indicative FHSFH(B)S is used as a second baseline as these regulations will likely be in place on adoption of the Joint Local Plan.

2.10.2 For South Oxfordshire District Council, the existing South Oxfordshire Local Plan includes Policy DES10. This policy requires a percentage reduction in carbon emissions using building regulations Part L methodology. Policy DES10 was disregarded as a baseline for two primary reasons; firstly, because it is relevant only for one district of this study, and secondly the 40% reduction would be lower than the estimated 75% reduction from the Future Homes (Building) Standard.

Table 2 - Fabric and services comparison with the 2021 Part L and draft Future Homes Standard specification

	Proposed 'zero carbon homes' standard[1]	Current 2013 Part L standard	2021 Part L Standard	Indicative FHS specification
Floor U-value ($W/m^2.K$)	0.13	0.13	0.13	0.11
External wall U-value ($W/m^2.K$)	0.18	0.18	0.18	0.15
Roof U-value ($W/m^2.K$)	0.13	0.13	0.11	0.11
Window U-value ($W/m^2.K$)	1.4	1.4	1.2	0.8
Door U-value ($W/m^2.K$)	1.0	1.0 - opaque 1.2 – semi-glazed	1.0	1.0
Air permeability at 50 Pa	5.0 $m^3/(h.m^2)$	5.0 $m^3/(h.m^2)$	5.0 $m^3/(h.m^2)$	5.0 $m^3/(h.m^2)$
Heating appliance	Gas boiler	Gas boiler	Gas boiler	Low-carbon heating (e.g. Heat pump)
Heat Emitter type	Regular radiators	Regular radiators	Low temperature heating	Low temperature heating
Ventilation System type	Natural (with extract fans)	Natural (with extract fans)	Natural (with extract fans)	Natural (with extract fans)
PV	30% ground floor area	No	40% ground floor area	None
Wastewater heat recovery	No	No	Yes	No
y value ($W/m^2.K$)	0.05	0.05	0.05	0.05

Notes:
1. This table reflects the zero carbon homes specification that was proposed under a previous Government.

Figure 10. Extract from the Future Homes Standard consultation.
(Note: Part L 2013 is no longer 'current' today; it is denoted as such in this table because this table is taken from a document published before Part L 2021 was implemented).

Existing buildings – retrofit baselines

2.10.3 There is great diversity in the existing buildings within the two districts, not only due to the size and shape of these buildings but also that they were built to previous versions of building regulations or even before energy performance was regulated. The study therefore looks to mean average performance[11] and age of each archetype as a

[10] Note that the Future Homes Standard refers to domestic buildings and the Future Buildings Standard refers to non-domestic buildings.

[11] Extracted Energy Performance Certificates and Display Energy Certificate registers.

reasonable baseline. The architectural design used is the same as the modern archetypes, although this. Although is not strictly accurate as older buildings are different sizes and shapes. It does, however, allow for direct comparisons with the selected archetype.

3 Proposed Policy Targets

3.1 Operational Energy & Carbon

3.1.1 The table below shows the key operational energy and carbon targets tested in this study. The LETI EUI and SHD targets[12] were used as a baseline as they align with national net zero targets. The technical appendix shows a summary of similar previous evidence bases[13] for other local plans have demonstrated that they are possible to achieve in different areas of the country. Please see Tasks 1&2 for further details on the policy targets. Note that the retrofit targets are advisory and outside of the scope of the policy recommendations.

Variant	Building Regulations Part L 2021	Future Homes Standard 2025	Proposed policy targets	*Residential retrofit advisory targets*
Annual net carbon per building (tonnes/yr)	Emission rate of building	Emission rate of building	0	*N/A*
Energy use intensity (kWh/m^2/yr)	N/A	N/A	35-55	*50*
Space heating demand (kWh/m^2/yr)	Fabric energy efficiency	Fabric energy efficiency	15	*50*
Onsite energy generation (kWhr/m^2/yr)	40% of ground floor area	0	Match EUI (or 120 kWh/m^2/sy$_{rup}$)	*Maximised*

Operational policy targets

3.1.2 The energy use intensity (EUI) is a range dependent on the use of the building. They are shown in the table opposite. This study uses eight archetypes to assess most buildings brought forward for development. Therefore the ‘other’ target allows for reasonable flexibility. For unassessed archetypes the unregulated EUI must be justified in the energy statement to be as efficient as is reasonable for the use. It maintains robustness with a fixed regulated EUI target which can be reasonably inferred by the study and largely unaffected by the specific use of the building.

Archetype	Residential	Retail	School	Office	Warehouse	Other
Energy use intensity - Total (kWh/m^2/yr)	35	35	55	55	35	Justified in energy statement
Energy use intensity - Regulated (kWh/m^2/yr)[14]	N/A	30	30	30	30	40

EUI policy targets

3.2 Onsite energy generation

Primary target

3.2.1 As described above, to achieve net zero operational energy, the on-site supply of energy needs to match the energy use of the building. Therefore, the primary target is that onsite energy supply must match the energy use intensity over one year.

Secondary target

3.2.2 The proposed local plan encourages more dense developments. Dense developments tend to be taller and therefore have less available roof space compared to the floor area. For example, a three-storey office building could meet the proposed EUI target of 55kWh/m2/yr, but the PV generation from the roof will typically only supply enough energy for two of the three storeys. The secondary target recognises this and proposes a 120kWh/m2 projected building footprint/year minimum PV generation when an energy balance is not possible. This is approximately 70% of the roof area, as measured by the projected footprint[15] of the building. This is considered reasonable as it

[12] The LETI Climate Emergency Design Guide contains targets for the different archetypes
[13] Specifically, the Central Lincolnshire Local Plan - Climate Change Evidence base, the Essex Net Zero Policy –Technical Evidence Base, the Cornwall Climate Emergency Development Plan Document and the Evidence Base for West of England Net Zero Building Policy
[14] It is accepted that in some circumstances, unregulated energy loads for the specific use of a non-residential building may result in a total energy use that exceeds the limits set out above. In these cases, applicants are required to demonstrate that regulated energy is limited to 30 kWh/m2/year. Unregulated energy loads must be justified in energy statement. Other building types not listed are required to demonstrate that regulated energy is limited to 40 kWh/m2/year. Unregulated energy loads must be justified in energy statement.
[15] Projected footprint is taken from Passivhaus methodology. It is selected as the most accurate method of assessing area available for PV. Ground floor footprint would ignore overhangs and projections such as colonnades and balconies. Roof area can change significantly depending on the pitch of the pitch of the roof.

optimises the amount possible to generate whilst allowing design flexibility. An absolute target is given instead of a percentage as current regulations. A percentage target could lead to low efficiency installation to meet the policy wording rather than actual energy supplied.

3.3 Space heating demand

3.3.1 Key to achieving the net zero carbon and energy use intensity targets, was a targeting of the space heat demand of a building. The space heating demand tends to be both the highest energy of current buildings and the area where the greatest improvements can be made. 15kWh/m2/yr is proposed as the maximum space heating target which aligns with targets set by Passivhaus and LETI[16]. It is considered the optimum target[17] for new build.

3.3.2 For the retrofit options LETI targets have also been used[18]. LETI Best Practice retrofit, SHD less than 50kWhr/m^2/yr and an EUI of around 50kWhr/m^2/yr, was used as the retrofit target. Both the SHD and EUI targets are less stringent than those for new build, in recognition of the challenges of working with an existing building.

3.4 Embodied carbon

3.4.1 As described in paragraph 2.6.1, LETI upfront embodied carbon targets have been selected for testing. The below table shows a banding of embodied carbon targets proposed by LETI[19]. Band C is selected as the minimum target because a previous study[20] demonstrated that band C[21] is possible with minimal changes to a current building regulation compliant building. Band A, also referred as the 2030 target, was selected as maximum because it aligns with the time frame[22] of the local plan. An interim band B was also tested as an interim target should an 'A' be too costly for the current market.

3.4.2 A retrofit option was also tested to produce evidence that improvement of the existing buildings in the districts is the most effective route to minimising embodied carbon. This aimed for an A++ band.

Band	Office	Residential (6+ storeys)	Education	Retail
A++	<100	<100	<100	<100
A+	<225	<200	<200	<200
A	<350	<300	<300	<300
B	<475	<400	<400	<425
C	<600	<500	<500	<550
D	<775	<675	<625	<700
E	<950	<850	<750	<850
F	<1100	<1000	<875	<1000
G	<1300	<1200	<1100	<1200

Figure 11. Table from the LETI Embodied Carbon Alignment

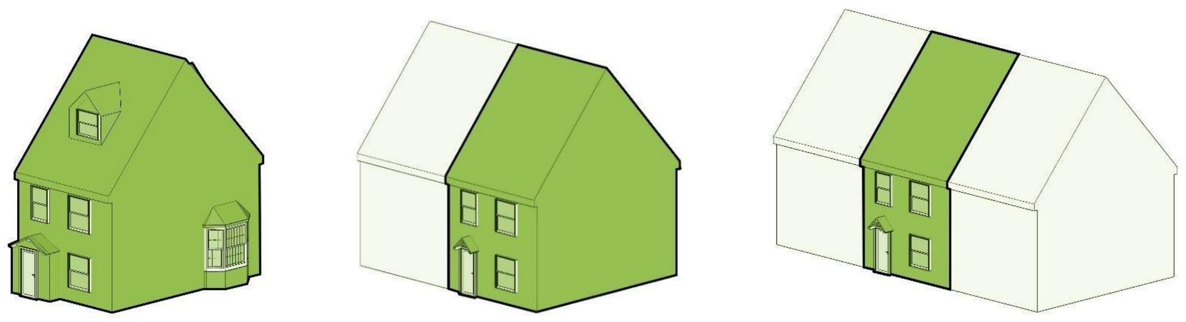
[16] Passivhaus requirements and LETI target
[17] Firstly, this target optimises comfort, so efficiency savings are unlikely offset by occupants. Secondly much beyond this target the costs are outweighed by a diminishing return on performance.
[18] LETI Climate Emergency Retrofit Guide
[19] Note that these align with RIBA and RICS targets although calculated differently. Please see the LETI Embodied Carbon Alignment for further details.

[20] West of England, Evidence base for WOE net zero building policy
[21] Band A is sometimes described as a 2030 target and Band C as a 2020 target.
[22] The embodied carbon of materials will decrease over time as the electricity grid decarbonises and material reuse increases (circular economy) and reduce in cost as the market matures. Therefore, the A and B targets are reasonable for the time scale of the proposed local plan.

4 Archetype specification

4.1.1 The following contains an outline specification for each archetype. This is a basic text description containing information on materials and services within the building. The technical appendix contains a performance specification of the construction and building services. This includes the technical numbers e.g., insulation values and heat pump sizes. The same specifications were used as the basis for the costs described in the separate Task 4 report.

4.2 Archetype A, B, C - Domestic (Houses)



4.2.1 The terrace, semi-detached and detached archetypes have been assessed against the following energy scenarios. Two additional Value Engineering options were explored for the domestic properties. As well as investigating a retrofit option, against an existing building baseline.

Scenario	Details
Part L 2021	Compliant with a Part L 2021 notional building specification. A brick and block cavity wall with mineral wool insulation. Beam and block floor with EPS insulation. uPVC windows; timber truss roof with concrete tiles and mineral wool insulation at loft level. A PV array equivalent in size to 40% of the footprint is included.
Future Homes Standard (FH(B)S)	This standard is based on the indicative Future Homes Standard and combines an improved performance fabric with a heat pump, natural ventilation and no PV and no wastewater heat recovery system. It uses the same building materials as stated in the Part L variant but with higher levels of insulation.
Zero operational carbon	This scenario includes triple glazed windows and doors, a good mechanical ventilation heat recovery (MVHR) system, air source heat pump (ASHP) and no wastewater heat recovery system. It uses the same building materials as stated in the Part L variant but with higher levels of insulation and triple glazed uPVC windows. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m^2_{fp}/yr.
Zero operational carbon with embodied carbon reduced - specification 1	This specification has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. This includes an a biobased (timber frame and timber fibre insulation) external wall construction, an insulated raft flooring and timber triple glazed windows. This scenario meets the embodied carbon LETI A target.
Zero operational carbon with embodied carbon reduced - specification 2	As per specification 1 but with the following cost savings to address achieve a lower embodied carbon target: standard polystyrene insulation and low carbon concrete for the floor insulation and the biobased external wall construction is replaced with a timber frame and mineral wool. The clay board was replaced with standard gypsum plaster. This scenario meets the embodied carbon LETI A target.
Value engineering – MVHR and ASHP	This value engineering option combines uses lower efficiency ASHP and MVHR installations. This reduces costs but increases the SHD and EUI.
Value engineering – no water-based heating system (e.g., water filled radiators) and a compact heat pump providing heating and hot water	This value engineering option combines fabric levels of the 'zero operational carbon' scenario but utilises a compact heat pump supplemented with minimal direct electric panel heaters in place of water filled radiators. This compact heat pump includes for MVHR ventilation, 180ltr domestic hot water storage and heating and cooling systems via air. No wastewater heat recovery system is included in this option. A PV array equivalent in size to 40% of the footprint is included.
Existing building	This scenario looks at existing housing stock from 1954 – 68 as a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, double glazed doors and windows, a gas boiler, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Triple glazed windows, an air source heat pump is also added alongside PVs on the roof and MVHR ventilation.

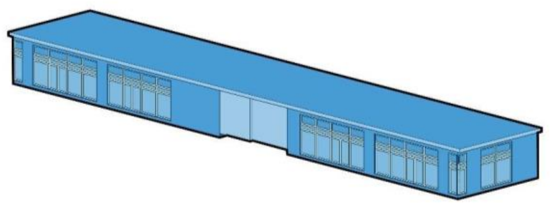
4.3 Archetype D – Domestic (Flats)

4.3.1 The two stories of additional residential above the retail development have been modelled separately and do not include any costs of the retail development[23] below. The retail Archetype shown in the non-domestic section below corresponds to this retail development. High level details of the scenarios assessed can be found in the table to the right:

Scenario	Details
Part L 2021	Compliant with current Part L 2021 standard, this option specifies a gas boiler and no PV provision. Materials include: concrete frame with a reinforced concrete slab and EPS insulation, uPVC double glazed windows, steel stud internal walls, gypsum plasterboard internally, concrete block external walls with PIR insulation, metal rainscreen cladding and a single ply roof with PIR insulation. A PV array equivalent in size to 40% of the footprint is included.
Future Homes Standard (FH(B)S)	This standard utilises an air source heat pump, improved fabric performance against Part L 2021 and no PV.
Zero operational carbon	This standard utilises an air source heat pump and improves on the fabric performance of the FBS option. The materials are the same as Part L but with higher levels of insulation and uPVC triple glazing. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m$^2_{fp}$/yr.
Zero operational carbon with embodied carbon reduced - specification 1	Specification 1 has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. Materials include: glulam and cross laminated timber (CLT) superstructure, timber frame external walls with cellulose insulation and timber cladding, timber stud internal walls, clayboard on all internal walls, timber triple glazed windows and reduced carbon concrete EPS insulated slab. This scenario meets the embodied carbon LETI A target.
Zero operational carbon with embodied carbon reduced - specification 2	Specification 2 focuses on reducing embodied carbon and is reflective of the specification 1 but with the following changes: the glulam and CLT superstructure is replaced with a concrete frame and composite steel and concrete deck. The insulation in the external walls are replaced for mineral wool and gypsum plasterboard is used instead of clayboard. This scenario meets the embodied carbon LETI B target.
Existing building	This scenario is a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, double glazed doors and windows, a gas boiler, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Triple glazed windows, an air source heat pump is also added alongside PVs on the roof and MVHR ventilation.

[23] The green in the residential above, and the blue the retail below.

4.4 Archetype 1 - Retail



Freestanding

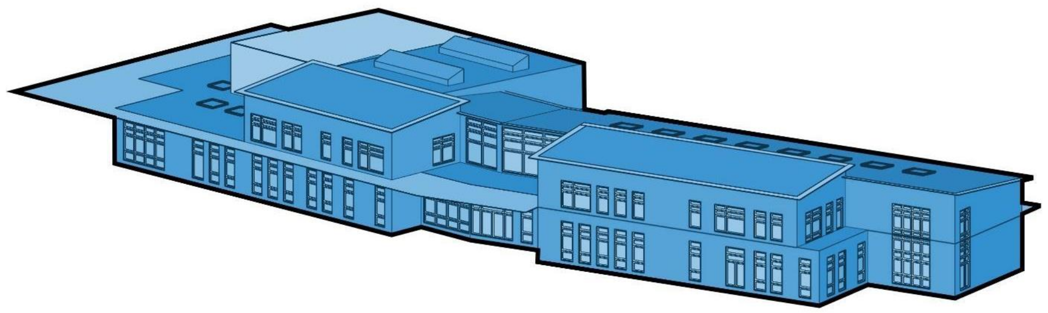
Inbuilt

4.4.1 Both a single storey stand-alone retail building and a retail unit beneath residential flats, each with four units, were modelled against different energy scenarios. Modelling the building as standalone or inbuilt enabled the study to test the effect of form factor[24] on the archetype. Two different use variants were also explored for this archetype - a clothing store and a grocery store (to investigate the impact of high unregulated energy use resulting from the presence of fridges/freezers in the grocery store variant). A retrofit option was also explored, against an existing building baseline. High level details of the scenarios assessed can be found in the table to the right.

Scenario	Details
Part L 2021	Compliant with current Part L 2021 standard, this option contains variable refrigerant flow (VRF) technology with standard fabric levels and no PV provision. It uses the freestanding form. Materials include: concrete frame with a reinforced concrete slab and EPS insulation, uPVC double glazed windows, steel stud internal walls, gypsum plasterboard internally, concrete block external walls with PIR insulation, metal rainscreen cladding and a single ply roof with PIR insulation. A PV array equivalent in size to 40% of the footprint is included.
Future Buildings Standard (FBS)	This standard utilises an air source heat pump, improved fabric performance against Part L 2021 and no PV. It uses the freestanding form.
Zero operational carbon – Freestanding shoe shop	This standard utilises an air source heat pump. The materials are the same as Part L but with higher levels of insulation and uPVC triple glazing. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m^2_{fp}/yr. These two scenarios are explored for both if the retail space were to be used as a clothing store or as a grocery store.
Zero operational carbon – Freestanding grocery	This is the same as the retail scenario above, but the unregulated energy use has been changed to a convenience grocer with chilled storage and display.
Zero operational carbon – Inbuilt grocery use	This was modelled with the same fabric as the previous two zero operational carbon scenarios. It has convenience grocers use. The key difference is the form of the building which is inbuilt in this scenario.
Zero operational carbon with embodied carbon reduced - specification 1	Specification 1 has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. Materials include: glulam and cross laminated timber (CLT) superstructure, timber frame external walls with cellulose insulation and timber cladding, timber stud internal walls, clayboard on all internal walls, timber triple glazed windows and reduced carbon concrete EPS insulated slab. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m^2_{fp}/yr. These two scenarios are explored for both if the retail space were to be used as a clothing store or as a grocery store. It uses the freestanding form. This scenario meets the embodied carbon LETI A+ target.
Zero operational carbon with embodied carbon reduced - specification 2	Specification 2 focuses on reducing embodied carbon and is reflective of specification 1 but with the following changes: the glulam and CLT superstructure is replaced with a concrete frame and composite steel and concrete deck. The insulation in the external walls are replaced for mineral wool and gypsum plasterboard is used instead of clayboard. It uses the freestanding form. This scenario meets the embodied carbon LETI A target.
Existing building	This scenario is a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, single glazed doors and windows, a VRF, electric panel heaters, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Triple glazed windows, an air source heat pump is also added alongside PVs on the roof and MVHR ventilation.

[24] In the freestanding version has significantly more roof to lose heat through, the inbuilt spatial variant will lose less heat due to its form but will also have much less roof area for PV installations.

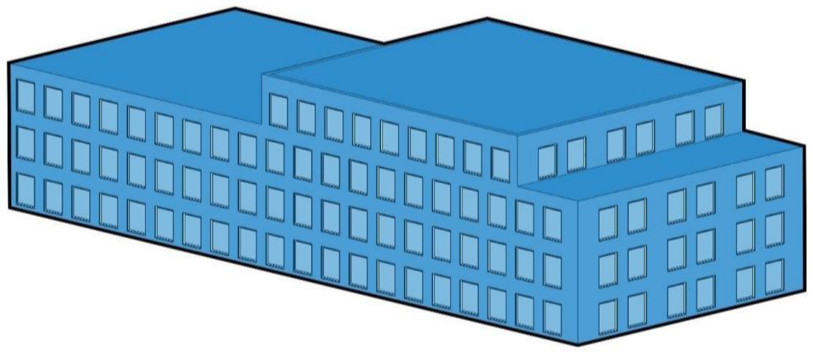
4.5 Archetype 2 - School archetype



4.5.1 A two-storey primary school building was modelled against different energy scenarios. As well as investigating a retrofit option, against an existing building baseline. These scenarios have then been incorporated into the capital cost model to determine fabric, services, PV and overall cost for the specifications. High level details of the scenarios assessed can be found in the table to the right:

Scenario	Details
Part L 2021	Compliant with current Part L 2021 standard, this option utilises a gas boiler, with radiators in classrooms and offices and fan convectors in the hall. No PV has been allocated. Materials include: steel frame for large spans, structural blockwork with pre-cast concrete floors, a concrete slab with EPS insulation, uPVC double glazed windows, steel stud internal walls, gypsum plasterboard internally, external walls have PIR insulation and are clad in half brick and half timber and a single ply roof with PIR insulation. A PV array equivalent in size to 40% of the footprint is included.
Future Buildings Standard (FBS)	This scenario utilises a gas boiler and low temperature radiators, with an improved fabric performance against Part L 2021 and no PV has been allocated.
Zero operational carbon	This standard utilises an air source heat pump and the specification improves on the fabric performance of the FBS option. The materials are the same as Part L but with higher levels of insulation and uPVC triple glazing. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m$^2_{fp}$/yr.
Zero operational carbon with embodied carbon reduced - specification 1	Specification 1 has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. Materials include: glulam and cross laminated timber (CLT) superstructure, timber frame external walls with cellulose insulation and timber cladding, timber stud internal walls, clayboard on all internal walls, timber triple glazed windows and reduced carbon concrete EPS insulated slab. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m$^2_{fp}$/yr. This scenario meets the embodied carbon LETI A target.
Zero operational carbon with embodied carbon reduced - specification 2	Specification 2 focuses on reducing embodied carbon and is reflective of specification 1 but with the following changes: the glulam and CLT superstructure is replaced with steel frame for large spans, structural blockwork with pre-cast concrete floors. The insulation in the external walls is replaced for mineral wool and gypsum plasterboard is used instead of clayboard. uPVC windows instead of timber. This scenario meets the embodied carbon LETI B target.
Existing building	This scenario is a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, double glazed doors and windows, a gas boiler, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Triple glazed windows, an air source heat pump is also added alongside PVs on the roof and natural ventilation.

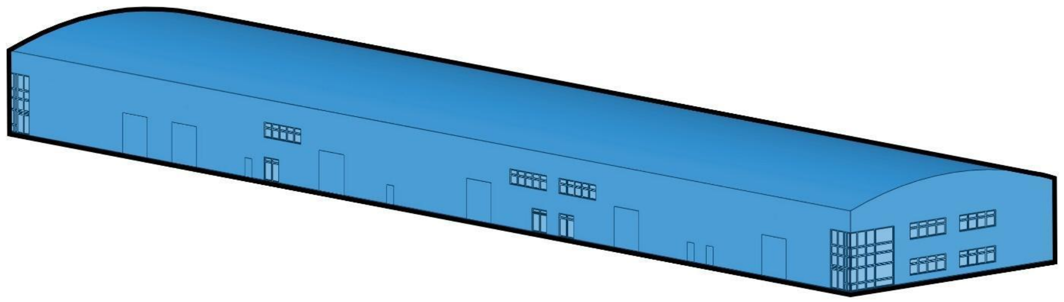
4.6 Archetype 3 - Office archetype



4.6.1 An office building was modelled against 4 different energy scenarios. As well as investigating a retrofit option, against an existing building baseline. These scenarios have then been incorporated into the capital cost model to determine fabric, services, PV and overall cost for the specifications. High level details of the scenarios assessed can be found in the table to the right:

Scenario	Details
Part L 2021	Compliant with current Part L 2021 standard, this option utilises a gas boiler, with trench heaters at the perimeter and VRF units in the suspended ceiling. Materials include: steel frame with a reinforced concrete slab and EPS insulation, composite steel and concrete decks, uPVC double glazed windows, steel stud internal walls, gypsum plasterboard internally, concrete block external walls with PIR insulation, metal rainscreen cladding and a single ply roof with PIR insulation. A PV array equivalent in size to 40% of the footprint is included.
Future Buildings Standard (FBS)	This scenario utilises a gas boiler with trench heaters at the perimeter and VRF units in the suspended ceiling. The scenario has an improved fabric performance against Part L 2021 and no PV has been allocated.
Zero operational carbon	This standard utilises an air source heat pump. The materials are the same as Part L but with higher levels of insulation and uPVC triple glazing. Heating distribution is primarily via supply air heating and localised VRF to provide comfort/heating and cooling. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m^2_{fp}/yr.
Zero operational carbon with embodied carbon reduced - specification 1	Specification 1 has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. Materials include: glulam and cross laminated timber (CLT) superstructure, timber frame external walls with cellulose insulation and timber cladding, timber stud internal walls, clayboard on all internal walls, timber triple glazed windows and reduced carbon concrete EPS insulated slab. Heating distribution is primarily via supply air heating and localised VRF to provide comfort/heating and cooling. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m^2_{fp}/yr. This scenario meets the embodied carbon LETI A target.
Zero operational carbon with embodied carbon reduced - specification 2	Specification 2 focuses on reducing embodied carbon and is reflective of specification 1 but with the following changes: the glulam and CLT superstructure is replaced with a concrete frame and composite steel and concrete deck. The insulation in the external walls are replaced for mineral wool and gypsum plasterboard is used instead of clayboard. uPVC windows. This scenario meets the embodied carbon LETI B target.
Existing building	This scenario is a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, double glazed doors and windows, a gas boiler, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Triple glazed windows, an air source heat pump is also added alongside PVs on the roof and MVHR ventilation.

4.7 Archetype 4 - Warehouse archetype



4.7.1 A warehouse building with offices over two stories was modelled against 4 different energy scenarios. Two different use variants were also explored for this archetype - a storage facility and a data centre. As well as investigating a retrofit option, against an existing building baseline. These scenarios have then been incorporated into the capital cost model to determine fabric, services, PV and overall cost for the specifications. High level details of the scenarios assessed can be found in the table to the right:

Scenario	Details
Part L 2021	Compliant with current Part L 2021 standard, this option utilises suspended heaters and gas in the warehouse area with domestic gas boiler in the offices (5nr 12 kW) one per block). Materials include: steel frame with a reinforced concrete slab and EPS insulation, composite steel and concrete decks, uPVC double glazed windows, steel stud internal walls, gypsum plasterboard internally, external walls and roof are made from aluminium SIPs panels with metal cladding and roof finish. A PV array equivalent in size to 40% of the footprint is included.
Future Buildings Standard (FBS)	This standard this utilises suspended heaters and gas in the warehouse area with domestic gas boiler in the offices (5nr 12 kW) one per block), an improved fabric performance against Part L 2021 and no PV provision.
Zero operational carbon	This standard utilises a VRF system and distribution via supply air heating. The localised VRF provides comfort/heating and cooling. The materials are the same as Part L but with higher levels of insulation and uPVC triple glazing. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m$^{2}_{fp}$/yr.
Zero operational carbon with embodied carbon reduced - specification 1	This standard utilises a VRF system and distribution via supply air heating. The localised VRF provides comfort/heating and cooling. Specification 1 has the same fabric performance of the zero operational carbon but reduces the embodied carbon by replacing certain materials. Materials include: glulam and cross laminated timber (CLT) superstructure, timber frame external walls with hemp lime block insulation and timber cladding, timber stud internal walls, clayboard on all internal walls, timber triple glazed windows and reduced carbon concrete EPS insulated slab. Two scenarios have been explored for PV allocation, one for to achieve an energy generation level that balances demand and alternatively to maximise energy generation by installing a PV array of 120 kWh2/m$^{2}_{fp}$/yr. This scenario meets the embodied carbon LETI A target.
Zero operational carbon with embodied carbon reduced - specification 2	Specification 2 focuses on reducing embodied carbon and is reflective of specification 1 but with the following changes: the glulam and CLT superstructure is replaced with a steel frame and composite steel and concrete deck. The external walls and roof are made from aluminium SIPs panels, as outlined in the Part L spec and gypsum plasterboard is used instead of clayboard. uPVC windows. This scenario meets the embodied carbon LETI A target.
Existing building	This scenario is a baseline for the retrofit scenario. It involves no insulation in the floors, minimal insulation in the roof and walls, double glazed doors and windows, a gas boiler, natural ventilation, drafty and no PVs on the roof.
Retrofit	This retrofit option involves improving the insulation in the walls, floors, and roof, as well as installing membranes and repairs to reduce draft. Windows are triple glazed. An air source heat pump is also added alongside PVs on the roof and natural ventilation with MVHR.

5 Results and analysis

5.1.1 Each building[25] selected as an archetype was energy modelled to establish the baselines of performance and what specifications would be required to achieve the proposed policy targets. The energy performance variants are as follows:

1. Existing – the energy performance of typical buildings already built.
2. Part L – current building regulations
3. Future Buildings/Homes Standard – proposed building regulations
4. Retrofit of existing building – LETI best practice retrofit
5. Zero operational energy – proposed joint local plan policy targets
6. Reduced embodied carbon – proposed joint local plan policy targets

5.1.2 What follows is a high-level analysis of all the archetypes pulling out high level trends with a focus on policy relevance. This includes:

- Space Heating Demand
- Energy Use Intensity
- Photovoltaic Sizing
- Net zero operational energy
- Embodied Carbon
- Impact on architectural design

5.1.3 An archetype-by-archetype analysis is included in the technical appendix but omitted from this section to avoid complexity.

5.1.4 It is worth noting that on the graphs within this section, Archetypes A, B and C (the detached, semi-detached and terrace) are referred to as 'Houses' because their performance is very similar. Where necessary the text describes findings that are unique to each specific archetype.

5.1.5 When reading the tables please note that the shade of the colour indicates performance: yellow indicates a near miss of the proposed policy target and the closer to red the worse the performance; all the green is proposed policy compliant, but the darker shade shows better performance.

5.2 Space Heating Demand (SHD)

5.2.1 Figure 14 below shows the combined space heat demand of the modelled archetypes at the baselines and policy targets described in section 3. The space heating demand shows the efficiency of the building's combined walls, floors, roofs and glazing. The policy targets of 15kWhr/m^2 for new developments and 50kWhr/m^2 for retrofits are shown. Where a bar is below the target line, the SHD policy target has been achieved.

5.2.2 The existing buildings energy efficiencies are higher, often considerably so, than current building regulations. This shows the improvement of regulation over time.

5.2.3 Current building regulations Part L and the Future Homes Standard archetypes modelled are significantly over the 15kWhr/m^2/yr space heating demand (SHD) target and therefore non-compliant with the proposed policy targets. All the net zero operational energy and reduced embodied carbon scenarios are below the proposed targets and show the policy is technically feasible.

5.2.4 Of note is that the insulation values of the walls, floors and roofs are the same in the Future Homes Standard as the 'net zero' scenarios. The step change in performance in the net zero scenarios is due primarily to improved air tightness and mechanical ventilation with heat recovery rather than the thermal performance of the building. The policy is non-specific on airtightness and ventilation systems, but it is unlikely that the policy targets will be achieved without these measures.

5.2.5 There is no difference in the space heating demand of the reduced embodied carbon scenario and the net zero operational energy scenario. This is because the insulation and air tightness are the same but achieved with different materials. For example, the home is timber frame with wood rather than brick and concrete block.

5.2.6 The retrofits perform better than current and emerging building regulations.

Domestic

5.2.7 All tested archetypes are within policy targets. Although simpler forms will be incentivised by the proposed policy the study does not indicate that architectural design options will be unduly curtailed.

5.2.8 An example of this is the detached which was expected to be the worst performing because it has most complexity, bay windows and dormers, and more external walls and roofs (dormers, bay and porch) to lose heat through. Despite having identical insulation and air tightness to the terrace and semi-detached, the added surface area increases the heating demand. However, being three storeys, this assists the detached performance due to better form factor. So, if planning policy requires dormers, bay windows or similar for a street scene this proposed policy will be compatible.

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[25] An explanation of the selection rationale is given in the technical appendix.

Space heating demand kWh/m²/yr

	Detached	Semi	Terrace	Flat
Existing building	126	120	100	115
Part L	82	78	65	75
Future homes standard	60	57	48	70
Retrofit	47	45	38	17
NZOC standard EC	13	11	7	11
NZOC with reduced EC	13	11	7	11

- Not policy compliant - worst performance
- Not policy compliant (greater than 15)
- Best practice retrofit - (around 50)
- Policy compliant (less than 15)
- Policy compliant - best perfomance

Table showing Space Heating Demand[26]

5.2.9 The flat is low rise with four units over two stories. This accounts for the equivalent performance with the houses. A higher unit would achieve the proposed policy with even greater ease[27] and reduced costs.

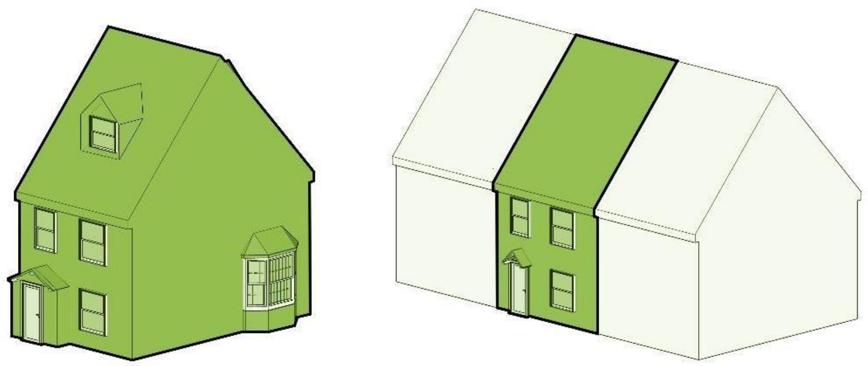

Figure 12. Comparison of form and complexity of housing archetypes

Non-Domestic

5.2.10 The effect of architectural form can be observed through the modelling. Firstly, in comparison with the domestic archetype: the better form factors of the non-domestic archetypes make the space heating target easier by having less building envelope to lose heat from. Secondly by comparing the retail unit with the office block, both were modelled with the same insulation values and airtightness. But very different forms result in a higher space heating demand by the retail unit. The retail unit has far more roof, wall and floor area for the floor area. In comparison the office has a very compact form of several floors. Because of this, the policy may encourage more efficient building forms, but as shown does not preclude with less efficient forms (thus offering flexibility for instances where form may be somewhat constrained by site shape or surroundings).

Space heating demand kWh/m²/yr

	Retail	School	Office	Warehouse
Existing building	324	171	92	177
Part L	82	73	52	51
Future Building Standard	50	58	45	35
Retrofit	23	16	5	8
NZOC standard EC	10	8	5	7
NZOC with reduced EC	10	8	5	7

- Not policy compliant - worst performance
- Not policy compliant (greater than 15)
- Best practice retrofit - (around 50)
- Policy compliant (less than 15)
- Policy compliant - best perfomance

Table showing Space Heating Demand

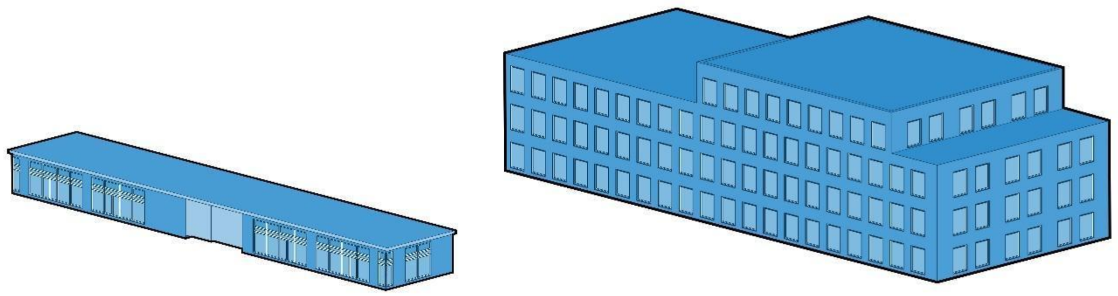

Figure 13. Comparison of form between the single storey retail and the multistorey office

[26] Where the colours differ in tone it indicates better or worse performance in excess of policy. E.g. yellow just misses compliance, red is the worst performance and orange the mid-point; a darker green a better performing zero carbon building.

[27] This is because the form-factor of the building improves. Less building area to lose heat through and money required to build.

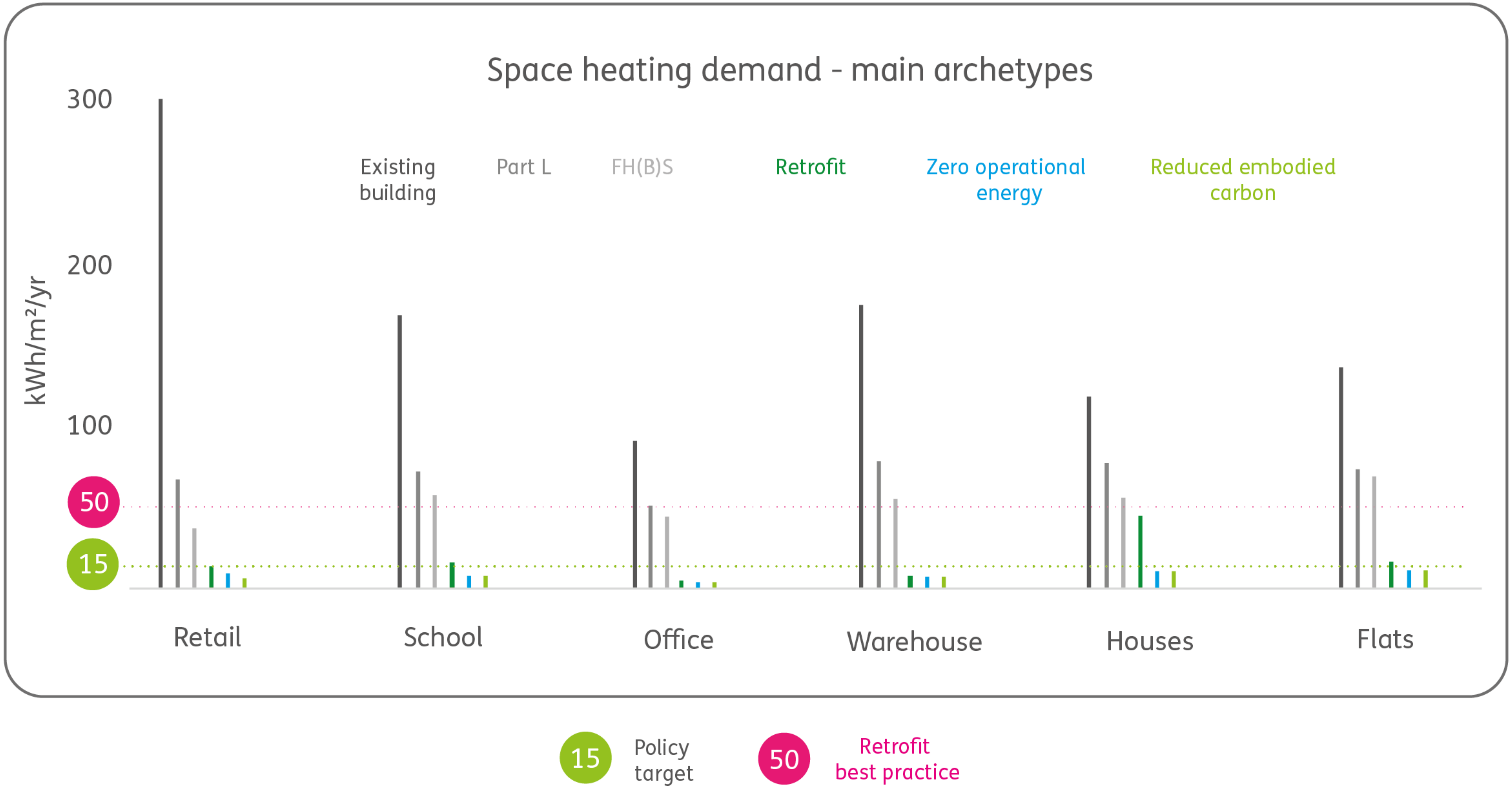

Figure 14. Space heating demand graph for domestic and non-domestic archetypes

5.3 Energy Use Intensity (EUI)

5.3.1 The comparison of the energy use intensity (EUI) allows for a more complete analysis of the whole energy use of the building than the space heating demand. This section shows the results for each of the archetypes. Figures 15, 16 and 17 show the EUI of the archetypes and the proposed policy targets:

Archetype	Residential	Retail	School	Office	Warehouse	Other
Energy use intensity - Total (kWh/m²/yr)	35	35	55	55	35	Justified in energy statement
Energy use intensity - Regulated (kWh/m²/yr)[28]	N/A	30	30	30	30	40

Figure 15 highlights the total EUI between the varying levels of performance from the baselines to zero operational energy. Figure 16 examines the role of unregulated EUI and the use of the building.

Domestic

Energy use intensity kWh/m²/yr

	Detached	Semi	Terrace	Flat
Existing building	138	153	128	159
Part L	97	108	90	96
Future homes standard	62	69	58	48
Retrofit	52	58	48	35
NZOC standard EC	30	32	29	30
NZOC with reduced EC	30	32	29	30

- Not policy compliant (worst performance)
- Not policy compliant (greater than 35)
- Best practice retrofit (around 50 to 60)
- Policy compliant (less than 35)
- Policy compliant (best perfomance)

Table showing Energy Use Intensity

Non-Domestic

Energy use intensity kWh/m²/yr

	Retail	School	Office	Warehouse
Existing building	360	203	131	213
Part L	109	136	96	83
Future building standard	42	59	57	55
Retrofit	33	44	47	28
NZOC standard EC	31	41	46	27
NZOC with reduced EC	29	41	46	27

- Not policy compliant (worst performance)
- Not policy compliant EUI
- Best practice retrofit (around 50 to 60)
- Policy compliant EUI
- Policy compliant (best perfomance)

Table showing Energy Use Intensity

5.3.2 Figure 15 shows that the current Part L scenario exceeds the proposed EUI targets considerably across all archetypes, with the emerging Future Homes Standards exceeding the target by a lesser extent. Whereas all the zero operational energy scenarios are comfortably within the policy targets. This indicates no issues of technical feasibility of the targets.

5.3.3 The retrofit detached and semi-detached archetype doesn't quite achieve the advisory LETI best practice 50kWhr/m²/yr. As retrofit performance targets are not included within the policy recommendation this does not present a problem of policy feasibility, but it does highlight the challenge of high performing retrofits.

5.3.4 Figure 16 shows the EUI per archetype but with two additions. Firstly, a split of regulated and unregulated EUI is shown. The orange shows the unregulated EUI and indicates what is currently omitted from building regulations. For existing buildings and Part L unregulated energy is a smaller proportion of the total EUI, but as the building fabric improves in the zero carbon scenarios it becomes proportionally more significant. As can be seen on the school, office and flats, the FH(B)S would meet the EUI target if the unregulated was not included in the predictive energy modelling. This supports the

[28] It is accepted that in some circumstances, unregulated energy loads for the specific use of a non-residential building may result in a total energy use that exceeds the limits set out above. In these cases, applicants are required to demonstrate that regulated energy is limited to 30 kWh/m2/year. Unregulated energy loads must be justified in energy statement. Other building types not listed are required to demonstrate that regulated energy is limited to 40 kWh/m2/year. Unregulated energy loads must be justified in energy statement.

policy recommendations to use a suitably rigorous energy modelling methodology which includes a reasonable estimate of unregulated energy use.

5.3.5 The second addition to Figure 16 is two 'use variants'. This allowed the retail and warehouse archetypes to model two different uses within the same building to assess the effect of unregulated loads. The retail was changed from a generic use with low unregulated energy use, for example a shoe shop, into a convenience grocer with significant energy use for chilled storage and display. The warehouse was changed from simple storage to an energy hungry data centre[29]. The results very clearly show that high unregulated loads specific to non-domestic use may exceed the policy targets. This is shown separately on Figure 17, which shows how the unregulated energy can far exceed regulated energy in certain uses.

5.3.6 To prevent the proposed policy from precluding desirable developments[30] with high unregulated loads, the policy proposals provide flexibility set out above, and in tasks 1 and 2. This flexibility (while maintaining good ambitions for carbon reduction) is delivered through proposing a regulated-only energy use intensity target for non-residential use types that are anticipated not to be able to hit the total EUI targets (and any proposed buildings of archetypes that have not been modelled here). The proposed regulated-only energy target of 30kWhr/m^2/yr is supported as all the archetypes, of various shapes and scales, all beneath achieve the proposed target.

[29] Data centres are essential infrastructure for the internet and contain multiple servers.

[30] Research and development labs are a good example which have strong economic importance for the districts.

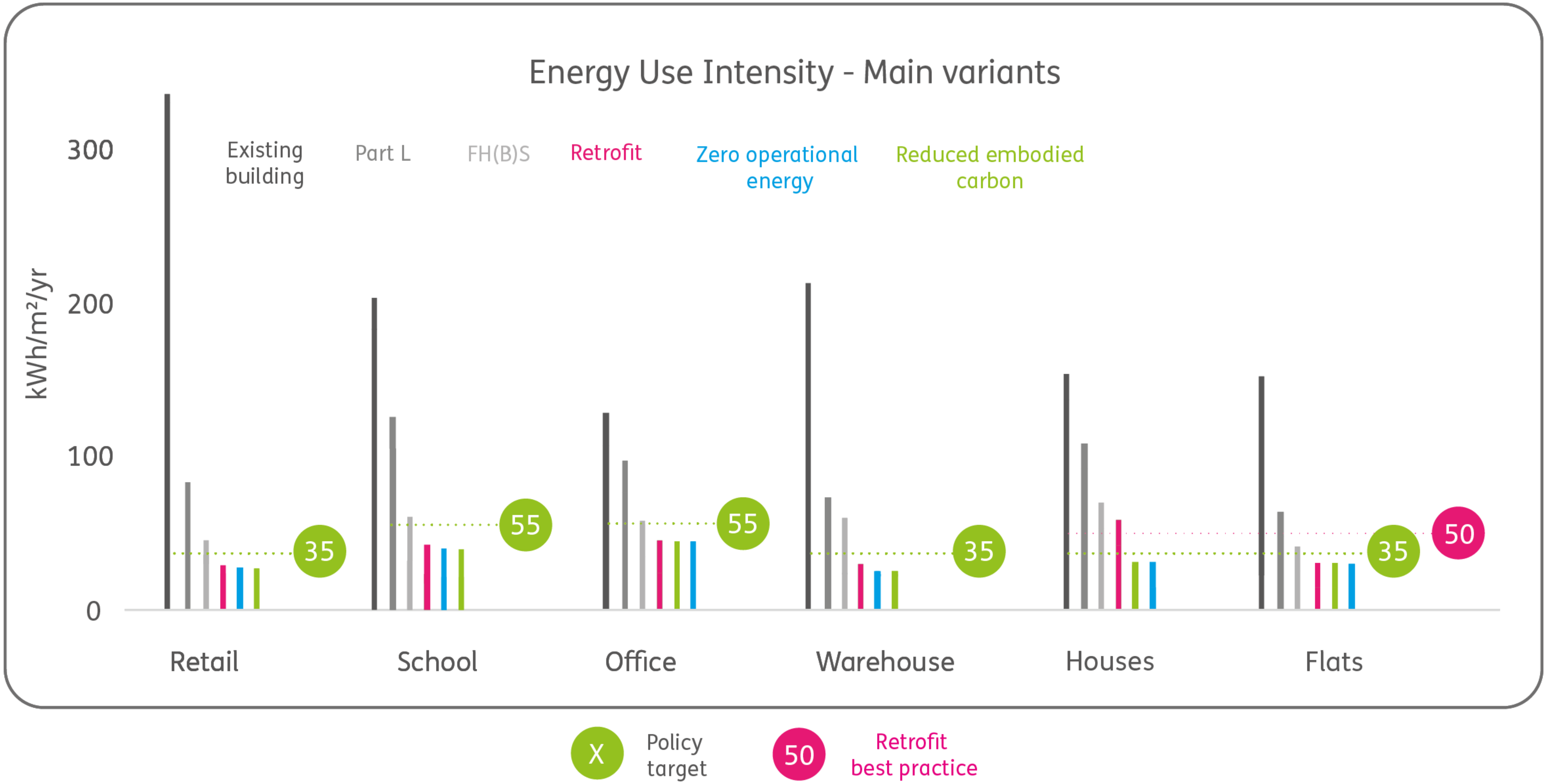

Figure 15. Energy use intensity graph for domestic and non-domestic archetype

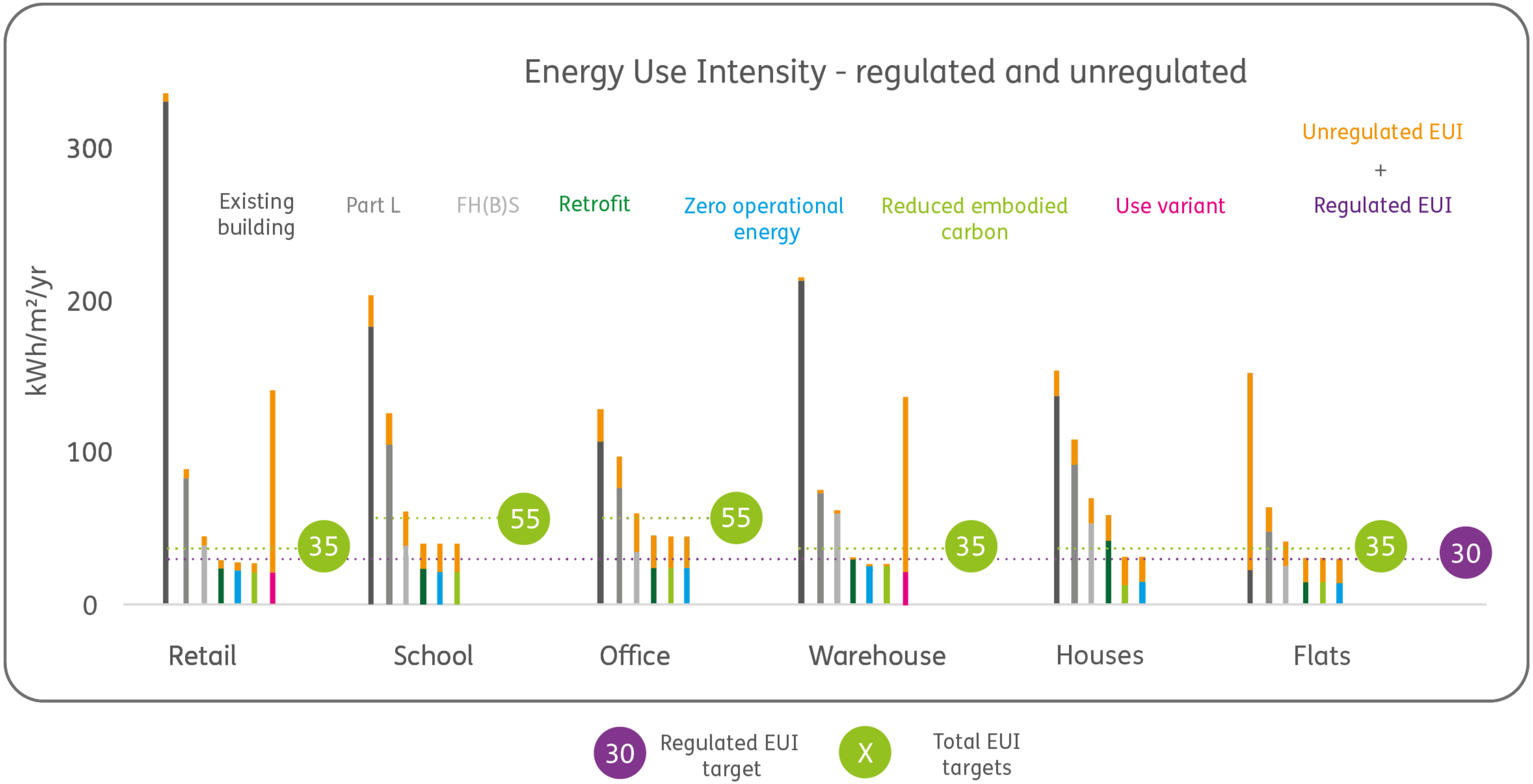

Figure 16. Energy use intensity graph showing regulated and unregulated energy for domestic and non-domestic archetypes

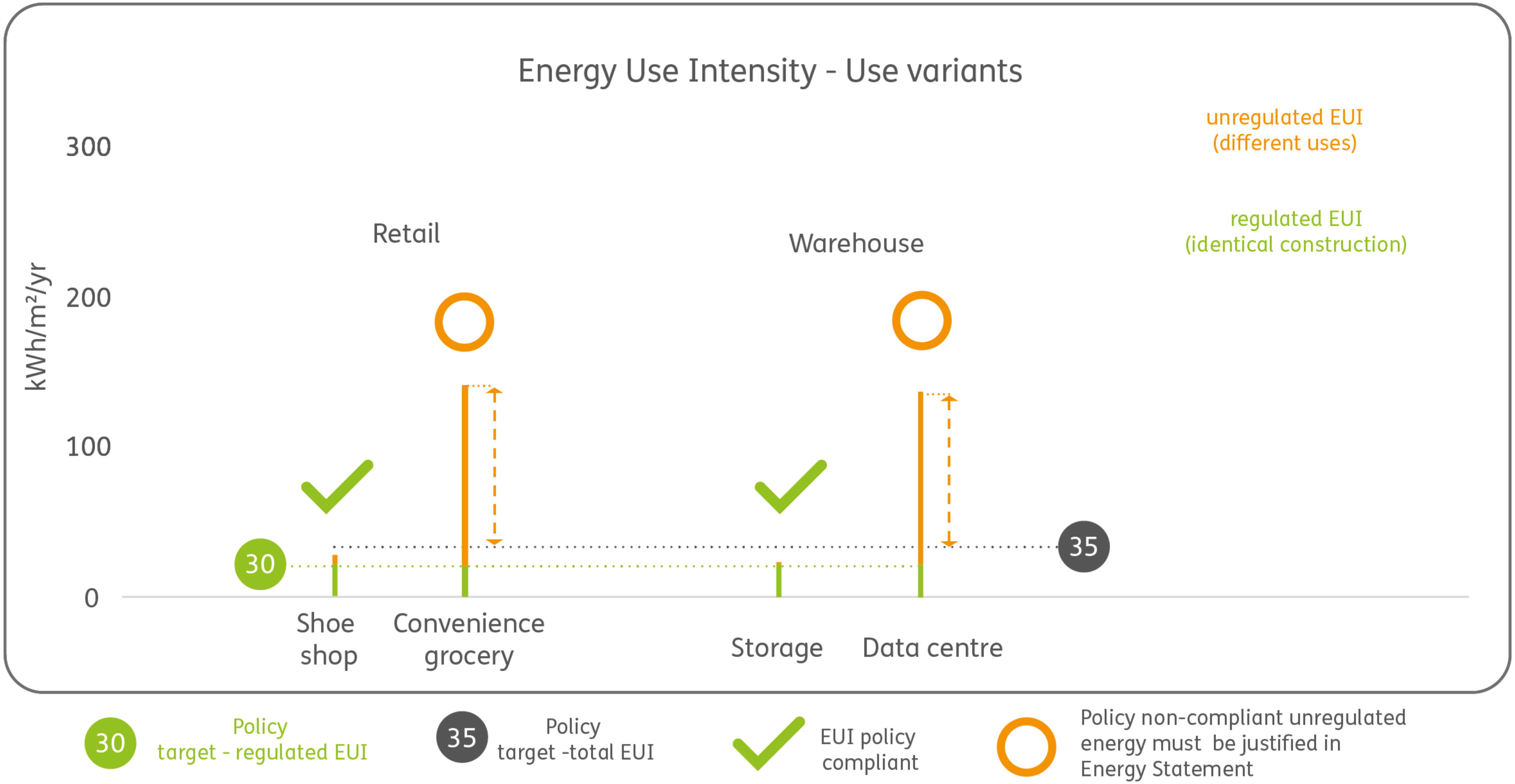

Figure 17. Energy Use Intensity graph showing implication of alternative uses for retail and warehouse archetypes.

5.4 Photovoltaic sizing

5.4.1 To achieve net zero operational energy, the supply of on-site energy must match the energy demand of the building. As described above and in Tasks 1 and 2 there are reasonable situations where the energy demand of the building cannot reasonably be met by onsite supply. Therefore, the proposed minimum photovoltaic target of 120 kWhr/m2/yr was applied where net zero operational energy was not possible. Only the office was unable to achieve net zero operational energy with the 120 kWhr/m2/yrfp ; all other archetypes met this target.31

5.4.2 Please note a critical difference in the units between the EUI and PV generation. Both are kWhr/m²/yr but the m² for the EUI is for the floor area, whereas the m² for the PV is for the projected footprint of the building. As the number of storeys increase the floor area will increase but the footprint will remain constant. Therefore, even if the two values match this does not mean an energy balance has been achieved. Please see section 5 for the energy balance which assess that whole building areas rather than the meter squared.

Domestic

Photovoltaic generation kWhr/m²/yr (projected footprint)

	Detached	Semi	Terrace	Flat
Existing building	0	0	0	0
Part L	72	72	72	70
Future homes standard	0	0	0	0
Retrofit	84	98	92	56
NZOC standard EC	66	55	48	54
NZOC with reduced EC	66	55	48	54
Optimised PV	84	122	122	120

- Not policy compliant (worst performance)
- Not policy compliant (demand greater then PV generation)
- Policy compliant (PV generation equals demand)
- Best practice retrofit (blanced or maximised)
- Optimised PV (export potenital)

Table showing domestic PV generation.

Non-domestic

Photovoltaic generation kWhr/m²/yr (projected footprint)

	Retail	School	Office	Warehouse
Existing building	0	0	0	0
Part L	73	60	75	79
Future building standard	0	0	0	0
Retrofit	21	66	120	36
NZOC standard EC	20	63	120	33
NZOC with reduced EC	20	63	120	33
Optimised PV	120	120	120	120

- Not policy compliant (worst performance)
- Not policy compliant (demand greater then PV generation)
- Policy compliant (PV generation equals demand)
- Best practice retrofit (balance or maximised)
- Policy compliant (PV target met but not balanced)
- Optimised PV (export potenital)

Table showing non-domestic PV generation.

5.4.3 As the Notional Building specification shown in section 2.1 part L requires 40% of the building footprint, but the emerging FH(B)S does not require any PV hence the zeros on this row. The office shows that it is possible to optimise the PV on the roof in line with the proposed policy, but not achieve a balance as discussed in section 4.5.25

[31] Excluding the data centre and convenience grocery 'use variants'.

5.5 Net zero operational energy

5.5.1 For the building to achieve net zero operational energy performance, the energy demand of the building (annual EUI multiplied by the total meters squared floor space) needs to be balanced with the on-site energy production. This means combining the results of the previous two sections: demand EUI; and photovoltaic generation. The graphs and tables below show this for each archetype and their respective scenarios. Key to note in the figures below is that the supply and demand are the total for the building and not divided by the metre squared of floor area. Figures rounded to the closest 1.1tn of carbon.

Domestic

5.5.2 The graphs in the following section with associated description analyse the finding on an archetype-by-archetype basis. The below chart shows a succinct overview that proposed policy compliant domestic variants all achieve net zero operational carbon[32]. Current Part L and the emerging FH(B)S do not.

Net zero operational carbon Tonnes CO_2/yr

	Detached	Semi	Terrace	Flat
Existing building	3.5	3	2.5	30
Part L	1.1	1	0.9	10
Future homes standard	1.2	1.1	1	9
Retrofit	0.3	0	0	0
NZOC standard EC	0	0	0	0
NZOC with reduced EC	0	0	0	0

- Not policy compliant (worst performance)
- Not policy compliant (annual carbon emmions)
- Best practice retrofit
- Policy compliant (**no** annual carbon emmisions)

Table showing net zero operational carbon in tonnes.

[32] The total energy demand has been converted to tonnes of carbon by simply multiplying the total energy demand by the carbon factors in SAP 10 and subtracting the carbon saved from the PV supply.

How to read the following graphs

5.5.3 Each graph contains the main variations for each archetype. Each variant has a pair of columns: the green is the total annual energy demand of the building. The second is the annual supply of energy from PV panels. The colours of the PV graph represent the respective policy of the variant: grey is Part L, yellow the proposed balance and blue the reasonable maximum PV generation. All figures are shown in MWhr/yr, note this is not per metre squared and represents the whole building area. As can be seen, the domestic are in tens of megawatt hours, and some of the large non-domestic archetypes are in the many hundreds of megawatt hours.

5.5.4 When the two columns are of equal height a net zero operational energy balance has been achieved. This is indicated by a green tick and achieves the primary aim of the proposed policy. In some cases, the energy demand is larger than the supply but still policy compliant, this is indicated by a blue circle. This is when the space heating demand, energy use intensity and PV generation targets have been met but a net zero energy balance achieved. The dashed orange box and arrow indicates the offsite energy required to offset the difference. Where the net zero energy balance and the SHD, EUI and PV are all missed the building is not policy compliant and indicated with a red cross.

5.5.5 There is no proposed retrofit policy, but as early sections best practice targets are indicated and marked with a magenta circle on these graphs.

5.5.6 Finally, a dashed yellow line indicates the reasonable maximum[33] of PV possible for the building. There is no policy proposed for a net positive energy export, but this potential is indicated by a dashed yellow box or a yellow arrow. As described in the whole life carbon section in the technical appendix this energy represents what could be used to offset the embodied carbon.

[33] The proposed policy of 120 kWhr/m^2/yr(fp) is used.

Archetype B

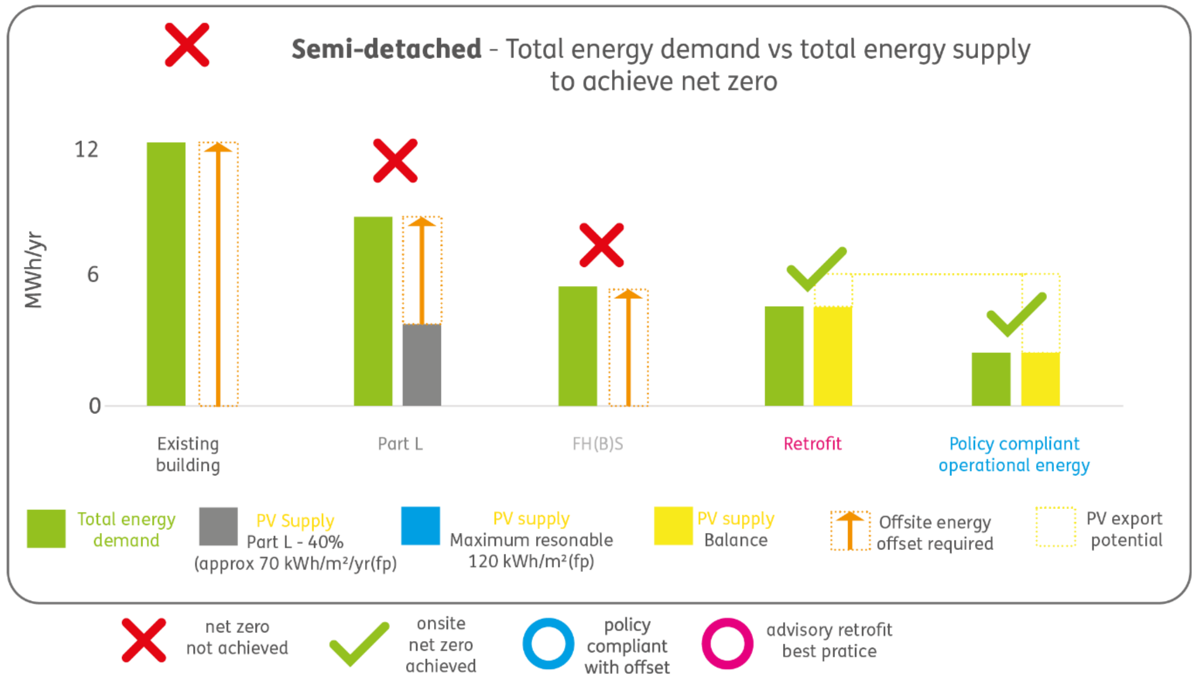

Figure 18. Graphing showing the energy balance of the semi-detached archetype variants

5.5.7 The semi-detached, archetype B, is spatial variant of A and C. The terrace (Archetype C) has two party walls instead of one but has an identical floor plan. The detached (Archetype A) has a third floor and various elaborations: internal porch, dormer, and bay windows. Figure 18 shows just the semi-detached and the main scenarios and Figure 19 the nuances between the spatial variants.

5.5.8 As expected, the existing building, built last century with an EPC C, is the worst performing. There is then a steady decrease in the total energy demand and the policy and associated performance increases. The FHS and Part L have a similar net negative balance but achieved in a different way, the FH(B)S has a lower energy demand as a result of a more efficient building. The Part L building is less efficient, but this is offset by on-site energy supply. Both do not meet the proposed net zero policy.

5.5.9 The net zero variant is compliant with some room to spare. The potential PV is around double the energy use. This is indicated with a dotted yellow line; it demonstrates how much addition PV could be generated on site that could be exported to the grid as in excess the homes energy needs. The balance between supply and demand allows for design flexibility[34] for future applicants governed by this policy. It is worth noting that reducing the demand first is better for the electricity grid than a higher demand met by more solar[35].

5.5.10 The retrofit best practice is achieved with a small net negative energy balance. Best practice retrofits tend to struggle to achieve net zero unless the highest targets [36]are met.

Archetypes A, B, C

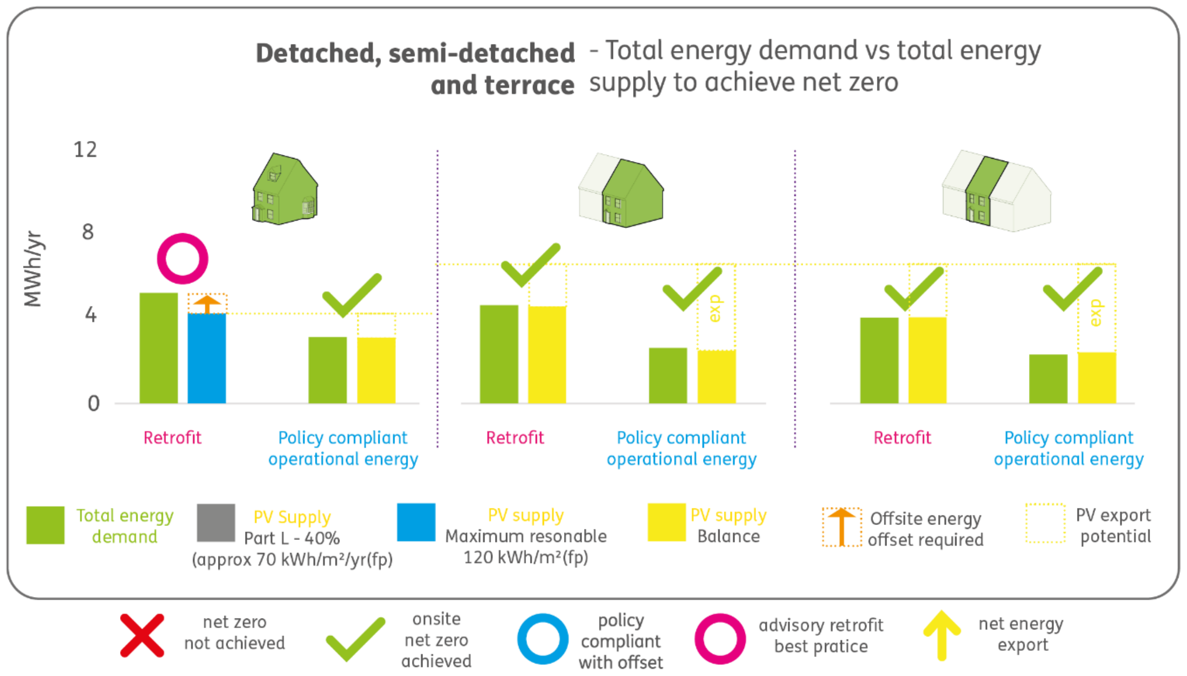

Figure 19. Graph showing the total energy demand vs total energy supply of the domestic archetypes.

5.5.11 Figure 19 shows the houses in three spatial variants at the net zero operational energy and best practice retrofit performance. All are proposed policy compliant but there is a nuanced performance between the three. The terrace performs best due to the lower heat loss area, with the semi-only a slightly higher energy demand due to the external gable wall. The detached in total terms is worse because it had both a bigger

[34] E.g., a more complex form could be used for architectural concepts which increase the demand energy, but this could be offset by a larger PV. Or this flexibility could be translated for further value engineering purposes to reduce costs.

[35] The demand energy demand of a building is often not aligned with energy supply. For example, a cold winter evening will have little sun but a higher heating demand. So, achieving carbon neutrality with lower demand and supply will out less pressure on the electricity grid.
[36] For example, a Passivhaus retrofit standard called Ener Hit has space heating demand of 25kWhr/m²/yr half that of the best practice proposed here.

floor area and more external walls. Furthermore, the addition of the dormer window reduces the roof space for PVs, so only just achieves an energy balance. Note the dashed yellow line is higher on the terrace and semi-detached because there is more roof area for potential PV installations.

5.5.12 The retrofit variants highlight this further with a higher total energy demand resulting from a less efficient fabric. The detached has the highest negative balance due to the higher energy demand and smaller PV generation potential.

Archetype D

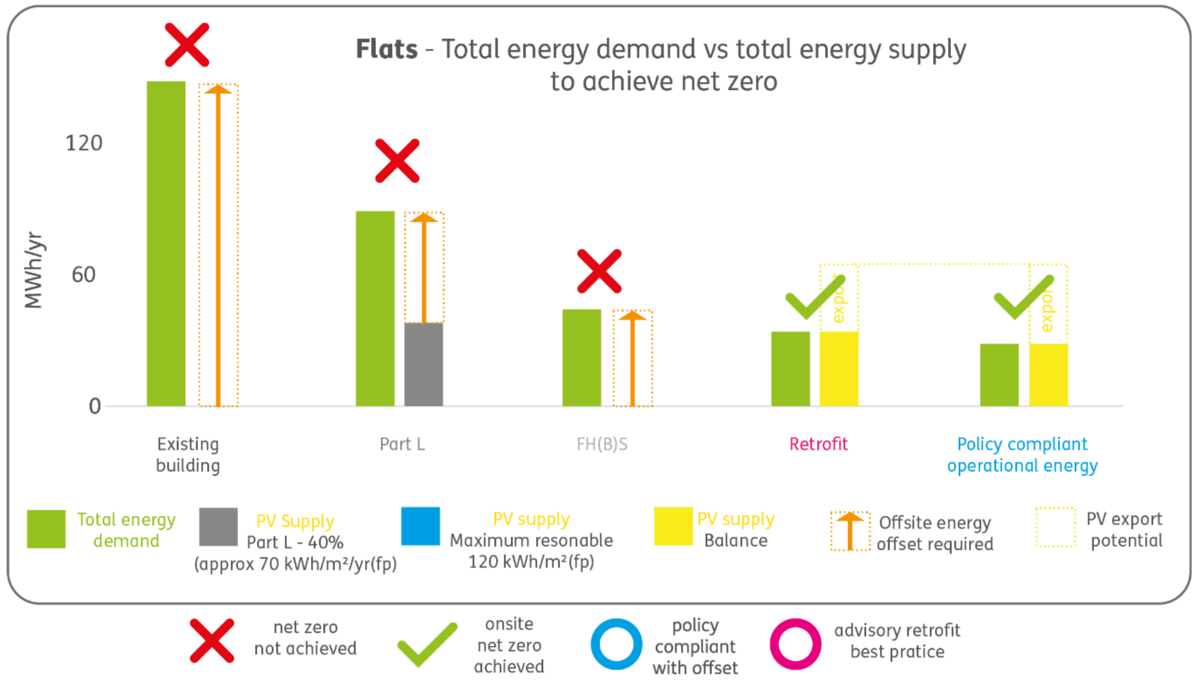

Figure 20. Graph showing the total energy demand vs total energy supply of the flat archetype.

5.5.13 Archetype D is a block of four flats, hence the greater total energy demand even if the relative performance with the houses is similar. Also note this is a low-rise block of flats so the improved form factor of a medium or high-rise block of flats is not observable. As described in the archetype selection, low rise or low medium rise flats are more likely to be built in the districts.

5.5.14 The results follow a trend seen across the study with the existing being the worst, the Part L and FH(B)S perform better but are not net zero energy. The policy compliant SHD and EUI easily achieve a net zero energy balance with around half of the roofs PV potential used. The export potential shows a supply around twice that of the demand.

This shows that the flats could be twice as high, four stories, and still achieve the proposed policy. Alternatively, this excess PV could be used for a mixed-use function on the ground floor as shown in archetype 1.

5.5.15 The retrofit performs almost as well as the net-zero new build and better than the future homes standard. This is because the approach, unlike for the houses, assumes the building is stripped back to the concrete fame super-structure and an entirely new, higher performing envelope construction.

Non-domestic

5.5.16 The summary chart below shows a similar storey to the domestic archetypes. In general, the increased physical scale results in a greater mass of carbon. The existing, part L and FH(B)S result in net carbon emissions in decreasing magnitudes. The outliers are the warehouse and retail archetypes, where the Part L variant outperforms the FH(B)S standard, the reason is discussed in the archetype selection.

5.5.17 All the proposed policy variants are shown to be compliant from the predictive energy modelling. The higher density office archetype, which is over three storeys, demonstrates the utility of the flexible policy proposals. Although net zero operational energy is not achieved it is proposed policy compliant through the building fabric efficiency and the on-site PV generation.

5.5.18 This is now discussed per archetype.

Net zero operational carbon Tonnes CO_2/yr

	Retail	School	Office	Warehouse
Existing building	9	109	137	199
Part L	1	46	76	8
Future building standard	2	18	38	33
Retrofit	0	0	3	0
NZOC standard EC	0	0	3	0
NZOC with reduced EC	0	0	3	0

- Not policy compliant (worst performance)
- Not policy compliant (annual carbon emmions)
- Best practice retrofit
- Policy compliant (**no** annual carbon emmisions)
- Policy compliant (**not** net zero but EUI and PV targets met)

Table showing net zero operational carbon in tonnes.

Archetype 1 - Retail

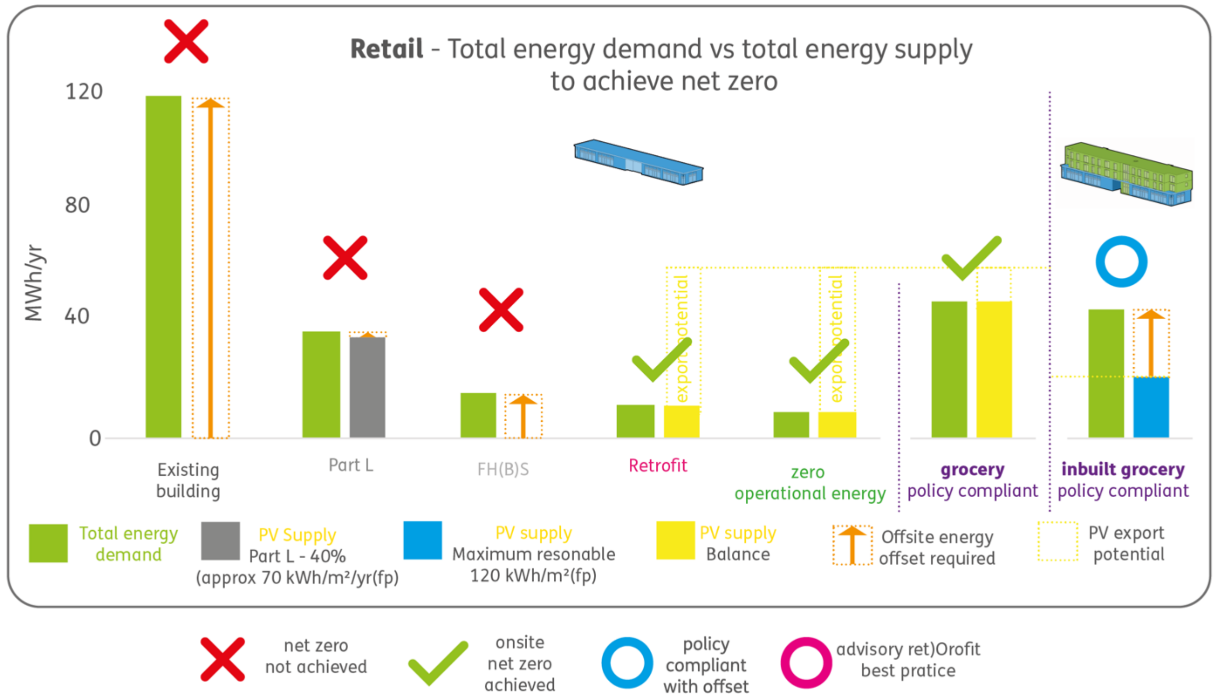

Figure 21. Graph showing the total energy demand vs total energy supply of the retail archetype.

5.5.19 The spatial (freestanding vs inbuilt) and use variants (shoe shop vs grocery) of this archetype provides useful insights. The first five columns are for generic retail (e.g., a shoe shop) as a freestanding building. The poor form factor results in very high energy use of the existing building mainly due to heat loss through a large number of leaky walls and large roof and floor.

5.5.20 The Part L, despite having a larger total energy demand, has a lower net zero energy balance due to the presence of PV required by Part L but absent in the FH(B)S. Because it is a single storey building the roof area is large as a proportion to the floor area. This PV nearly offsets the demand and nearly achieves net zero operational energy. This path to net zero operational energy differs from the policy proposal because it is achieved by a high PV supply balancing a building with non-optimised space heating and energy use intensity. Were this to be the in-built variant over three storeys, net zero would not be possible due to the reduction of available roof space.

5.5.21 The convenience grocery variant shows the significant effect of unregulated energy (see figure 17). The total demand is significantly higher due to the requirements of chilled storage and display. As a freestanding budling with large roof space available the higher demand can be met by a large PV generation. However, in the inbuilt variant, the four flats above reduce the available roof space by one third. As a result of the much-reduced PV generation, a larger amount of offsite offset is required. This inbuilt, grocery variant is still policy compliant despite the unregulated energy resulting in a non-policy compliant EUI, it meets the secondary 30kWhr/m2/yr regulated energy target.

5.5.22 This flexibility is prudent to ensure compatibility with spatial planning policy. Otherwise put, medium-to-high mixed-use developments with grocery stores beneath flats are desirable and should be made compatible with the proposed policy.

Archetype 2 - School

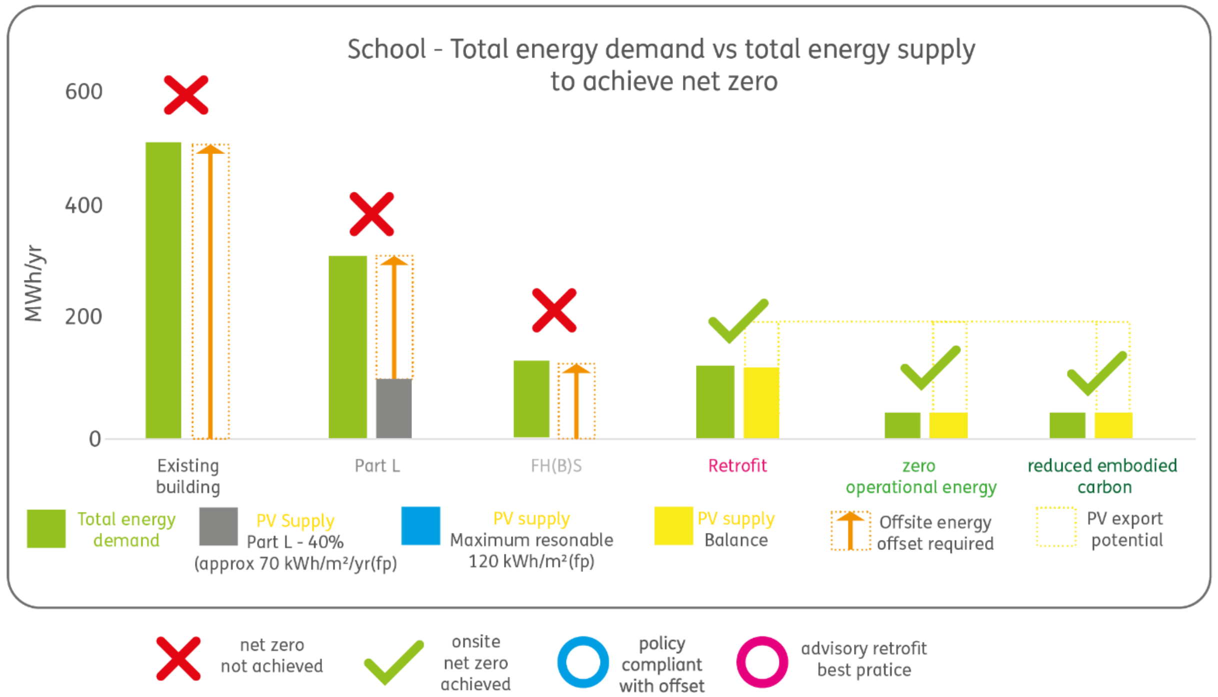

Figure 22. Graph showing the total energy demand vs total energy supply of the school archetype.

5.5.23 The general trend of energy reduction can be seen from existing buildings through current policy and proposed policy. Where the SHD and EUI targets are achieved the net zero operational carbon is easily met. The school is two storeys high so has ample space for PV so there is a PV potential many times greater than the demand.

5.5.24 A reduced embodied carbon option is shown to demonstrate that reducing the *embodied* carbon, whilst still meeting the EUI and SHD targets, has no effect on achieving net zero *operational* carbon.

Archetype 3 – Office

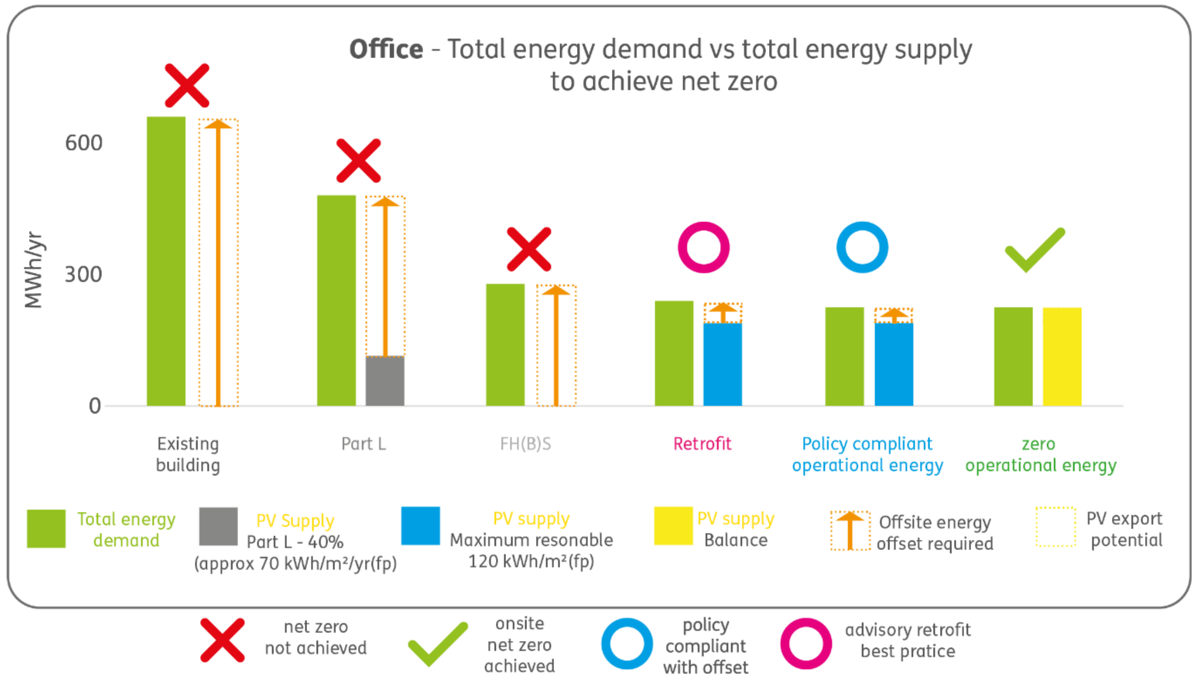

Figure 23. Graph showing the total energy demand vs total energy supply of the office archetype.

5.5.25 The office shows that a building may be policy compliant for the SHD, EUI and PV generation and still not achieve a zero energy balance without the need to offset. The reason is the height of the building. For every extra storey there is additional EUI demand from the additional floor area. However, no matter how many additional storeys, the roof area for PV generation remains the same. Beyond three storeys, like the office, the electricity generation from the roof does not supply enough energy even though it is policy compliant. The two districts do not contain significantly dense urban areas, if they did then it is likely more archetypes would be policy compliant but not zero carbon.

5.5.26 The offset on Figure 23 shows the small amount of acceptable offsite energy offset for buildings like the office archetype. This is particularly relevant for research and development, laboratories and similar which will be similar to the office archetype. The building form and regulated energy will be equivalent, but the unregulated energy loads significantly higher in the research / laboratories etc.

5.5.27 The column on the far right shows how an energy balance could be achieved by a small increase (around 5%[37]) to the PV installation. This shows how applicants could choose to make commercial decisions[38] to go beyond policy targets to mitigate offset costs.

Archetype 4 - Warehouse

5.5.28 The results are similar with the retail archetype. The large available roof area and ratio to floor area results in Part L nearly achieving a net zero operation energy balance. The net zero operational energy variant is policy compliant. As the PV potential is significant on warehouse roofs, they present an opportunity for offsite energy offsetting for other developments.

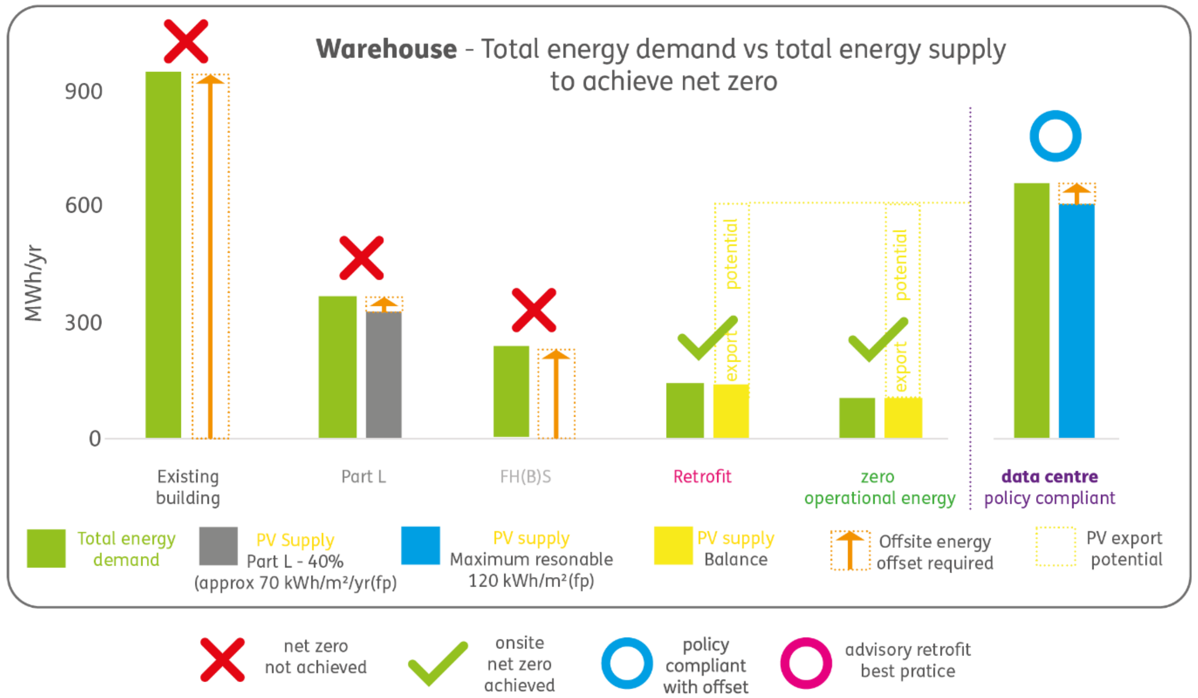

Figure 24. Graph showing the total energy demand vs total energy supply of the warehouse archetype.

5.5.29 Warehousing tends to have low energy use compared to other uses. However, the flexibility of the building, large affordable open space, makes them easily adaptable into other higher energy uses e.g., manufacture, light industry, data centres etc. To test this a data centre use was inserted into this archetype to understand the policy ramifications. The significant unregulated energy increase can be seen in figure 17. This can be further seen by comparing the zero operational energy variant with the data centre: the regulated performance is identical, but the unregulated use energy increases the total by a factor of around five. Even with a very large PV array (800kWp) a balance

[37] From 70% to 75%, or 120 to 131 kWh2/m$^2_{\text{projected footprint}}$/yr

[38] For example, it may be cheaper to slightly increase the size of PV array than the cost of the ongoing carbon offset costs.

cannot be achieved with some offsite offset. It should be noted that data centres are some of the highest energy uses and light industrial etc will likely be much lower.

5.5.30 This use variant shows, alongside the retail and office as research lab demonstrates how important the unregulated energy use is to achieving true net zero carbon. The policy contains the flexibility to keep these uses policy compliant, but the bespoke energy statements of each application should be scrutinised to ensure the unregulated energy is being reasonably minimised.

5.6 Embodied Carbon

5.6.1 The table below summarises the embodied carbon results relating to the LETI banding as outlined in the earlier 'Policy Targets' section (please refer to Figure 11). This is shown using the same colours, where light orange represents a LETI C (2020) target, yellow is LETI B and the light green is LETI A (2030). The embodied carbon for each archetype has been calculated from the amount of the materials and equipment within the variants (see Section 4 for further details of the specifications). The results show an increase in embodied carbon across all archetypes from Part L to Net Zero Operational Energy due to the higher amounts of insulation and low carbon technology included within these specifications. The LETI C (2020) target is easily achieved for these 'business as usual' variants[39] and indicates that we can be more ambitious in the targets we set in terms of embodied carbon. Two further variants have been tested, one that achieves the lowest embodied carbon possible (specification 1) and the second that lowers the embodied carbon but has less of a cost impact (specification 2). For further details on the cost uplift of these tested scenarios please see the Task 4 report.

Key for table opposite

LETI D	Orange
LETI C	Light orange
LETI B	Yellow
LETI A	Light green
LETI A+	Green
LETI A++	Dark green

Variant	Part L 2021	Net zero operational energy (NZE)	NZE with reduced embodied carbon specification 1	NZE with reduced embodied carbon specification 2	Best practice retrofit
Houses	599	606	223	237	142
Low rise flats	412	492	224	362	95
Retail	331	340	164	245	74
Primary school	419	514	292	358	138
Offices	500	543	231	428	80
Warehouse	374	415	261	377	114

Table showing embodied carbon results for each archetype and variant.

Domestic archetypes

5.6.2 For archetypes A, B and C (shown in the table as 'semi-detached') both low embodied carbon scenarios (specification 1 and 2) significantly reduce upfront emissions and can easily achieve LETI band A, whilst having a cost uplift likely to be viable in most scenarios (please refer to Task 4 for further details). This is due to the industry for housebuilding being set up to use timber frame construction in terms of skills, regulations etc., meaning switching from higher embodied carbon materials like blockwork is possible in the current market. The flats are constructed differently to the other domestic archetypes: they use a concrete frame and different regulations apply due to the overall height of the building. Therefore, achieving a LETI A in flats means a significantly higher cost and so LETI B is the recommended target.

Non-domestic archetypes

5.6.3 The remaining archetypes similarly cannot achieve LETI A in the current market without a significant cost uplift. This is because reducing the embodied carbon in these archetypes means using materials and skills that are not currently industry standard e.g., cross-laminated timber, bio-based alternatives to plasterboard etc. However, it is likely that these materials and methods will become more commonplace in the future and so perhaps in 5-10 years' time they will become more affordable. By contrast, the reduced embodied carbon specification 2 scenario (aligning with a minimum of LETI B across all archetypes) has also been explored in the separate 'Task 4' costs report for which there are cost uplifts of between 7-10% depending on the non-domestic archetype.

[39] The Part L, Future Homes (Building) Standard and Net Zero Operational Carbon

5.6.4 For these reasons (and subject to viability testing in the separate viability assessment being commissioned for the Plan), it is recommended that LETI B is set as the target for now with this increasing to LETI band A from 2030. We expect that LETI A will become more achievable over time as lower embodied carbon materials become more available and a 'industry standard'. We recommend taking a hybrid approach, where some bio-based materials are used within a steel or concrete frame, as this minimises changes to industry standard construction.

Retrofit

5.6.5 Across all archetypes it is apparent that retrofits have the lowest embodied carbon. This is because the existing materials are not included in the upfront emissions, only the insulation and new services. All archetypes achieve at least a LETI A+ and demonstrate that if embodied carbon is a priority in terms of policy, then a retrofit-first approach should be prioritised.

Other considerations

5.6.6 It is worth noting which materials and elements of the building have the biggest effect on embodied carbon. Steel has a significant impact; this is most apparent in the archetypes where a steel frame, steel studwork and metal cladding are used. Within the LETI B variant, we swapped all internal steel studwork for timber and changed the cladding for a biobased material, which drastically reduced emissions. This also highlights that the internal walls within the non-domestic archetypes account for a large proportion of materials used, and therefore swapping steel for timber is an easy way to meet the embodied carbon target.

5.7 Design constraints

5.7.1 Alongside meeting energy targets, an important question is to what extent will the architectural design be affected by the policy requirement to meet specific space heat and EUI targets. There are several criteria to judge this against:

- Limitation in form factor/complexity
- Reduced material palette from embodied carbon materials
- Constraints to roof plan to allow for PV

5.7.2 The stand-alone retail and the detached house have the worst form-factors. Although the detached has the worst performing SHD and EUI of the houses it still achieves the proposed policy targets. Therefore, the proposed policy does not preclude dormers, bays, porches etc. For the retail, the poor form factor also provides a good floor area to roof space ratio, allowing a greater amount of PV, so maintaining net zero feasibility.

5.7.3 At the 'reduced embodied carbon' (LETI A) levels of performance, there is sufficient flexibility to use high embodied carbon cladding materials, such as brick, whilst achieving the overarching embodied carbon targets through improvements made elsewhere in the building.

5.7.4 The policy will incentivise roofs to be designed to meet the PV supply needs of the proposed policy.

5.7.5 In summary, the policy will and should affect architectural design. If it did not then the policy would only affect performance specifications, and not incentivise good energy efficient architectural design. However, if an energy optimised form is not chosen, there is sufficient flexibility for architects to instead meet the targets by increasing the performance specification of the building and on-site renewable energy generation.

5.8 Retrofit

5.8.1 The subsequent discussion delves into the outcomes of the retrofit study, providing insights contextualised within the districts of South Oxfordshire's and Vale of the White Horse's existing buildings. It's important to note that there are currently no proposed specific targets for retrofit policy as a result of this. This is because, although this modelling has shown that it is feasible in a representative 'typical' existing building of each archetype to retrofit to a good performance. In reality, there is dramatic variation in types and ages of existing building and therefore it cannot be assumed that it would be feasible to hit those same energy targets in every existing building in the district.

5.8.2 Retaining an existing building's foundations, substructure and above ground construction can lead to a substantial reduction in embodied carbon. Retrofitting a building can therefore be an opportunity in reducing whole life carbon when compared to a new building.

5.8.3 The retrofit standard airtightness target is better than the Future Homes and Future Buildings standards and incorporates MVHR. This results in a significant reduction in Space Heating Demand, as less heat is being lost through infiltration and controlled ventilation. By reducing the Space Heating Demand, Net Zero Carbon is possible in some archetypes, and in all cases performs better than the Future Homes and Building Standard. The domestic scale archetypes are generally more difficult to achieve net zero operational energy when compared to the non-domestic archetypes. This is partly due to the poorer form factor for the domestic, which leads to a required better u-value to meet the same performance. The non-domestic archetypes are also easier to retrofit, due to the construction type – the framed construction can be retained, and new fabric installed with a minimum of thermal bridges, whilst domestic buildings are often load-bearing masonry or stick frame construction, which can be more problematic and disruptive to retrofit.

6 Conclusions

6.1.1 The study demonstrates that the proposed policy is technically feasible for all the archetypes modelled. It has shown that reasonable flexibility in the proposed policy will allow for compliant buildings even if they do not achieve net zero operational energy. This is essential to prevent unintended consequences such as discouraging denser developments[40] or precluding research labs[41] and manufacturing developments which legitimately have larger unregulated energy requirements.

6.1.2 Although regulated energy is generally the largest proportion, the analysis shows that the inclusion of unregulated energy is essential (in most archetypes) to achieve holistic net zero targets.

6.1.3 Having embodied carbon as part of the proposed policy is essential to close a major source of carbon emissions associated with new developments.

6.1.4 The policy will incentivise less complicated and more compact architectural forms, but the study has shown that more complex designs and worse form factors can still achieve compliance. This is critical to ensure the policy allows for quality, spatial and material architecture.

6.1.5 Task 4 of this evidence base has tested archetype scenario specifications for cost implications that can be fed into the separate viability study commissioned by the districts.

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[40] Denser development is desirable for other climate-related reasons including that they can help to reduce car use (by reducing urban sprawl and therefore reducing distance between destinations) and improve land use efficiency (thus keeping more land available for essential functions like food production and green space for biodiversity, sustainable drainage and/or carbon sequestration.

[41] Early on during this task, it was queried whether such high-energy-intensity developments should be welcomed when they may place a disproportionate burden on the districts in terms of carbon emissions and/or energy demand. However, research facilities are desirable not only for economic and social reasons but also potentially for climate reasons in that scientific and technological innovation is a necessary part of the country's carbon reduction trajectory – for example research into new forms of clean energy generation, carbon capture, smart energy systems, biotechnology and many other areas.

7 Technical appendix

7.1 Performance specifications

Low rise – Archetypes A, B and C

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit - Proposed
Walls	0.18	0.15	0.15	0.12	0.6	0.2
Floors	0.13	0.11	0.11	0.11	3.6	0.18
Roof	0.11	0.11	0.11	0.11	0.35	0.12
Windows	1.6	1.2	0.8	0.8	4.8	0.8
Doors	1.2	1	0.8	0.8	4.8	1.0
Heating	Gas boiler	Heat pump	Heat pump	Compact HP	Gas boiler	Heat Pump
Heat recovery	dMEV	dMEV	MVHR	MVHR	None	MVHR
Airtightness n50 ($m^3/m^3/hr$)	5	5	0.6	0.6	15	1
PVs	4kWp	No PV	3kWp	3kWp	0kWp	5.4kWp

Medium rise – Archetype D

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit - Proposed
Walls	0.18	0.15	0.1	0.1	0.45	0.18
Floors	0.15	0.11	0.1	0.1	0.34	0.18
Roof	0.15	0.11	0.1	0.1	1.00	0.12
Windows	1.6	1.2	0.8	0.8	4.80	0.8
Doors	1.5/1.3	1	1.0	1.0	4.80	1.0
Heating	Gas boiler	Heat pump	Heat pump	Compact HP	Gas Boiler	Heat pump
Heat recovery	dMEV	dMEV	MVHR	MVHR	none	MVHR
Airtightness n50 ($m^3/m^3/hr$)	5	5	0.6	0.6	15	1
PVs	47 kWp	No PV	36 kWp	82 kWp	No PVs	36 kWp

Retail – Archetype 1

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit - Proposed
Walls	0.18	0.15	0.1	0.1	0.43	0.18
Floors	0.15	0.11	0.1	0.1	0.35	0.18
Roof	0.15	0.11	0.1	0.1	1.0	0.12
Windows	1.6	1.2	0.8	0.8	4.80	0.8
Doors	1.5	1	1.0	1.0	4.80	1
Heating	Gas boiler	Heat pump	Heat pump	Compact HP	Gas Boiler	Heat pump
Heat recovery	cMEV	cMEV	MVHR	MVHR	none	MVHR
Airtightness n50 $(m^3/m^3/hr)$	5	5	0.6	0.6	15	1
PVs	47kWp	No PV	66 kWp	82 kWp	No PVs	66kWp

Primary School - Archetype 2

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit - Proposed
Walls	0.18	0.15	0.1	0.1	No change	No change
Floors	0.15	0.11	0.1	0.1	0.35	0.18
Roof	0.15	0.11	0.1	0.1	1.00	0.23
Windows	1.6	1.2	0.8	0.8	4.80	0.8
Doors	1.2	1	1.0	1.0	4.80	1
Heating	Gas boiler	Gas boiler	Heat pump	Compact HP	Gas Boiler	Heat pump
Heat recovery	None	None	None	None	None	None
Airtightness n50 $(m^3/m^3/hr)$	5	5	0.6	0.6	15	1
PVs	166 kWp	No PV	154kWp PVs	290kWp PVs	No PVs	161kWp PVs

Office - Archetype 3

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit
Walls	0.18	0.15	0.1	0.1	No change	No change
Floors	0.15	0.11	0.1	0.1	0.35	0.18
Roof	0.15	0.11	0.1	0.1	1.0	0.23
Windows	1.6	1.2	0.8	0.8	4.8	0.8
Doors	1.2	1	1.0	1.0	4.8	1.0
Heating	Gas boiler	Gas boiler	Heat pump	Compact HP	Gas boiler	Heat pump
Heat recovery	None	None	None	None	None	MVHR
Airtightness n50 ($m^3/m^3/hr$)	5	5	0.6	0.6	15	1
PVs	160 kWp	No PV	280 kWp	280 kWp	No PVs	280 kWp

Warehouse - Archetype 4

Variant	Part L 2021	Future Homes Standard 2025	Zero Operational Carbon	ZOC + Reduced Embodied Carbon	Retrofit - Existing	Retrofit - Proposed
Walls	0.18	0.15	0.12	0.12	1.0	0.12
Floors	0.15	0.12	0.1	0.1	0.7	0.1
Roof	0.15	0.12	0.7	0.7	1.0	0.7
Windows	1.6	1.2	0.8	0.8	4.8	0.8
Doors	1.9	1	0.8	0.8	3.5	0.8
Heating	Gas boiler	Gas boiler	VRF	VRF	Gas boiler	Heat pump
Heat recovery	None	None	None	None	None	None
Airtightness n50 ($m^3/m^3/hr$)	5	5	0.6	0.6	15	1
PVs	457 kWp	No PVs	195 kWp	800 kWp	No PVs	207 kWp

8

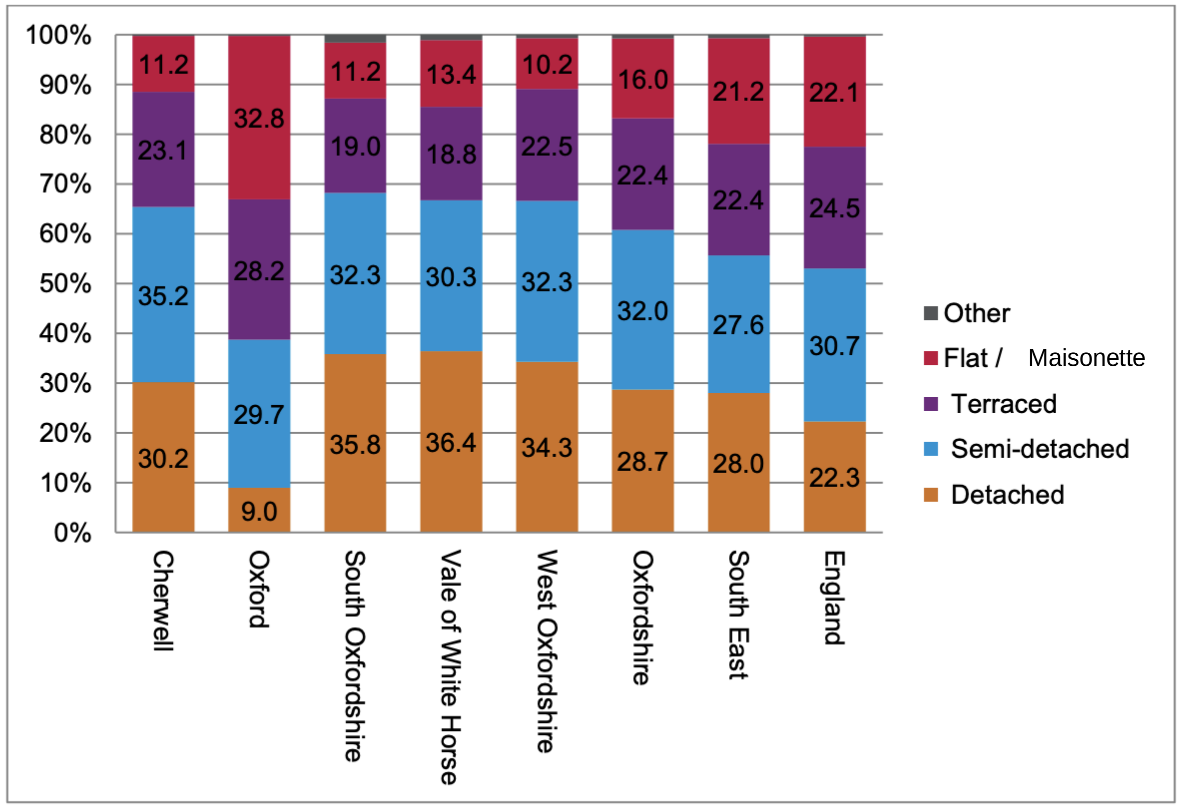
8.1 Archetype selection

8.1.1 The study needed to reasonably assume the most likely archetypes of future domestic and non-domestic developments. To extract this meta-data from the planning portal would have both legal implications and data handling complications. Therefore, qualitative and proxy data was used.

Domestic

8.1.2 The census data shows detached and semi-detached as over two thirds of the existing stock. Although flats are less than 15%, the trend and policy direction are towards densification. Using the planning portal, an archetypal house was identified which was relatively easy to modulate between a simple terrace, basic semi-detached and a larger and more complex detached (inclusive of dormers, internal porch and bay window). A separate apartment block was selected. This allows for a comparison of form factors and complexity. They were all selected to be around 10% bigger than nationally described space standards. All represented typical mass housebuilder designs.

Figure 3: House Types: % Dwellings in 2011



Source: Census, 2011

Non-domestic

8.1.3 The Joint Local Plan was used to understand future development. Schools are a key need, with a two-form entry being the most common building and therefore selected archetype.

8.1.4 Planning policy for retail favours a town-centre approach over out-of-town. Therefore, a residential integrated convenience grocery unit was chosen. This was integrated with domestic flat archetype.

8.1.5 Initially, Research & Development (R&D) was selected prominent non-domestic use in the districts. However, data from the Employment Land Needs Assessment that set out the existing employment floorspace in the districts did not support this – see below. Therefore, the most frequently occurring archetype is an office.

- R&D	18 properties	160,000m2
- Industrial processes	83 properties	88,000m2
- General Industrial	211properties	283,000m2
- Storage and Distribution	206 properties	738,000m2
- Offices	722 properties	638,000m2

Data from the Employment Land Needs Assessment showing the existing employment floorspace in the districts.

8.1.6 Despite R&D being a prominent non-domestic use in the districts, the relative amount is low. This has therefore been excluded from the archetype list.

8.1.7 Storage represents the greatest floor area due to the large nature of the use and the amount coming forward in future could potentially continue to grow with online shopping trends. This was added as an extra archetype in addition to standard offices which are the most frequently occurring non-residential use in the districts.

8.2 Retrofit assumptions and targets

8.2.1 The study is primarily new build. However, retrofit was included to ensure there is an evidence base to ensure the benefits are not disincentivised for high performance new build. An efficient methodology was to use the same design as the new build but to treat the fabric as the stock median as follows:

- EPCs from districts showed an average of 63-64 which was converted into relative performance specification when calculated in PHPP
- Nationally, post 1919 to 1950s era houses represent the majority[42] of English homes. This can be reasonably assumed to be the case in the South Oxfordshire and Vale of

[42] English Housing Survey

White Horse. Consequently, these construction methods were assumed for the existing build ups.

- PAS2035 best practice has been used
- LETI 'best practice' was selected as the target

8.3 Whole life carbon (WLC)

8.3.1 This study does not include a detailed examination of whole life carbon analysis. In general terms, none of the archetypes studied achieve net zero whole life carbon due to the upfront embodied carbon emitted during construction. This upfront carbon ranges from twenty tonnes for LETI A houses to hundreds of tonnes for LETI B non-domestic archetypes.

8.3.2 A net-zero operational energy building, which by definition produces no energy surplus, could theoretically offset grid electricity carbon emissions. Optimising photovoltaic (PV) generation on all archetypes could provide a crude embodied carbon payback for the embodied energy. The following is heavily caveated as very simplified calculations for a complex methodology with significant variables. Four examples are given.

- Optimised PV on the semi-detached could offset around 0.5 tonnes of carbon per year, requiring approximately 40 years to achieve net zero whole life carbon. For retrofits, this drops to 12 years due to the lower embodied carbon of existing buildings.
- If the flats had optimised PV, a LETI A could achieve payback in 25 years, while a LETI A++ retrofit could achieve it in just 10 years.
- There is no opportunity for surplus PV generation on the office, so achieving net zero whole life carbon is not feasible.
- Freestanding retail, with a large roof area for potential PV, could achieve payback in 10 years at LETI A embodied carbon. However, no payback is possible for the grocery function, either freestanding or inbuilt, over 60[43] years.

8.3.3 The policy proposals for operational carbon in this study are ambitious and signify a notable improvement over existing and emerging Part L regulations. They also set ambitious targets for embodied carbon where no regulations currently exist. However, the study lacks the necessary evidence to propose or estimate the costs associated with whole life carbon initiatives. Whole life carbon analysis represents a potential next step in zero carbon policy development, as it provides a more comprehensive understanding of the environmental impact of buildings. Notably, having a large upfront embodied carbon implies longer payback periods, emphasising the importance of considering the entire life cycle of buildings.

8.4 Equivalent local plan targets

8.4.1 Delivering Net Zero (not local plan policy)

(1) 70 kWh/m2 GIA for offices

(2) 65 kWh/m2 GIA for schools

(3) 35 kWh/m2 GIA for industrial buildings

(4) 160 kWh/m2 GIA for hotels

8.4.2 Essex County Council (not local plan policy)

(1) Offices – 70 kWh/m2 GIA/year

(2) Schools – 65 kWh/m2 GIA/year

(3) Light Industrial – 35 kWh/m2 GIA/year

8.4.3 Leeds City Council (draft policy)

(1) Offices, retail, GP surgery, hotels and university facilities – 55 kWh/m2/year

(2) Schools – 65 kWh/m2/year

(3) Leisure – 100 kWh/m2/year

(4) Light industrial uses – 110 kWh/m2/year

(5) Research facility – 150 kWh/m2/year

8.4.4 Central Lincs (adopted policy)

(1) 70-90 kWh/m2/year

8.4.5 Greater Cambridge (draft policy)

(1) Office, retail, higher education, hotel, GP surgery: 55 kWh/m2/year

(2) School: 65 kWh/m2/year

(3) Leisure: 100 kWh/m2/year

(4) Light industrial: 110 kWh/m2/year

8.4.6 Merton (draft policy)

(1) Offices, retail, GP surgery, hotels and higher education – 55 kWh/m2/yr

(2) Schools – 65 kWh/m2/yr

[43] RICS uses 60 years as the standard lifespan of a building when calculating whole life carbon.

8.4.7 Leisure – 100 kWh/m2/yr

8.4.8 Light industrial uses – 110 kWh/m2/yr