Central Lincolnshire Authorities

Central Lincolnshire Local Plan: Climate Change Evidence Base

Task G – Feasibility Assessment

Feb 2021 I Rev C

Bioregional Etude Currie & Brown

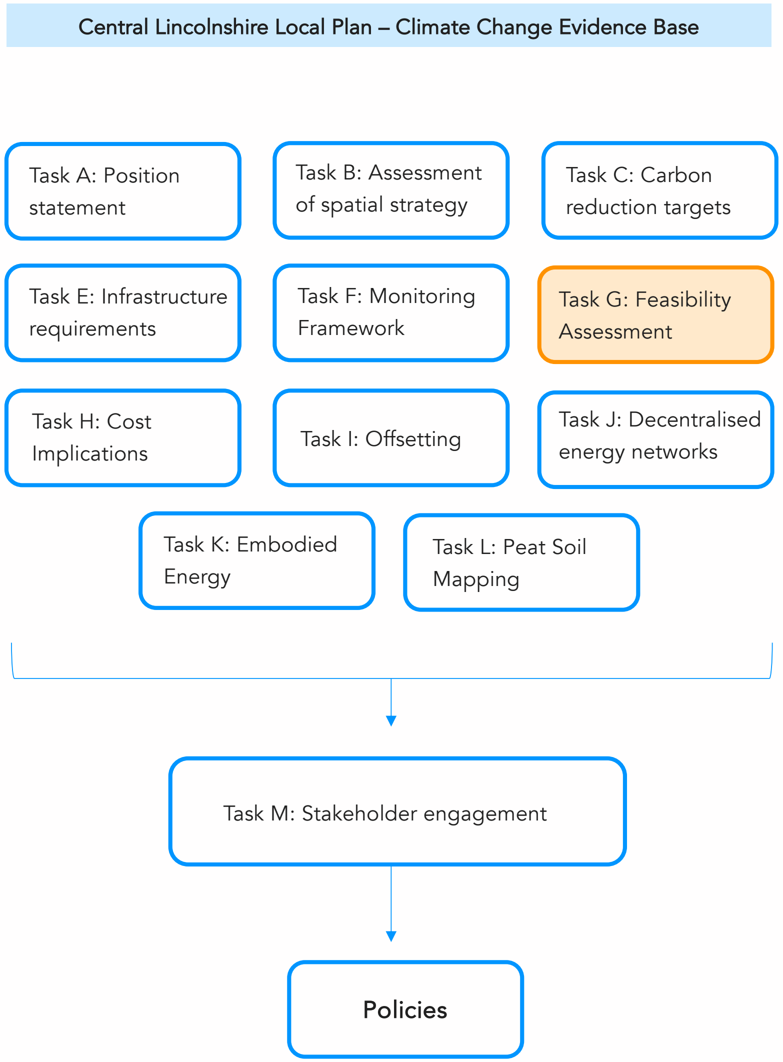
Task G

Technical Feasibility

This report assesses the technical feasibility of achieving the targets identified in “Task C: Developing emissions reductions targets and recommending policies”.

We look at the feasibility of constructing different types of building to zero carbon standards.

The analysis is based on types of building and scales of development that are likely to be relevant for new buildings in Central Lincolnshire.



Central Lincolnshire Local Plan – Climate Change Evidence Base

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1.1 Our approach to determining technical feasibility

Step 1: Define what makes a building zero carbon

1.1.1 A general definition of a zero carbon building can be found in "Task A – Position Statement". We convert this into three areas of technical performance that can be modelled: energy efficiency, low carbon heating and renewable energy. This helps frame the analysis for our feasibility study.

Step 2: Model areas of performance

1.1.2 Five building typologies were chosen for detailed energy modelling: detached house, semi-detached house, bungalow, primary school and light industrial unit. These building types were selected because they represent the most common type of building likely to be built in Central Lincolnshire over the next plan period. For each typology our models assessed:

Energy efficiency – The levels of energy efficiency required for net zero carbon buildings are investigated through two metrics: space heating demand and metered energy use. Metered energy use per square metre of internal floor area is also referred to as the building's Energy Use Intensity, or EUI.

Low carbon heating - Different types of low carbon heating system that can deliver net zero carbon buildings are considered. We assess how they affect metered electricity use.

Renewable energy generation - We assess the potential for on-site renewable energy generation to meet or exceed the metered electricity use.

Step 3: Consider net zero carbon feasibility in context

1.1.3 Other building types will feature in new development in Central Lincolnshire. Case studies for low-energy built examples of other typologies have been reviewed. This aids in providing a more complete view of new building stock potential.

The technical modelling, and case studies, can help inform new building policy decisions in Central Lincolnshire.

Figure 1.1 - Five building types modelled as part of this technical evidence base: semi-detached house; detached house; bungalow; primary school and a light industrial unit.

Task G

Technical Feasibility

2.0 Definition of a net zero carbon building

This section explores the definition of a net zero carbon building.

2.1 Definition of a net zero carbon building

Definition of a Net Zero Carbon building

2.1.1 We have assessed the technical feasibility of net zero carbon buildings against guidance issued by the UK Committee on Climate Change[01], the London Energy Transformation Initiative[02], RIBA 2030 Climate Challenge[03], and the Passive House Institute[04]. Performance must be assured across three separate aspects of any new building to ensure it achieved net zero carbon emissions:

1. Energy efficiency

2.1.2 New buildings must use energy efficiently if they are to achieve net zero carbon emissions. This can be measured using two key metrics:

- **Space heating demand**, which is a measure of the thermal efficiency of the building. For a net zero carbon building it should be around 15-20 kWh/m^2/yr.
- **Metered energy use**, which is a measure of the total energy consumption of the building including the heating system, hot water, ventilation, appliances and lighting. For domestic buildings it should be around 35 kWh/m^2/yr, with non-commercial targets varying depending on type.

2. Low carbon heating

2.1.3 Low carbon heat sources are clearly a fundamental requirement of any net zero carbon building. In practice this means space heating and hot water should be provided by heat pumps and/or direct electrical heating. No combustion of carbon containing fuels to produce heat should take place.

3. Renewable energy

2.1.4 Renewable energy generation should be at least equal to energy use of the building for a building to qualify as Net Zero Carbon. This is straightforward to achieve on site for most buildings through the use of solar photovoltaic panels, though some buildings will need to invest in additional off-site renewable energy generation.

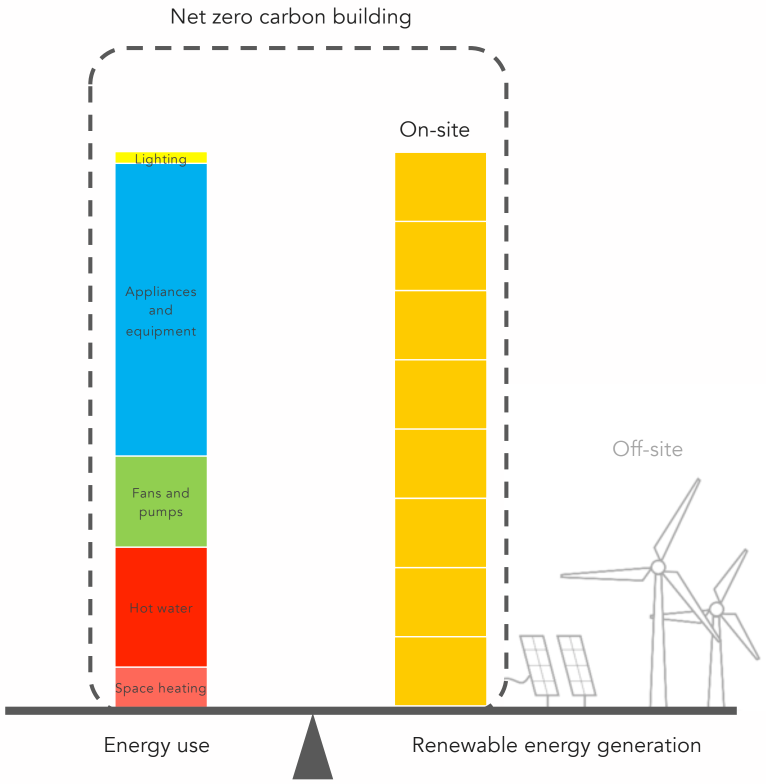


Figure 2.1 – To achieve net zero carbon in a new building, the energy consumption of a building should be matched by renewable energy generation. The example shown is for an energy efficient house that is heated by a heat pump. Each yellow block represents the energy produced by a single solar photovoltaic panel. In this case, off-site generation is not required to achieve net zero.

2.2 Definition of a net zero carbon building | 1 - Energy efficiency in depth

Building fabric

2.2.1 The Committee on Climate Change indicate that a space heat demand of 15-20 kWh/m²/yr is required for new housing if the UK is to meet its net zero carbon commitments. This level of performance is also closely aligned with the Passivhaus Institute's Passivhaus Standard of 15kWh/m²/yr. As this represents a sensible upper limit of building fabric efficiency, it is also a sensible target for most other building types.

2.2.2 There are many examples of buildings that have achieved this standard in the UK and abroad, both residential and non-residential, proving the technical feasibility of this standard. Typical measures used to achieve this level of performance are summarised below:

- **Building Form -** A simple building form minimizes the area of the building exposed to cold air and reduces the number of complex junctions. This reduces heat loss, often for little to no cost.
- **High Performance Glazing –** Triple glazing and insulated window/door frames are combined with careful optimization of glazing proportions to utilize solar gains in winter, while reducing the impact of summertime overheating.
- **Insulation –** Excellent levels of insulation are combined with thermal bridge free design to minimize heat loss through floors, walls, roofs, and junctions between parts of the building.
- **Airtightness –** An airtight thermal envelope is required to limit heat loss due to infiltration of cold outdoor air. With good design, it can offer a very cost-effective way of reducing energy consumption.
- **Heat Recovery Ventilation** – Ventilation is essential to a healthy indoor environment. Mechanical Ventilation with Heat Recovery provides fresh air while recovering up to 90% of heat from the outgoing air.

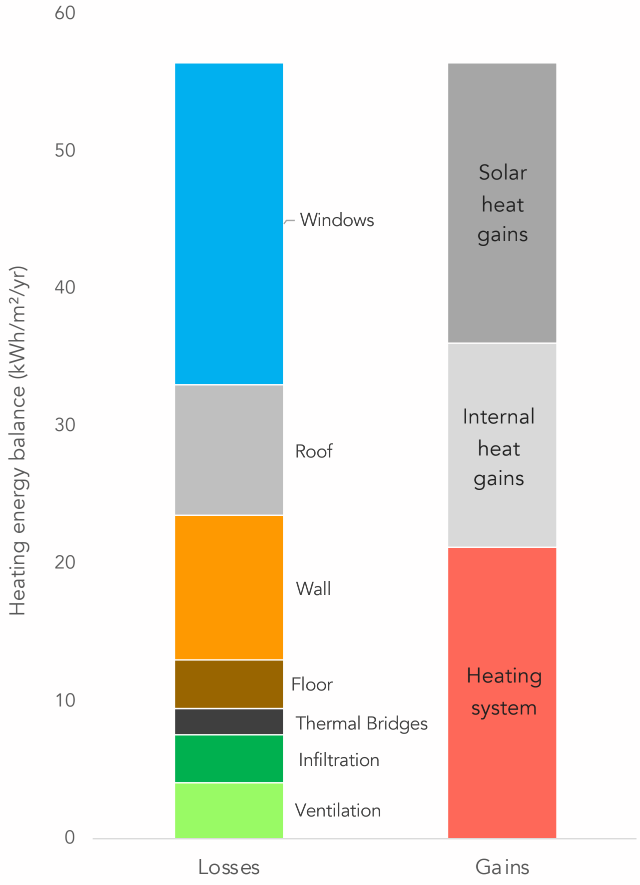


Figure 2.2 – Typical balance of heating energy losses and gains for a very efficient building. Heat gains come from useful solar gains, internal heat gains from occupants and appliances, with the remainder provided by the building's heating system.

2.3 Definition of a net zero carbon building | 2 - Low carbon heating in depth

Heat pumps

2.3.1 Heat pumps use refrigerant to efficiently take low temperature heat from a source outside the building and move it inside the building while raising it to a useful temperature. Heat sources can include outside air, the ground or a local water source. Efficiencies vary from around 180% to over 500%, with higher efficiencies associated with smaller temperature differences between the outside heat source and the indoor heat sink.

Direct electric heating

2.3.2 Direct electric heating systems convert electricity directly into heat through resistive heating. It is typically 100% efficient. The price of electricity can make this a relatively expensive means of heating buildings and providing hot water, unless cheaper off-peak electricity is used.

Carbon based fuels

2.3.3 Heating systems that use carbon-based fuels are not compatible with achieving net zero emissions. This includes gas boilers, oil boilers and in most cases stoves and boilers that burn biomass. The net balance of atmospheric carbon that results from burning biomass, whether as 'green gas' or directly as woody fuels, is highly variable and complex to calculate. The total potential for sustainable biomass combustion without carbon capture and storage is also very limited.

Hydrogen

2.3.4 The Committee on Climate Change indicate that hydrogen is unlikely to play any significant role in heating new buildings[05]. As production, storage, transport and conversion of hydrogen into useful heat is a relatively inefficient process it would also likely be a particularly expensive form of heating. Other uses such as industrial process heating and back-up power generation are likely to be more appropriate uses of a resource that is so energy intensive to produce.

Impact of heating system on energy use

2.3.5 The choice of heating system significantly affects the energy use of a building for space heating and hot water provision. Gas boilers and other combustion-based heating systems increase energy use above the space heat and hot water demand as some of the heat they generate is lost in the flue. Direct electric heating does not create any losses in the building, so is slightly better. Heat pumps require significantly less energy to provide heat as they are so efficient. This reduces the amount of renewable energy required to make a building net zero carbon.

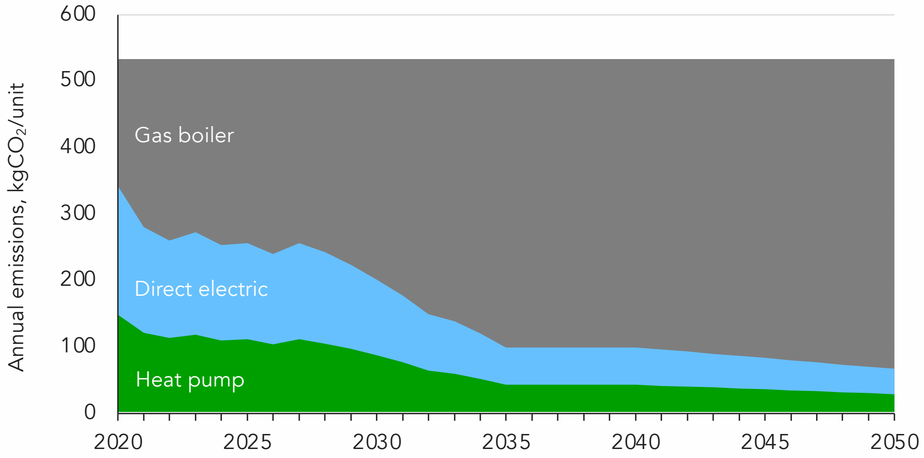


Figure 2.3 - Projected annual CO$_2$ emissions of different heating systems for an energy efficient 2-bed flat. Systems fuelled by electricity show decreasing annual emissions due to the electricity grid getting cleaner over time. Heat pumps offer the lowest emission solution.

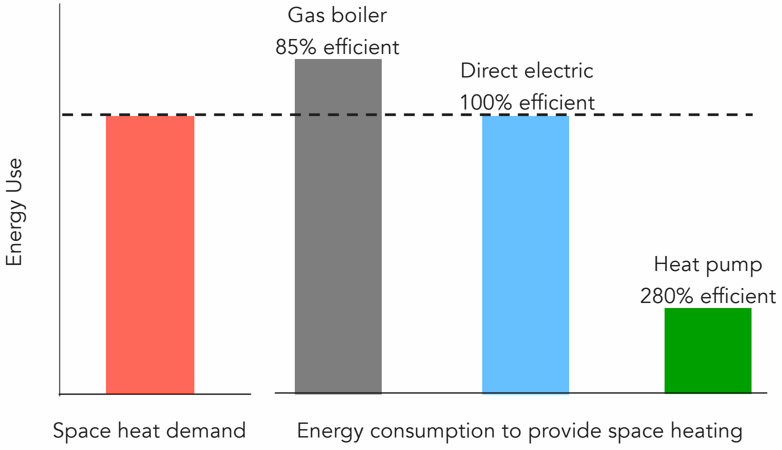


Figure 2.4 – Choice of heating system affects energy use significantly. Heat pumps are very efficient, helping buildings to meet the net zero requirements for low energy use.

2.4 Definition of a net zero carbon building | 3 - Renewable energy in depth

Solar photovoltaic panels

2.4.1 Solar photovoltaic panels generate electricity when exposed to sunlight. They are usually the most appropriate form of renewable energy generation for a building as they are simple, durable, and can be installed on both roofs and suitable facades. For these reasons, we have considered the provision of on-site renewable energy through photovoltaics in our technical feasibility analysis.

2.4.2 The latest energy scenarios produced by the National Grid[06] indicated that the UK needs to increase its solar photovoltaic capacity by around five times current levels to achieve net zero carbon. We have taken a view that it is better to install this on buildings than on greenfield sites that are likely to be required for farming, or for tree planting to provide carbon sequestration and reverse biodiversity loss.

2.4.3 Generating electricity at the point of use offers several advantages, including: provision of cheap electricity close to demand that can offset electricity consumption at full retail price, the ability to directly power building systems or charge electric vehicles from rooftop solar energy, and immediate decarbonisation of electricity supplies (rather than having to wait for the UK grid to decarbonise).

2.4.4 Our modelling considers the feasibility of generating enough renewable electricity on-site to match the energy use of each building. In cases where there was additional roof space we have also considered the ability of buildings to become net producers of clean electricity. We have assumed deployment of good-practice solar technology, including efficient monocrystalline silicone solar panels and use of DC Optimisers or Microinverters.

Performance metrics

2.4.5 In our modelling, we assess solar photovoltaic electricity generation in terms of kilowatt hours generated per square metre of building footprint (kWh/m^2_{fp}). The building footprint is effectively the same as the total roof area of the building. This metric provides a straightforward indication of how well solar technology has been deployed on a given building. Installation of more solar panels, higher efficiency panels, or use of technologies such as microinverters would all increase this figure.

Other technologies

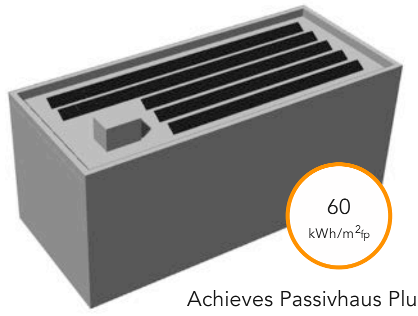
2.4.6 We have not considered solar water heating as the electricity generated by solar photovoltaic panels is a more valuable form of energy than hot water, and in most cases solar photovoltaic systems offer better value and are more reliable. The use of small-scale wind turbines has also not been considered as studies have shown these devices typically perform poorly at such small scales in turbulent urban/suburban environments.

How much energy can solar photovoltaics generate?

2.4.7 The roof design often has the greatest impact on the amount of solar electricity that can be generated on a building, relative to other measures. The three main design approaches are illustrated below.

Flat roof - business as usual

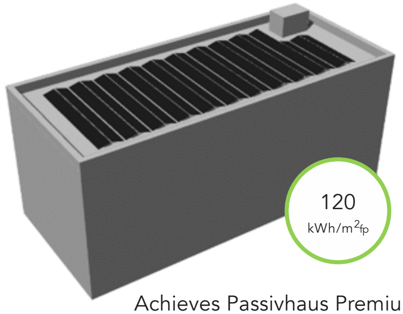
2.4.8 The solar panels are positioned at a 30 degree tilt angle and oriented South. Energy generation per panel is maximised, but the large gap required between rows to avoid shading results in poor utilisation of the roof for energy generation.



Achieves Passivhaus Plus

Flat roof - good practice

2.4.9 Improved approach where the solar array is at a 10-15 degree tilt angle and oriented to the East/West (+/- 45 degrees). This results in lower energy generation per panel, but much higher panel density for the roof, significantly increasing energy generation.



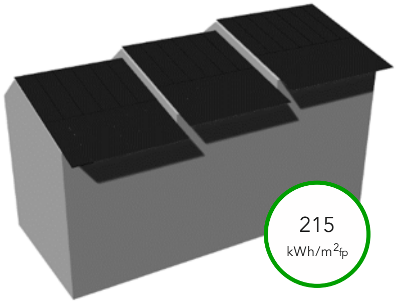
Achieves Passivhaus Premium

Net zero possible up to four storeys

Best practice

2.4.10 The roof is designed specifically to maximise solar generation. Large monopitch planes allow high panel density with no shading.

Plant areas, stair cores and lift overruns are located in a strip along the north side of the building, partially covered by the solar roof structure. Any terraced areas are located under the solar array.



✓ Net zero possible up to six storeys

2.5 Net zero carbon and density of development

The challenge of taller buildings

2.5.1 Energy consumption increases with every storey added to a building, but the roof area does not change. If solar panels are only mounted to rooftops it would mean that the taller a building is, the more difficult it becomes to meet energy consumption through on-site solar generation. This is illustrated in Figure 07 for a block of flats and terraced houses.

Façade mounted solar photovoltaics

2.5.2 One solution to this is to mount solar panels vertically on building facades, as shown in Figure 06. In Central Lincolnshire, this would result in a modest 11% (south-facing) to 18% (south east or west facing) reduction in energy generation per panel relative to a concertina type rooftop system mounted at a 15˚ tilt angle in an east-west orientation.

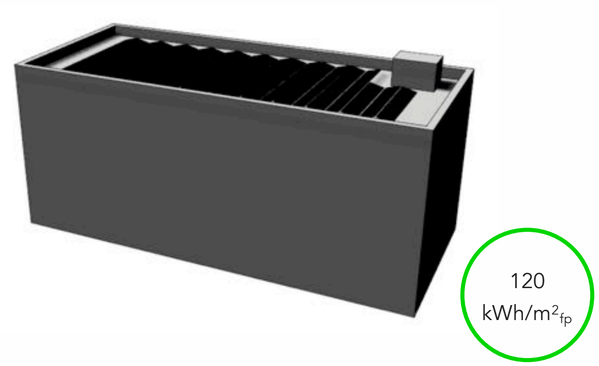
Achieving net zero carbon with groups of buildings

2.5.3 Another solution is to group buildings in a way that ensures that new development is, on average, net zero across Central Lincolnshire. This could be achieved by introducing policies that encourage developers to ensure that low rise developments are net producers of solar energy, balancing the needs of taller buildings.

Figure 2.5 - With 576kW of solar photovoltaic panels installed, the CIS tower in Manchester was Europe's largest vertical solar array when completed in 2006.

Four storey block of flats

86% of energy use generated by solar on site



Two storey terraced houses

240% of energy use generated by soar on site

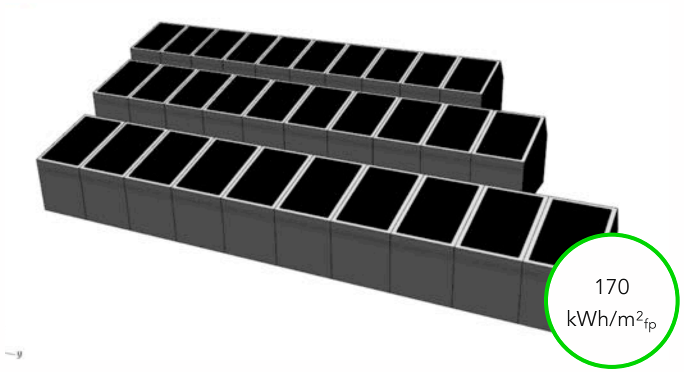


Figure 2.6 - Comparison of renewable energy generation by density. Both the block of flats and the terraced houses have the same internal floor area. The block of flats has much less roof space, so is not able to generate enough renewable energy on site to be net zero carbon. Mechanisms could be introduced to planning policy to encourage surplus energy generation on low-density sites to offset higher density buildings that cannot achieve net zero on site.

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Technical Feasibility

3.0 Energy modelling methodology

This section presents the methodology used for energy modelling of the five different types of building that are expected to be common in new builds across Central Lincolnshire.

3.1 How we model energy consumption

Predictive energy modelling

3.1.1 The accuracy of energy modelling is important to ensure it provides a reasonable indication of real-world performance. While behaviours may vary once a building is occupied, energy modelling can be used to reliably establish baseline energy consumption. The main approaches used for energy modelling in the UK are:

SAP – developed by the Building Research Establishment (BRE) as a tool to calculate the regulated energy performance and CO_2 emissions and use them for Part L calculations.

SBEM – used to assess the energy performance of new and existing non-domestic buildings.

Passivhaus Planning Package (PHPP) – developed by the Passivhaus Institute to model the energy performance of very low energy buildings.

3.1.2 As SAP and SBEM have been designed primarily as a tool to show compliance with building regulations they are generally not accurate at predicting operational energy use. They do not include certain categories of energy use and tend to overestimate the amount of 'free heat' available. Conversely, post occupancy studies in the UK[07] and Europe[08] have shown that PHPP is generally accurate at predicting operational energy; PHPP is the tool used in this study.

Baseline

3.1.3 Designs taken from recent developments and planning applications will be used as the basis for our models. A 'business-as-usual' baseline for each building type is set assuming gas heating and fabric requirements that meet current building regulations. Energy results for the baseline models are not given as they are not relevant and do not adhere to net zero carbon standards. Baselines are used to calculate cost uplifts in our cost feasibility analysis.

Net zero analysis

3.1.4 Iterations of each domestic building model have been run to test two levels of fabric performance and two heating solutions: air-source heat pump and direct electric. A single fabric improvement is modelled for the school and the light industrial, alongside two low carbon heating systems. A PV assessment then outlines, for each iteration, whether the building is net zero carbon on-site and the extent of any surplus renewable generation.

3.1.5 For the semi-detached building we also modelled an alternate design, termed the 'optimised' building. This optimised design is a theoretical development designed in view of meeting net zero carbon and subsequently has improved form, orientation and glazing proportions. The idea was to test how designing with net zero carbon principles from the offset could affect both the technical and cost conclusions on net zero carbon feasibility.

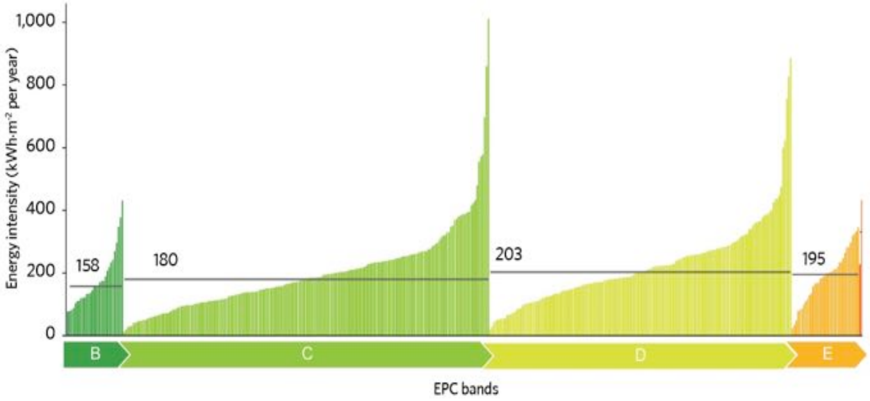

Figure 3.1.1 - Comparison of the Energy Performance Certificate (EPC) energy efficiency rating, as calculated by SAP, with metered energy consumption of 420 homes: There is little correlation between EPC band and actual energy consumption. © Etude

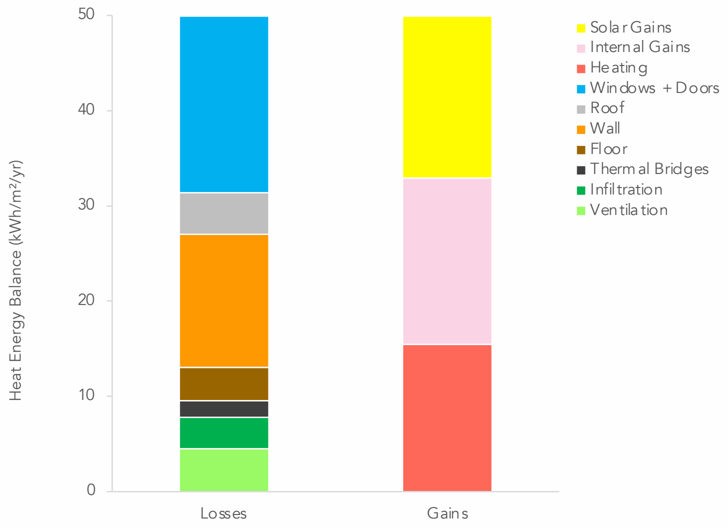

Figure 3.1.2 - Typical output of PHPP energy modelling: Building performance shown in detail

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Task G

Technical Feasibility

4.0 Energy modelling results

This section presents the results of energy modelling for five different types of building that are expected to be common in new builds across Central Lincolnshire.

4.1 Semi detached house | Net Zero Carbon technical feasibility | Fabric and ventilation

4.1.1 This page focuses on building fabric and ventilation for energy efficiency. It is based on predictions of the space heating demand using PHPP software.

Building form

4.1.2 The analysis is based on a typical developer spec form for a 3-bed home. The third bedroom is located in a warm roof with a dormer; insulation at rafter level. The case study house has a form factor of 2.84 and faces south-west.

Space heating demand

4.1.3 We have tested two levels of building fabric efficiency above the baseline (72 kWh/m²/yr) for this scenario:

i) 15 kWh/m²/yr (this is in alignment with Passivhaus standards and the recommendations of the Committee on Climate Change)

ii) 30 kWh/m²/yr (this is in alignment with the Passivhaus Low Energy Building standard)

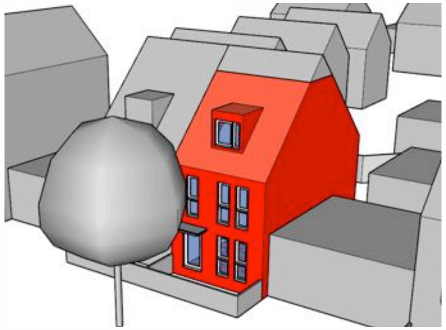
4.1.4 The performance required to meet these two levels of fabric efficiency are detailed in the table to the right, along with an indicative strategy.

Alternative designs and specifications

4.1.5 This typical building was not designed to be a low energy. This makes it challenging to achieve a space heat demand of 15kWh/m²/yr without relying on extremely high specification materials or products. This has implications on both cost and build-up thicknesses.

4.1.6 Better design could achieve improved performance and/or maintain current performance but reduce cost. As an example, combining split windows into single windows, or making the windows smaller, would reduce heat loss improving energy performance.

4.1.7 For comparison, the scenario on the next page is of a semi-detached house with optimised building form.



- 100 sqm GIA
- 84 sqm TFA
- 46 sqm building footprint
- 117 sqm external walls
- 17 sqm windows/doors

Figure 4.1 - **Semi detached house modelled:** from an example developer spec

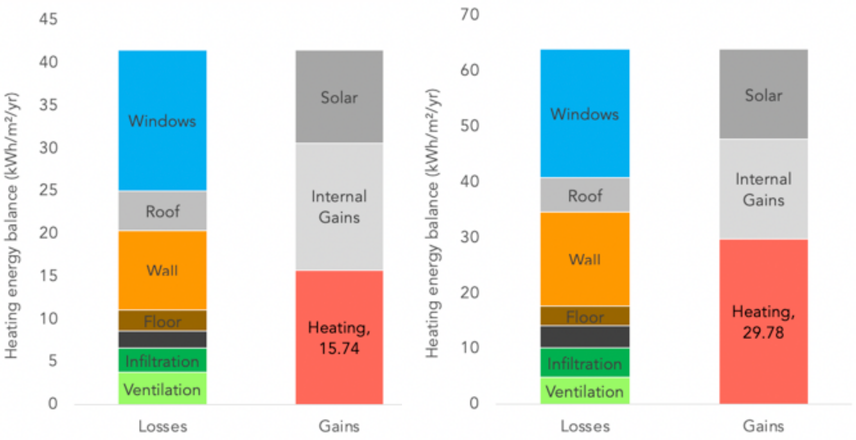


Figure 4.2 - **Space heating demand**: The house would achieve a space heating demand of 15.7 kWh/m²/yr and 29.8 kWh/m²/yr respectively with the specifications outlined below

	Baseline performance for viability	Required performance: 15-20 kWh/m²/yr	Indicative solution (how to achieve the spec)	Required performance: 30 kWh/m²/yr	Indicative solution (how to achieve the spec)
Floor U-value	0.13 W/m²K	0.09 W/m²K	250mm PIR board	0.11 W/m²K	200mm PIR board
Wall U-value	0.18W/m²K	0.09 W/m²K	230mm PIR board with cavity	0.15 W/m²K	210mm mineral wool full-fill
Roof U-value	0.13 W/m²K	0.09 W/m²K	110mm PIR board, rafters with 225mm rockwool in between	0.11 W/m²K	70mm PIR board, rafters with 225mm rockwool in between
Window U-value	1.40 W/m²K	0.90 W/m²K	Triple glazing, argon filled, low-e coatings	1.20 W/m²K	High spec double glazing, argon filled, low-e coatings
Thermal bridging	5 kWh/m²/yr	2 kWh/m²/yr	e.g. thermally broken lintels, thermal break at wall base, insulated SVPs.	4 kWh/m²/yr	e.g. reasonable design, thermally broken lintels, thermal break at base of wall.
Ventilation	Continuous extract SFP= 0.25Wh/m³	MVHR 88% heat recovery SFP=0.45Wh/m³	e.g. Zehnder Comfoair Q450	MVHR 84% heat recovery SFP<0.45Wh/m³	e.g. Zehnder Comfoair 350
Airtightness	<5m³/m²h	<0.60m³/m²h	Airtight layer, service grommets	1.0 m³/m²h	Airtight layer, service grommets

Figure 4.3 – **Semi-detached house fabric and ventilation specifications**

4.2 Semi detached house | Net Zero Carbon technical feasibility | Optimised building

Building form

4.2.1 This page details an optimised building form and orientation. The optimised building GIA is equivalent to the typical model outlined on the previous page, with a slight increase in building footprint. All three bedrooms are on the first floor, with insulation at ceiling level.

4.2.2 Window proportions have been chosen to help improve winter solar heat gain whilst minimising heat loss. The house is south-facing with larger glazing areas on this front elevation (compared to the glazing area facing north).

4.2.3 The optimised form has an asymmetric roof, enabling 20 panels to fit on the south-facing pitch.

4.2.4 The optimised case study house has an improved form factor of 2.56.

Space heating demand

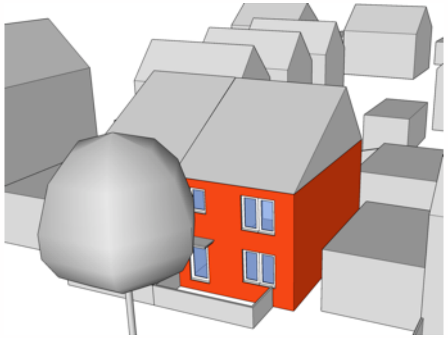
4.2.5 We have tested two levels of building fabric efficiency for this scenario:

i) 15 $kWh/m^2/yr$ (this is in alignment with Passivhaus standards and the recommendations of the Committee on Climate Change)

ii) 30 $kWh/m^2/yr$ (this is in alignment with the Passivhaus Low Energy Building standard)

4.2.6 The performance required to meet these two levels of fabric efficiency are detailed in the table to the right, along with an indicative strategy.

4.2.7 With a preferential form, and a design that embodies net zero carbon principles from the offset, the fabric required to achieve respective levels of energy efficiency are significantly less onerous. Indeed, it is possible to meet a 30 $kWh/m^2/yr$ space heating demand by introducing mechanical heat recovery and ensuring a good degree of airtightness, with little change to the fabric.



- 100 sqm GIA
- 87 sqm TFA
- 53 sqm building footprint
- 100 sqm external walls
- 14 sqm windows/doors

Figure 4.4 - **Semi detached house modelled:** The optimised semi detached house is based on a known development

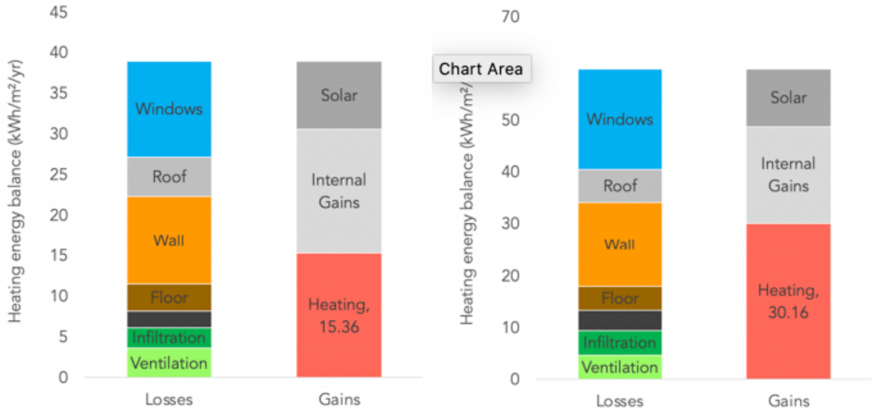


Figure 4.5 - **Space heating demand**: The house would achieve a space heating demand of 15.4 $kWh/m^2/yr$ and 30.2 $kWh/m^2/yr$ respectively with the specifications outlined below

	Baseline performance for viability	Required performance: 15-20 $kWh/m^2/yr$	Indicative solution (how to achieve the spec)	Required performance: 30 $kWh/m^2/yr$	Indicative solution (how to achieve the spec)
Floor U-value	0.13 W/m^2K	0.11 W/m^2K	200mm PIR board	0.13 W/m^2K	170mm PIR board
Wall U-value	0.18W/m^2K	0.13 W/m^2K	250mm PIR board with cavity	0.18 W/m^2K	170mm mineral wool full-fill
Roof U-value	0.13 W/m^2K	0.11 W/m^2K	200mm mineral wool, 150mm timber joists with mineral wool	0.13 W/m^2K	150mm mineral wool, 150mm timber joists with mineral wool
Window U-value	1.40 W/m^2K	0.90 W/m^2K	Triple glazing, argon filled, low-e coatings	1.20 W/m^2K	High spec double glazing, argon filled, low-e coatings
Thermal bridging	5 $kWh/m^2/yr$	2 $kWh/m^2/yr$	e.g. thermally broken lintels, thermal break at wall base, insulated SVPs.	4 $kWh/m^2/yr$	e.g. reasonable design, thermally broken lintels, thermal break at base of wall.
Ventilation	Continuous extract SFP= 0.25Wh/m^3	MVHR 88% heat recovery SFP=0.45Wh/m^3	e.g. Zehnder Comfoair Q450	MVHR 84% heat recovery SFP<0.45Wh/m^3	e.g. Zehnder Comfoair 350
Airtightness	<5m^3/m^2h	<0.60m^3/m^2h	Airtight layer, service grommets	1.0 m^3/m^2h	Airtight layer, service grommets

Figure 4.6 – **Optimised semi-detached house fabric and ventilation specifications**

4.3 Semi detached house | Net Zero Carbon technical feasibility | Low carbon heat

4.3.1 This page focuses on the low carbon heating system and the resulting metered energy use. It is based on a detailed prediction of the total operational energy consumption of this dwelling, using PHPP software.

Metered Energy Use

4.3.2 Total energy use, as measured at the meter, includes not only consumption for space heating and hot water, but all electrical loads such as lighting, small power and pumps.

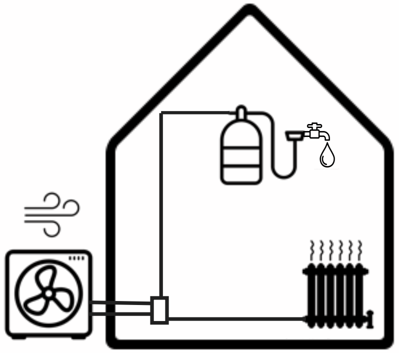
4.3.3 The two heating systems most likely to be specified for a house targeting net zero carbon are an air source heat pump or direct electric heating. The former has an efficiency in converting electrical energy to heat of greater than 100%. For a space heating demand of 15kWh/m²/y:

- The dwelling would achieve metered energy use of $27kWh/m^2_{GIA}$ /yr with a standard air source heat pump. This is comfortable under the target of 35 $kWh/m2_{GIA}$/yr.
- The dwelling would achieve metered energy use of $43kWh/m^2_{GIA}$ /yr with direct electric heating. This does not meet the target of 35 $kWh/m2_{GIA}$/yr but does demonstrate good performance; net zero could still be met through maximising on-site generation.

Discussion on other heating systems

4.3.4 There are several other types of heat pump that could be used to achieve net zero carbon. Options include:

- Air-air heat pumps, commonly known as split air conditioners. These are relatively low cost but provide space heating and cooling only so a separate hot water heater is required.
- Ground source heat pumps are usually more expensive but typically last longer and perform better in colder conditions.
- Heat pump water heaters provide hot water only.
- Exhaust air heat pumps combine the functions of a heat recovery ventilation system with a heat pump that can heat water and provide some space heating.

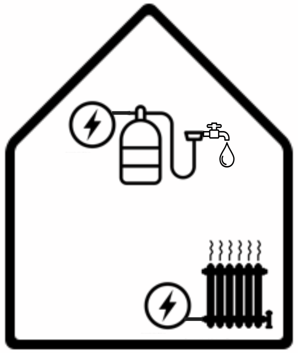


Air source heat pump located on external wall gathers heat from surrounding air

The heat pump alternates between providing space heating and hot water in the dwelling.

Heating system	Air source heat pump	e.g. 5kW Mitsubishi Ecodan
Hot water cylinder	150 litres with losses <1.0 kWh/day	e.g. Mitsubishi heat pump cylinder
Emitters	Wet heating system 2 small radiators	e.g. 450mm x 700mm Stelrad Softline K2

Figure 4.7 - Heating system



Domestic hot water is provided through an electric immersion heater in a hot water tank.

Space heating is provided by direct electric radiators.

Heating system	Direct electric heating	
Hot water cylinder	150 litres with losses < 0.9 kWh/day	e.g. Dimplex ECSd
Emitters	3 panel heaters	

Figure 4.8 - Alternative heating system

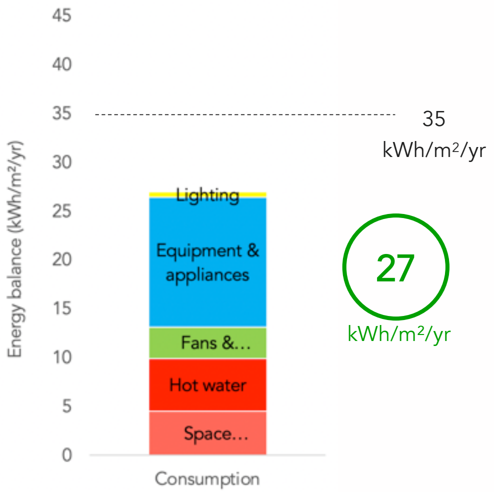


Figure 4.9 - Metered energy use: With an air source heat pump, the semi-detached house would achieve metered energy use of 27 kWh/m²/yr

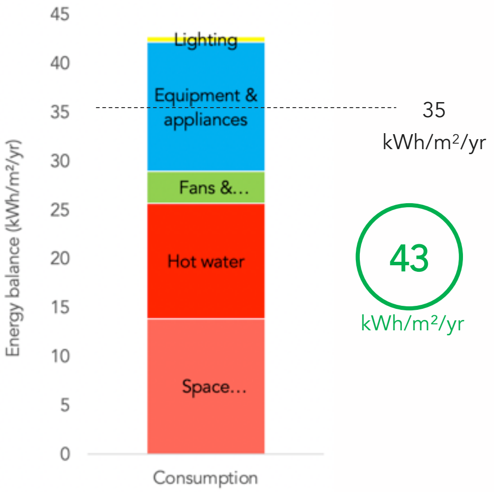


Figure 4.10 - Metered energy use: With direct electric heating, the semi-detached house would achieve metered energy use of 43 kWh/m²/yr

4.4 Semi detached house | Net Zero Carbon technical feasibility | Renewable energy generation

Solar generation greater than metered energy use

4.4.1 Eight high efficiency solar panels could be sufficient for the house (with air-source heat pump) to generate as much electricity as it uses over the year. If oriented East-West, and the roof lights are relocated, the roof has space for up to 20 panels. This more than doubles energy generation, enabling the house to be energy positive.

Discussion on PV layouts

4.4.2 The main risks to being able to install sufficient solar capacity to achieve net zero is through roof design that incorporates rooflights or dormers that prevent installation of solar panels.

4.4.3 In this case the rooftop dormer reduces available area for PV by the equivalent of four panels and creates partial shading on at least two of the remaining panels. Removing the dormer window, would allow up to 24 panels to be installed.

4.4.4 An asymmetric roof, as modelled for the 'optimised' dwelling, is another way to increase the number of panels.

Ensuring residents benefit from solar

4.4.5 Residents of single homes with solar panels on the roof benefit from direct consumption of solar electricity and from export tariff payments for exported electricity.

4.4.6 Typically, homes consume around 15-30% of solar energy directly though this can increase to 50-70% with smart control of space and water heating. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat so the heating can be run when solar energy is available and turned down at other times.

4.4.7 Surplus electricity could be used for charging an electric vehicle, which typically require around 3,000 kWh per year. Smart charging of electric vehicles can increase self-consumption of solar electricity above 70%.

Typical development

Space heating demand:
15 kWh/m²/yr

Orientation: **south-southwest**

2.7 kWp — Nominal array power

62 kWh/m$^2_{fp}$ — Specific energy generation

Figure 4.11- **Minimum solar generation for net zero carbon:** 8 x 340W solar photovoltaic panels would be sufficient to generate 27 kWh/m2/yr and therefore achieve net zero carbon (in the case of an air source heat pump heating system).

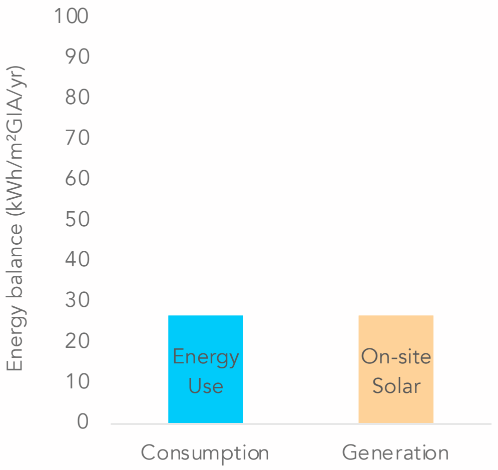
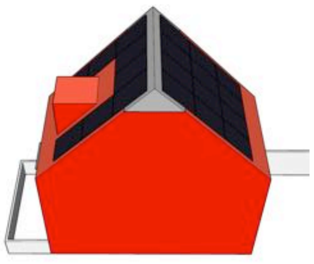


Figure 4.13 - **Net zero energy balance:** The house could generate as much solar electricity as it consumes with a south-west facing 8 panel solar array.

Typical development

Space heating demand:
15 kWh/m²/yr

Orientation: **west**



6.8 kWp — Nominal array power

154 kWh/m$^2_{fp}$ — Specific energy generation

Figure 4.12 - **Maximising solar generation:** 20 x 340W solar photovoltaic panels would enable the house to be energy positive if in an east-west orientation.

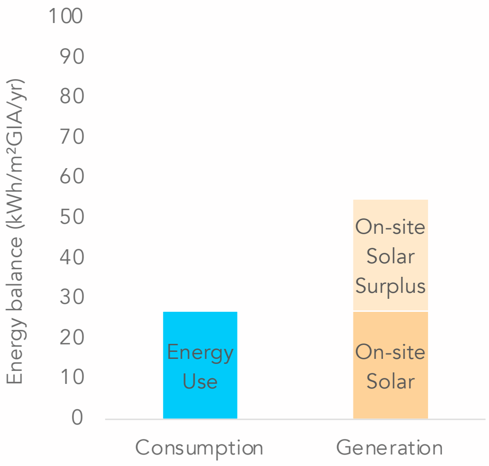
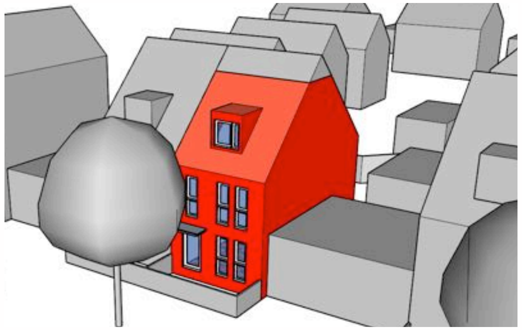


Figure 4.14 - **Net zero energy balance:** The house is a net producer of clean electricity with east and west facing solar arrays.

4.5 Semi detached house | Net Zero Carbon technical feasibility | Sensitivity analysis

Typical Form

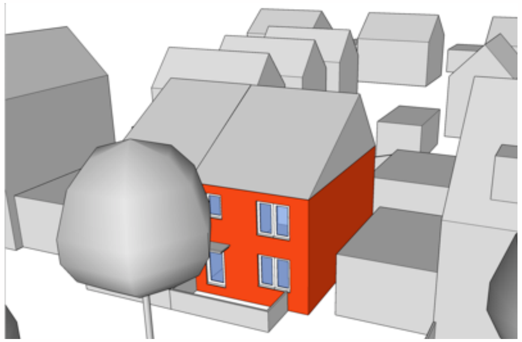


Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation (8 panels)	Net zero on-site?	On-site surplus PV generation kWh/yr
15	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.09 W/m^{2}K 0.09 W/m^{2}K 0.09 W/m^{2}K 0.9 W/m^{2}K 2 kWh/m^2/yr MVHR 88% <0.6m^3/m^{2}h	Air source heat pump: 27	62 kWh/m$^2_{fp}$ (8 panels)	Yes	146
			Direct electric: 43	62 kWh/m$^2_{fp}$ (8 panels)	No* (66% of consumption met)	-
30	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.11 W/m^{2}K 0.15 W/m^{2}K 0.11 W/m^{2}K 1.2 W/m^{2}K 4 kWh/m^2/yr MVHR 84% <1.0m^3/m^{2}h	Air source heat pump: 31	62 kWh/m$^2_{fp}$ (8 panels)	No* (92% of consumption met)	-
			Direct electric: 54	62 kWh/m$^2_{fp}$ (8 panels)	No** (53% of consumption met)	-

*could achieve net zero if dormer was removed

** could achieve net zero if dormer was removed and an asymmetric roof was implemented, or house was orientated east-west

Optimised Form



Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation (for net zero)	Net zero on-site?	Potential surplus PV generation (20 panels) kWh/yr
15	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.11 W/m^{2}K 0.13 W/m^{2}K 0.11 W/m^{2}K 0.9 W/m^{2}K 2 kWh/m^2/yr MVHR 88% <0.6m^3/m^{2}h	Air source heat pump: 27	55 kWh/m$^2_{fp}$ (8 panels)	Yes	4,681
			Direct electric: 43	83 kWh/m$^2_{fp}$ (12 panels)	Yes	3,077
30	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.13 W/m^{2}K 0.18 W/m^{2}K 0.13 W/m^{2}K 1.2 W/m^{2}K 4 kWh/m^2/yr MVHR 84% <1.0m^3/m^{2}h	Air source heat pump: 31	62 kWh/m$^2_{fp}$ (9 panels)	Yes	4,242
			Direct electric: 54	111 kWh/m$^2_{fp}$ (15 panels)	Yes	1,839

4.6 Bungalow | Net Zero Carbon technical feasibility | Fabric and ventilation

4.6.1 This page focuses on building fabric and ventilation for energy efficiency. It is based on predictions of the space heating demand using PHPP software.

Building form

4.6.2 This page details an example developer spec building form and orientation for a three-bed home. Although the design could be optimised further with regard to thermal performance the chosen example is reasonable with a south-facing front. The case study house has a form factor of 4.75.

Space heating demand

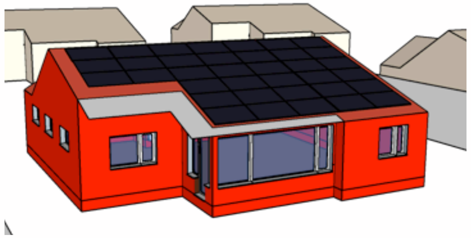
4.6.3 We have tested two levels of building fabric efficiency for this scenario:

i) 15-20 kWh/m²/yr (this is in alignment with the recommendations of the Committee on Climate Change. The Passivhaus Classic target of 15 kWh/m²/yr is onerous for this typology and so performance at 20 kWh/m²/yr is shown)

ii) 30 kWh/m²/yr (this is in alignment with the Passivhaus Low Energy Building standard)

4.6.4 The performance required to meet these two levels of fabric efficiency are detailed in the table to the right, along with an indicative strategy.

4.6.5 Unsurprisingly, due to its poorer form factor, higher levels of fabric specification are required for the bungalow to meet the relative space heating demands in comparison to the semi-detached house.



- 134 sqm GIA
- 99 sqm TFA
- 134 sqm building footprint
- 161 sqm external walls
- 30 sqm windows/doors

Figure 4.15 - **Bungalow modelled:** A single bungalow from a typical development has been investigated

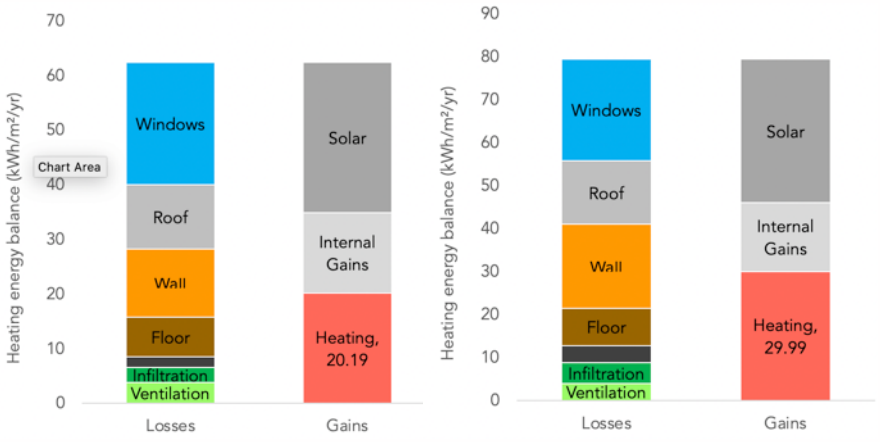


Figure 4.16 - **Space heating demand:** The bungalow would achieve a space heating demand of 20.2 and 30.0 kWh/m²/yr respectively with the specifications outlined below

	Baseline performance for viability	Required performance: 15-20 kWh/m²/yr	Indicative solution (how to achieve the spec)	Required performance: 30 kWh/m²/yr	Indicative solution (how to achieve the spec)
Floor U-value	0.13 W/m²K	0.10 W/m²K	220mm PIR board	0.11 W/m²K	200mm PIR board
Wall U-value	0.18W/m²K	0.10 W/m²K	210mm PIR board with cavity	0.15 W/m²K	210mm mineral wool full-fill
Roof U-value	0.13 W/m²K	0.10 W/m²K	90mm PIR board, rafters with 225mm rockwool in between	0.12 W/m²K	50mm PIR board, rafters with 225mm rockwool in between
Window U-value	1.40 W/m²K	0.90 W/m²K	Triple glazing, argon filled, low-e coatings	0.90 W/m²K	Triple glazing, argon filled, low-e coatings
Thermal bridging	5 kWh/m²/yr	2 kWh/m²/yr	e.g. thermally broken lintels, thermal break at wall base, insulated SVPs.	4 kWh/m²/yr	e.g. reasonable design, thermally broken lintels, thermal break at base of wall.
Ventilation	Continuous extract SFP= 0.25Wh/m³	MVHR 88% heat recovery SFP=0.45Wh/m³	e.g. Zehnder Comfoair Q450	MVHR 88% heat recovery SFP<0.45Wh/m³	e.g. Zehnder Comfoair Q450
Airtightness	<5m³/m²h	<0.60m³/m²h	Airtight layer, service grommets	1.0 m³/m²h	Airtight layer, service grommets

Figure 4.17 – **Bungalow fabric and ventilation specifications**

4.7 Bungalow | Net Zero Carbon technical feasibility | Low carbon heat

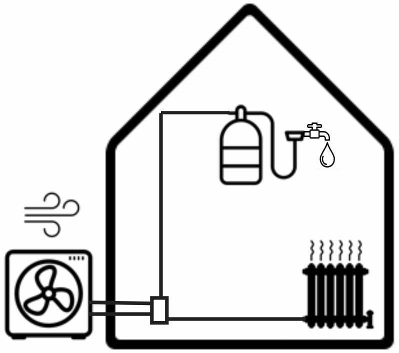
4.7.1 This page focuses on the low carbon heating system and the resulting metered energy use. It is based on a detailed prediction of the total operational energy consumption of this dwelling, using PHPP software.

Metered Energy Use

4.7.2 Total energy use, as measured at the meter, includes not only consumption for space heating and hot water, but all other electrical loads such as lighting, small power and pumps.

4.7.3 The two heating systems most likely to be specified for a semi detached house targeting net zero carbon are an air source heat pump or direct electric heating. The former has an efficiency in converting electrical energy to heat of greater than 100%. For a space heating demand of 15kWh/m^2/y:

- The bungalow would achieve metered energy use of 24kWh/m^2_{GIA} /yr with a standard air source heat pump.
- The bungalow would achieve metered energy use of 40kWh/m^2_{GIA} /yr with direct electric heating. This does not meet the target of 35 kWh/$m2_{GIA}$/yr but does demonstrate good performance; net zero could still be met through maximising on-site generation with careful roof design.



Air source heat pump located on external wall gathers heat from surrounding air

The heat pump alternates between providing space heating and hot water in the dwelling.

Heating system	Air source heat pump	e.g. 5kW Mitsubishi Ecodan
Hot water cylinder	200 litres with losses <1.0 kWh/day	e.g. Mitsubishi heat pump cylinder
Emitters	Wet heating system 3 small radiators	e.g. 450mm x 700mm Stelrad Softline K2

Figure 4.18 - Heating system

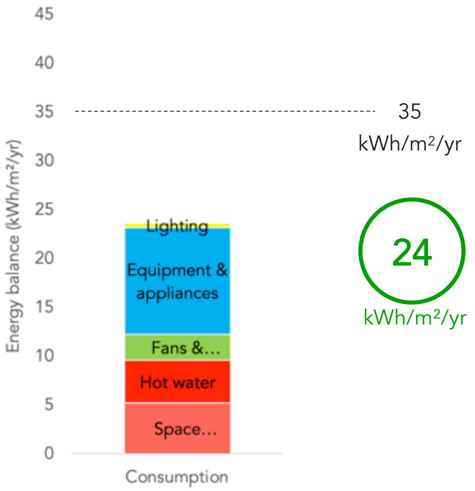
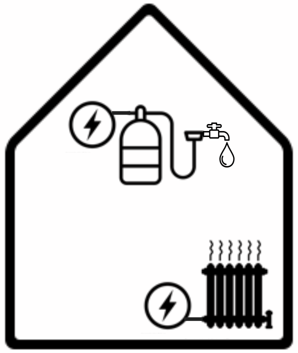


Figure 4.20 - Metered energy use: With an air source heat pump, the bungalow would achieve metered energy use of 24 kWh/m^2/yr



Domestic hot water is provided through an electric immersion heater in a hot water tank.

Space heating is provided by direct electric radiators.

Heating system	Direct electric heating	
Hot water cylinder	210 litres with losses < 0.9 kWh/day	e.g. Dimplex ECSd
Emitters	4 panel heaters	

Figure 4.19 - Alternative heating system

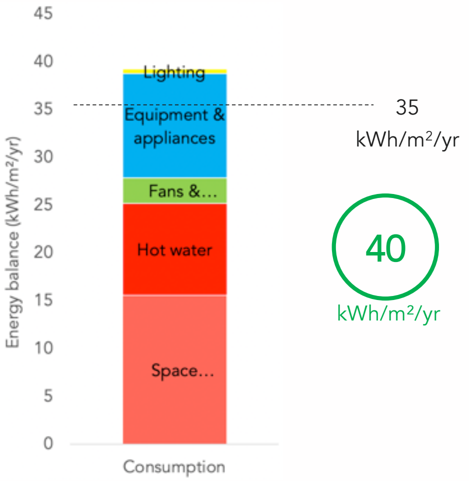


Figure 4.21 - Metered energy use: With direct electric heating, the bungalow would achieve metered energy use of 40 kWh/m^2/yr

4.8 Bungalow | Net Zero Carbon technical feasibility | Renewable energy generation

Solar generation greater than metered energy use

4.8.1 This condition is generally very straightforward to satisfy on low rise buildings, particularly bungalows, as they have a high ratio of roof area to energy consumption.

4.8.2 Ten high efficiency solar panels could be sufficient for the bungalow (with air-source heat pump) to generate as much electricity as it uses over the year. If a direct electric approach to heating was taken 16 panels would be required. However, the roof has space for up to 36 panels, enabling the dwelling to be energy positive.

Discussion on other PV layouts

4.8.3 The example bungalow has an asymmetric south-facing rooftop which is ideal for energy generation from PV. If the dwelling was to follow an east-west orientation a greater number of panels could be installed, with a higher surplus generation even though energy generation per panel would be slightly lower.

Ensuring residents benefit from solar

4.8.4 Residents of single homes with solar panels on the roof benefit from direct consumption of solar electricity and from export tariff payments for exported electricity.

4.8.5 Typically, homes consume around 15-30% of solar energy directly though this can increase to 50-70% with smart control of space and water heating. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat so the heating can be run when solar energy is available and turned down at other times.

4.8.6 Surplus electricity could be used for charging an electric vehicle, which typically require around 3,000 kWh per year. Smart charging of electric vehicles can increase self-consumption of solar electricity above 70%.

Example dwelling

Space heating demand:

20 kWh/m²/yr

Orientation: **South**

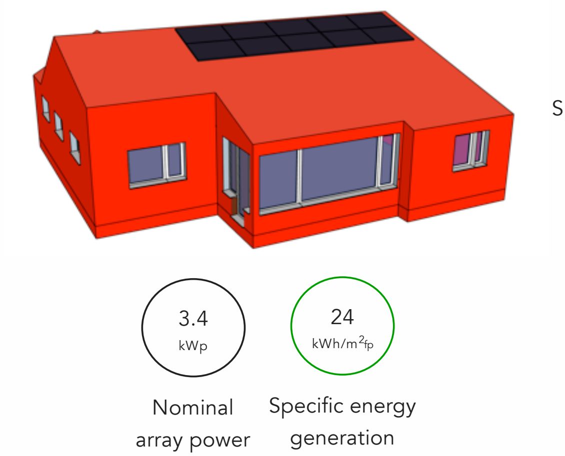


Figure 4.22 - **Minimum solar generation for net zero carbon**: 10 x 340W solar photovoltaic panels would be sufficient to generate at least 24 kWh/m2/yr and therefore achieve net zero carbon (in the case of an air source heat pump heating system).

Figure 4.23 - **Maximising solar generation**: up to 36 solar photovoltaic panels could fit on the south-facing roof and enable the house to be energy positive.

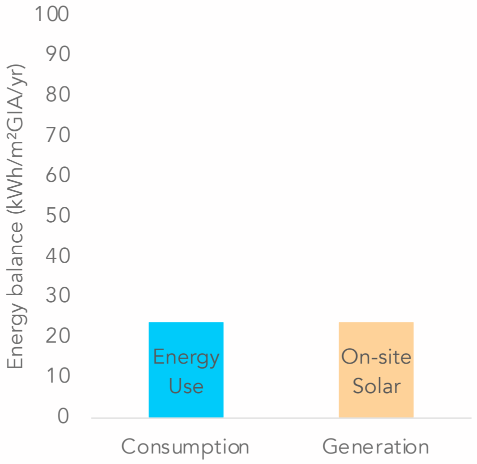


Figure 4.24 - **Net zero energy balance**: The bungalow can easily generate as much solar electricity as it consumes.

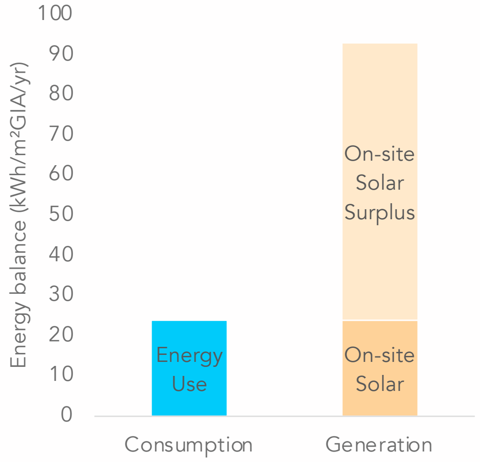
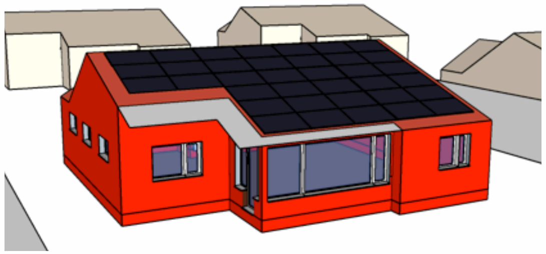


Figure 4.25 - **Net zero energy balance**: The bungalow could be a net producer of clean electricity if PV were maximised.

4.9 Bungalow | Net Zero Carbon technical feasibility | Sensitivity analysis

Example dwelling



Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation	Net zero on-site?*	Potential surplus PV generation (36 panels) kWh/yr
20	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.10 W/m^{2}K 0.10 W/m^{2}K 0.10 W/m^{2}K 0.9 W/m^{2}K 2 kWh/m^2/yr MVHR 88% <0.6m^3/m^{2}h	Air source heat pump: 24	26 kWh/m$^2_{fp}$ (10 panels)	Yes	9,363
			Direct electric: 40	41 kWh/m$^2_{fp}$ (16 panels)	Yes	7,262
30	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.11 W/m^{2}K 0.15 W/m^{2}K 0.12 W/m^{2}K 0.9 W/m^{2}K 4 kWh/m^2/yr MVHR 88% <1.0m^3/m^{2}h	Air source heat pump: 26	28 kWh/m$^2_{fp}$ (11 panels)	Yes	9,033
			Direct electric: 46	47 kWh/m$^2_{fp}$ (18 panels)	Yes	6,331

*due to a high roof area to GIA ratio bungalows can relatively easily generate enough on-site energy to reach net-zero through the installation of a greater number of panels. However bungalows have a poorer form factor and generally require higher levels of fabric performance to meet heating targets.

4.10 Detached house | Net Zero Carbon technical feasibility | Fabric and ventilation

4.10.1 This page focuses on building fabric and ventilation for energy efficiency. It is based on predictions of the space heating demand using PHPP software.

Building form

4.10.2 This page details an example developer spec building form for a four-bed home. Although the design could be optimised further with regard to thermal performance the chosen example is reasonable with a south-facing front. The case study house has a form factor of 2.95.

Space heating demand

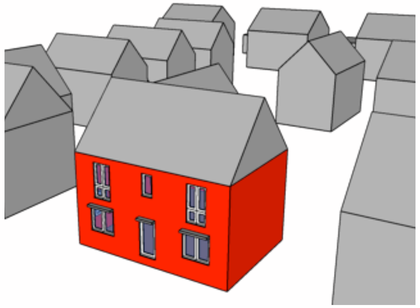
4.10.3 We have tested two levels of building fabric efficiency for this scenario:

i) 15-20 kWh/m²/yr (this is in alignment with the recommendations of the Committee on Climate Change. The Passivhaus Classic target of 15 kWh/m²/yr is onerous for this typology and so performance at 20 kWh/m²/yr is shown)

ii) 30 kWh/m²/yr (this is in alignment with the Passivhaus Low Energy Building standard)

4.10.4 The performance required to meet these two levels of fabric efficiency are detailed in the table to the right, along with an indicative strategy.

4.10.5 Although the detached house has a 'worse' form than the semi-detached with regards to energy efficiency it is an improvement over the single storey bungalow. It is possible to achieve a space heating demand of 30 kWh/m²/yr with double glazing.



- 142 sqm GIA
- 131 sqm TFA
- 84 sqm building footprint
- 185 sqm external walls
- 18 sqm windows/doors

Figure 4.26 - **Detached house modelled:** A single detached house from a typical development has been investigated

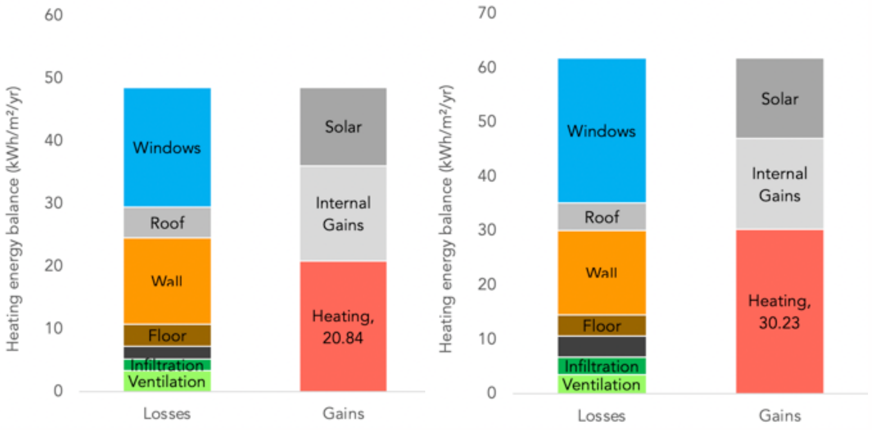


Figure 4.27 - **Space heating demand:** The house would achieve a space heating demand of 20.8 kWh/m²/yr and 30.2 kWh/m²/yr respectively with the specifications outlined below

	Baseline performance for viability	Required performance: 15-20 kWh/m²/yr	Indicative solution (how to achieve the spec)	Required performance: 30 kWh/m²/yr	Indicative solution (how to achieve the spec)
Floor U-value	0.13 W/m²K	0.10 W/m²K	220mm PIR board	0.10 W/m²K	220mm PIR board
Wall U-value	0.18W/m²K	0.13 W/m²K	250mm mineral wool full-fill	0.14 W/m²K	230mm mineral wool full-fill
Roof U-value	0.13 W/m²K	0.10 W/m²K	240mm mineral wool, 150mm timber joists with mineral wool	0.10 W/m²K	240mm mineral wool, 150mm timber joists with mineral wool
Window U-value	1.40 W/m²K	0.90 W/m²K	Triple glazing, argon filled, low-e coatings	1.20 W/m²K	Triple glazing, argon filled, low-e coatings
Thermal bridging	5 kWh/m²/yr	2 kWh/m²/yr	e.g. thermally broken lintels, thermal break at wall base, insulated SVPs.	4 kWh/m²/yr	e.g. reasonable design, thermally broken lintels, thermal break at base of wall.
Ventilation	Continuous extract SFP= 0.25Wh/m³	MVHR 88% heat recovery SFP=0.45Wh/m³	e.g. Zehnder Comfoair Q450	MVHR 88% heat recovery SFP<0.45Wh/m³	e.g. Zehnder Comfoair Q450
Airtightness	<5m³/m²h	<0.60m³/m²h	Airtight layer, service grommets	1.0 m³/m²h	Airtight layer, service grommets

Figure 4.28 – **Detached house fabric and ventilation specifications**

4.11 Detached house | Net Zero Carbon technical feasibility | Low carbon heat

4.11.1 This page focuses on the low carbon heating system and the resulting metered energy use. It is based on a detailed prediction of the total operational energy consumption of this dwelling, using PHPP software.

Metered Energy Use

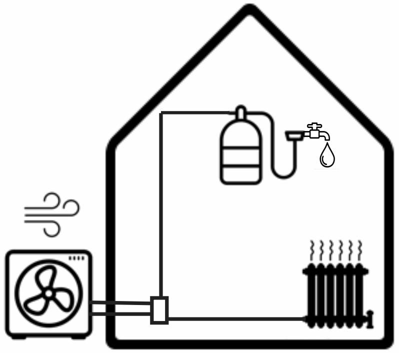
4.11.2 Total energy use, as measured at the meter, includes not only consumption for space heating and hot water, but all other electrical loads such as lighting, small power and pumps.

4.11.3 The two heating systems most likely to be specified for a semi detached house targeting net zero carbon are an air source heat pump or direct electric heating. The former has an efficiency in converting electrical energy to heat of greater than 100%. For a space heating demand of 15kWh/m^2/yr:

- The detached house would achieve metered energy use of 27kWh/m^2_{GIA} /yr with a standard air source heat pump.
- The detached house would achieve metered energy use of 45kWh/m^2_{GIA} /yr with direct electric heating. This does not meet the target of 35 kWh/m2$_{GIA}$/yr but does demonstrate good performance; net zero could still be met through maximising on-site generation with careful roof design.

Air source heat pump located on external wall gathers heat from surrounding air

The heat pump alternates between providing space heating and hot water in the dwelling.



Heating system	Air source heat pump	e.g. 5kW Mitsubishi Ecodan
Hot water cylinder	200 litres with losses <1.0 kWh/day	e.g. Mitsubishi heat pump cylinder
Emitters	Wet heating system 3 small radiators	e.g. 450mm x 700mm Stelrad Softline K2

Figure 4.29 - Heating system

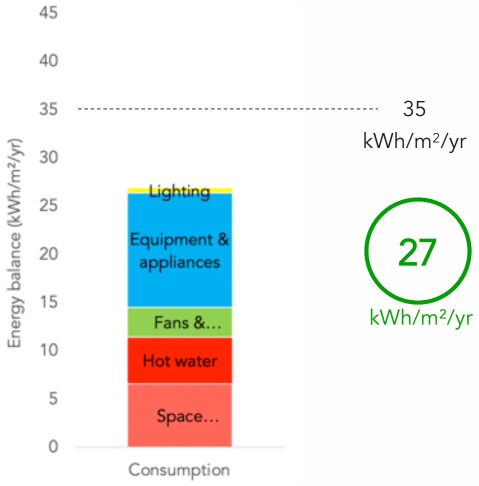
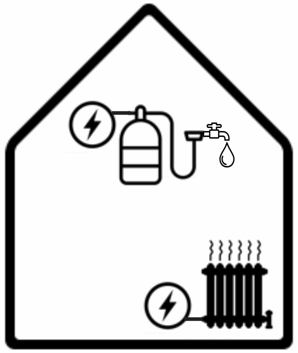


Figure 4.31 - Metered energy use: With an air source heat pump, the detached house would achieve metered energy use of 27 kWh/m^2/yr

Domestic hot water is provided through an electric immersion heater in a hot water tank.

Space heating is provided by direct electric radiators.



Heating system	Direct electric heating	
Hot water cylinder	210 litres with losses < 0.9 kWh/day	e.g. Dimplex ECSd
Emitters	4 panel heaters	

Figure 4.30 - Alternative heating system

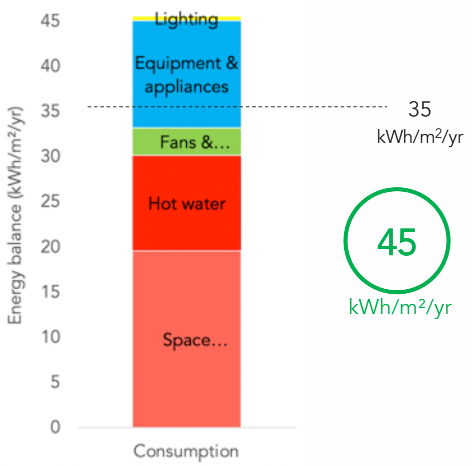


Figure 4.32 - Metered energy use: With direct electric heating, the detached house would achieve metered energy use of 45 kWh/m^2/yr

Solar generation greater than metered energy use

4.12.1 Eleven high efficiency solar panels could be sufficient for the detached house (with air-source heat pump) to generate as much electricity as it uses over the year. If a direct electric approach to heating was taken 18 panels would be required. The roof has space for up to 26 panels, enabling the dwelling to be energy positive.

Discussion on other PV layouts

4.12.2 The example detached house has a large south-facing rooftop, good for PV. Nonetheless, moving the main ridgeline north slightly, creating an asymmetric roof, would easily enable another 5 panels to fit. To maximise the generation on the current roof design, it has been assumed that a small number of panels could also be installed on the east-west pitches to the back of the house.

4.12.3 If the dwelling was to follow an east-west orientation entirely a greater number of panels could be installed, with a higher surplus generation even though energy generation per panel would be slightly lower.

Ensuring residents benefit from solar

4.12.4 Residents of single homes with solar panels on the roof benefit from direct consumption of solar electricity and from export tariff payments for exported electricity.

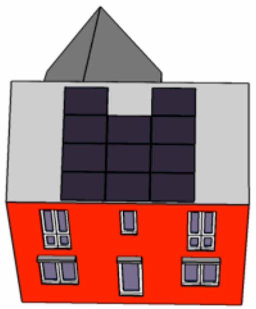
4.12.5 Typically, homes consume around 15-30% of solar energy directly though this can increase to 50-70% with smart control of space and water heating. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat so the heating can be run when solar energy is available and turned down at other times.

4.12.6 Surplus electricity could be used for charging an electric vehicle, which typically require around 3,000 kWh per year. Smart charging of electric vehicles can increase self-consumption of solar electricity above 70%.

Example dwelling

Space heating demand:
20 kWh/m²/yr

Orientation: **South**



3.7 kWp
Nominal array power

48 kWh/m^2_{fp}
Specific energy generation

Figure 4.33 - **Minimum solar generation for net zero carbon:** 11 x 340W solar photovoltaic panels would be sufficient to generate at least 27 kWh/m2/yr and therefore achieve net zero carbon (in the case of an air source heat pump heating system).

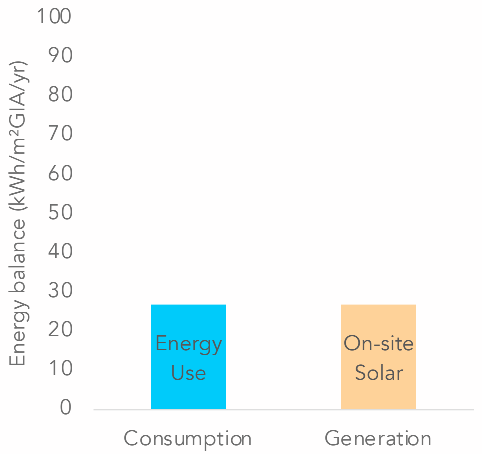
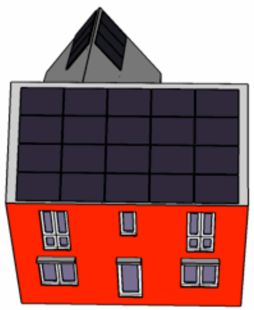


Figure 4.35 - **Net zero energy balance:** The detached house can easily generate as much solar electricity as it consumes.

Example dwelling

Space heating demand:
20 kWh/m²/yr

Orientation: **South**



8.8 kWp
Nominal array power

114 kWh/m^2_{fp}
Specific energy generation

Figure 4.34 - **Maximising solar generation:** for this dwelling up to 26 solar photovoltaic panels could fit on the roof and enable the house to be energy positive.

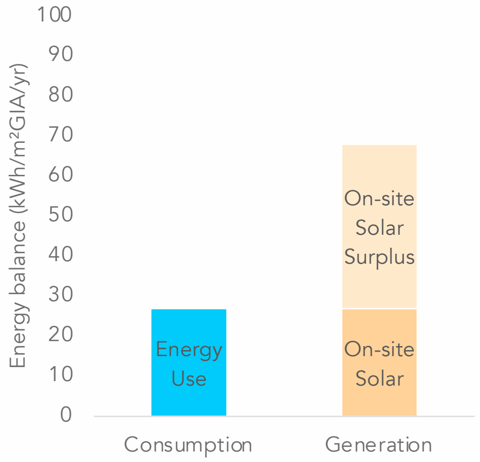
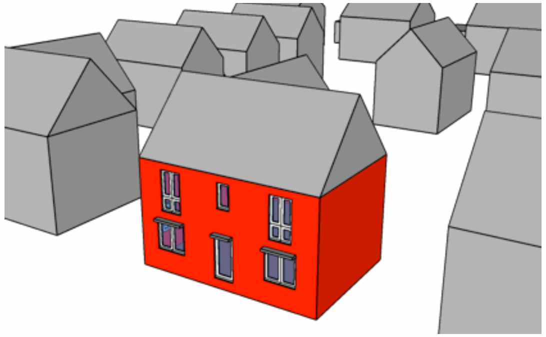


Figure 4.36 - **Net zero energy balance:** The detached house could be a net producer of clean electricity if PV were maximised.

4.13 Detached house | Net Zero Carbon technical feasibility | Sensitivity analysis

Example dwelling



Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation	Net zero on-site?	Potential surplus PV generation (26 panels) kWh/yr
20	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.10 W/m^{2}K 0.13 W/m^{2}K 0.10 W/m^{2}K 0.9 W/m^{2}K 2 kWh/m^2/yr MVHR 88% <0.6m^3/m^{2}h	Air source heat pump: 27	48 kWh/m$^2_{fp}$ (11 panels)	Yes	5,893
			Direct electric: 45	79 kWh/m$^2_{fp}$ (18 panels)	Yes	3,267
30	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.10 W/m^{2}K 0.14 W/m^{2}K 0.10 W/m^{2}K 1.2 W/m^{2}K 4 kWh/m^2/yr MVHR 88% <1.0m^3/m^{2}h	Air source heat pump: 30	53 kWh/m$^2_{fp}$ (12 panels)	Yes	5,462
			Direct electric: 54	92 kWh/m$^2_{fp}$ (21 panels)	Yes	2,059

4.14 Light industrial unit | Net Zero Carbon technical feasibility | Fabric and ventilation

4.14.1 This page focuses on building fabric and ventilation for energy efficiency. It is based on predictions of the space heating demand using PHPP software.

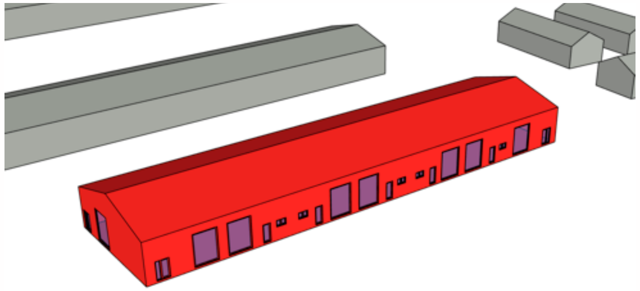
4.14.2 The analysis for the light industrial unit differs from that done for the residential typologies. Light industrial units are unlikely to be airtight often having large sectional doors for vehicle entry etc. A baseline building has been set and a single improved fabric scenario tested against this. We have considered heating to be supplied either by suspended fan heaters or radiant panels.

Building form

4.14.3 This page details an example developer spec for a light industrial building. The building contains 9 individual units, each with a large sectional door, an office and a WC. The units are single storey with a pitched roof and high clearance (over 5 metres). The light industrial unit has a form factor of 3.17.

Space heating demand

4.14.4 We have not tested a particular space heating target for the light industrial unit. Throughout the heating season it is assumed to be heated to meet an internal temperature of 18°C, although in practice this would vary depending on the level of activity or the nature of any stored materials. Due to the large internal air volume and limited air-tightness assumed a space heating demand of 78 kWh/m²/yr is achieved with improved fabric. The fabric could be improved further but the suitability of such efforts would depend on the intended use of the space and heating strategy (i.e. convective versus radiant).



- 977 sqm GIA
- 938 sqm TFA
- 1,032 sqm building footprint
- 728 sqm external walls
- 107 sqm windows/doors

Figure 4.37 - **Light industrial unit modelled:** The example building is based on a recent planning application

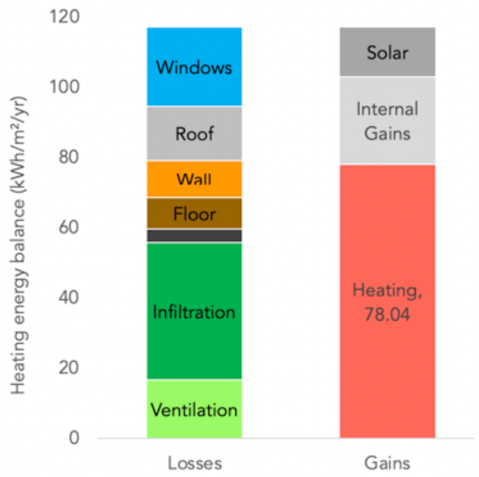


Figure 4.38 - **Space heating demand:** The light industrial unit would achieve a space heating demand of 78 kWh/m²/yr with the specification outlined below

	Baseline performance for viability testing	Improved performance	Indicative solution (how to achieve the spec)
Floor U-value	0.25 W/m²K	0.20 W/m²K	220mm PIR board
Wall U-value	0.35W/m²K	0.20 W/m²K	250mm mineral wool full-fill
Roof U-value	0.25 W/m²K	0.20 W/m²K	240mm mineral wool, 150mm timber joists with mineral wool in between
Window U-value	2.20 W/m²K	1.20 W/m²K	High spec double glazing
Thermal bridging	5 kWh/m²/yr	4 kWh/m²/yr	Thermally broken lintels and low conductivity wall ties.
Ventilation	Continuous extract ventilation SFP = 0.25Wh/m³	Continuous extract ventilation SFP = 0.25Wh/m³	
Airtightness	<10m³/m²h	<5m³/m²h	Airtight layer considered, use of sealants

Figure 4.39 – **Light industrial unit fabric and ventilation specifications**

4.15 Light industrial unit | Net Zero Carbon technical feasibility | Low carbon heat

4.15.1 This page focuses on the low carbon heating system and the resulting metered energy use. It is based on a detailed prediction of the total operational energy consumption of this building type, using PHPP software.

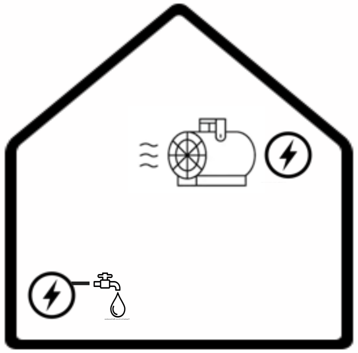
4.15.2 Energy use of light industrial buildings can vary significantly depending on how the space is used. In our model we have assumed the units to be predominantly warehouse facilities with a small onsite office (i.e. no high load from specialist machinery). Heating is supplied either by suspended fan heaters or radiant panels.

Metered Energy Use

4.15.3 The two heating systems most likely to be specified for a light industrial unit are fan heaters or radiant heaters. The choice of system is likely to be dictated by the specific application of the space. To align with a low carbon heating strategy it is assumed both options are run from electricity (i.e. no gas use). For a space heating demand of 78kWh/m²/yr:

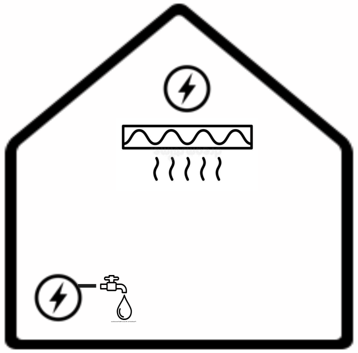
- The light industrial unit would achieve metered energy use of 110kWh/m^2_{GIA}/yr with convective fan heating.
- The light industrial unit would achieve metered energy use of 105kWh/m^2_{GIA}/yr with radiant panel heating.

4.15.4 In reality the energy consumption from equipment and appliances might be more significant. It is not uncommon for light industrial units to be converted into offices or used as workshops, either of which would result in greater plug-in loads. Cooling may also be required for an office environment, workshop, or if the space is used for sensitive storage. Conversely, units with low occupancy levels or high activity may require less heating.



Heating system	Electric fan heater	e.g. 9 x 5kW ceiling suspended heaters
Hot water	Point of use water heater	

Figure 4.40 - Heating system: Convective heating is provided by suspended fan heaters



Heating system	Electric radiant panels	e.g. 65 x 1kW ceiling suspended panels
Hot water	Point of use water heater	

Figure 4.41 - Alternative heating system: Radiant heating is provided by electric panel heaters

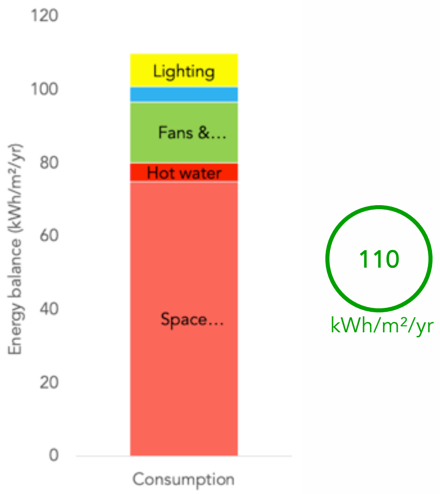


Figure 4.42 - Metered energy use: With electric fan heating, the light industrial unit would achieve metered energy use of 110 kWh/m²/yr

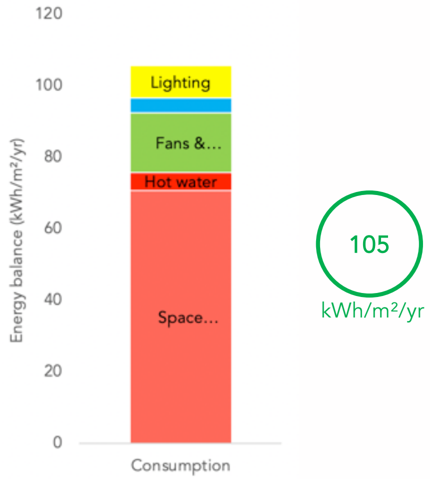


Figure 4.43 - Metered energy use: With electric radiant heating, the light industrial unit would achieve metered energy use of 105 kWh/m²/yr

4.16 Light industrial unit | Net Zero Carbon technical feasibility | Renewable energy generation

Solar generation greater than metered energy use

4.16.1 This condition is generally very straightforward to satisfy on low rise buildings as they have a high ratio of roof area to energy consumption.

4.16.2 Three hundred and forty one high efficiency solar panels would be sufficient for the modelled light industrial unit to generate as much electricity as it uses over the year. This assumes approximately two-thirds of the roof area is covered in panels.

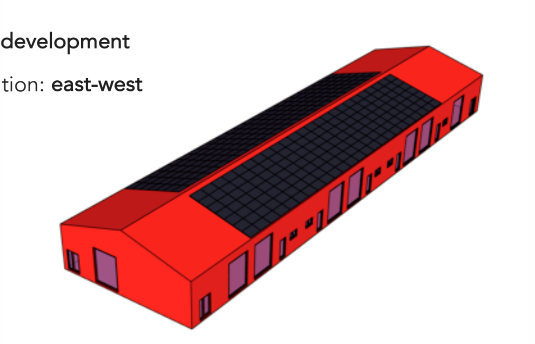
Discussion on other PV layouts

4.16.3 As with the domestic build types, generation from PV can be maximised by selecting an east-west orientation, or designing an asymmetric south-facing roof.

4.16.4 For the unit modelled, an asymmetric roof would enable generation in excess of 163 kWh/m$^2_{fp}$. For context, this surpasses the 120 kWh/m$^2_{fp}$ renewable energy target required for Passivhaus Premium buildings.

Typical development

Orientation: **east-west**



116 kWp
Nominal array power

104 kWh/m$^2_{fp}$
Specific energy generation

Figure 4.44- **Minimum solar generation for Net Zero Carbon:** 341 x 340W solar photovoltaic panels would be sufficient to achieve net zero carbon for the modelled unit.

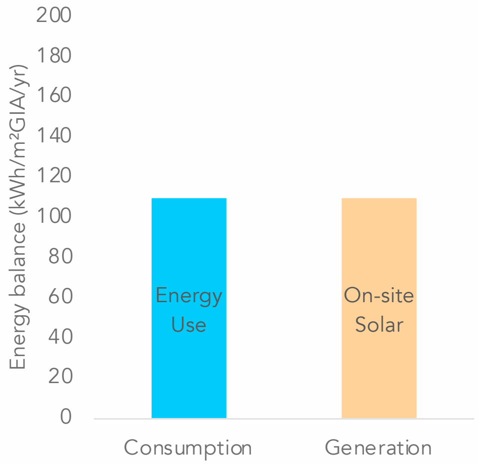
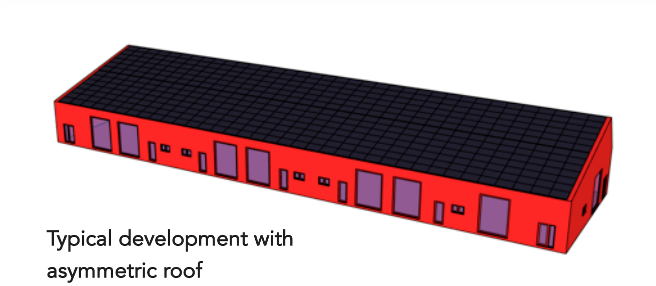


Figure 4.46 - **Net zero energy balance:** The light industrial unit can easily generate as much solar electricity as it consumes.



Typical development with asymmetric roof

Orientation: **south**

159 kWp
Nominal array power

163 kWh/m$^2_{fp}$
Specific energy generation

Figure 4.45 - **Maximising solar generation:** 468 x 340W solar photovoltaic panels would enable the light industrial unit to generate significant surplus energy.

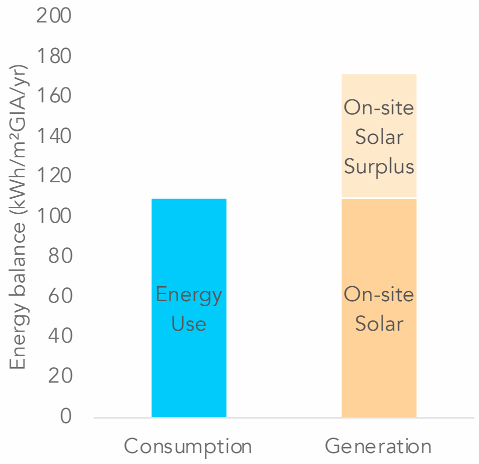
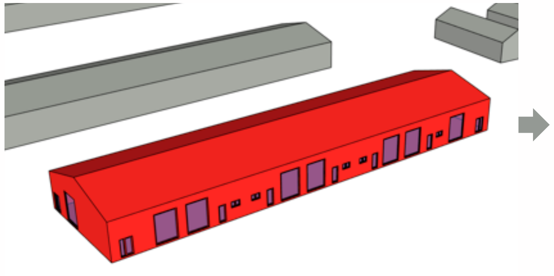


Figure 4.47 - **Net zero energy balance:** The light industrial unit could be a net producer of clean electricity.

4.17 Light industrial unit | Net Zero Carbon technical feasibility | Sensitivity analysis

Typical development



Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation	Net zero on-site?*	Potential surplus PV generation (468 panels) kWh/yr
78	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.20 W/m^2K 0.20 W/m^2K 0.20 W/m^2K 1.2 W/m^2K 4 kWh/m^2/yr 0.25 Wh/m^3 <5 m^3/m^2h	Electric fan heater: 110	104 kWh/m^2_{fp} (341 panels)	Yes	61,197*
			Electric radiant panel: 105	100 kWh/m^2_{fp} (328 panels)	Yes	64,372*

*This surplus energy generation is is equivalent to the annual consumption of approximately 20 low-energy dwellings.

4.18 School | Net Zero Carbon technical feasibility | Fabric and ventilation

4.18.1 This page focuses on building fabric and ventilation for energy efficiency. It is based on predictions of the space heating demand using PHPP software.

Building form

4.18.2 This page details an example developer spec building form for a primary school. This school has a form factor of 2.32.

Space heating demand

4.18.3 The building fabric and ventilation systems summarised on this page comfortably achieve a space heating demand of less than 15 kWh/m²/yr, in line with best practice levels of fabric efficiency.

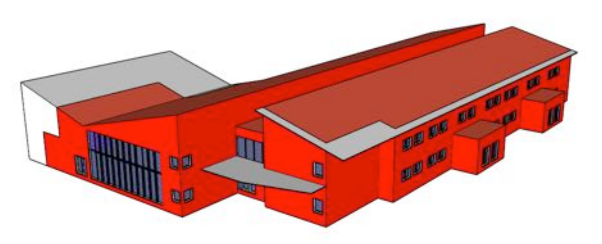
4.18.4 Excellent levels of thermal performance are achieved through good levels of insulation, triple glazing, thermal bridge free junctions, airtight construction and a mechanical ventilation system with heat recovery.

Alternative designs and specifications

4.18.5 The baseline building was not designed to be a low energy building. As it has a good form factor it is possible to achieve a space heat demand of under 15kWh/m2/yr without relying on excessively high specification materials or products.

4.18.6 Better design could maintain current performance but reduce cost. For example, reducing glazed areas on Northern facades or combining split windows into single windows would reduce heat loss, improving energy performance.

4.18.7 A building such as this should be able to achieve similar levels of performance in different orientations, providing the glazing proportions are adjusted on each façade to make the most of useful solar gains.



- 3,280 sqm GIA
- 2,630 sqm TFA
- 1,940 sqm building footprint
- 1,828 sqm external walls
- 281 sqm windows/doors/rooflights

Figure 4.48 – **School modelled:** A typical primary school building has been investigated.

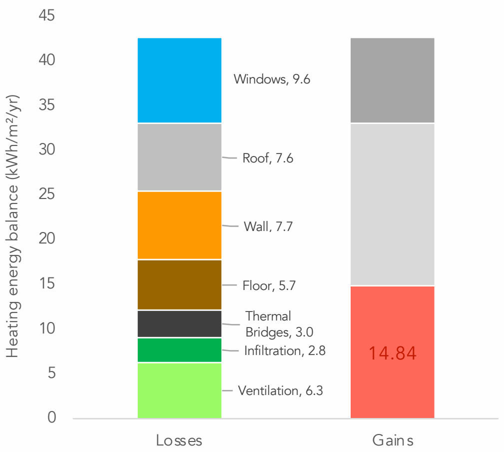


Figure 4.49 - **Space heating demand:** The school would achieve a space heating demand of 15 kWh/m²/yr with the specifications below

	Baseline performance for viability testing	Required performance	Indicative solution (how to achieve the specs)
Floor U-value	0.60 W/m²K	0.15 W/m²K	140mm PIR insulation
Wall U-value	0.18 W/m²K	0.13 W/m²K	270mm Mineral wool
Roof U-value	0.15 W/m²K	0.12 W/m²K	320mm EPS insulation
Window U-value	1.55 W/m²K	0.95 W/m²K	Triple glazing with low-e coatings and warm edge spacers
Thermal bridging	5 kWh/m²/yr	3 kWh/m²/yr	Good design, thermally broken lintels and wall ties. Thermal break at base of wall or insulation wrap around slab edge.
Ventilation	Continuous extract ventilation SFP < 0.24Wh/m³	MVHR 80% heat recovery SFP < 0.45Wh/m³	Commercial ventilation unit with heat recovery
Airtightness	<5m³/m²h	<0.65m³/m²h	Airtight layer, tape and service grommets

Figure 4.50 – **School fabric and ventilation specifications**

4.19 School | Net Zero Carbon technical feasibility | Low carbon heat

4.19.1 This page focuses on the low carbon heating system and the resulting metered energy use. It is based on a detailed prediction of the total operational energy consumption, using PHPP software.

Metered Energy Use

4.19.2 Total energy use, as measured at the meter, includes not only consumption for space heating and hot water, but all other electrical loads such as lighting, small power and pumps.

4.19.3 The RIBA 2030 Climate Challenge provides a target of 55kWh/m^2 /yr of energy use for non-domestic buildings.

4.19.4 The two heating systems most likely to be specified for a school targeting Net Zero Carbon are an air source heat pump or ground source heat pump. For the fabric and ventilation specifications described on the previous page:

- The school would achieve metered energy use of 38kWh/m$^2_{GIA}$ /yr with a standard air source heat pump
- The school would achieve metered energy use of 35kWh/m$^2_{GIA}$ /yr with a ground source heat pump

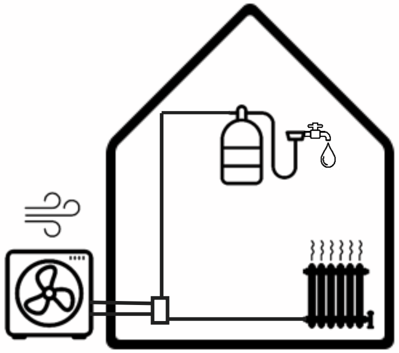
Discussion on other heating systems

4.19.5 The main other type of heat pump that could be used to achieve net zero carbon is an air-air heat pump, commonly known as VRF air conditioning. These can efficiently shuttle heat between different parts of the building and provide cooling as well as heating.

A dedicated heat pump water heater is another option, which would provide hot water only.

Air source heat pump located on external wall gathers heat from surrounding air

The heat pump alternates between providing space heating and hot water in the dwelling.



Heating system	Air source heat pump	e.g. 2 x 14kW Mitsubishi Ecodan
Hot water cylinder	2 x 250 litres with losses <1.6 kWh/day	e.g. Mitsubishi heat pump cylinder
Emitters	Wet heating system 40 x radiators	e.g. 450mm x 900mm Stelrad Softline K2

Figure 4.51 - Heating system

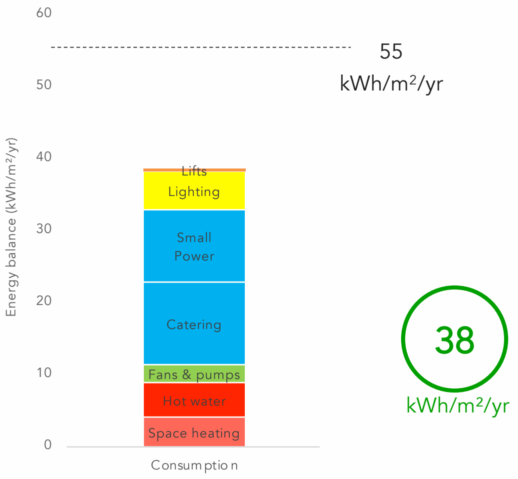
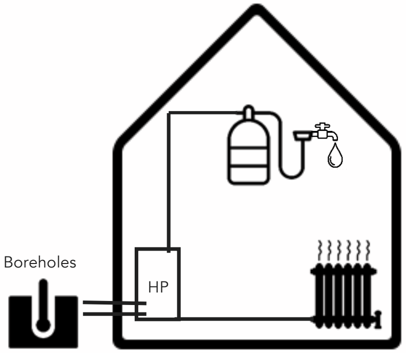


Figure 4.53 - Metered energy use: with an air source heat pump, the school would achieve metered energy use of 38 kWh/m^2/yr, compliant with Net Zero Carbon

Ground source heat pump located in plant room gathers heat from borehole array

The heat pump alternates between providing space heating and hot water in the building.



Heating system	Ground source heat pump	e.g. 24kW Kensa Twin Compact
Hot water cylinder	2 x 250 litres with losses <1.6 kWh/day	e.g. Generic heat pump cylinder
Emitters	Wet heating system 40 x radiators	e.g. 450mm x 900mm Stelrad Softline K2

Figure 4.52 - Alternative heating system

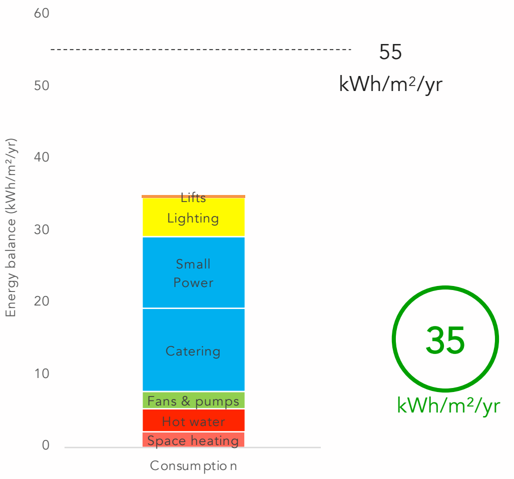


Figure 4.54 - Metered Energy Use: with a ground source heat pump, the school would achieve metered energy use of 35 kWh/m^2/yr, compliant with Net Zero Carbon

4.20 School | Net Zero Carbon technical feasibility | Renewable energy generation

Solar generation greater than metered energy use

4.20.1 A total of 376 high efficiency solar panels would be required for the school to generate as much electricity as it uses over the year.

4.20.2 The roof has space for up to 754 panels, split between the east and west sides. Installing these and specifying even higher power 370W panels would almost double energy generation and enable the school to become energy positive.

Discussion on other PV layouts

4.20.3 The school's roof faces south west. Orientating the building to face east/west would be optimum.

4.20.4 The main risks to being able to install sufficient solar capacity to achieve net zero is through roof design that incorporates large terraced areas, skylights, or rooftop services that prevent installation of panels.

Ensuring occupants benefit from solar

4.20.5 Owners of schools with PV on the roof benefit from direct consumption of solar electricity and from export tariff payments for exported electricity.

4.20.6 Direct consumption of solar electricity in schools can be highly variable, depending on how the building is managed and used both within term time, and at other times of the year. Smart control of space and water heating offers the potential to maximise direct consumption. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat; heating can be run when solar energy is available and turned down at other times.

4.20.7 Surplus electricity could be used for charging staff owned electric vehicles, which typically require around 2,500 kWh per year. Smart charging of electric vehicles could increase self-consumption to high levels.

Typical development

Orientation: **south west**

Figure 4.55 - **Minimum solar generation for Net Zero Carbon:** 384 x 340W solar photovoltaic panels would be sufficient to generate 38 kWh/m2/yr and therefore achieve Net Zero Carbon

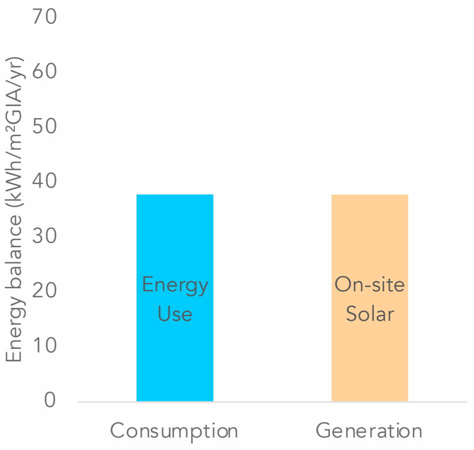


Figure 4.57 - **Net zero energy balance:** The school can generate as much solar electricity as it consumes with a south-west facing 376 panel solar array.

Typical development

Orientation: **east-west**

Figure 4.56- **Maximising solar generation:** 754 x 370W solar photovoltaic panels would enable the school to be energy positive. On an annual basis, it would generate 215% of the annual energy it will consume.

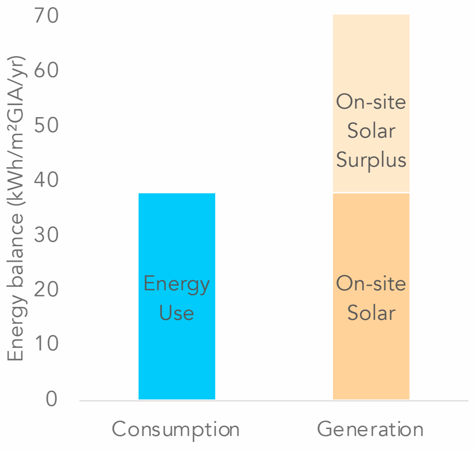
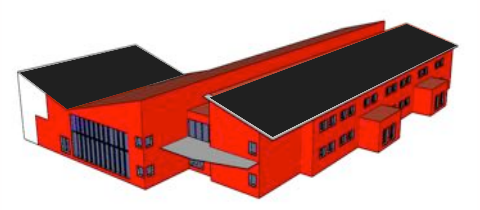


Figure 4.58 - **Net zero energy balance:** The school is a net producer of clean electricity with east and west facing solar arrays.

4.21 School | Net Zero Carbon technical feasibility | Sensitivity analysis

Typical development



Space heating demand kWh/m^2/yr	Fabric and ventilation specification		Metered energy use kWh/m^2/y	PV generation	Net zero on-site?*	Potential surplus PV generation (754 panels) kWh/yr
15	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.15 W/m^{2}K 0.13 W/m^{2}K 0.12 W/m^{2}K 0.95 W/m^{2}K 3 kWh/m^2/yr MVHR 80% <0.65 m^3/m^{2}h	Air source heat pump: 38	63 kWh/m$^2_{\text{fp}}$ (384 panels)	Yes	99,958
			Ground source heat pump: 35	57 kWh/m$^2_{\text{fp}}$ (348 panels)	Yes	111,710

Task G

Technical Feasibility

5.0 Other building types

This section explores the potential for a variety of other building types that were not modelled to achieve net zero carbon. This is achieved through application of low energy building principles and use of case studies where available.

5.1 Technical Feasibility | Case Studies and Design Principles

Introduction

5.1.1 There are a number of common building types in Central Lincolnshire that have not been modelled. These building types vary widely, making it difficult to reliably determine generic forms, energy consumption or occupancy models.

5.1.2 We have researched and suggested provisional energy performance targets for these building types, based on limited benchmark data and built examples, which we have summarised in this section. However, further work is required to determine if these targets are appropriate to be implemented through policy.

Case Study Types

5.1.3 This section looks at case studies for the following typologies:

Offices

Multi-residential Blocks

Student Accommodation

Small Retail Units

Leisure Centres

Research Facilities

Existing Buildings

Figure 5.1 - There are a wide variety of building types in Central Lincolnshire beyond the five we have modelled for this evidence base. © University of Lincoln

5.1.4 For each type, we have considered five areas of performance required to achieve a net zero carbon building:

1 – Type specific considerations

We have described typical features for each type that are relevant to the energy performance, though the design and layout of buildings varies widely, even within a particular type.

2 - Building Fabric

A target for space heating demand is provided and, where relevant, cooling demands, glazing percentage and any risks related to the building's fabric, such as overheating.

3 - Heating System

Options for low carbon systems for space heating and domestic hot water are considered for each building type.

4 - Renewable Energy

Targets for solar energy generation are considered, based on the building footprint.

5 – Net Zero Carbon Feasibility

An indicative target for total energy use is established and compared to renewable generation to determine if the building type is likely to be able to achieve net zero carbon on site.

5.2 Net Zero Carbon for an office I Technical summary and recommendations

1 - Type specific considerations

5.2.1 Offices tend to have long cooling seasons due to their relatively high internal space loads.

Highly glazed facades are common in new build offices. Speculative offices often have higher internal design loads than owner occupied in order to make provision for the widest possible range of potential occupiers. This can lead to oversized and inefficient plant sizing for most occupiers.

2 - Building Fabric

5.2.2 Building fabric performance should target a space heating demand of 15kWh/m². Glazing should be between 25 and 40% of the façade (all elevations) with solar shading and separate VDU users' glare control.

5.2.3 Effective solar control enables low impact mechanical cooling systems to be used, where comfort cooling is required.

3 - Heating System

5.2.4 Heat pumps – whether ground or air source – or a Variable Refrigerant Volume system, if a low Ozone Depletion Potential and low Global Warming Potential refrigerant can be used.

4 - Renewable Energy

5.2.5 Solar photovoltaic arrays to generate minimum 120kWh/m²/yr (footprint).

5 - Net Zero Carbon Feasibility

5.2.6 Two-storey office buildings can achieve net zero carbon through a combination of Passivhaus levels of fabric efficiency, heat pumps and best practice solar photovoltaic technology. Taller buildings may also need some off site renewable energy.

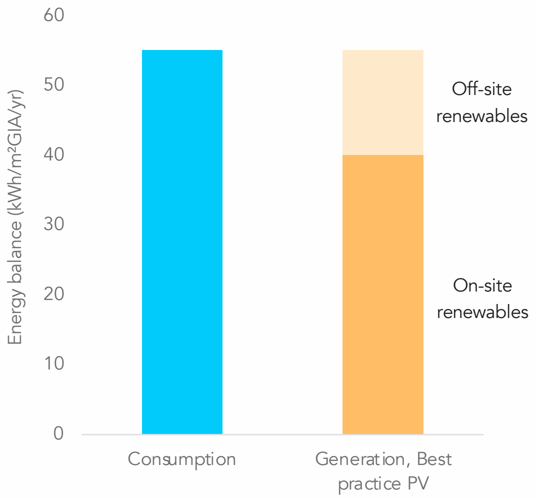


Figure 5.2 - Typical net energy balance for a 3-storey office building, best practice efficiency

Provisional Targets

55 kWh/m²$_{GIA}$/yr	>120 kWh/m²$_{FP}$/yr
Total energy consumption	Solar generation

Case study examples

Carbon Negative Office - Passivhaus certified net energy positive office in Watermead Business Park, Leicestershire

BSD Office - 420m² Passivhaus certified office in Kettering with total energy use of 104 kWh/m²

Enterprise Centre - 3,400m² Passivhaus certified office in Norwich with total energy use of 70 kWh/m²

Canolfan Hyddgen - 400m² Passivhaus certified office in Machynlleth with total energy use of 95 kWh/m²

National Energy Foundation - 430m² low energy office in Milton Keynes with total energy use of 81 kWh/m²

Tour Elithis - 5,000m² net energy positive office in Dijon

5.3 Net Zero Carbon for a block of flats I Technical summary and recommendations

1 - Type Specific Considerations

5.3.1 The feasibility of achieving net zero on-site depends on the height of the block. For example, a 10-storey block of flats may be similar in layout to a 4-storey block of flats, but there will be two main differences:

- The form factor will reduce
- The roof area per flat will be smaller.

2 - Building Fabric

5.3.2 Due to the improved form factor, heat loss per flat will be reduced compared to housing. Reduced floor, wall or roof U-values may be acceptable to achieve the same space heating demand.

5.3.3 Glazing should be minimised on North elevations, 10% to 15% on East or West elevations, and can be higher for South elevations if there is good solar control. Overheating is a significant risk as these are high density buildings and likely to be located in noisy urban areas.

3 - Heating System

5.3.4 Communal air or ground source heat pumps are good candidates for medium to high density residential buildings to provide low carbon heat. Ambient Loop configurations reduce distribution losses and can support active cooling on sites where overheating may be an issue.

4 - Renewable Energy

5.3.5 Solar photovoltaic arrays to generate minimum 120kWh/m²/yr (footprint).

5 - Net Zero Carbon Feasibility

5.3.6 The ability to achieve net zero carbon on site will be limited by the roof area per flat. It is likely that a 3, 4 or 5-storey block of flats will be able to generate as much electricity as it consumes.

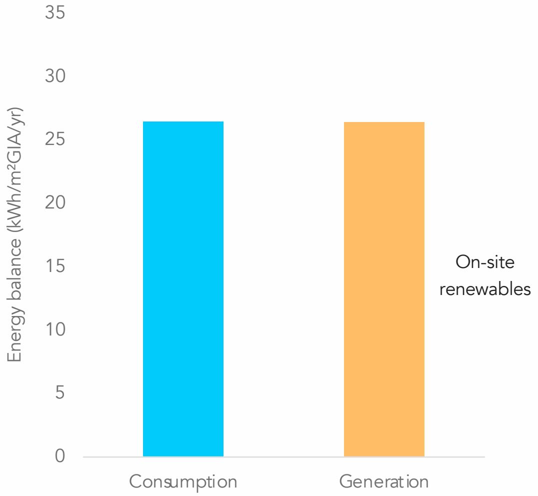


Figure 5.3 - Typical net energy balance for a 4-storey block of flats, best practice efficiency

Provisional Targets

35 $kWh/m^2{}_{GIA}/yr$

Total energy consumption

>120 $kWh/m^2{}_{FP}/yr$

Solar generation

Case study examples

Agar Grove Phase 1 - 38 Passivhaus Certified apartments in , Camden, London

Chester Balmore - 53 Passivhaus Certified residential units in Camden, London

5.4 Net Zero Carbon for a student block I Technical summary and recommendations

1 - Type Specific Considerations

5.4.1 Student accommodation is comparable to blocks of flats, though some differences in proportions of energy by end use are expected. Student accommodation typically has high occupancy, fewer kitchens and more bathrooms and therefore more hot water usage. The overall energy intensity is not expected to be substantially different from a block of flats.

2 - Building Fabric

5.4.2 Glazing should be minimised on North elevations, 10% to 15% on East or West elevations, and can be higher for South elevations if there is good solar control. Overheating is a significant risk as these are high density buildings

3 - Heating System

5.4.3 Communal air or ground source heat pumps are the best option to provide low carbon heat, although direct electric heating may be possible if the fabric performance is exemplary.

5.4.4 Hot water generation is a key issue in these buildings. Centralised 'hotel' type strategies may provide the best approach but distribution losses will be critical and the physical configuration of central stores relative to end uses should be analysed in detail on a per building basis.

4 - Renewable Energy

5.4.5 Solar photovoltaic arrays to generate minimum 120kWh/m^2/yr (footprint).

5 - Net Zero Carbon Feasibility

5.4.6 These buildings are generally low rise and should be able to achieve net zero carbon through a combination of Passivhaus levels of fabric efficiency, heat pumps and best practice solar photovoltaic technology.

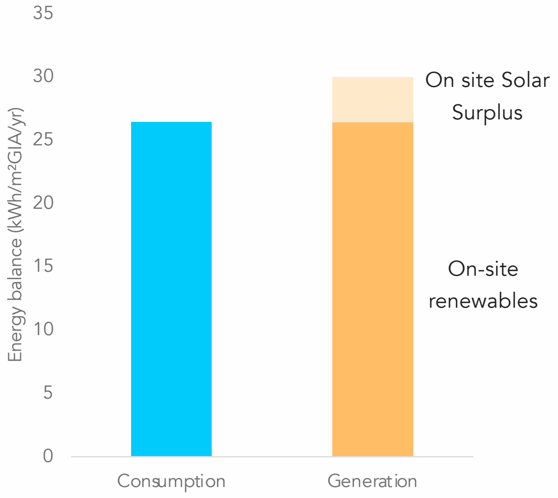


Figure 5.4 - Typical net energy balance for four storey student accommodation, best practice efficiency

Provisional Targets

35

kWh/m$^2_{GIA}$/yr

Total energy consumption

>120

kWh/m$^2_{FP}$/yr

Solar generation

Case study examples

The House, Cornell Tech, USA - Passivhaus certified 26 storey student accommodation with 352 units

Garden House, Kings College Cambridge - Proposed Passivhaus certified student accommodation

5.5 Net Zero Carbon for small retail units I Technical summary and recommendations

1 - Type Specific Considerations

5.5.1 Retail units vary from small kiosks to large superstores. Energy demand can vary widely depending on the type of store. Supermarkets, for example, use a lot of energy for refrigeration. If energy efficiency measures compromise sales retailers will reject them, therefore appropriate measures must be carefully planned.

2 - Building Fabric

5.5.2 Building fabric performance should target a space heating demand of 15-30kWh/m^2. Further research is required to establish whether there may be specific challenges to achieving this in some buildings, for example due to high traffic entrance doors or loading bays.

5.5.3 Food refrigeration may introduce additional challenges due to additional heat load if equipment is all located within the building.

3 - Heating System

5.5.4 Heat pumps with low Ozone Depletion Potential and low Global Warming Potential refrigerants both for space heating and cooling, and for refrigeration of food.

4 - Renewable Energy

5.5.5 Solar photovoltaic arrays to generate up to 200kWh/m^2/yr (footprint) are likely to be appropriate and achievable for stores with higher energy demands.

5 - Net Zero Carbon Feasibility

5.5.6 Typical high street retail units without large refrigeration loads should be able to achieve net zero carbon with relative ease. Stores with large specialised loads are less likely to be able to achieve net zero on site. Further research is required to determine appropriate classes of store and associated total energy consumption and renewable energy generation targets.

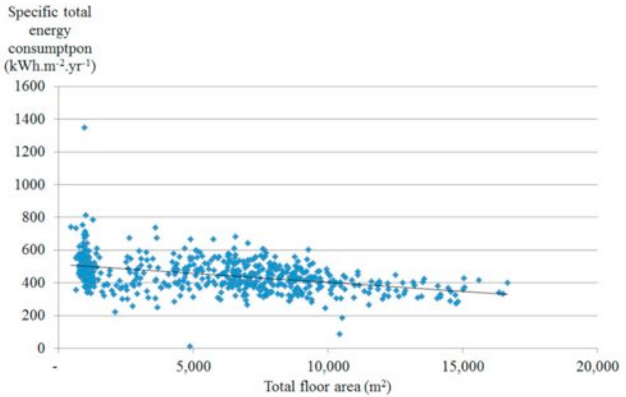


Figure 5.5 - Specific total energy consumption in 2015 for 565 supermarket stores – highly variable. M Kolokotroni et al (2019) Supermarket Energy Use in the UK. Energy Procedia 161.

Provisional Targets

55+
kWh/m$^2_{GIA}$/yr

Total energy consumption

<200
kWh/m$^2_{FP}$/yr

Solar generation

Case study examples

REWE Supermarket – The first Passivhaus supermarket in Germany was created in 2014 in Hanover. It has a space heat demand of just 12kWh/m^2/yr and uses 30% less energy than a conventional supermarket. ©PassREg

TESCO Eco Store – The first Passivhaus supermarket in the world was created in 2008 in Tramore, Ireland. It has solar photovoltaic panels and a ground source heat pump that provides water heating from waste heat taken from the cooling cabinets. ©Joseph Doyle Architects

5.6 Net Zero Carbon for a leisure centre | Technical summary and recommendations

1 - Type Specific Considerations

5.6.1 Leisure Centres generally will have large deep plan, artificially lit spaces as a necessary part of the function, requiring extensive ventilation systems. Best can deliver very substantial savings in energy use compared to standard design practice.

2 - Building Fabric

5.6.2 Key to energy efficient swimming pools is to maintain high humidity in the pool hall to suppress evaporation of pool water. Maintenance of high internal surface temperatures including of glazing is essential to avoid excessive condensation. Air tightness, elimination of thermal bridges and glazing U values are key performance measures.

5.6.3 For other sports facilities, efficient heat recovery in ventilation systems, measures to limit fan power and a predominantly radiant heating delivery can maximise performance.

3 - Heating System

5.6.4 Air or ground source heat pumps are a good source of low carbon heat for both pools and for other general leisure spaces.

5.6.5 The temperatures at which swimming pools operate are a particularly good match for waste heat recovery applications.

4 - Renewable Energy

5.6.6 Solar photovoltaic arrays up to 200kWh/m2/yr are likely to be appropriate and achievable for buildings with higher energy demands.

5 - Net Zero Carbon Feasibility

5.6.7 Leisure Centres without swimming pools should be able to achieve net zero carbon on site. Where swimming pools form part of the centre, unless there is a local source of waste heat, some off site renewables are likely to be necessary

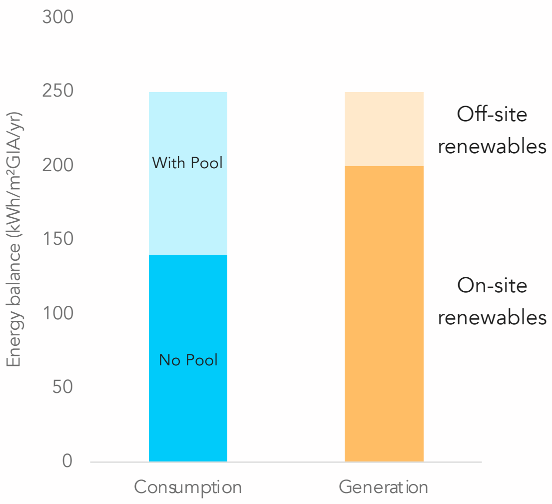


Figure 5.6 - Indicative net energy balance for a leisure centre with and without a pool. Energy use based on Passivhaus Institute recommendations, and assuming use of a heat pump.

Provisional Targets

<250 kWh/m$^2_{GIA}$/yr

Final energy Consumption (with pool)

<200 kWh/m$^2_{FP}$/yr

Solar generation

Case study examples

Lippe Bad Lünen Pool – This Passivhaus Certified leisure complex in Germany has 3 indoor pools and 1 outdoor pool. It opened in 2011.

St Sidwell's Point – This 4,850m^2 leisure centre in Exeter is aiming to be Passivhaus certified.

5.7 Net Zero Carbon for a research facility | Technical summary and recommendations

1 - Type Specific Considerations

5.7.1 Research facilities are superficially similar to offices as a building type, but where there are fume cupboard laboratories in the building, these substantially increase the overall energy demand. Research Facilities are most often part of University or other education institutions and therefore they generally also have teaching spaces and ancillary accommodation.

2 - Building Fabric

5.7.2 Building fabric performance should target a space heating demand of 15kWh/m² and an overall EUI of 100kWh/m² with particular attention required to energy efficient ventilation heat recovery and mechanical cooling systems.

5.7.3 Where there are laboratories with fume cupboards these should incorporate best practice control systems such as automated sash closing to minimum opening and night time set back ventilation rates. Other processes should be carefully considered in terms of heat recovery and out of hours operation conditions to limit energy waste mechanical ventilation rates to empty buildings.

3 - Heating System

5.7.4 Heat pumps – whether ground or air source – or a Variable Refrigerant Volume system, if a low Ozone Depletion Potential and low Global Warming Potential refrigerant can be used.

4 - Renewable Energy

5.7.5 Solar photovoltaic arrays to generate up to 180kWh/m²/yr (footprint).

5 - Net Zero Carbon Feasibility

5.7.6 Most research facilities will not be able to achieve net zero carbon operation on site and some off site renewable energy will be required.

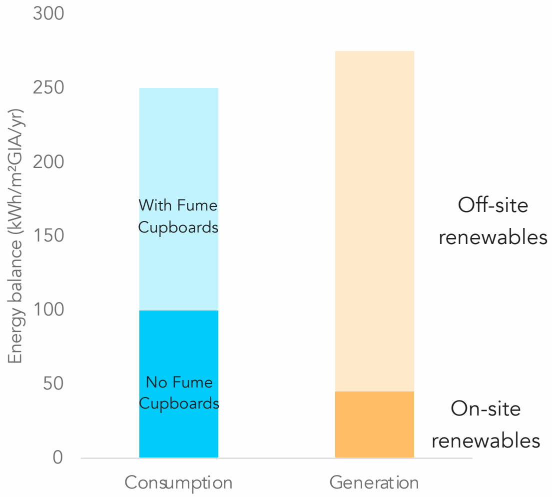


Figure 5.7 - Indicative net energy balance for a laboratory building based on energy modelling of labs aiming to achieve net zero carbon and reported energy consumption of the GSK laboratory for sustainable chemistry.

Provisional Targets

250 $kWh/m^2_{GIA}/yr$	<180 $kWh/m^2_{FP}/yr$
Total energy consumption	Solar generation

Case study examples

University of Leicester Centre for Medicine – This 13,000m² building has a 300 seat lecture theatre, laboratories and teaching spaces. It is Passivhaus certified with a primary energy use of just 116kWh/m².

University of Nottingham GSK Laboratory for Sustainable Chemistry – This 4,200m² building contains laboratories and general teaching spaces. It is BREEAM Outstanding and LEED Platinum.

5.8 Net Zero Carbon for existing buildings | Technical summary and recommendations

1 - Type Specific Considerations

5.8.1 'Existing buildings' covers so many types, ages and purposes that it is difficult to draw a standard conclusion. Each building will have to be considered on its own merits.

2 - Building Fabric

5.8.2 Building fabric performance should target a space heating demand of between 15kWh/m² and 25kWh/m². Glazing often drives both heating and cooling demands, so replacement of existing single or double glazing with triple glazing is likely to create a significant improvement in energy performance. Improving air tightness can also deliver substantive savings without wholesale fabric changes. Insulation and thermal bridge improvements are more complex and particular attention is needed on moisture and condensation risks that can result from the misapplication of insulation.

3 - Heating System

5.8.3 Heat pumps can be retrofitted in many buildings with existing 'wet' heating and/or cooling systems. Variable Refrigerant Volume systems, if a low Ozone Depletion Potential and low Global Warming Potential refrigerant can be used where there is no existing pipework distribution internally.

4 - Renewable Energy

5.8.4 PV arrays can be installed on any building where the roof is strong enough.

5 - Net Zero Carbon Feasibility

5.8.5 The feasibility of net zero carbon performance will vary widely with building type and use, however it will be technically feasible to achieve net zero carbon on many types of building through a combination of fabric retrofit work, heat pumps and solar photovoltaics.

Cedar Court – A set of 1960s residential tower buildings with 314 homes that is targeting EnerPHit certification in Glasgow

Case study examples

Cre8 Barn – A derelict barn converted to an EnerPHit certified community visitor and education centre in Huddersfield, W. Yorks

Hiley Road – A Victorian Terraced house retrofitted to achieve Passivhaus certification with a space heating demand of just 15kWh/m², Located in Kensal Green, London

Task G

Technical Feasibility

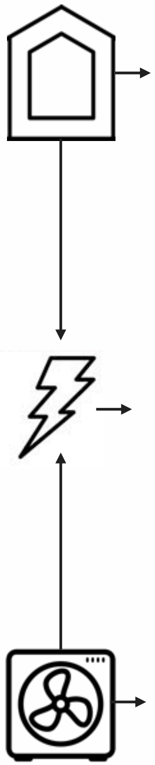
6.0 Relating results to policy

This section explores the implications of technical feasibility on policy for Central Lincolnshire.

6.1 What does the feasibility analysis tell us?

6.1.1 The results from our analysis show that building to net zero carbon standard is feasible in Central Lincolnshire, at least for the modelled typologies, which all met the criteria for net zero carbon onsite. This is encouraging as these typologies represent the most common type of building likely to be built in Central Lincolnshire over the next plan period.

6.1.2 Our case studies have suggested that some of the other building typologies may need a level of offsite renewable energy generation to achieve net zero.



Space heating

6.1.3 This is particularly important for residential buildings for which space heating often represents the largest proportion of energy use. All modelled dwelling types (semi-detached, detached and bungalow), as well as the school, could achieve a space heating demand of 20 kWh/m^2/yr or better without improvements in form and glazing proportions.

6.1.4 For commercial buildings the heating load depends on the use of the space and the extent of internal gains. For certain typologies, such as retails / industrial units, 20 kWh/m^2/yr may be challenging to meet.

Energy Use Intensity

6.1.5 This presents the overall energy efficiency of the building. With an air source heat pump the modelled dwelling typologies all had an EUI of less than 35 kWh/m^2/yr, which is a recognised indicator of net zero carbon performance in the UK. With direct electric heating the EUIs varied from 40-45 kWh/m^2/yr.

6.1.6 The school had a similar EUI of 35-38 kWh/m^2/yr; the light industrial unit had a modelled EUI of just over 100 kWh/m^2/yr, it is likely this could vary quite considerably depending on plug-in power use.

Low carbon heat

6.1.7 This involves avoiding combustion of carbon-based fuels and may rely on electrical grid infrastructure. In our modelling low carbon heat was supplied either by heat pumps or direct electric heating in the form of panel radiators, immersion elements and fan heaters. The advantage of heat pumps is that they effectively have efficiencies above 100%, minimizing the resulting EUI for each building; consequently less PV is required for net zero onsite, and more surplus electricity can be exported..

Renewable energy generation

6.1.8 This should meet total energy consumption, either on a building by building basis or collectively across the new building stock. This is discussed further in section 6.6.0.

6.1.9 All typologies modelled were low-rise and had the ability to generate surplus energy if PV space on the roof was maximised. The detached house could generate a surplus of almost 6,000kWh per annum, enough to run two electric vehicles. The light industrial unit has the potential to be a large exporter of electricity, up to over 60,000kWh per annum.

6.1.10 Conversely, case studies of other building types suggested that many of these, such as offices, research and leisure facilities, would require a proportion of off-site generation to reach net zero carbon.

Optimising the design

6.1.11 Our technical analysis also considered the benefits of designing for net zero carbon from inception. For this an ‘optimised’ semi-detached house was modelled alongside the example developer spec version. This ‘optimised’ house had improved shape, orientation and window proportions, as well as an asymmetric roof to help maximise the number of PV panels. Whereas the ‘typical’ house could only meet net zero onsite with high specification materials, the strictest fabric performance (15 kWh/m^2/yr) and an air-source heat pump, all iterations of the ‘optimised’ house were net positive, with the ability to export up to 4,600 kWh of renewable energy per annum. This shows that implementing the fundamentals of energy efficient design can lead to greater flexibility in other areas as well as less onerous requirements to meet specific levels of performance. Optimising the design in this way is also likely to lead to cost savings or minimise cost uplift.

Relating results to policy

6.1.12 Despite feasibility, the key difficulty is in setting policy that ensures future buildings can, and will be, delivered to a net zero carbon standard whilst allowing a level of flexibility in doing so. For this, it is likely a range of metrics will need to be established covering the above elements; these metrics are discussed in the pages that follow.

6.2 Elements of net zero carbon new building policy

6.2.1 The agreed zero carbon buildings policy for Central Lincolnshire should be decided in conjunction with the Central Lincolnshire planning policy team, taking into consideration feasibility and costs. To aid this decision three options have been proposed, "composed" using different targets from the 4 key elements of a zero carbon buildings policy outlined below.

6.2.2 An explicit recommendation for the 'performance gap' element is not given, however this issue is discussed further in section 7.0.0.

Space Heating

6.2.3 Space heating demand targets are useful because they prioritise energy efficiency and protect against wasteful use of energy.

Benefits:
- Also impacts the total energy use of the building / the EUI – EUI will decrease proportionally, depending on what heating system is used
- Reduce risk of high heating costs for residents
- Helps ensure thermal comfort
- Easy to evidence technical feasibility for all building types

Considerations:
- Ignores cooling demand in non-domestic buildings
- Can't be easily measured without access to sub-metering data or derivation from actual EUI
- Technology neutral

Energy Use Intensity (EUI)

6.2.4 An EUI target covers all energy uses and encourages both the heating system and building services to be energy efficient.

Benefits:
- Provides total energy use for evaluation against net zero
- Measurable post-occupancy
- Covers all energy uses
- Increasingly accepted industry metric
- Data on how energy is actually used in buildings would become available to better inform future policy

Considerations:
- Not technology neutral - indirectly benefits specification of heat pumps over direct electric
- Less efficient fabric can be masked by use of heat pumps
- Less evidence of appropriate EUIs for non-residential buildings

PV Generation

6.2.5 A "zero carbon building" will generate all of its energy needs using renewable energy technology on-site, and where this is not possible, off-site.

Benefits:
- Provides renewable electricity to offset energy use
- Measurable post-occupancy
- Many buildings can net energy positive and export electricity
- Delivers energy where it is needed and can protect greenfield sites

Considerations:
- Buildings with high loads or over six storeys have less potential to achieve zero carbon on-site
- Additional mechanisms may be required to agree net zero carbon for all buildings

Performance Gap

6.2.6 Policy must ensure predicted energy/carbon performance is achieved in practice. The performance gap and options to address this are discussed in detail in section 7.0.0.

Benefits:
- Links to quality assurance
- Encourages data collection and feedback
- Helps foster industry knowledge

Considerations:
- Practicalities of implementation at LA level
- Cost of implementation of assured standards

6.3 Buildings: energy policies – options for space heating target

6.3.1 Improving fabric efficiency minimizes the need for space heating, reducing energy wastage and the risk of high heating costs. Below outlines several options for setting a space heating demand target. The lower the space heating target the higher the cost uplift for building fabric, however the roof area required for PV and number of panels needed to meet net zero onsite will decrease.

"No Requirement" policy

6.3.2 A policy which does not require a space heating target is not recommended. It could be permissible to not have a space heating target if an "Energy Use Intensity" target was used in its place.

"30 kWh/m^2/yr" policy

6.3.3 A space heating target of 30 kWh/m2/yr is a good improvement on existing building regulations (new buildings typically achieve approximately 70 kWh/m2/yr). Costs increases approximately 2-3% above a standard build can be expected.

6.3.4 Energy efficiency can be pushed further than this, at increased cost (see below). The considerations to bear in mind with a mid-range energy efficiency are increased running costs, and higher peak space heating loads compared to what is possible (although this can be lessened through use of heat pumps).

"20 kWh/m^2/yr" policy

6.3.5 This level of building fabric efficiency is in line with the recommendations from the Committee on Climate Change (CCC) and the Royal Institute of British Architects (RIBA)). Construction costs increases approximately 4-5% above a standard build can be expected.

"15 kWh/m^2/yr" policy

6.3.6 This level of building fabric efficiency is in line with Passivhaus standards, as well as the London Energy Transformation Initiative (LETI) target for all building types. It is technically achievable (there are many buildings already built to this standard). Construction costs increases approximately 5-6% above a standard build can be expected.

6.3.7 Relaxations for specific non-domestic buildings may be required with the lower space heating targets.

Space heating demand

This is to ensure that space heating is reduced and that inefficiency is not 'masked' by the heat pump, helping to reduce the risk of high heating costs.

No requirement

30 kWh/m^2/yr

20 kWh/m^2/yr

15 kWh/m^2/yr

6.4 Buildings: energy policies – options for energy use intensity

6.4.1 It is the EUI that the renewable energy generation must match in order for a building to be zero carbon; the lower the EUI, the less renewable energy required, lower cost of PV.

6.4.2 EUIs can be estimated at the design and construction stage through modelling and assumptions about user behaviour. A standardised way of predicting the EUI of a building will be required for planning submissions. This may entail making assumptions in addition to SAP, performing TM54 analysis, or using another energy modelling software. In practice the actual energy used by a building will vary depending on how it is used.

Residential

6.4.3 The London Energy Transformation Initiative (LETI) and the Royal Institute of British Architects (RIBA) both recommend that residential buildings achieve maximum EUIs of 35 kWh/m2/yr. This is in line with PassivHaus standards.

6.4.4 Our modelling shows that EUIs of **35 kWh/m^2/yr** are achievable for domestic buildings with the use of heat pumps (and will be even easier to meet in flats and terraces). The inclusion of heat pumps led to a cost increase of 1.5-2.5% above a standard build (assuming gas boiler). Although it should be recognised that gas boilers are likely to be phased out in the near future. None of the scenarios modelled using direct electric heating were able to meet this EUI target.

6.4.5 If policy were to enable electric heating to be used in domestic buildings, the EUI target would need to sit at at least **45 kWh/m^2/yr.** However, this also opens to the door to utilising an inefficient building fabric and achieving the EUI figure through using a heat pump. We would therefore recommend the EUI target sit alongside a minimum space heating target to ensure efficiency of the building fabric remains a priority. Direct electric heating leads to a cost saving of 1-2% compared to a standard build.

Non-residential

6.4.6 LETI recommends offices and schools achieve an EUI of **55** and **65 kWh/m^2/yr** respectively. RIBA recommend that all non-domestic buildings achieve **55 kWh/m^2/yr.**

6.4.7 Our modelling of a school shows that these targets are reasonable. The model of the light industrial unit showed the EUI coming out at around 105 kWh/m^2/yr. The desktop studies for different building typologies also showed varying total energy uses. It may be necessary to vary requirements depending on the building use type, or allow relaxation for buildings with specific loads (i.e. machinery, research equipment, heated pool, etc). Given the uncertainty over non-residential EUI targets, space heating targets become a more necessary backstop.

Energy Use Intensity Resi I non-resi	
This covers all energy uses, reduce the risk of high energy heating system. It also provides the 'energy use' number for Net Zero and a simple metric for users post completion.	
No requirement	
60 kWh/m^2/yr	100 kWh/m^2/yr
45 kWh/m^2/yr	65 kWh/m^2/yr
35 kWh/m^2/yr	55 kWh/m^2/yr

6.5 Buildings: energy policies – options for PV generation target

6.5.1 Renewable energy generation should meet total energy consumption in order for a building / group of buildings to be considered zero carbon. Different combinations of policy targets will lead to different amounts of renewable energy required on-site, varying on-site cost uplift, and varying amounts of off-site renewable capacity.
There are two main approaches that can be taken when determining an appropriate policy: enough to match the EUI of the building or asking for a minimum amount of PV to be added according to available roof area.

"No Requirement" policy – 6.5.2 not recommended.

Enough to match EUI

6.5.3 Policy is designed to ensure each building is zero carbon but asks for no more. A key advantage is that this is relatively simple to implement, however:

- Some roofs will only be partially covered in PV – i.e. some roof space that is suitable for PV may not be utilised.
- An offsetting setting mechanism will be necessary for typologies that cannot meet this
- May also need a way of incentivising maximum use of on-site PV for buildings that cannot meet requirements (e.g. through a "minimum utilisation target", or setting price of energy offset higher than it would be to provide energy on-site).

6.5.4 For the residential models our analysis indicated that matching EUI increases build cost by 2-3%.

A generation target depending on building footprint (e.g. 120 kWh/m²/yr)

6.5.5 Policy is designed to ensure the roof of each building is used to maximum effect in generating renewable energy, this can make up for buildings less able to generate 100% of their energy requirements. The advantages are:

- simple requirement based on maximising roof space.
- new development across Central Lincolnshire can collectively be "zero carbon" without relying on additional off-site renewable energy capacity, this also avoids penalising high density development.
- planning officers can visually tell whether the policy is being adhered to.
- Net export is encouraged on low rise development.

Other

6.5.6 An alternative could be to tie the target to a specific standard, such as Passivhaus Plus or Premium. In the case of the Passivhaus standards, the renewable energy target is also based on the building footprint.

PV generation

This addresses the need for greater PV deployment in an obvious location for them: the roof of new buildings.

No requirement

Enough to match EUI

120 kWh/m²/yr

Other
(e.g. renewable requirement of Passivhaus premium)

6.6 The need for off-site renewables (or not)

Off-site

6.6.1 Renewable energy is a vital component of a net zero carbon building. Most of the typologies we modelled had enough roof area to generate enough renewable energy to cover all their energy needs over the course of the year.

6.6.2 Tall buildings, or those with higher energy demands, will find it challenging or impossible to generate enough energy to be “zero carbon” on-site.

6.6.3 In our report on Offsetting (Task I) we propose an energy offsetting mechanism is created in order that buildings that cannot generate enough energy to match their energy use, can comply with the policy requirement by paying for an equivalent amount of renewable energy to be installed off-site.

6.6.4 We have tested different policy options for the cumulative impact on the amount of off-site renewables required across all projected new builds in Central Lincolnshire over the life of the local plan:

6.6.5 Key findings include:

- A renewable energy policy that requires renewable energy generation to match energy use intensity will result in off-site renewables being required to make up the “deficit” of renewable energy generation from some buildings which are technically unable to comply with the policy on-site.
- Energy use intensity targets have a cumulative impact on the amount of off-site renewables required: if taking residential buildings alone in a “medium” density scenario across Central Lincolnshire, and we compare a EUI requirement of 35 vs 45 kWh/m^2/yr, we can see that we would need 300% more installed wind turbine capacity to satisfy the deficit (see Appendix F and G for calculations).

A policy option that would not required off-site renewables

6.6.6 Our analysis shows that if new build roof spaces are utilised well with photovoltaic panels (i.e. achieving an output of 120 kWh for every m^2 of building footprint) then collectively, new builds across Central Lincolnshire could collectively generate as much energy, if not more, as they use, i.e. they could be zero carbon. This is because some buildings will generate more energy than they would use, making up for those that cannot produce so much renewable energy. This is true if best practice energy efficiency policies (EUI targets) are put in place for all building types. The analysis is sensitive to the assumptions made, all of which can be found alongside calculations in Appendix F & G.

6.6.7 A policy requiring a specific PV output of 120 kWh/m^2 footprint may prove to be financially unviable for developers to meet costs themselves. However if an innovative offset fund could be set up to fund anything over and above matching the EUI of the building this could be a possibility.

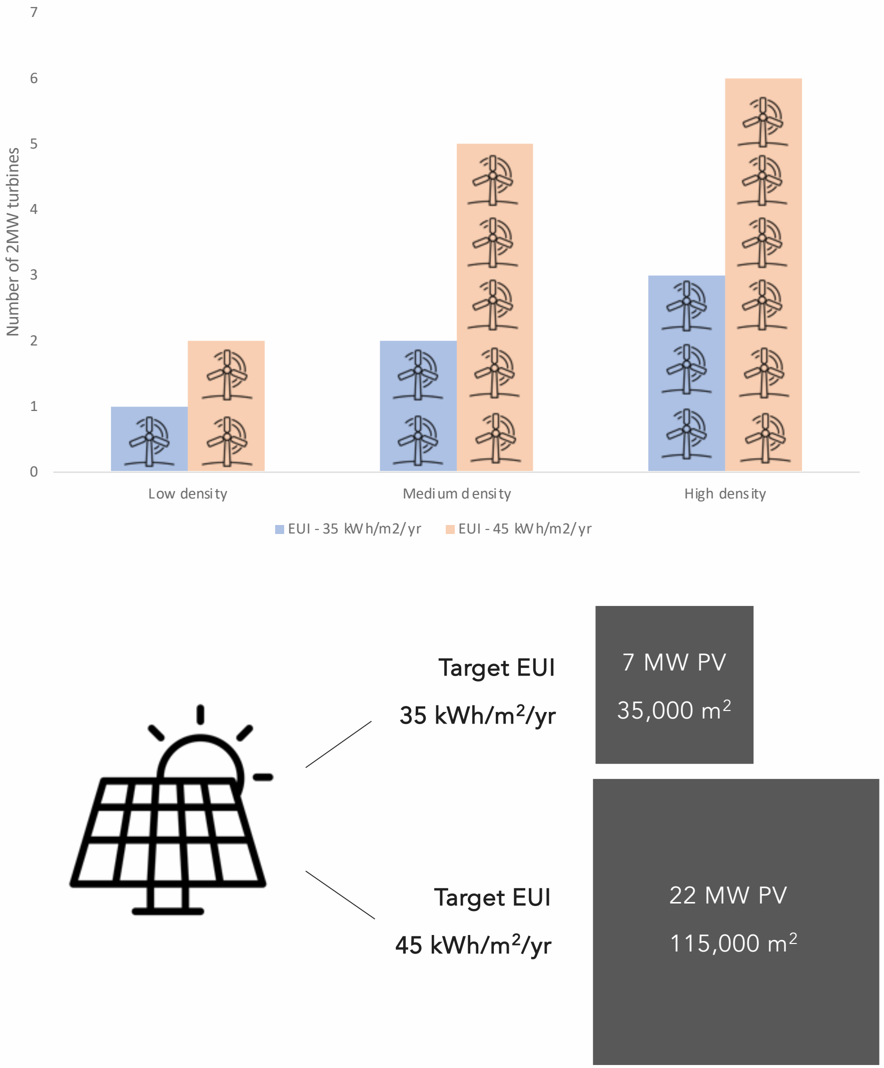
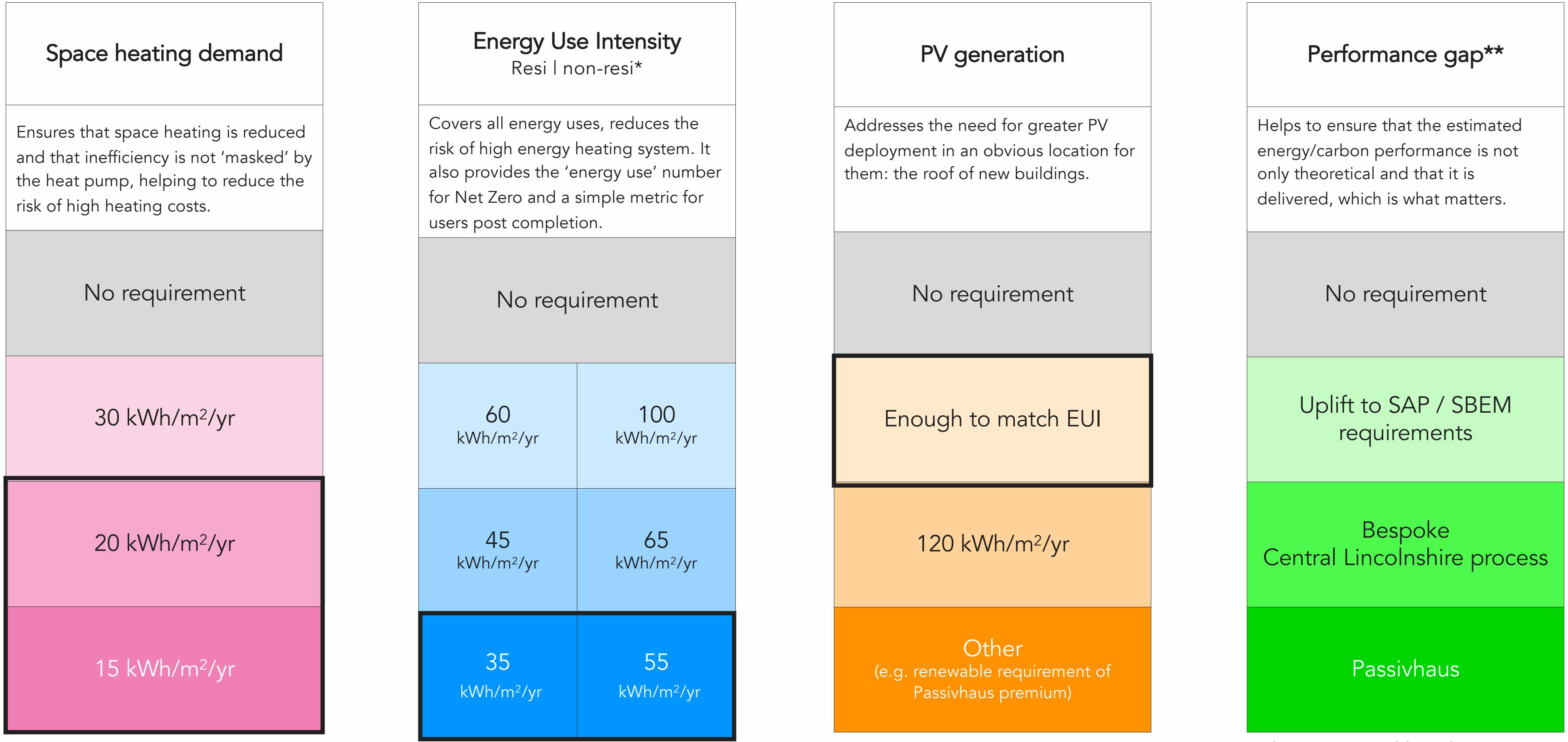


Figure 6.1 - Comparison of the effect of residential Energy Use Intensity (EUI) targets on the likely offsite wind or solar capacity required to achieve net zero carbon across all new builds (at medium density). Results are shown in number of 2MW turbines and area of photovoltaic panel.

6.7 Buildings: energy policies – option 1

6.7.1 **Option 1** is the most ambitious and shown below. Our technical analysis indicates that these targets are feasible; strong targets for both space heating and EUI ensure efficient use of energy is at the core of a building's operation, protecting occupants from any volatility in energy prices. It will minimise the amount of offsite renewables required, lessen the need for peak load management and has the lowest running costs of all options. Heat pumps are required to achieve the low energy use. Heat pumps can also provide summer cooling, which is likely to become more important in a warming climate.

6.7.2 Option 1 entails a total cost uplift of 8-11% (from improved fabric, choice of heating system, and inclusion of PV). See Appendix E for a summary of costs and "Task H – Cost Implications" report. Operational fuel costs are lowest for this policy option – representing an 80% reduction compared to the baseline building.



Space heating demand	Energy Use Intensity Resi I non-resi*		PV generation	Performance gap**
Ensures that space heating is reduced and that inefficiency is not 'masked' by the heat pump, helping to reduce the risk of high heating costs.	Covers all energy uses, reduces the risk of high energy heating system. It also provides the 'energy use' number for Net Zero and a simple metric for users post completion.		Addresses the need for greater PV deployment in an obvious location for them: the roof of new buildings.	Helps to ensure that the estimated energy/carbon performance is not only theoretical and that it is delivered, which is what matters.
No requirement	No requirement		No requirement	No requirement
30 kWh/m^2/yr	60 kWh/m^2/yr	100 kWh/m^2/yr	Enough to match EUI	Uplift to SAP / SBEM requirements
20 kWh/m^2/yr	45 kWh/m^2/yr	65 kWh/m^2/yr	120 kWh/m^2/yr	Bespoke Central Lincolnshire process
15 kWh/m^2/yr	35 kWh/m^2/yr	55 kWh/m^2/yr	Other (e.g. renewable requirement of Passivhaus premium)	Passivhaus

*relaxation or a bespoke target is likely necessary for certain typologies

**the options to address this are discussed in detail in the next section

6.8 Buildings: energy policies – options 2 & 3

6.8.1 **Option 2** retains a strong space heating demand target, at 15-20 kWh/m^2/yr. However the EUI target is slightly less stringent, at 45 kWh/m^2/yr for residential development and 65 kWh/m^2/yr otherwise.

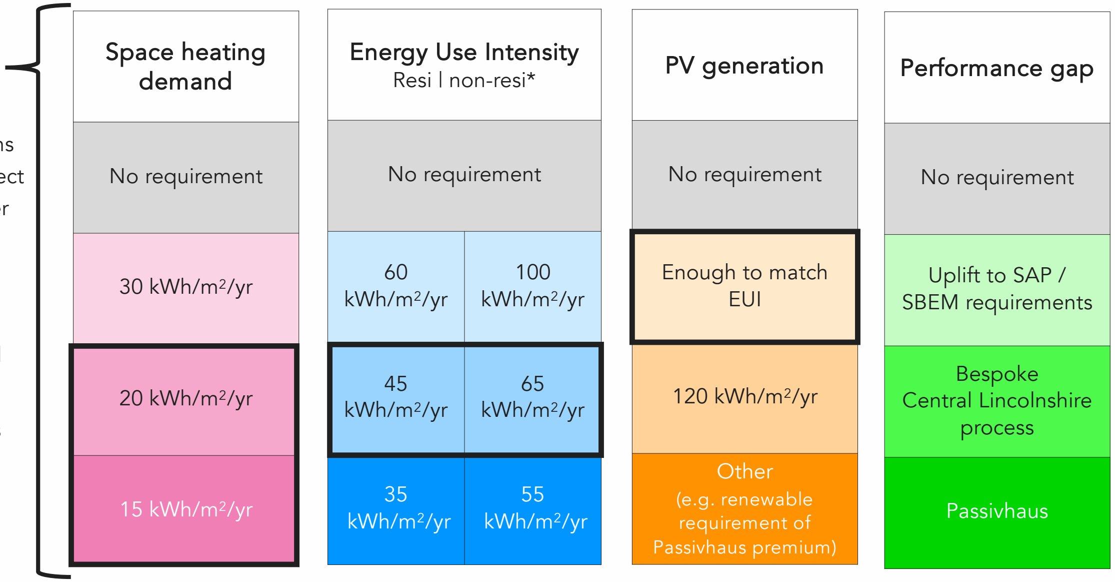
6.8.2 The relaxation of the EUI target enables the install of direct electric heating systems whilst managing potential fuel poverty (thanks to high levels of fabric performance). Direct electric heating can lead to a capital cost saving compared to the baseline. On the other hand, fuel bills will still be higher than compared to a heat pump.

6.8.3 The effect of raising the EUI to this level will likely require a 300% increase off site additional renewable energy generation compared with a lower EUI policy.

6.8.4 Again, enough renewable generation to match the EUI is seen as the simplest and most viable option for Central Lincolnshire.

6.8.5 Option 2 leads to a total construction cost uplift of 4.5-9%. Operational fuel costs would likely be 20-80% lower than the baseline depending on building form.

6.8.6 See Appendix E for a summary of costs and "Task H – Cost Implications" report.



Space heating demand	Energy Use Intensity Resi I non-resi*		PV generation	Performance gap
No requirement	No requirement		No requirement	No requirement
30 kWh/m^2/yr	60 kWh/m^2/yr	100 kWh/m^2/yr	Enough to match EUI	Uplift to SAP / SBEM requirements
20 kWh/m^2/yr	45 kWh/m^2/yr	65 kWh/m^2/yr	120 kWh/m^2/yr	Bespoke Central Lincolnshire process
15 kWh/m^2/yr	35 kWh/m^2/yr	55 kWh/m^2/yr	Other (e.g. renewable requirement of Passivhaus premium)	Passivhaus

*relaxation or a bespoke target is likely necessary for certain typologies

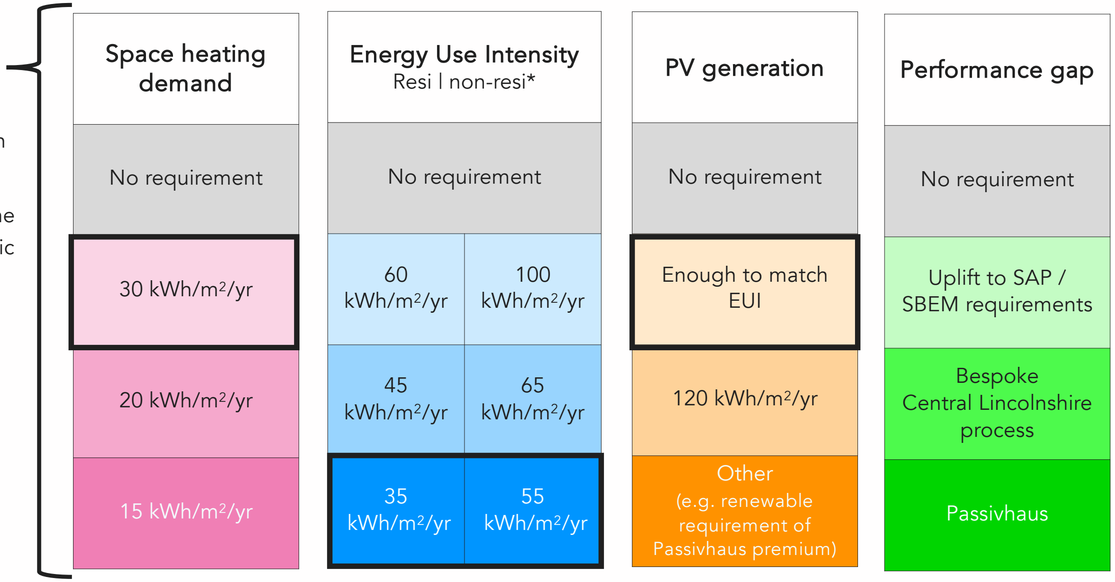
6.8.7 **Option 3** relaxes the space heating demand target to 30 kWh/m^2/yr. However the EUI target is set at 35 kWh/m^2/yr for residential development and 55 kWh/m^2/yr otherwise.

6.8.8 A good, but less stringent space heating demand target, may enable some design flexibility, but inevitably will lead to the building of less energy efficient developments.

6.8.9 This option again encourages the use of heat pumps, which could help manage the impact a higher space heating demand allowance would have on fuel bills. Direct electric would not be a possibility for low-rise residential development.

6.8.10 The PV generation target remains 'enough to match EUI'.

6.8.11 Option 3 leads to total construction cost uplift of 5-8%. Operational fuel costs likely to be 20% that of the baseline building (i.e. an 80% saving).



Space heating demand	Energy Use Intensity Resi I non-resi*		PV generation	Performance gap
No requirement	No requirement		No requirement	No requirement
30 kWh/m^2/yr	60 kWh/m^2/yr	100 kWh/m^2/yr	Enough to match EUI	Uplift to SAP / SBEM requirements
20 kWh/m^2/yr	45 kWh/m^2/yr	65 kWh/m^2/yr	120 kWh/m^2/yr	Bespoke Central Lincolnshire process
15 kWh/m^2/yr	35 kWh/m^2/yr	55 kWh/m^2/yr	Other (e.g. renewable requirement of Passivhaus premium)	Passivhaus

6.8.12 **Option 4** - An option with a space heating demand target of 30 kWh/m^2/yr and EUI targets of 45 kWh/m^2/yr & 65 kWh/m^2/yr is not recommended. As indicated by the modelling of the typical semi-detached house, this combination of policy elements increases the risk of even low-rise development not meeting net zero on-site. While representing the lowest capital cost, it also represents the highest running costs for future occupants.

6.9 Estimated impact of proposed policies on construction costs: residential

What is the baseline construction cost used?

6.9.1 The report "Task H – Cost Implications" by Currie and Brown, which forms part of this evidence base, has taken each of the typologies used in the technical feasibility analysis to assess cost implications of achieving the zero carbon buildings policies. The technical specifications used by Etude have been used to assess the cost implications relative to current building regulations compliant dwellings using gas boilers.

6.9.2 It should be noted that when these policies become effective, buildings regulations standards would have improved further, hence, the cost implications summarised will likely be an overestimation.

6.9.3 The new build costs are based on Currie & Brown's professional experience of project costs. They are for a medium sized developer. The construction capital costs analysis is presented in full in their report and is only summarised here. Costs are based on the increase in materials required to achieve the specification and do not include design fees or fixed site costs. It is important to remember that the variables involved are extensive and therefore a benchmark cost analysis is only indicative.

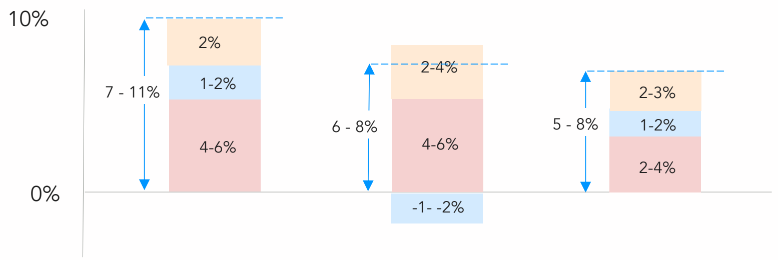
What is the impact of the proposed policies on construction costs?

6.9.4 **Policy requirement A.1.1 - Space heating demand <20 kWh/m²/yr.** This policy impacts on the building fabric and ventilation costs. The additional costs of the changes considered in this evidence base are 4-6%.

6.9.5 **Policy requirement A.1.2 - EUI <35 kWh/m²/yr.** Assuming the policy above is met, this policy impacts mainly on the choice of heating system. The additional costs of the changes considered in this evidence base are 1-2%.

6.9.6 **Policy requirement A.1.3 – Renewable energy generation on-site.** PVs have to either provide > 120 kWh/$m^2_{footorint}$/yr and/or achieve a Net Zero Carbon balance. This policy would require the installation of PV panels and their additional costs depends on how many of them are required. It would cost 2-3% to install enough PVs to match the EUI and achieve Net Zero Carbon on-site.

6.9.7 **Policy requirement A.1.4 – Offsetting.** Where enough renewable energy cannot be provided on-site to match annual energy demand (through for example not enough roof space), then a mechanism for collecting off-set payments to fund renewable energy provision off-site to make up for the short fall should be used. This should be priced at the rate of renewable energy provision plus perhaps an administration cost. Therefore, the need to off-set shouldn't in theory represent additional cost to the developer.



	Policy option 1 Fabric: 20 kWh/m²/yr EUI: 35 kWh/m²/yr PV: match EUI	Policy option 2 Fabric: 20 kWh/m²/yr EUI: 45 kWh/m²/yr PV: match EUI	Policy option 3 Fabric: 30 kWh/m²/yr EUI: 35 kWh/m²/yr PV: match EUI
Building fabric and ventilation	4-6%	4-6%	2-4%
Heating system	1-2%	-1 to -2%	1-2%
Renewable energy generation with PVs	2%	2-4%	2-3%
Total capital cost uplift	7-11%	6-8%	5-8%
Running costs/yr (as % of baseline)	-80%	-40%	-80%

Figure 5.2 - Summary of cost impacts of different policy options on four modelled typologies: by building fabric and ventilation, heating system and renewable energy provision. Uplifts are relative to the baseline building and reflect the cost of additional materials required to meet specs. Running costs are relative to running costs of the baseline building, and include for savings and returns from photovoltaic panels.

Task G

Technical Feasibility

7.0 Delivering Net Zero

This section explores how to ensure net zero carbon buildings policies are delivered in practice in Central Lincolnshire.

7.1 Compliance methods

Selecting the right compliance method

7.1.1 Ideally energy compliance methodologies already mandatory for new developments, such as Part L calculations via SAP/SBEM, would be used to ensure compliance with policy targets. However, at time of writing these methodologies are unlikely to deliver net zero carbon buildings consistently and at scale. There are existing low energy building standards, such as the Passivhaus Standard, that better predict the energy use of new developments.

7.1.2 Regardless of the calculation tool used to predict net zero carbon compliance , a rigorous quality assurance process is required throughout design and construction to ensure the "as built" performance meets the "design". For Passivhaus this is done by the inclusion of certified Passivhaus Consultant throughout the project and the submission of evidence from contractors at key stages of the build (e.g. delivery notes, photos).

7.1.3 A quality assurance process could equally be run in-house. Central Lincolnshire would need to establish a specialised inspection programme for buildings and provide training to building inspectors.

Utilising existing standards

7.1.4 The table below summarises possible options for verifying compliance with net zero carbon building policy elements.

Policy element	Residential	Commercial
Space heating	PHPP / SAP* calculations	PHPP / SBEM calculations
Energy use intensity	PHPP / SAP** calculations	PHPP / TM54 calculations
Renewable energy generation	Calculation from an MCS accredited installer	
Performance gap	Inherent in the Passivhaus or AECB standard process. If SAP/SBEM is used a rigorous inspection and commissioning programme may need to be established.	

*A significant performance gap is associated with the current version of SAP. A penalty may need to be applied.

**SAP does not calculate energy use from appliances and small-power, a level of post-analysis would be required to estimate the EUI.

Passivhaus Certification

7.1.5 Passivhaus is a leading comfort and energy efficiency standard for buildings. Key requirements include meeting targets for space heating demand and total energy consumption. These metrics must be calculated using the "Passivhaus Planning Package" (PHPP) software. An independent Passivhaus Certifier will then carry out quality checks on the design calculations and inspect evidence captured during construction.

AECB Standard

7.1.6 The AECB Building Standard aims to help deliver "high-performance buildings at little or no extra cost". It aligns quite closely with the Passivhaus methodology.

Energy calculations are carried out in PHPP, ideally by an experienced energy consultant who can also review the design and construction details.

The key difference is that the energy consultant can also self-certify the project.

SAP & SBEM calculation

7.1.7 Used to assess the energy and environmental performance of new residential and commercial buildings respectively. They are the basis for illustrating compliance with Part L of the UK building regulations.

SAP and SBEM calculate energy use for heating, cooling, lighting and ventilation systems, but ignore other building energy uses such as those associated with lifts, specialist equipment and small power loads.

TM54 calculation

7.1.8 CIBSE published TM54 "Evaluating Operational Energy Performance of Buildings at the Design Stage" in 2013 to help tackle the performance gap. It provides guidance on how to calculate the total energy use of a new building more accurately at design stage. The guide suggests dynamic simulation modelling is used to assess heating and cooling. It also provides steady state methodologies for calculating other areas of energy consumption.

7.2 Assured Performance

The Performance Gap

7.2.1 The actual energy performance of buildings often fails to meet the design standard. This difference is commonly referred to as ‘the Performance Gap’. The Zero Carbon Hub concluded in their Evidence Review Report in 2014 that a compliance process focused on design rather than as built performance is a key contributor to the Performance gap[09] . Closing the Performance Gap requires action at various stages through the design, construction and post occupancy phases of development

Accurate Modelling

7.2.2 Modelling to predict the energy performance of buildings is most often carried out in order to demonstrate regulatory compliance. Calculations for regulatory compliance do not account for all energy uses in buildings. There are calculation and modelling platforms that are more comprehensive, most notably the Passive House Planning Package (PHPP) but not all developers have ready access to these.

7.2.3 Policy should be that if developers use a comprehensive modelling package, such as PHPP, then the results can be used directly in submitted energy statements. But if developers prefer to use a compliance software package such as the Standard Assessment Procedure (SAP) for residential buildings or the Simplified Building Energy Model (SBEM) for other building types, then an uplift of a standard amount should be applied particularly when calculating renewable energy requirements to meet the zero carbon targets, to account for the uses not modelled.

7.2.4 Future development of SAP may begin to address this concern, and if so, the degree of uplift, or the need for any uplift at all, can be reviewed.

Construction Quality Management

7.2.5 Ensuring that buildings are constructed in accordance with the design has become increasingly important as energy targets have improved. In standard, ‘business as usual’ construction, a check on the thickness of insulation installed was good enough, but in a low energy building, there has to be far more emphasis on the detail. Building Control have limited attendance on site, so monitoring these details in every case is not practicable through that agency. Therefore another process of construction quality management is needed.

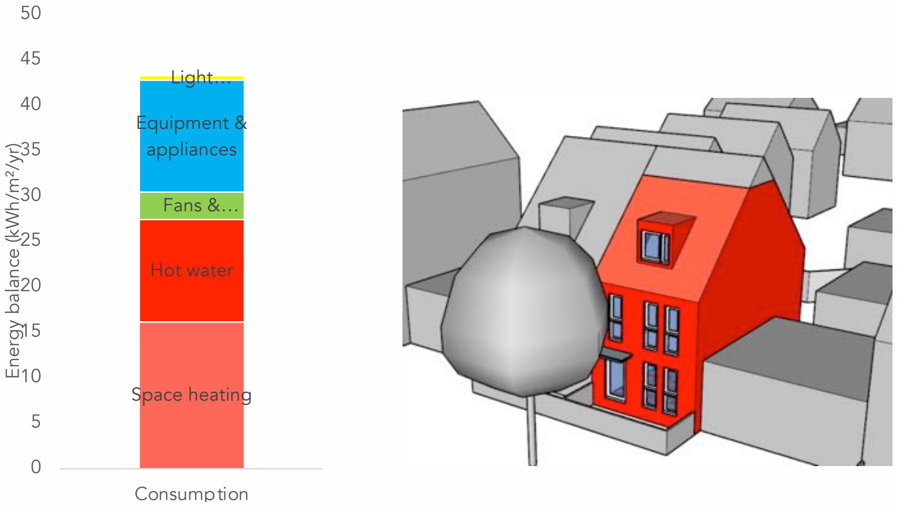


Figure 7.1 - PHPP modelling considers all energy uses in a building to predict the energy performance, including energy for uses and appliances that are excluded from Building Regulations compliance calculations. © Etude

Figure 7.2 - The design of every key junction in a low energy building may be modelled and relied upon for the overall energy performance of the building © Etude

Calculation by:	Etude
Calculated Ψ-value:	0.054W/mK

7.3 Assured Performance

Assured Performance Schemes

7.3.1 It is recommended that policy requires the adoption of an assured performance scheme. The choice of scheme can be left open, to suit each project and the capability of the project team.

7.3.2 There are a number of Assured Performance schemes, such as Passive House Certification or the AECB Building Standard. Passive House relies on independent certification, whereas the AECB standard can be certified by a member of the design team if they have the requisite skills. Both standards can be used for residential and non-residential development.

7.3.4 The Better Buildings Partnership have recently launched NABERS UK, which is an energy rating scheme based on actual performance data, specifically aimed at commercial buildings.

7.3.5 For residential developments, other potential Assured Performance schemes include The Assured Performance Process (APP) created by the National Energy Foundation (NEF) and The Building Energy Performance Improvement Toolkit (BEPIT) managed by BioRegional, either of which could provide the necessary oversight framework.

7.3.6 An Architect's certificate, or now the Professional Consultant's Certificate, certifies practical completion but currently there is no specific obligation to certify environmental performance. However, the Royal Institute of British Architects and the Architects Registration Board, along with other construction industry professional bodies, now have environmental initiatives relating to net zero ambitions and environmental performance[03] and the targets they advocate may in future be brought into definitions of Practical Completion. It is also possible that in future, new home warranty providers could offer this service.

Post Occupancy Monitoring

7.3.7 The extent to which the Performance Gap is driven by the occupants of buildings not using the installed systems to their best efficiency is not well understood. Post Occupancy Evaluations (POEs) can highlight where there are differences and 'soft landings'[10] programmes in public sector and commercial buildings seek to better train the users of buildings on how to control the installed systems. The take up of both in the UK is low and reliable data on the real performance of buildings as compared to the design is not widely available. A small number of studies have been published to collate what data there is, such as the Building Performance Network 'State of the Nation' report.[11]

7.3.8 Privacy concerns inhibit private sector developers from carrying out extensive POEs especially in residential developments. Mandatory participation in POE exercises is therefore not reasonable. However, developers should be encouraged to carry out POE studies in order ultimately to prove that the Performance Gap has been closed in practice.

NATIONAL ENERGY FOUNDATION

AECB building knowledge

Certified Passive House
Passive House Institute

BEPIT
Building Energy Performance Improvement Toolkit

NABERS
UNITED KINGDOM

References

[01] Climate Change Committee (2019) *UK housing: Fit for the future?*

[02] London Energy Transformation Initiative (2020) *Climate Emergency Design Guide*

[03] Royal Institute of British Architects (2019) *2030 Climate Challenge*

[04] Passivhaus Institute (2016) *Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard*

[05] Climate Change Committee (2019) *Net Zero: The UK's contribution to stopping global warming*

[06] National Grid (2020) *Future Energy Scenarios 2020*

[07] Passivhaus Trust (2017) *The performance of Passivhaus in new construction: Post occupancy evaluation of certified Passivhaus dwellings in the UK: Early Results*

[08] Passivhaus Institute (2003) *CEPHEUS – measurement results from more than 100 dwelling units in passive houses*

[09] Zero Carbon Hub (2014) *Performance Gap Evidence Review Report*

[10] BSRIA 2020, *About Soft Landings, <https://www.bsria.com/uk/consultancy/project-improvement/soft-landings/about-soft-landings/>*

[11] Building Performance Network (2020) *State of the Nation Review: Performance evaluation of new homes*

Task G

Technical Feasibility

Appendices

Appendix A: The vital role of solar photovoltaic technology

International Context

8.1.1 The International Renewable Energy Association reports that 75% of new power generating capacity installed globally in 2019 was from renewable sources. These include: solar photovoltaics, wind, hydro, bio, geothermal, ocean and concentrating solar power. Solar photovoltaics accounted for 115GW, or 57%, of this new renewable generation capacity. This far exceeded the 60GW of wind power, 16GW of hydropower and 10GW of other renewable sources that were installed. In simple terms, solar photovoltaic technology is the world's leading energy technology for new capacity additions.

National Context

8.1.2 The National Grid produces a set of future scenarios for the UK's electricity generation mix each year. Three out of four of the most recent scenarios are currently compliant with limiting global warming to less than 2°C: 'Consumer Transformation', 'System Transformation' and 'Leading the Way'. These scenarios are broadly compliant with Central Lincolnshire's ambition to achieve net zero emissions, albeit on a slightly longer timescale.

8.1.3 The adjacent figures explore these scenarios, with a particular focus on the 'Consumer Transformation' scenario. Our analysis suggests this scenario appears to be the most plausible as it relies on currently available technology. It is also likely to deliver the greatest benefits to the consumer, for example by minimizing inefficient use of hydrogen and placing a greater focus on distributed solar systems that directly benefit the owners of buildings on which they are installed.

8.1.4 All of the two-degree compliant scenarios require an increase of installed solar capacity in the UK by a factor of four to over five times within the next few decades. As shown in the figure below, this represents a substantial increase over current capacity of around 13GW.

Location: Buildings, Infrastructure or Fields?

8.1.5 New solar capacity can be installed on the roofs and walls of buildings, above car parks and other infrastructure, or on greenfield sites. While solar technology is relatively benign, and easy to remove in the future, the use of greenfield sites is considered to align poorly with several key environmental objectives. These include the need to rapidly increase afforestation and reforestation to provide carbon sinks, the need to slow and reverse biodiversity loss, and the need to use remaining land efficiently for essential purposes such as agriculture. Prioritising deployment of solar photovoltaic technology within the built environment clearly offers benefits in terms of avoiding use of grid electricity at retail prices and providing energy where it is required.

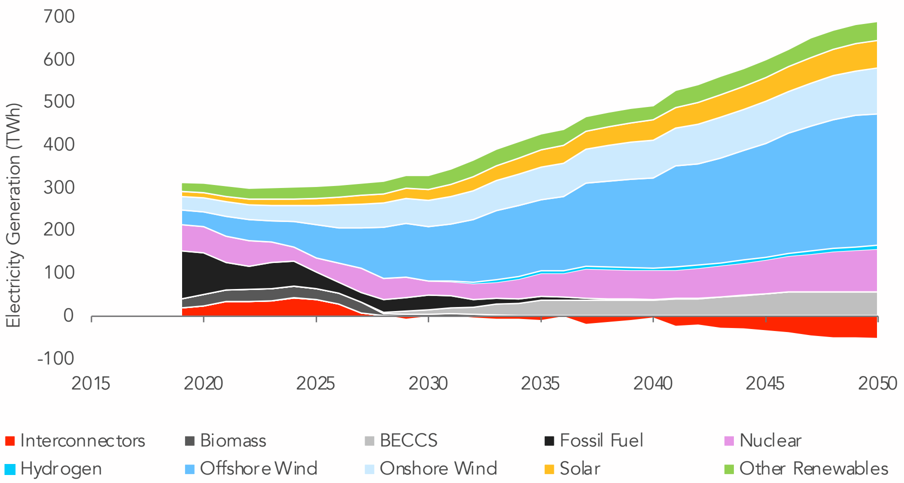


Figure 8.1 - The Consumer Transformation scenario is in line with limiting global warming to less than 2°C predominantly through the use of mature commercially available technologies (© National Grid, 2020)

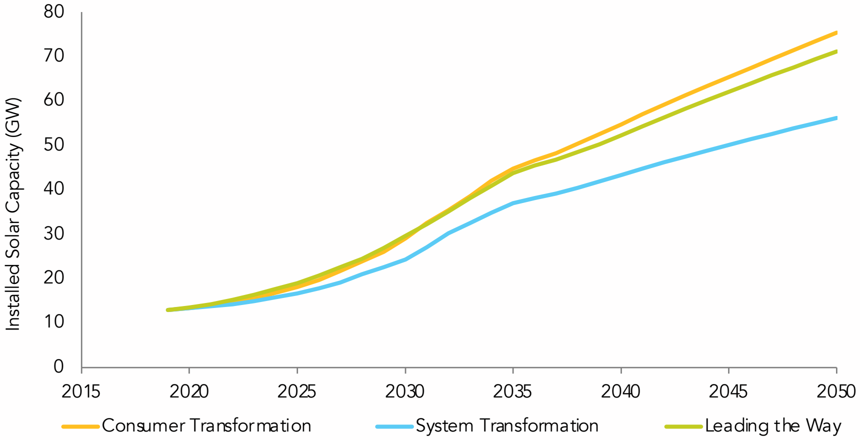


Figure 8.2 - Installed solar capacity needs to increase by around five times in the next few decades in the Consumer Transformation and System Transformation scenarios (© National Grid, 2020)

Appendix B: Solar energy and the Electricity Grid

The National Grid

8.2.1 The National Grid is one of the world's largest public listed utilities and is responsible for the transmission and distribution of electricity in the UK. Their Future Energy Scenarios are under constant development by teams of engineers and consider potential future technology mix options for the UK's electricity network.

8.2.2 The National Grid are clearly confident that the UK's electricity system can accommodate a massive increase in the amount of solar photovoltaic generation, as reflected by the large expansion in solar capacity in all three of the two degree compliant scenarios.

Distribution Networks

8.2.3 The regional Distribution Network Operators compile their own Distribution Future Energy Scenarios, based on combining different aspects of each of the National Grid's scenarios, in addition to their own local knowledge and planning. These scenarios are used to develop investment plans which are submitted to OFGEM based on forecast investment required in the distribution network. It is therefore important that DNO's are made aware of anticipated local solar capacity additions well in advance so they can plan and invest accordingly.

Core Strategies for Solar Integration

8.2.4 The following strategies will facilitate significant expansion of the UK's solar capacity:

Demand Side Management – Use of smart thermostats for space and water heating can enable operation of heating systems when solar energy is available. This takes advantage of the thermal mass of a building, hot water tank or a phase change material. Building fabric efficiency slows rates of heat loss, meaning heat can be stored for longer periods. Smart electric vehicle charging can also absorb significant amounts of distributed solar energy.

Export - Exporting surplus energy generation is an efficient way to deal with excess solar electricity with low environmental impact. Surplus solar power can be used locally, nationally, or even internationally via the UK's expanding network of interconnectors.

Storage – The UK's energy storage capacity is set to increase massively by 2050. Batteries alone are expected to deliver 23 to 40GW of capacity. Smart electric vehicle charging and the use of vehicle batteries to buffer the electricity grid is expected to deliver up to 29GW of additional demand flexibility. Liquid air storage, compressed air energy storage, pumped hydro and hydrogen are also expected to make meaningful contributions.

Curtailment – In some cases it is more cost and carbon efficient to simply curtail excess renewable energy, than to install the additional infrastructure necessary to store it.

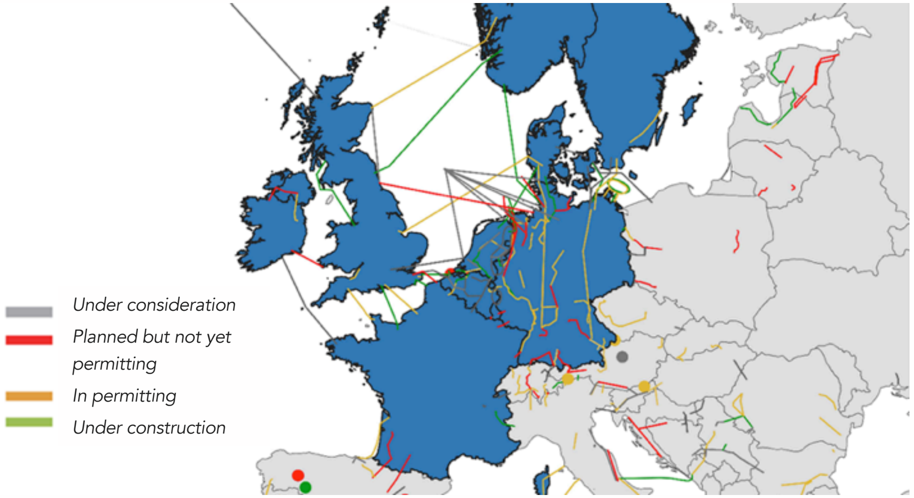


Figure 8.3 - The UK's existing interconnector capacity of 4.75GW increases to 21 - 27GW by 2050 in the National Grid's two degree compliant scenarios. Significant increases in interconnector capacity are already planned, in permitting or under construction.

Figure 8.4 - The UK's existing battery storage capacity of 3.75GW increases to 23 - 40GW by 2050 in the National Grid's two degree compliant scenarios.

Appendix C: Is solar generation in phase with energy demand?

Why time of generation is important

8.3.1 The time at which building mounted solar photovoltaic systems generate electricity matters. If solar electricity is available when energy is required, it can be consumed directly on site, which typically leads to the greatest financial savings. If excess solar energy is produced, it must be exported for use elsewhere, stored, or simply left unused.

8.3.2 The adjacent graph shows how the variation of monthly solar generation is strongly associated with the tilt angle of the solar panels. Systems at shallower tilt angles generate significantly more energy in the summer than in the winter, where as vertical solar panels generate more evenly throughout the year, at the expense of lower overall energy production. East/West facing systems produce a flatter daily generation curve than South facing systems, distributing energy generation more evenly throughout the day.

A traditional perspective: Is solar generation in phase with energy demand?

8.3.3 Solar generation is generally in phase with energy demand on a daily basis, accepting there will be variations due to occupant behaviour. This is useful and means that new solar capacity is currently very effective at displacing marginal generation plant (this is typically high carbon gas turbines). As the grid decarbonises, new solar capacity will continue to offer a useful form of energy generation due to the daily generation profile.

8.3.4 Many end uses of energy in a net zero carbon building are likely to be steady throughout the year. This is shown in the lower adjacent figure, where energy use for lighting, equipment and appliances, fans and pumps, and hot water generation are expected to exhibit a weak or no significant season variation. Energy use for space heating will naturally exhibit a strong seasonal variation, however it is a relatively small amount of total energy demand. This means that solar technology offers good potential to meet a significant proportion of a net zero building's energy needs, however export of excess energy is likely to occur from spring through to autumn unless it can be used for electric vehicle charging.

A net zero perspective: Can energy demand be in-phase with solar generation?

8.3.5 Building mounted solar energy is effectively 'free' to the occupant of the building, while grid energy prices are likely to become lower during periods when significant excess renewable energy generation is available on the national grid. As use of intermittent renewable energy grows, it is therefore likely that consumers will be financially motivated to use cheap clean energy when it is available. The most effective ways this is likely to be achieved are through smart thermostats controlling space and water heating, smart electric vehicle charging, and potentially battery storage if small scale systems become financially competitive.

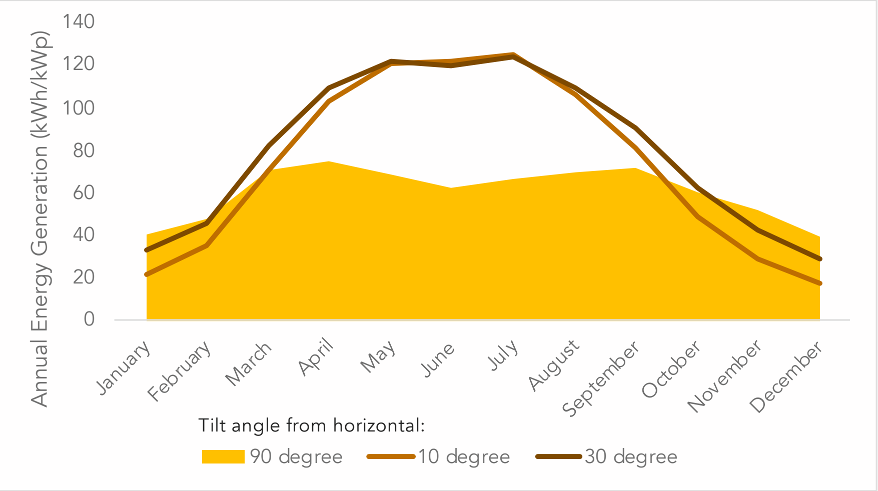


Figure 8.5 - Variation in monthly solar generation for Central Lincolnshire – South facing wall mounted systems generate 25% less energy than a rooftop system at a 30˚ tilt angle, but may be better suited to buildings with higher winter energy demand. (© EU Joint Research Centre PVGIS, 2020)

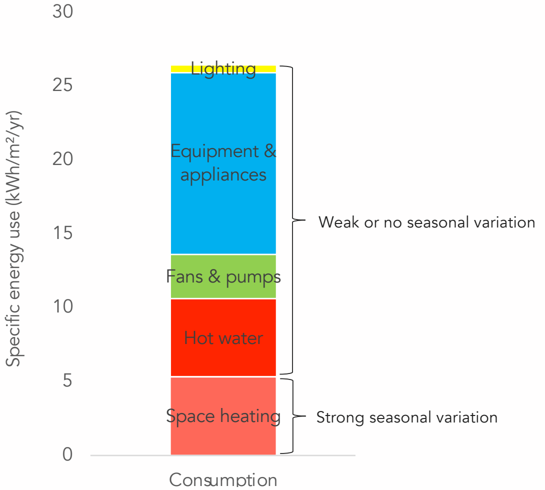


Figure 8.6 - The majority of energy use within a net zero carbon building with a heat pump is likely to show only a weak seasonal variation. (© Etude)

Appendix D: Embodied carbon of solar photovoltaics

Historical Trends

8.4.1 There has been a clear long-term trend for reductions in embodied energy and embodied carbon of crystalline solar technology, as shown in the adjacent figure. This is due to improvements in manufacturing efficiencies and decarbonisation of power supplies.

Future Trends

8.4.2 Louwen et al. project that by 2040 the lifecycle emissions of solar photovoltaic electricity will be just **8-11gCO_2e/kWh** for monocrystalline modules and **12-14gCO_2/kWh** for polycrystalline modules. A separate study by Pehl et al. projects that by 2050, in a world compliant with limiting warming to 2˚C, lifecycle emissions of solar photovoltaic electricity will be on average just **6gCO_2/kWh** (though will range from 3-21gCO_2/kWh, depending on location).

8.4.3 For context, BEIS' Digest of UK Energy Statistics (2020) reports for 2019 that the average carbon intensity of electricity supplied to the UK grid was 198gCO_2/kWh, while electricity from gas fire power stations was 371gCO_2/kWh. HM Treasury Green Book projections indicate an average grid carbon intensity of 28gCO_2e/kWh will be achieved by 2050.

Why 'Carbon Payback' is not a Sensible Metric

8.4.4 Carbon payback figures are typically quoted based on comparison of embodied carbon of solar photovoltaic systems with the operational carbon of the present or future UK grid. This is not an appropriate comparison as significant upstream emissions are associated with all sources of electricity, which are ignored by this approach.

8.4.5 Additionally, as the grid decarbonises (due to the deployment of solar and wind technology) the calculated carbon payback period will trend toward infinity. Even when the grid is, for practical purposes, completely decarbonised, new solar photovoltaic systems will still be required to replace existing systems at end of life and to meet any increases in demand for energy. Using a 'carbon payback' approach to justify new additions of solar photovoltaics is obviously not compatible with meeting this ongoing need for additional clean energy generation once the grid has decarbonised.

Atse Louwen et al. (2016) Re-assessment of net energy production and greenhouse gas emissions avoidance after 40 years of photovoltaics development, Nature Communications

Michaja Pehl et al (2017) Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling. Nature Energy.

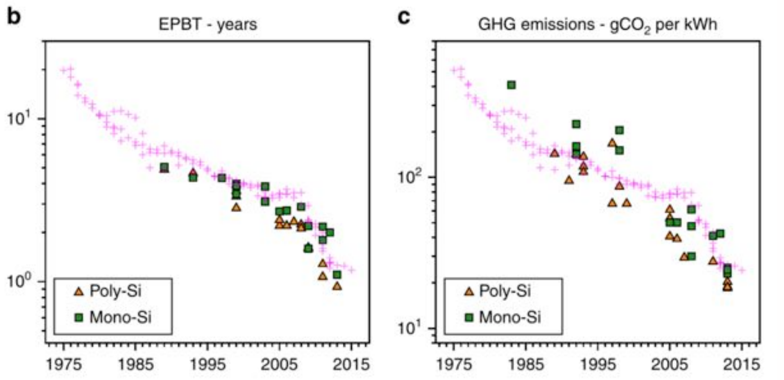


Figure 8.7 - The energy payback time and greenhouse gas emission intensity of solar photovoltaic technology has been steadily falling for decades and is forecast to continue to reduce. Source: Atse Louwen et al. (2016)

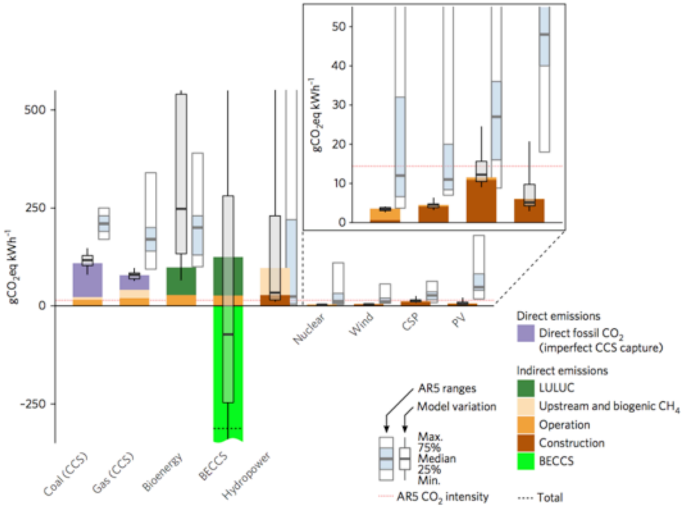
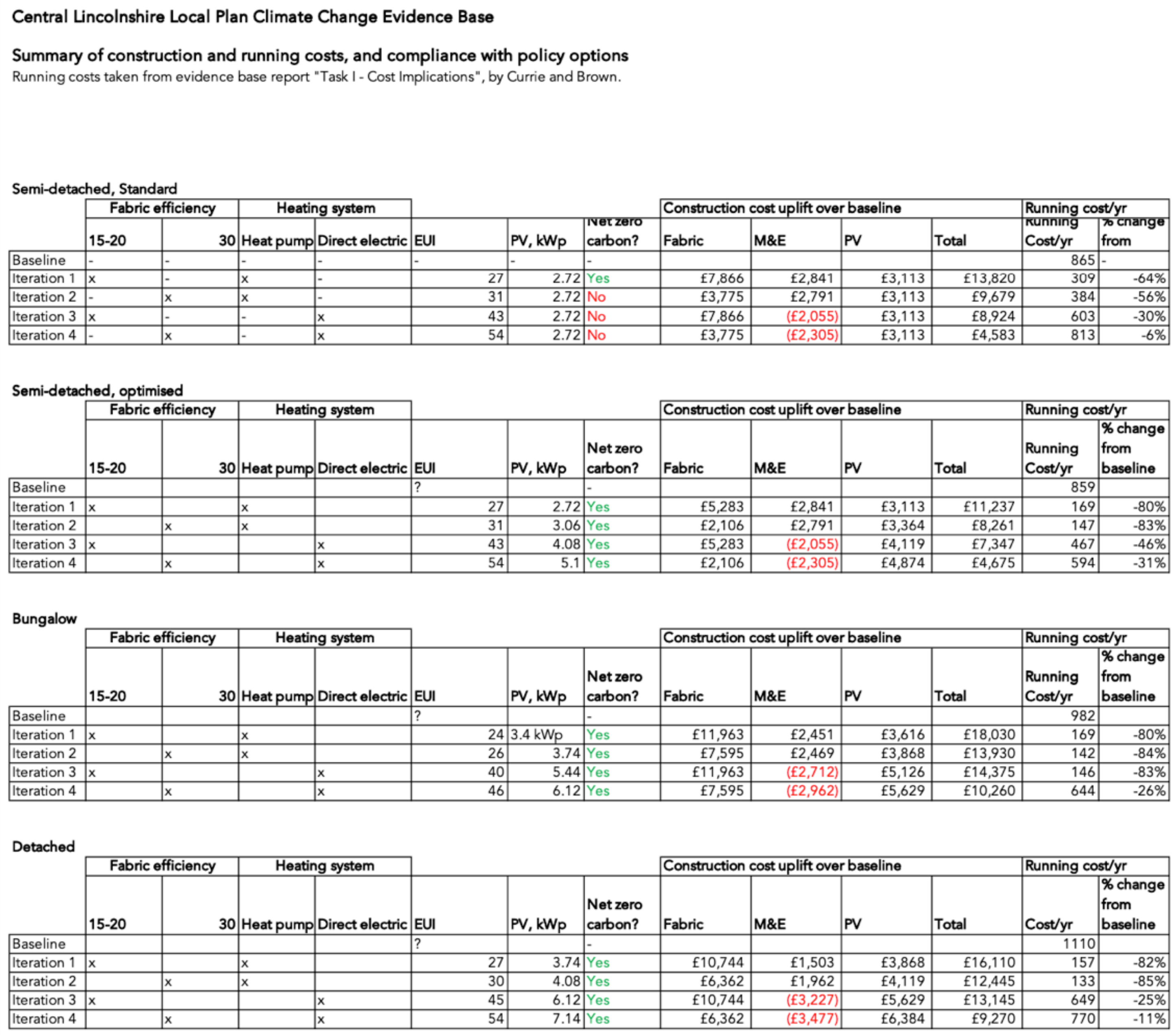


Figure 8.8 - Solar photovoltaics are on track to offer one of the lowest carbon sources of electricity. The coloured bars show lifecycle greenhouse emissions associated with generating a unit of electricity from different fuels, in a 2°C world in 2050. The white and light blue ranges show historic ranges published in the AR5 Intergovernmental Panel on Climate Change assessment. Source: Pehl et al. (2017)

Appendix E1: Cost analysis summary by Etude



Central Lincolnshire Local Plan Climate Change Evidence Base

Summary of construction and running costs, and compliance with policy options

Running costs taken from evidence base report "Task I - Cost Implications", by Currie and Brown.

Semi-detached, Standard

	Fabric efficiency		Heating system					Construction cost uplift over baseline				Running cost/yr	
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from
Baseline	-	-	-	-	-	-	-					865	-
Iteration 1	x	-	x	-	27	2.72	Yes	£7,866	£2,841	£3,113	£13,820	309	-64%
Iteration 2	-	x	x	-	31	2.72	No	£3,775	£2,791	£3,113	£9,679	384	-56%
Iteration 3	x	-	-	x	43	2.72	No	£7,866	(£2,055)	£3,113	£8,924	603	-30%
Iteration 4	-	x	-	x	54	2.72	No	£3,775	(£2,305)	£3,113	£4,583	813	-6%

Semi-detached, optimised

	Fabric efficiency		Heating system					Construction cost uplift over baseline				Running cost/yr	
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline					?		-					859	
Iteration 1	x		x		27	2.72	Yes	£5,283	£2,841	£3,113	£11,237	169	-80%
Iteration 2		x	x		31	3.06	Yes	£2,106	£2,791	£3,364	£8,261	147	-83%
Iteration 3	x			x	43	4.08	Yes	£5,283	(£2,055)	£4,119	£7,347	467	-46%
Iteration 4		x		x	54	5.1	Yes	£2,106	(£2,305)	£4,874	£4,675	594	-31%

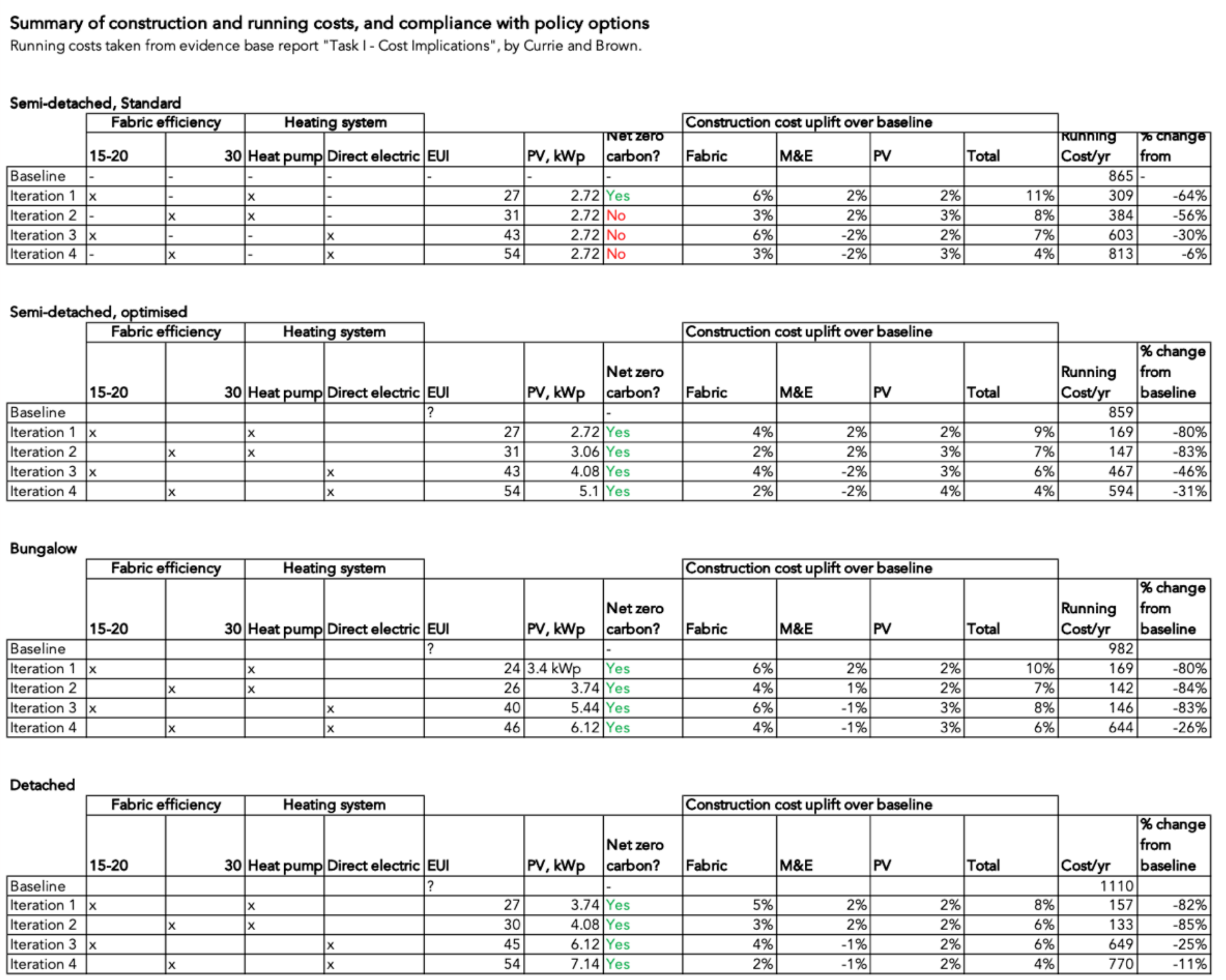
Bungalow

	Fabric efficiency		Heating system					Construction cost uplift over baseline				Running cost/yr	
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline					?		-					982	
Iteration 1	x		x		24	3.4 kWp	Yes	£11,963	£2,451	£3,616	£18,030	169	-80%
Iteration 2		x	x		26	3.74	Yes	£7,595	£2,469	£3,868	£13,930	142	-84%
Iteration 3	x			x	40	5.44	Yes	£11,963	(£2,712)	£5,126	£14,375	146	-83%
Iteration 4		x		x	46	6.12	Yes	£7,595	(£2,962)	£5,629	£10,260	644	-26%

Detached

	Fabric efficiency		Heating system					Construction cost uplift over baseline				Running cost/yr	
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Cost/yr	% change from baseline
Baseline					?		-					1110	
Iteration 1	x		x		27	3.74	Yes	£10,744	£1,503	£3,868	£16,110	157	-82%
Iteration 2		x	x		30	4.08	Yes	£6,362	£1,962	£4,119	£12,445	133	-85%
Iteration 3	x			x	45	6.12	Yes	£10,744	(£3,227)	£5,629	£13,145	649	-25%
Iteration 4		x		x	54	7.14	Yes	£6,362	(£3,477)	£6,384	£9,270	770	-11%

Appendix E2: Cost analysis summary by Etude



Summary of construction and running costs, and compliance with policy options

Running costs taken from evidence base report "Task I - Cost Implications", by Currie and Brown.

Semi-detached, Standard

	Fabric efficiency		Heating system					Construction cost uplift over baseline					
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from
Baseline	-	-	-	-	-	-	-					865	-
Iteration 1	x	-	x	-	27	2.72	Yes	6%	2%	2%	11%	309	-64%
Iteration 2	-	x	x	-	31	2.72	No	3%	2%	3%	8%	384	-56%
Iteration 3	x	-	-	x	43	2.72	No	6%	-2%	2%	7%	603	-30%
Iteration 4	-	x	-	x	54	2.72	No	3%	-2%	3%	4%	813	-6%

Semi-detached, optimised

	Fabric efficiency		Heating system					Construction cost uplift over baseline					
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline					?		-					859	
Iteration 1	x		x		27	2.72	Yes	4%	2%	2%	9%	169	-80%
Iteration 2		x	x		31	3.06	Yes	2%	2%	3%	7%	147	-83%
Iteration 3	x			x	43	4.08	Yes	4%	-2%	3%	6%	467	-46%
Iteration 4		x		x	54	5.1	Yes	2%	-2%	4%	4%	594	-31%

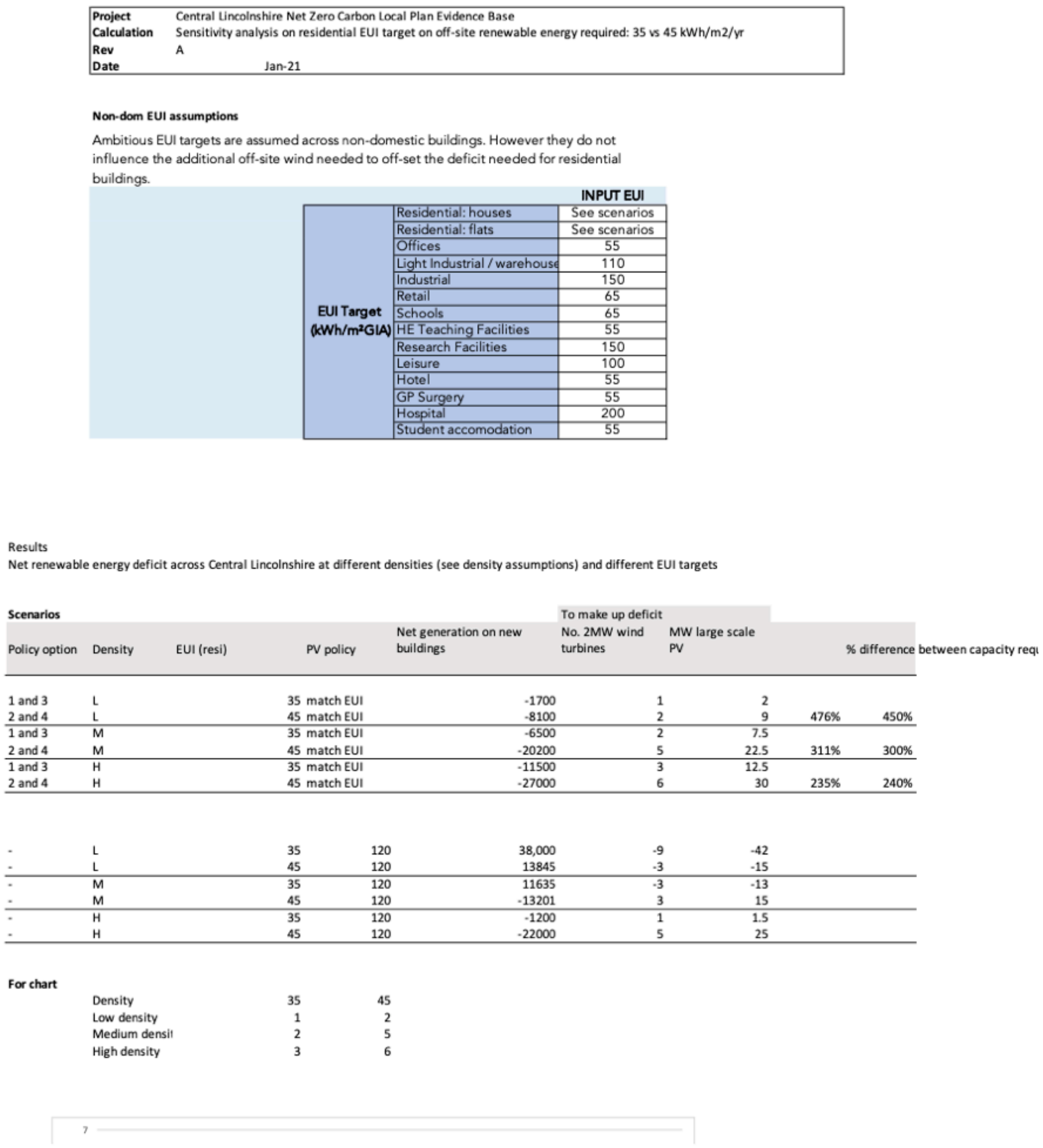
Bungalow

	Fabric efficiency		Heating system					Construction cost uplift over baseline					
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline					?		-					982	
Iteration 1	x		x		24	3.4 kWp	Yes	6%	2%	2%	10%	169	-80%
Iteration 2		x	x		26	3.74	Yes	4%	1%	2%	7%	142	-84%
Iteration 3	x			x	40	5.44	Yes	6%	-1%	3%	8%	146	-83%
Iteration 4		x		x	46	6.12	Yes	4%	-1%	3%	6%	644	-26%

Detached

	Fabric efficiency		Heating system					Construction cost uplift over baseline					
	15-20	30	Heat pump	Direct electric	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Cost/yr	% change from baseline
Baseline					?		-					1110	
Iteration 1	x		x		27	3.74	Yes	5%	2%	2%	8%	157	-82%
Iteration 2		x	x		30	4.08	Yes	3%	2%	2%	6%	133	-85%
Iteration 3	x			x	45	6.12	Yes	4%	-1%	2%	6%	649	-25%
Iteration 4		x		x	54	7.14	Yes	2%	-1%	2%	4%	770	-11%

Appendix F: Energy balance calculations



Project	Central Lincolnshire Net Zero Carbon Local Plan Evidence Base
Calculation	Sensitivity analysis on residential EUI target on off-site renewable energy required: 35 vs 45 kWh/m2/yr
Rev	A
Date	Jan-21

Non-dom EUI assumptions

Ambitious EUI targets are assumed across non-domestic buildings. However they do not influence the additional off-site wind needed to off-set the deficit needed for residential buildings.

		INPUT EUI
EUI Target (kWh/m²GIA)	Residential: houses	See scenarios
	Residential: flats	See scenarios
	Offices	55
	Light Industrial / warehouse	110
	Industrial	150
	Retail	65
	Schools	65
	HE Teaching Facilities	55
	Research Facilities	150
	Leisure	100
	Hotel	55
	GP Surgery	55
	Hospital	200
	Student accomodation	55

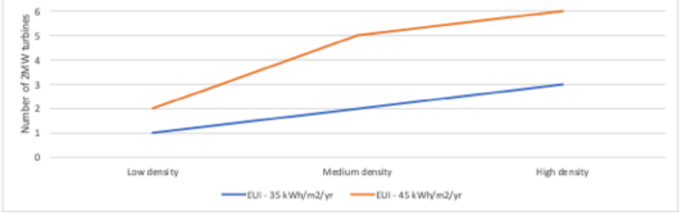
Results

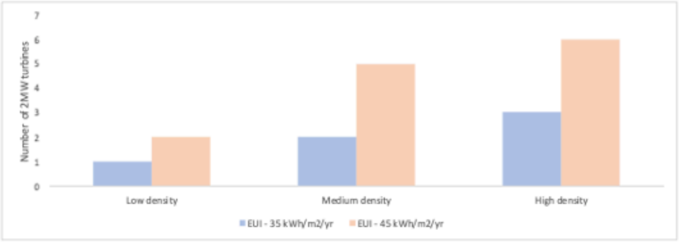
Net renewable energy deficit across Central Lincolnshire at different densities (see density assumptions) and different EUI targets

Scenarios					To make up deficit			
Policy option	Density	EUI (resi)	PV policy	Net generation on new buildings	No. 2MW wind turbines	MW large scale PV	% difference between capacity requ	
1 and 3	L	35	match EUI	-1700	1	2		
2 and 4	L	45	match EUI	-8100	2	9	476%	450%
1 and 3	M	35	match EUI	-6500	2	7.5		
2 and 4	M	45	match EUI	-20200	5	22.5	311%	300%
1 and 3	H	35	match EUI	-11500	3	12.5		
2 and 4	H	45	match EUI	-27000	6	30	235%	240%
-	L	35	120	38,000	-9	-42		
-	L	45	120	13845	-3	-15		
-	M	35	120	11635	-3	-13		
-	M	45	120	-13201	3	15		
-	H	35	120	-1200	1	1.5		
-	H	45	120	-22000	5	25		

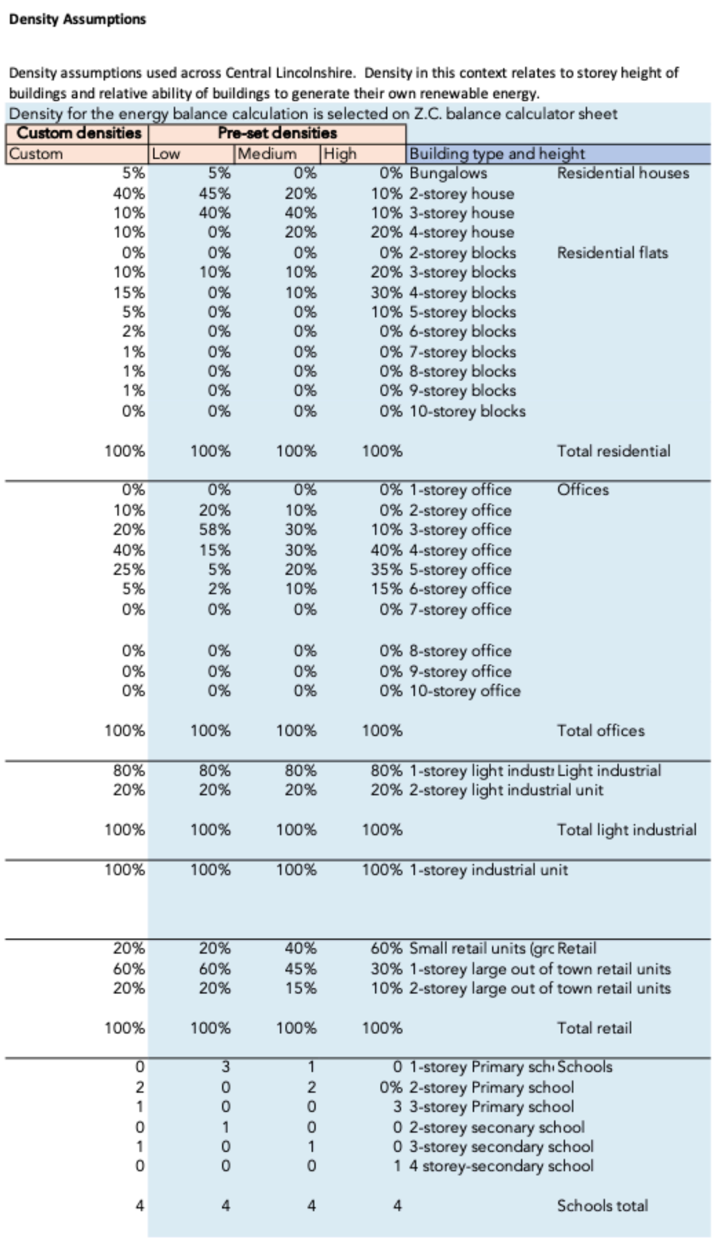
For chart

Density	35	45
Low density	1	2
Medium densit	2	5
High density	3	6





Appendix G: Energy balance calculations: density assumption

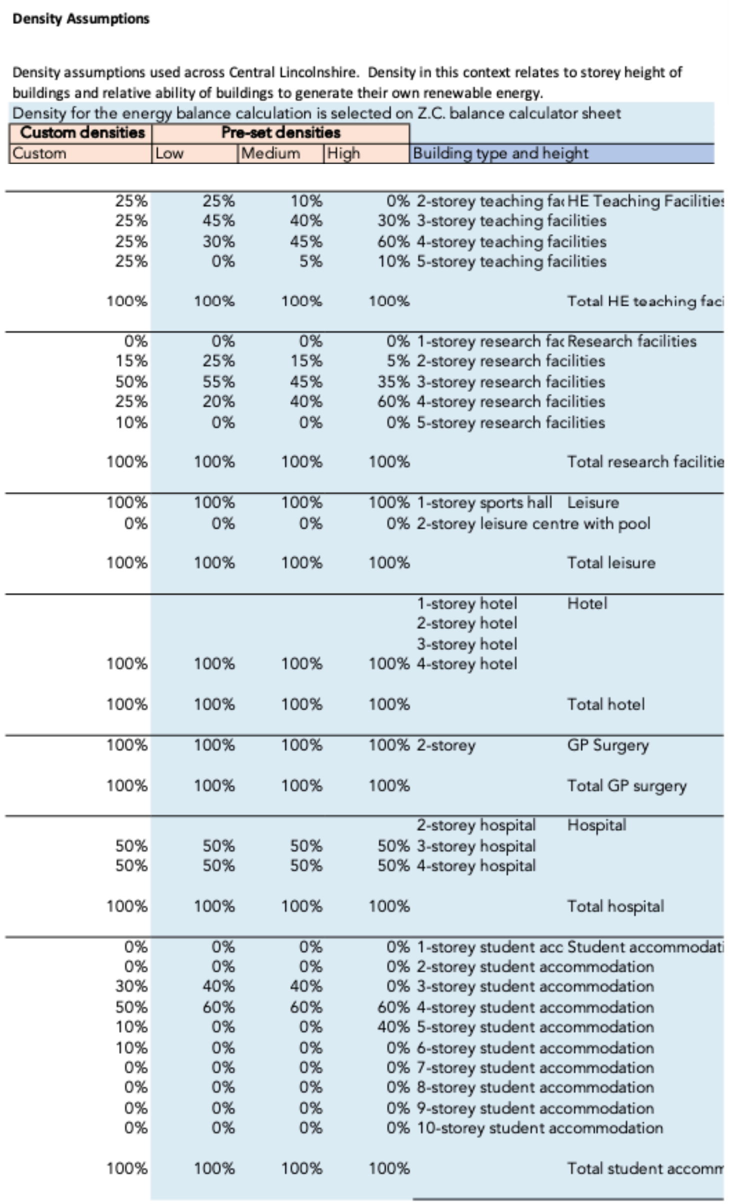


Density Assumptions

Density assumptions used across Central Lincolnshire. Density in this context relates to storey height of buildings and relative ability of buildings to generate their own renewable energy.

Density for the energy balance calculation is selected on Z.C. balance calculator sheet

Custom densities	Pre-set densities				
Custom	Low	Medium	High	Building type and height	
5%	5%	0%	0%	Bungalows	Residential houses
40%	45%	20%	10%	2-storey house	
10%	40%	40%	10%	3-storey house	
10%	0%	20%	20%	4-storey house	
0%	0%	0%	0%	2-storey blocks	Residential flats
10%	10%	10%	20%	3-storey blocks	
15%	0%	10%	30%	4-storey blocks	
5%	0%	0%	10%	5-storey blocks	
2%	0%	0%	0%	6-storey blocks	
1%	0%	0%	0%	7-storey blocks	
1%	0%	0%	0%	8-storey blocks	
1%	0%	0%	0%	9-storey blocks	
0%	0%	0%	0%	10-storey blocks	
100%	100%	100%	100%		Total residential
0%	0%	0%	0%	1-storey office	Offices
10%	20%	10%	0%	2-storey office	
20%	58%	30%	10%	3-storey office	
40%	15%	30%	40%	4-storey office	
25%	5%	20%	35%	5-storey office	
5%	2%	10%	15%	6-storey office	
0%	0%	0%	0%	7-storey office	
0%	0%	0%	0%	8-storey office	
0%	0%	0%	0%	9-storey office	
0%	0%	0%	0%	10-storey office	
100%	100%	100%	100%		Total offices
80%	80%	80%	80%	1-storey light industr	Light industrial
20%	20%	20%	20%	2-storey light industrial unit	
100%	100%	100%	100%		Total light industrial
100%	100%	100%	100%	1-storey industrial unit	
20%	20%	40%	60%	Small retail units (grc	Retail
60%	60%	45%	30%	1-storey large out of town retail units	
20%	20%	15%	10%	2-storey large out of town retail units	
100%	100%	100%	100%		Total retail
0	3	1	0	1-storey Primary sch	Schools
2	0	2	0%	2-storey Primary school	
1	0	0	3	3-storey Primary school	
0	1	0	0	2-storey seconary school	
1	0	1	0	3-storey secondary school	
0	0	0	1	4 storey-secondary school	
4	4	4	4		Schools total



Density Assumptions

Density assumptions used across Central Lincolnshire. Density in this context relates to storey height of buildings and relative ability of buildings to generate their own renewable energy.

Density for the energy balance calculation is selected on Z.C. balance calculator sheet

Custom densities	Pre-set densities				
Custom	Low	Medium	High	Building type and height	
25%	25%	10%	0%	2-storey teaching fac	HE Teaching Facilities
25%	45%	40%	30%	3-storey teaching facilities	
25%	30%	45%	60%	4-storey teaching facilities	
25%	0%	5%	10%	5-storey teaching facilities	
100%	100%	100%	100%		Total HE teaching faci
0%	0%	0%	0%	1-storey research fac	Research facilities
15%	25%	15%	5%	2-storey research facilities	
50%	55%	45%	35%	3-storey research facilities	
25%	20%	40%	60%	4-storey research facilities	
10%	0%	0%	0%	5-storey research facilities	
100%	100%	100%	100%		Total research facilitie
100%	100%	100%	100%	1-storey sports hall	Leisure
0%	0%	0%	0%	2-storey leisure centre with pool	
100%	100%	100%	100%		Total leisure
				1-storey hotel	Hotel
				2-storey hotel	
				3-storey hotel	
100%	100%	100%	100%	4-storey hotel	
100%	100%	100%	100%		Total hotel
100%	100%	100%	100%	2-storey	GP Surgery
100%	100%	100%	100%		Total GP surgery
				2-storey hospital	Hospital
50%	50%	50%	50%	3-storey hospital	
50%	50%	50%	50%	4-storey hospital	
100%	100%	100%	100%		Total hospital
0%	0%	0%	0%	1-storey student acc	Student accommodati
0%	0%	0%	0%	2-storey student accommodation	
30%	40%	40%	0%	3-storey student accommodation	
50%	60%	60%	60%	4-storey student accommodation	
10%	0%	0%	40%	5-storey student accommodation	
10%	0%	0%	0%	6-storey student accommodation	
0%	0%	0%	0%	7-storey student accommodation	
0%	0%	0%	0%	8-storey student accommodation	
0%	0%	0%	0%	9-storey student accommodation	
0%	0%	0%	0%	10-storey student accommodation	
100%	100%	100%	100%		Total student accomm