South Cambridgeshire District Council (SCDC)

Greater Cambridge Local Plan: Net Zero Carbon Evidence Base

Task D – Technical Feasibility

May 2021 I Rev I

Bioregional Etude Currie & Brown

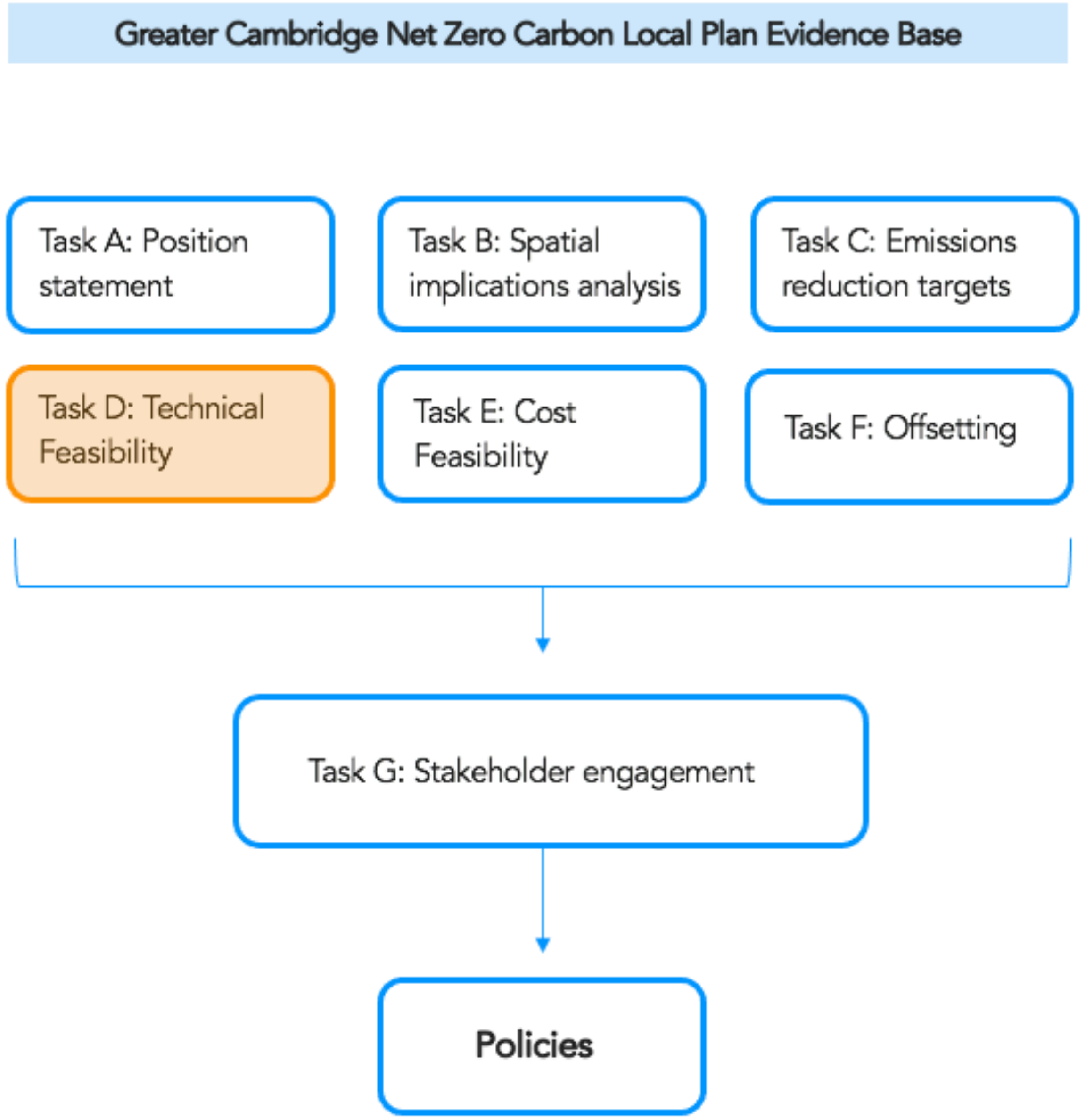
Task G

Technical Feasibility

This section assesses the technical feasibility of achieving the targets identified in “Task C: Carbon Reduction Targets”.

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 Cambridge and South Cambridgeshire.



Our approach to determining technical feasibility

Step 1: Define what makes a building zero carbon

The position statement provides a general definition of a zero carbon building. We convert this into three areas of technical performance that can be assessed: energy efficiency, low carbon heating and renewable energy.

Step 2: Investigate each area of performance

Energy efficiency – The levels of energy efficiency required for net zero carbon buildings are investigated through the simple metric of metered energy per square meter of internal floor area. This may also be called 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 asses the potential for on-site renewable energy generation to meet or exceed the metered electricity use, to achieve net zero carbon.

Step 3: Energy modelling results

The technical feasibility of four common types of new building are assessed in the context of Greater Cambridge. The performance of the three technical areas of performance above are calculated and assessed against requirements for net zero.

Step 4: Consider additional types of building

Other building types likely to feature in new development in Greater Cambridge have been selected for discussion. We comment on the feasibility of achieving net zero carbon and present case studies of built examples that meet some of the zero carbon indicators.

Figure 01 - Four building types modelled as part of this technical evidence base: semi-detached house; terraced house; 4-storey block of flats and a two-form entry primary school. Recent planning applications have been used as the basis for the modelling.

Task D

Technical Feasibility

Definition of a net zero carbon building

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

Definition of a net zero carbon building

Definition of a Net Zero Carbon building

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

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 most buildings it should be around 35-65 kWh/m^2/yr, though this varies by type.

2. Low carbon heating

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

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.

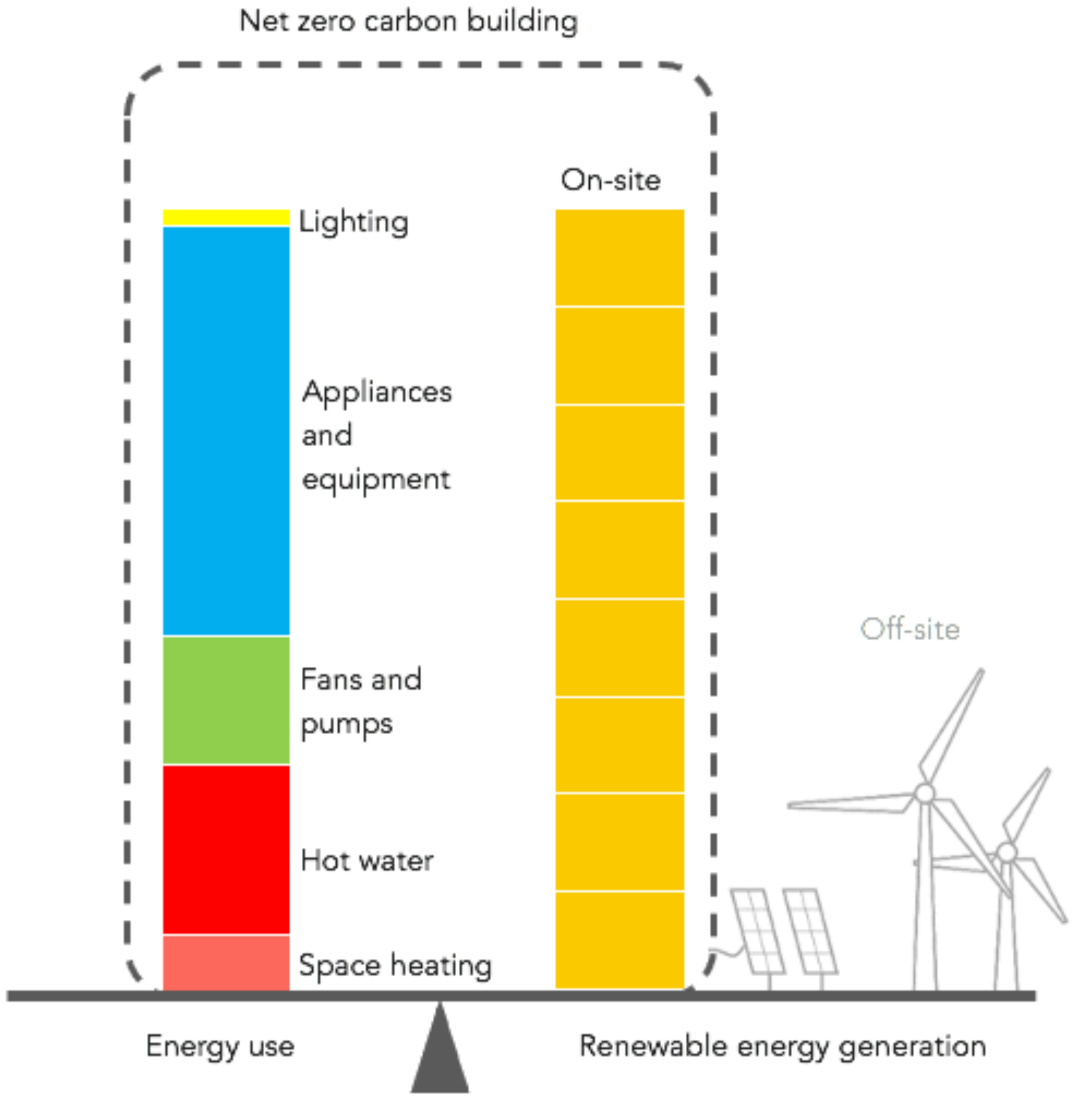


Figure 02 – To achieve net zero carbon in a new building, the energy consumption of a building should be matched by renewable energy generation. The example shown is for an energy efficient house that is heated by a heat pump. Each yellow block represents the energy produced by a single solar photovoltaic panel. In this case, off-site generation is not required to achieve net zero.

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

Building fabric

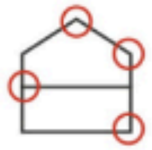
The Committee on Climate Change indicate that a space heat demand of 15-20 kWh/m²/yr is required for new housing if the UK is to meet its net zero carbon commitments[01]. This level of performance is also closely aligned with the Passivhaus Institute's Passivhaus Standard of 15kWh/m²/yr. As this represents a sensible upper limit of building fabric efficiency, it is also a sensible target for most other building types. For context, a Part L 2013 compliant home would typically have a space heat demand between 60-90 kWh/m²/yr.

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.

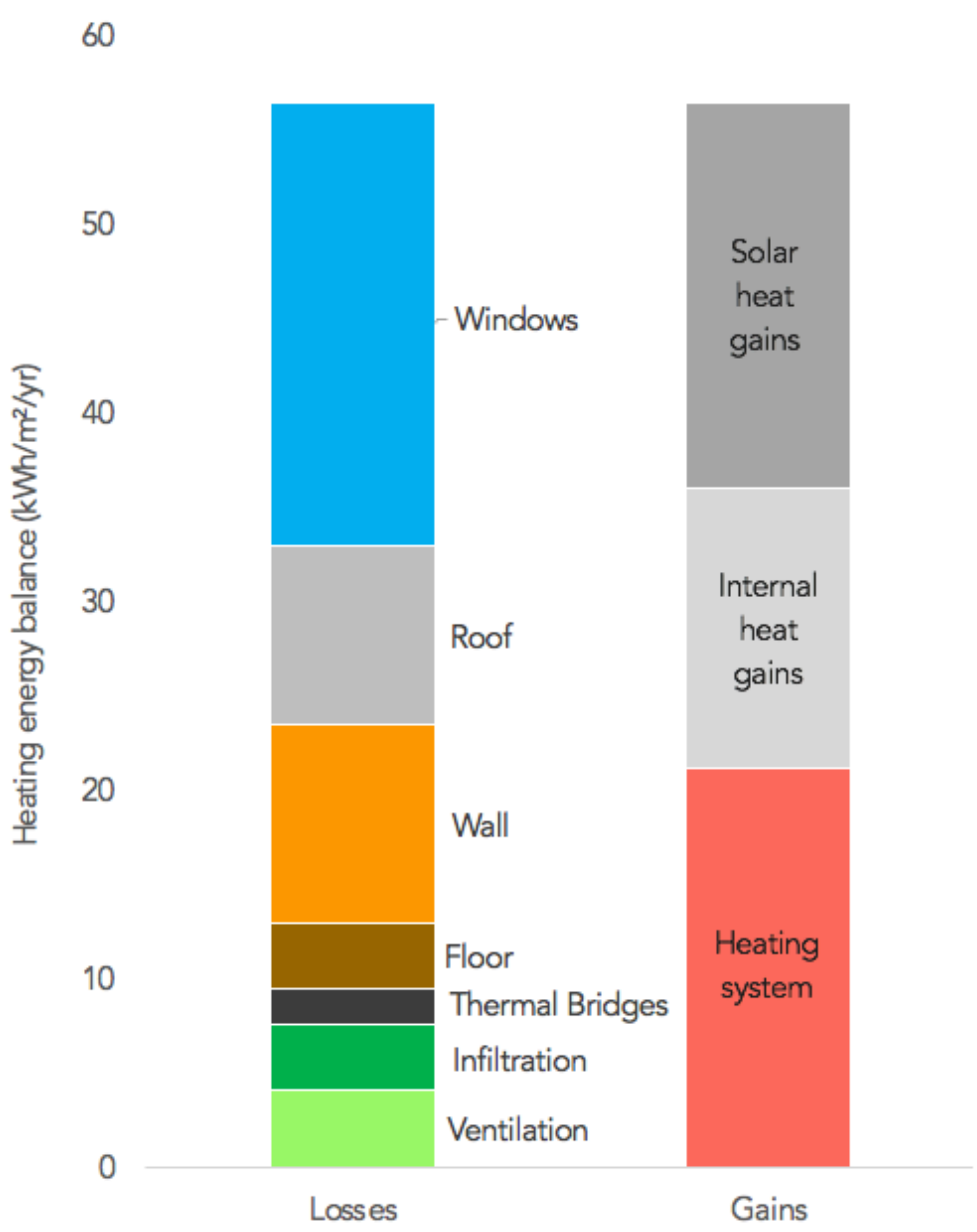
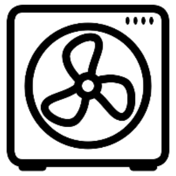


Figure 03 – Typical balance of heating energy losses and gains for a very efficient building. Heat gains come from useful solar gains, internal heat gains from occupants and appliances, with the remainder provided by the building's heating system.



Heat pumps

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

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

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

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

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.

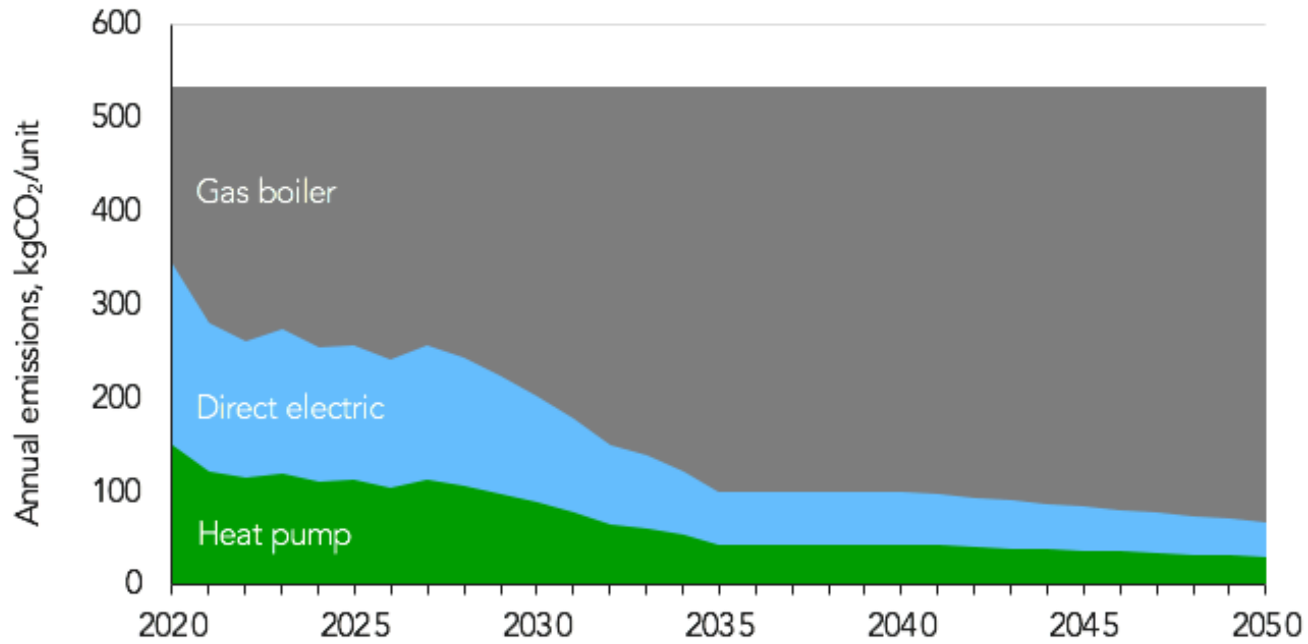


Figure 03 - Projected annual CO_2 emissions of different heating systems for an energy efficient 2-bed flat. Heat pumps offer the lowest emission solution.

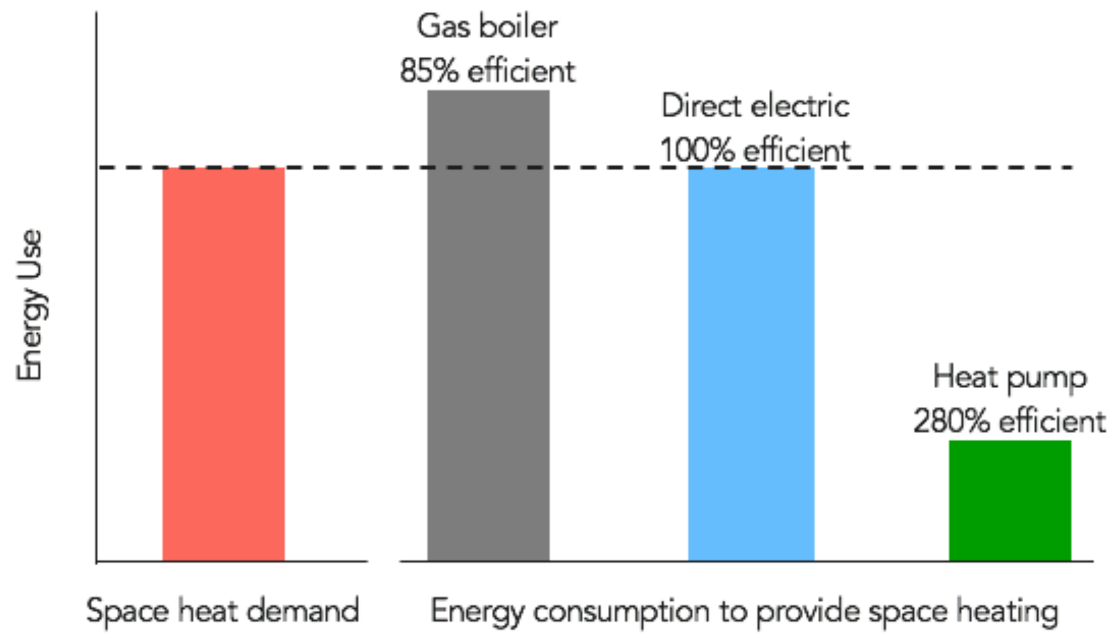


Figure 04 – Choice of heating system affects energy use significantly. Heat pumps are very efficient, helping buildings to meet the net zero requirements for low energy use.

Solar photovoltaic panels

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 solely through photovoltaics in our technical feasibility analysis.

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.

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).

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

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

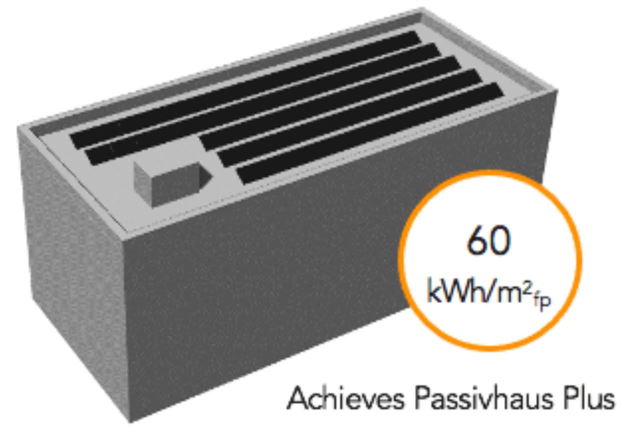
We have not considered solar water heating as the electricity generated by solar photovoltaic panels is a more valuable form of energy than hot water, and in most cases solar photovoltaic systems offer better value and are more reliable. The use of small-scale wind turbines has also not been considered 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?

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.

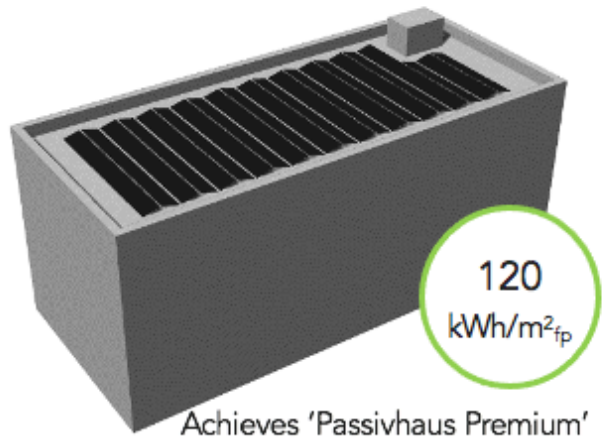
Flat roof - business as usual

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.



Flat roof - good practice

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.

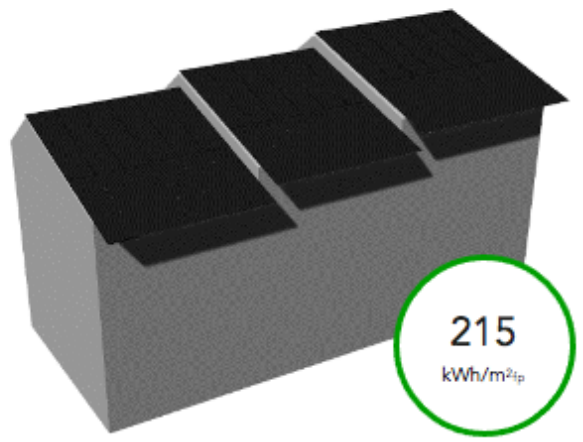


✓ Net zero possible up to four storeys

Best practice

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

Net zero carbon and density of development

The challenge of taller buildings

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 6 for a block of flats and terraced houses.

Façade mounted solar photovoltaics

One solution to this is to mount solar panels vertically on building facades, as shown in Figure 5. In Greater Cambridge, on a wall this would result in a modest 10% (South) to 20% (South East or West) 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

Another solution is to group buildings in a way that ensures that new development is, on average, net zero across Greater Cambridge. 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 05: With 576kW of solar photovoltaic panels installed, the CIS tower in Manchester was Europe's largest vertical solar array when completed in 2006.

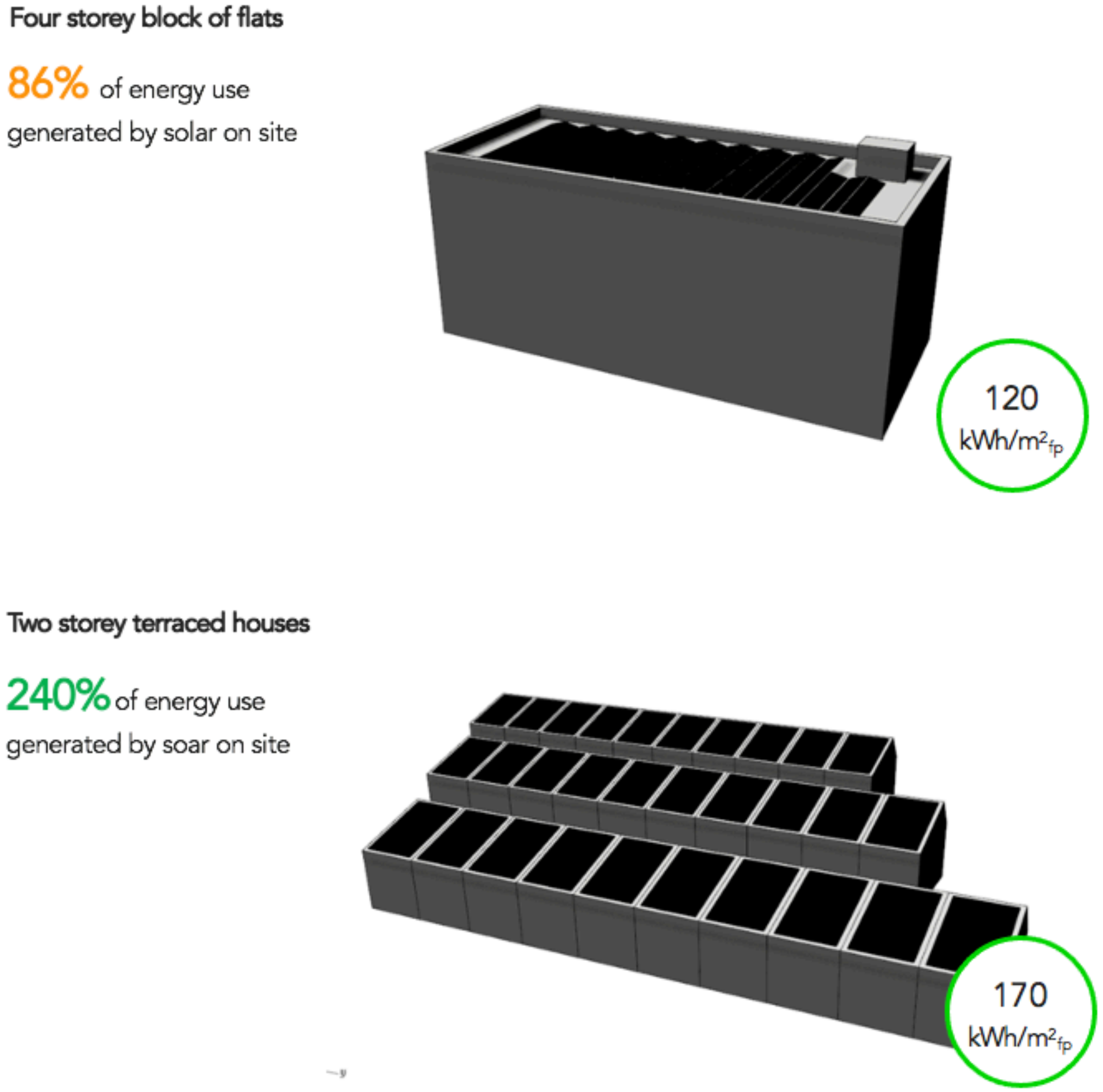


Figure 06: Comparison of renewable energy generation by density. Both the block of flats and the terraced houses have the same internal floor area. The block of flats has much less roof space, so is not able to generate enough renewable energy on site to be net zero carbon. Mechanisms could be introduced to planning policy to encourage surplus energy generation on low-density sites to offset higher density buildings that cannot achieve net zero on site.

Task D

Technical Feasibility

Energy modelling methodology

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

How we model energy consumption

Why energy modelling is useful

Energy modelling is required to predict and quantify how design and specification will affect energy use. It enables informed decisions when developing a design strategy.

Predicted energy modelling methodology

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. An update to SAP is currently being developed by BEIS.

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

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

It needs to be good at predicting energy use

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.

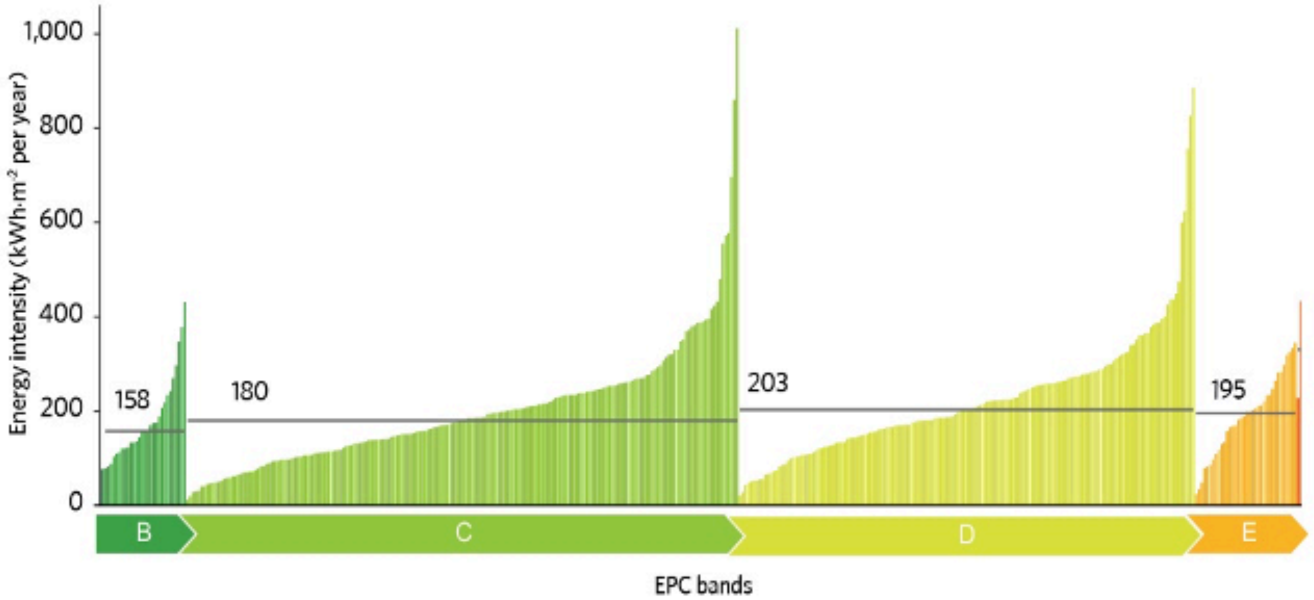
SAP and SBEM are used to produce Energy Performance Certificates (EPCs), which provide the energy rating for a home. They are generally not accurate at predicting energy use – they have been designed primarily as a tool to show compliance with building regulations, and do not include some categories of energy use. They tend to assume a building receives more 'free heat' than is usually the case in reality. Post occupancy studies in the UK[07] and Europe [08] have shown that PHPP is generally accurate. Until SAP, SBEM and EPCs are improved it is not recommended to use them as key performance indicators.

We believe the most robust energy modelling tool to evidence net zero carbon is PHPP. For this reason, our technical feasibility analysis uses PHPP to determine the compliance with "net zero carbon".

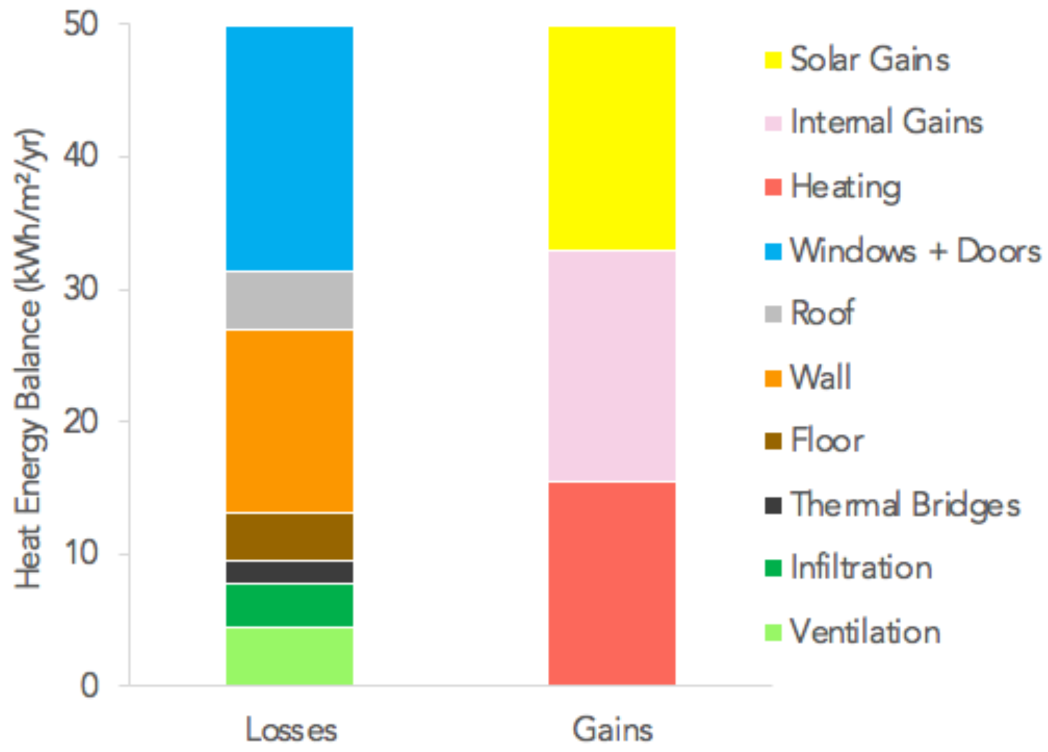
Baselines

Designs taken from recent planning applications will be used as the baseline. Our modelling is therefore indicative of what is currently being built in the region and we can test whether zero carbon is achievable without changes to the form and aesthetic.

Results for the baseline models are not given as they are not relevant. The baselines are used as the basis for cost uplifts in our cost feasibility analysis.



Comparison of the EPC energy efficiency rating with metered energy consumption of 420 homes: There is little correlation between EPC band and actual energy consumption. © Etude



Typical output of PHPP energy modelling: Building performance shown in detail © Etude

Task D

Technical Feasibility

Energy modelling results

This section presents the results of energy modelling for four different types of building that are expected to be common in new builds across Greater Cambridge.

Net Zero Carbon definition for this type

Net zero carbon can be achieved with:

1. Metered energy use of 35 kWh/m^2_{GIA}/year or less
2. No fossil fuel combustion on site
3. Solar generation that exceeds energy use on site

This page focuses on building fabric and ventilation and their contribution towards (1). It is based on PHPP energy modelling.

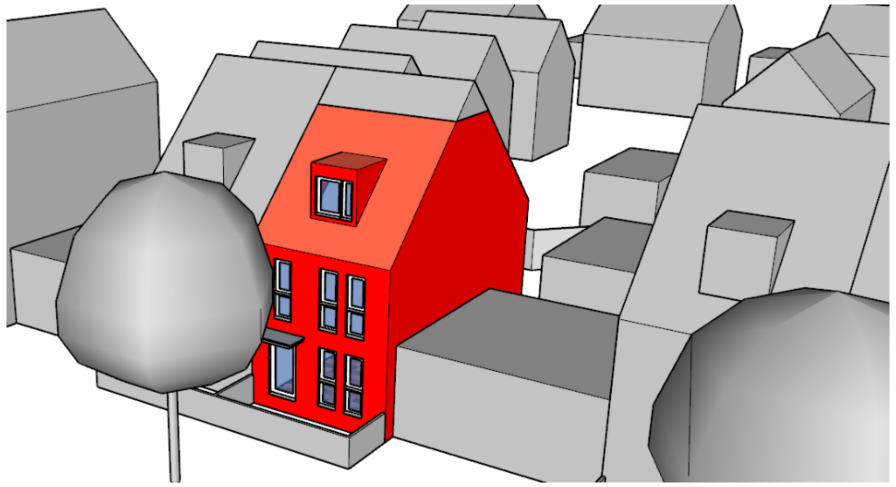
(1) Metered Energy Use < 35 kWh/m^2_{GIA}/yr

Efficient building fabric is the foundation of a net zero building. The fabric and ventilation systems summarised on this page are close to achieving a space heating demand of less than 15-20 kWh/m^2/yr, the range recommended by the Climate Change Committee.

This level of performance requires an efficient form and reasonable window proportions. 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.

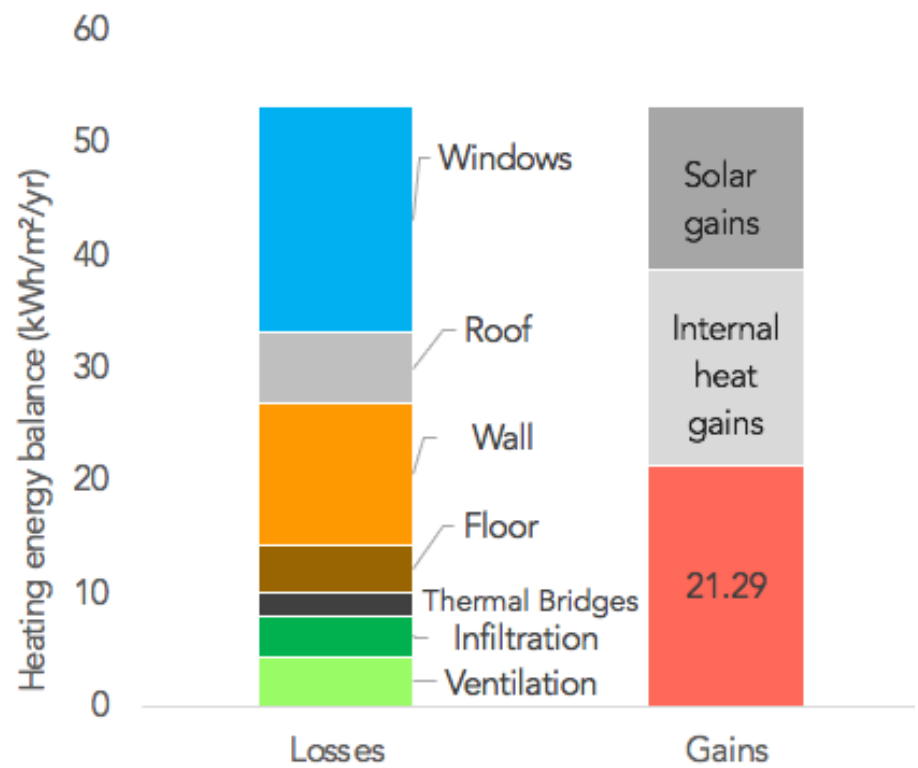
The baseline building was not designed to be a low energy building and has a space heating demand of 76kWh/m^2/yr. This makes it challenging to achieve a low space heat demand without relying on excessively high specification materials or products.

Better design could achieve improved performance and/or maintain current performance for reduced cost. For example, combining split windows into single windows, or making the windows smaller, would reduce both heat loss and cost.



- 78 sqm TFA
- 46 sqm building footprint
- 113 sqm external walls
- 7 sqm dormer walls and roof
- 17 sqm windows/doors
- Form factor: 3.05

Semi detached house modelled: *A single semi detached house from the Sheepfold development has been investigated.*



Space heating demand: *The house would achieve a space heating demand of 21 kWh/m^2/yr with the specifications below*

	Baseline performance	Required performance	Indicative solution (how to achieve the specs)
Floor U-value	0.15 W/m^2K	0.12 W/m^2K	300mm XPS insulation
Wall U-value	0.18W/m^2K	0.10 W/m^2K	200mm PIR insulation
Roof U-value	0.13 W/m^2K	0.10 W/m^2K	90mm PIR insulation on 150mm deep rafters with PIR insulation fitted between
Dormer U-value	0.2 W/m^2K	0.12 W/m^2K	180mm PIR insulation (structural insulated panels)
Window U-value	1.40 W/m^2K	0.90 W/m^2K	Triple glazed, low-e coating, warm edge spacer
Thermal bridging	5 kWh/m^2/yr	2 kWh/m^2/yr	Good design, thermally broken lintels. Insulation wrap around slab edge. Insulated soil vent pipe.
Ventilation	Continuous extract ventilation SFP < 0.24Wh/m^3	MVHR 88% heat recovery SFP < 0.45Wh/m^3	Zehnder Comfoair 160 with pre-insulated rigid ducting
Airtightness	<5m^3/m^2h	<0.55m^3/m^2h	Wet plaster applied to walls, airtight plasterboard or membrane in ceiling. Use of airtightness tape at all junctions and airtight grommets at service entries.

Building fabric and ventilation specifications: *A summary of key attributes assumed for the PHPP and cost modelling*

This page focuses on how low carbon heating can deliver net zero requirements (1) and (2).

(1) Metered Energy Use < 35 kWh/m$^2_{GIA}$/yr

The two low carbon heating systems most likely to be specified for a net zero semi detached house are an air source heat pump or direct electric heating.

- The semi detached house would achieve metered energy use of 26kWh/m$^2_{GIA}$ /yr with a standard air source heat pump
- The semi detached house would achieve metered energy use of 43kWh/m$^2_{GIA}$ /yr with direct electric heating

(2) No fossil fuel combustion on site

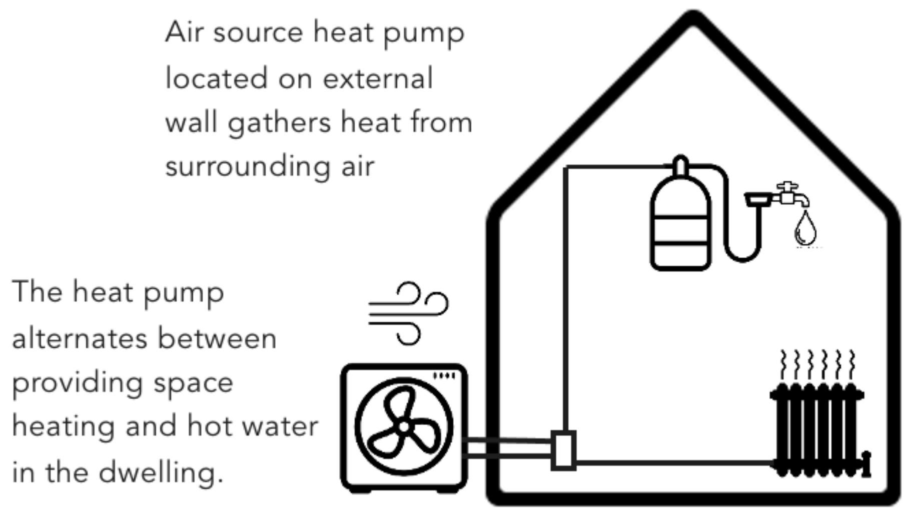
This condition will be met as long as the house is not heated by an individual gas or oil boiler, or by a communal or district-scale heating system using gas.

This is unlikely to represent an additional cost as it is set to become a baseline requirement for new buildings, based on Climate Change Committee guidance that: '*from 2025 at the latest, no new homes should be connected to the gas grid, with ultra-low energy houses and flats using low carbon heat instead*'

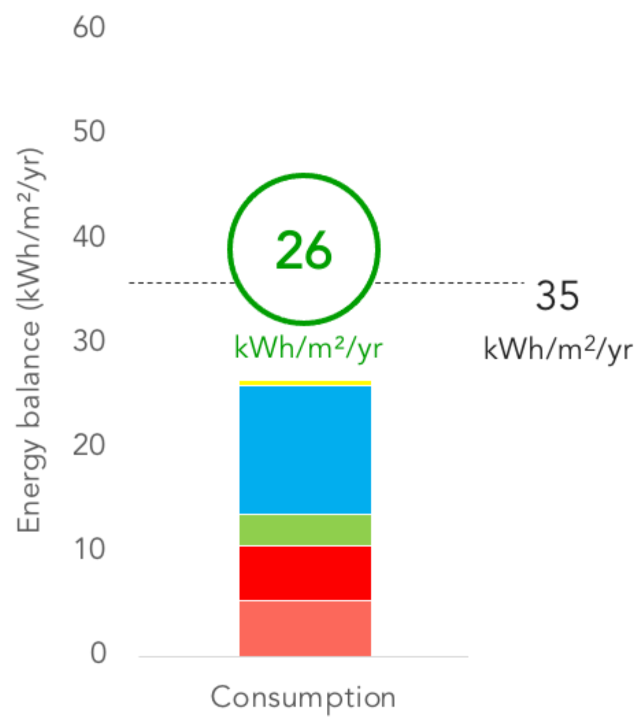
Discussion on other heating systems

There are several other types of heat pump that could be used to achieve net zero carbon. Options include: Air-air heat pumps, which are lower cost but provide space heating and cooling only. Ground source heat pumps, which are usually higher cost but longer lasting. 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 a limited amount of space heating.

Air source heat pump

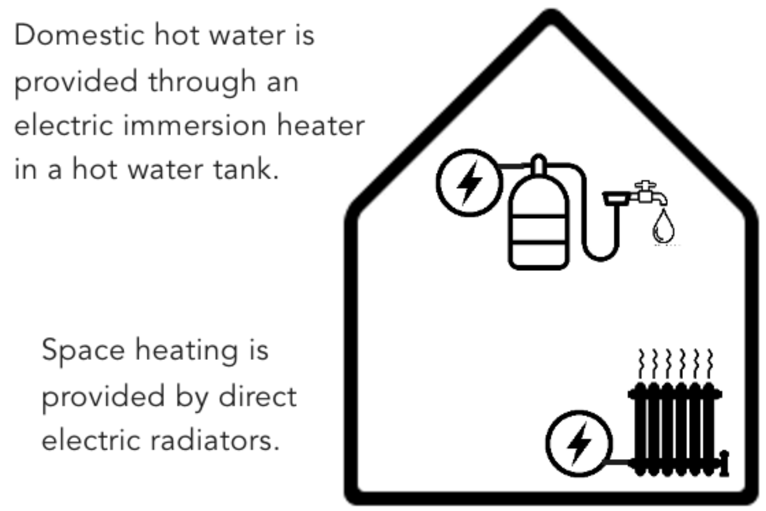


Heating system	Air source heat pump	e.g. 5kW Mitsu Ecodan
Hot water cylinder	150 litres with losses < 1.0 kWh/day	e.g. Mitsubishi cylinder
Emitters	Wet heating system 2 radiators	e.g. Stelrad Softline K2

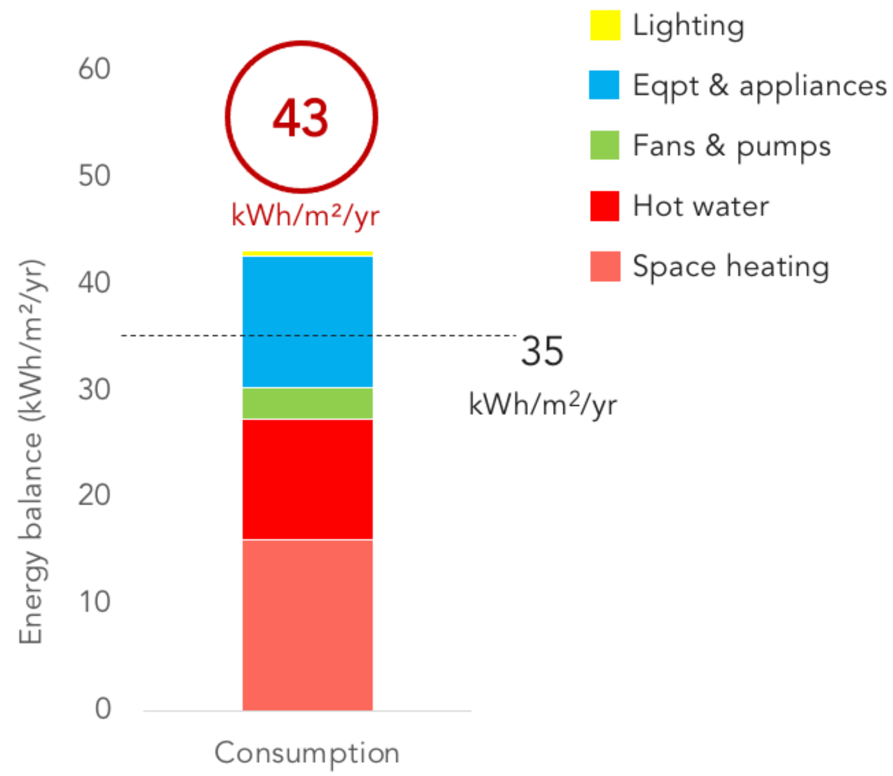


*With an **air source heat pump,** the house achieves metered energy use of 26 kWh/m²/yr, compliant with Net Zero Carbon*

Direct electric heating



Heating system	Direct electric heating	
Hot water cylinder	100 litres with losses < 0.8 kWh/day	e.g. Dimplex ECSd
Heat Emitters	3 panel heaters	



*With **direct electric heating,** the house achieves metered energy use of 43 kWh/m²/yr, exceeding 35 kWh/m²/yr. It could still achieve Net Zero Carbon if enough solar panels are installed.*

(3) Solar generation exceeds metered energy use

This condition is easily met on low rise buildings as they have a high ratio of roof area to energy use.

Just 8 solar panels would be sufficient for the house to generate as much electricity as it uses over a year. Energy generation could almost double if the building is oriented East-West and the roof lights are relocated.

Discussion on other PV layouts

Removing the dormer window allows up to 24 panels by eliminating shading and freeing up more roof area. Moving the ridgeline North on South facing buildings to create an asymmetric roof allows up to 16 panels to be installed on the Southern roof.

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

Ensuring residents benefit from solar

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.

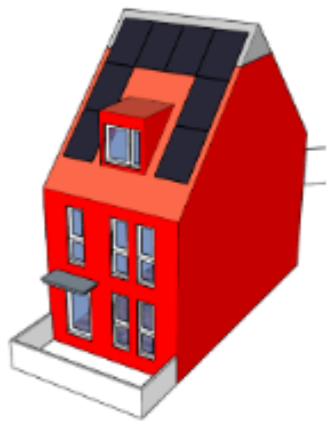
Typically, homes consume around 15-30% of solar energy directly, though 50-70% is possible with smart control of space and water heating. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat so the heating can be run when solar energy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

Surplus electricity could also be used for charging an electric vehicle, which typically require around 2,500 kWh per year. This could increase self-consumption of solar electricity above 70%.

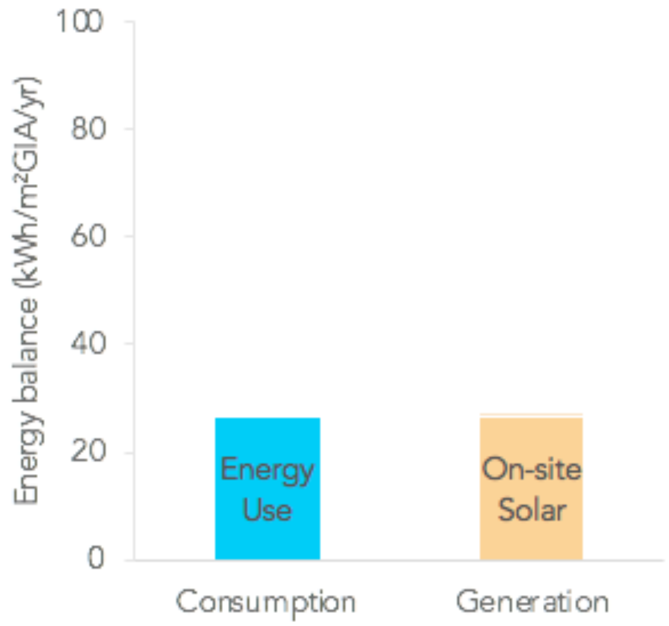
Minimum solar for Net Zero Carbon

2.9 kWp
Nominal array power

62 kWh/m²$_{fp}$
Specific energy generation



8 x 380W solar photovoltaic panels would be sufficient to generate 28 kWh/m2/yr and therefore achieve Net Zero Carbon

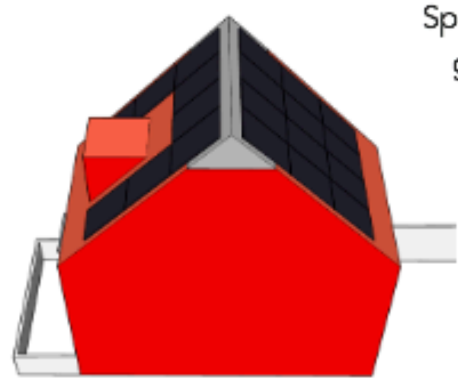


***Net zero energy balance:** The house can generate as much solar electricity as it consumes with a South West facing 8 panel solar array.*

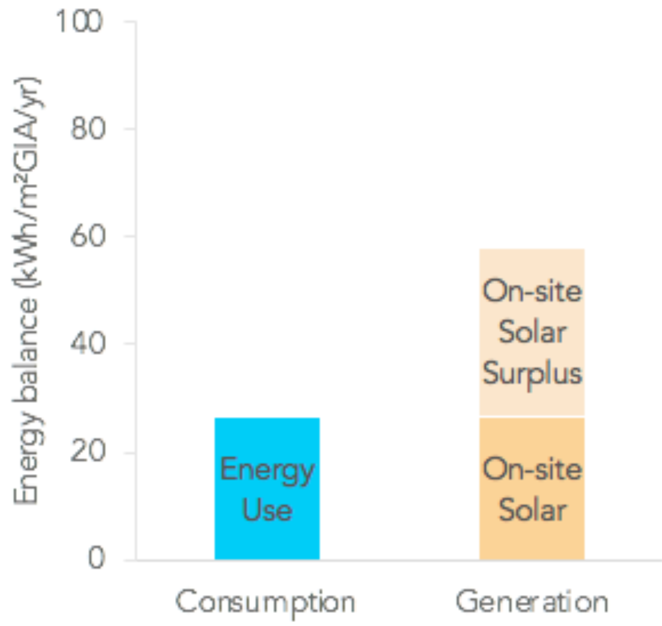
Maximum solar potential

7.2 kWp
Nominal array power

122 kWh/m²$_{fp}$
Specific energy generation



20 x 360W solar photovoltaic panels would enable the house to be energy positive if in an East-West orientation. Solar generation would be 195% of annual energy use.

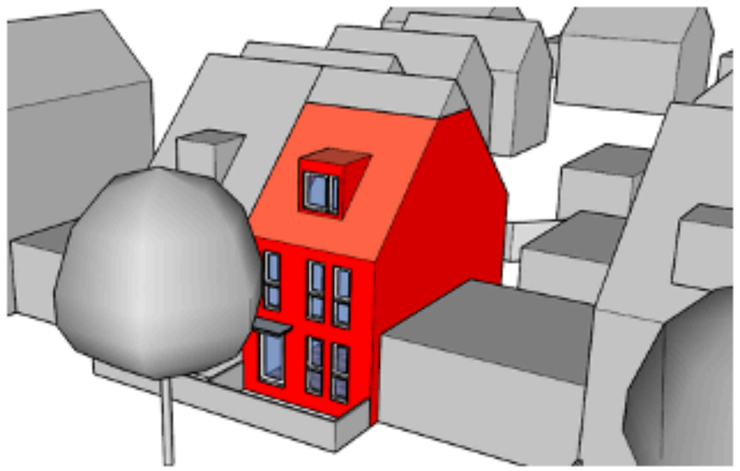


***Net zero energy balance:** The house is a net producer of clean electricity with East and West facing solar arrays.*

Testing the impact of form on ability to achieve zero carbon

The semi-detached house modelled on pages 13 to 15 struggles to meet a space heating demand of 15 kWh/m2/yr in its current design. We tested how optimising building form might impact this particular dwelling's ability to meet this target. We found that u-values could be significantly relaxed. This is therefore a cost-neutral option for reducing construction costs while not compromising on energy targets.

Typical Form

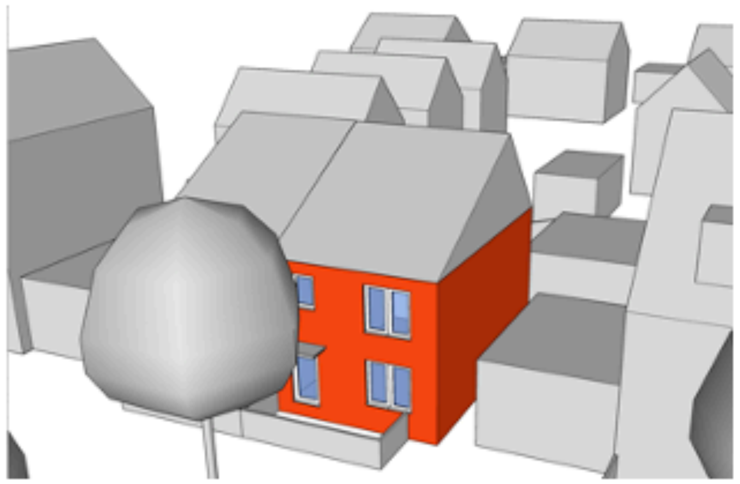


Space heating demand kWh/m²/yr	Fabric and ventilation specification		Metered energy use kWh/m²/y	PV generation (8 panels)	Net zero on-site?	On-site surplus PV generation kWh/yr
15	Floor U-value Wall U-value Roof U-value Window U-value Thermal bridging Ventilation Airtightness	0.09 W/m²K 0.09 W/m²K 0.09 W/m²K 0.9 W/m²K 2 kWh/m²/yr MVHR 88% <0.6m³/m²h	Air source heat pump: 27	62 kWh/m²$_{fp}$ (8 panels)	Yes	146
			Direct electric: 43	62 kWh/m²$_{fp}$ (8 panels)	No* (66% 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/m²/yr	Fabric and ventilation specification		Metered energy use kWh/m²/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/m²K 0.13 W/m²K 0.11 W/m²K 0.9 W/m²K 2 kWh/m²/yr MVHR 88% <0.6m³/m²h	Air source heat pump: 27	55 kWh/m²$_{fp}$ (8 panels)	Yes	4,681
			Direct electric: 43	83 kWh/m²$_{fp}$ (12 panels)	Yes	3,077

Net Zero Carbon definition for this type

Net zero carbon can be achieved with:

1. Metered energy use of 35 kWh/m^2_{GIA}/year or less
2. No fossil fuel combustion on site
3. Solar generation that exceeds energy use on site

This page focuses on building fabric and ventilation and their contribution towards (1). It is based on PHPP energy modelling.

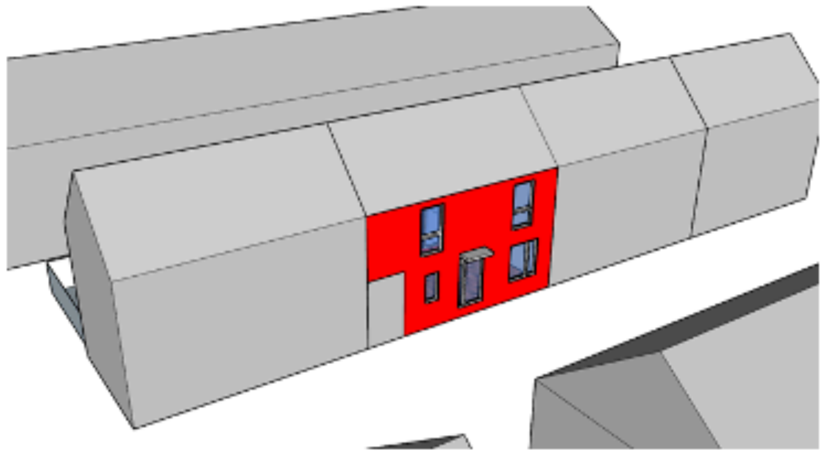
(1) Metered Energy Use < 35 kWh/m^2_{GIA}/yr

Efficient building fabric is the foundation of a net zero building. The fabric and ventilation systems summarised on this page are close to achieving a space heating demand of less than 15-20 $kWh/m^2/yr$, the range recommended by the Climate Change Committee.

This level of performance requires an efficient form and reasonable window proportions. 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.

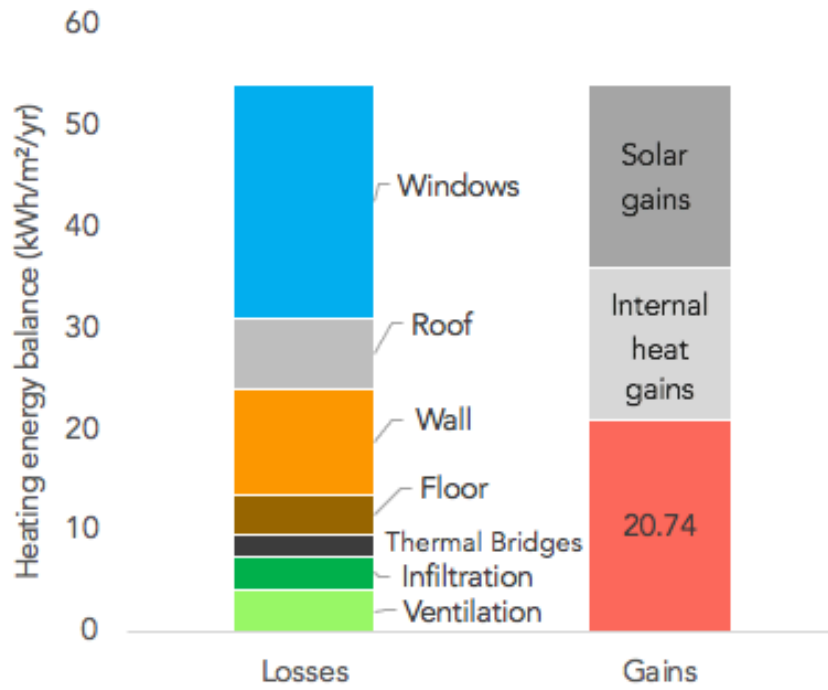
The baseline building was not designed to be a low energy building. This makes it challenging to achieve a space heat demand of under 21kWh/m2/yr without relying on excessively high specification materials or products.

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. Windows could also be optimised to increase solar gains on North/South facing terraces.



- 76 sqm TFA
- 48 sqm building footprint
- 103 sqm external walls
- 23 sqm windows/doors
- Form factor: 3.75

Terrace house modelled: *A single terraced house from Phase 1 of the Wing development has been investigated.*



Space heating demand: *The house would achieve a space heating demand of 21kWh/m²/yr with the specifications below*

	Baseline performance	Required performance	Indicative solution (how to achieve the specs)
Floor U-value	0.15 W/m^2K	0.12 W/m^2K	300mm XPS insulation
Wall U-value	0.18W/m^2K	0.10 W/m^2K	200mm PIR insulation
Roof U-value	0.13 W/m^2K	0.10 W/m^2K	450mm Mineral wool insulation
Window U-value	1.40 W/m^2K	0.90 W/m^2K	Triple glazed, low-e coating, warm edge spacer
Thermal bridging	5 $kWh/m^2/yr$	2 $kWh/m^2/yr$	Good design, thermally broken lintels. Insulation wrap around slab edge. Insulated soil vent pipe.
Ventilation	Continuous extract ventilation SFP < 0.24Wh/m^3	MVHR 88% heat recovery SFP < 0.45Wh/m^3	Zehnder Comfoair 160 with pre-insulated rigid ducting
Airtightness	<5m^3/m^2h	<0.55m^3/m^2h	Wet plaster applied to walls, airtight plasterboard or membrane in ceiling. Use of airtightness tape at all junctions and airtight grommets at service entries.

Building fabric and ventilation specifications: *A summary of key attributes assumed for the PHPP and cost modelling*

This page focuses on how low carbon heating can deliver net zero requirements (1) and (2).

(1) Metered Energy Use < 35 kWh/m$^2_{GIA}$/yr

The two low carbon heating systems most likely to be specified for a net zero semi detached house are an air source heat pump or direct electric heating.

- The terraced house would achieve metered energy use of 32kWh/m$^2_{GIA}$/yr with a standard air source heat pump
- The terraced house would achieve metered energy use of 52kWh/m$^2_{GIA}$/yr with direct electric heating

(2) No fossil fuel combustion on site

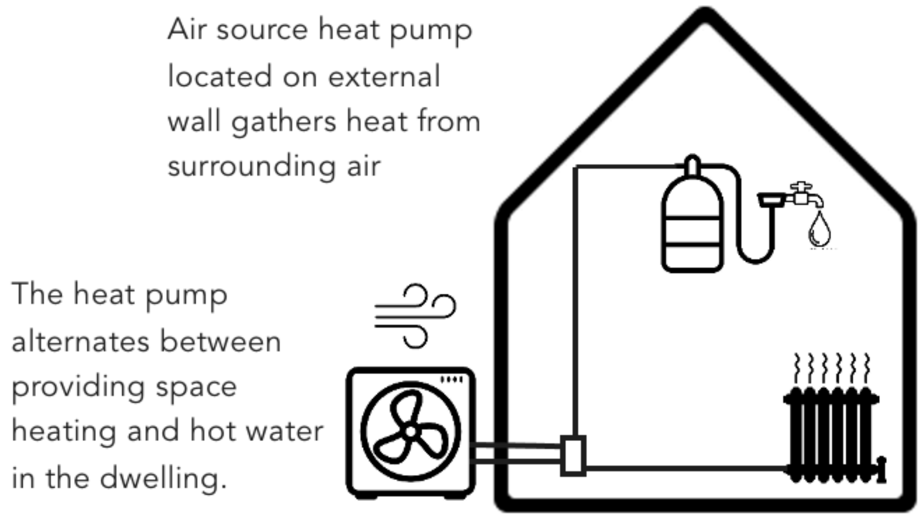
This condition will be met as long as the house is not heated by an individual gas or oil boiler, or by a communal or district-scale heating system using gas.

This is unlikely to represent an additional cost as it is set to become a baseline requirement for new buildings, based on Climate Change Committee guidance that: '*from 2025 at the latest, no new homes should be connected to the gas grid, with ultra-low energy houses and flats using low carbon heat instead*'

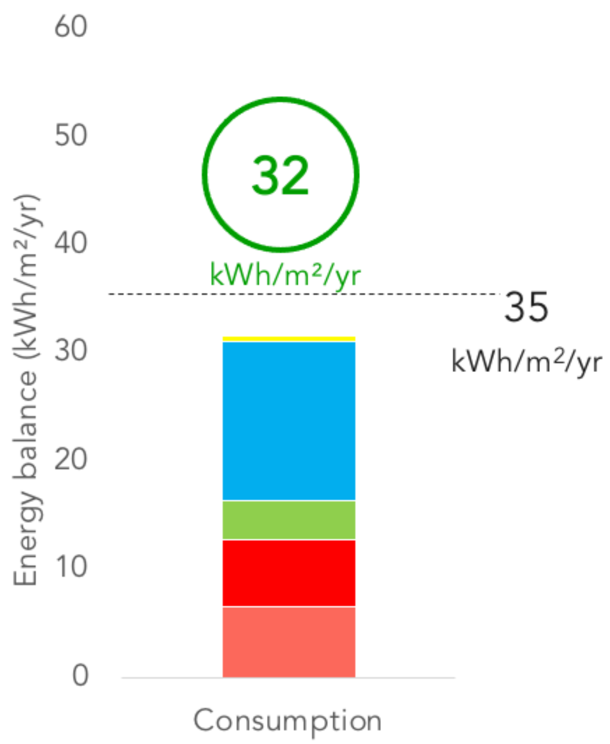
Discussion on other heating systems

There are several other types of heat pump that could be used to achieve net zero carbon. Options include: Air-air heat pumps, which are lower cost but provide space heating and cooling only. Ground source heat pumps, which are usually higher cost but longer lasting. 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 a limited amount of space heating.

Air source heat pump

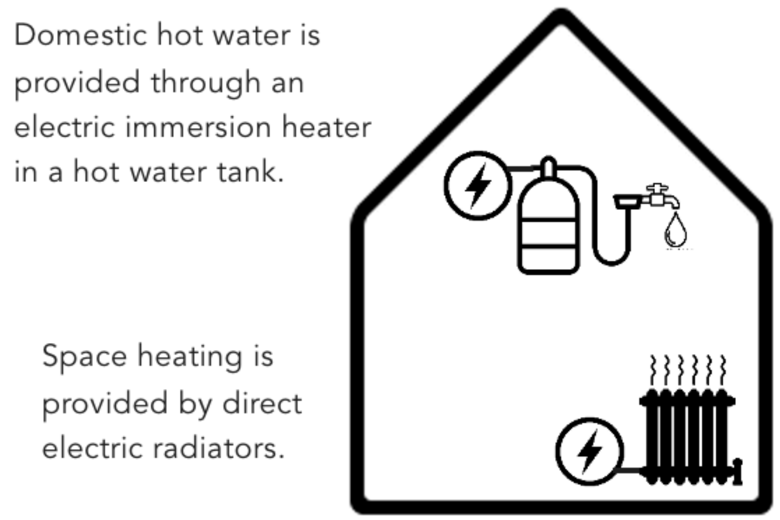


Heating system	Air source heat pump	e.g. 5kW Mitsu Ecodan
Hot water cylinder	150 litres with losses < 1.0 kWh/day	e.g. Mitsubishi cylinder
Emitters	Wet heating system 2 radiators	e.g. Stelrad Softline K2

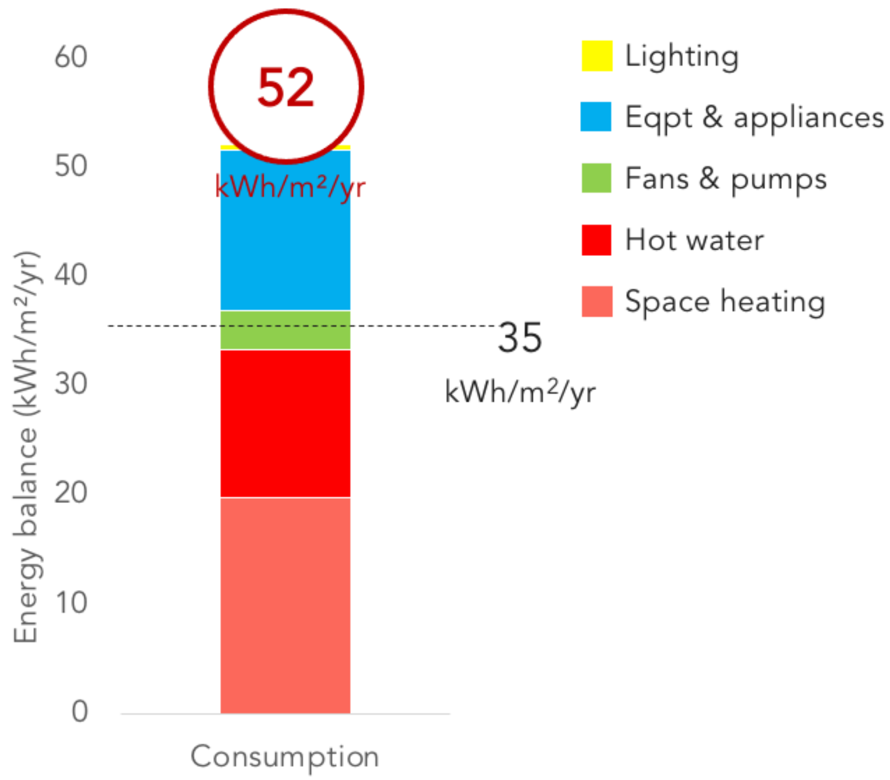


*With an **air source heat pump,** the house achieves metered energy use of 32 kWh/m²/yr, compliant with Net Zero Carbon*

Direct electric heating



Heating system	Direct electric heating	
Hot water cylinder	100 litres with losses < 0.8 kWh/day	e.g. Dimplex ECSd
Heat Emitters	3 panel heaters	



*With **direct electric heating,** the house achieves metered energy use of 52 kWh/m²/yr, exceeding 35 kWh/m²/yr. It could still achieve Net Zero Carbon if enough solar panels are installed.*

(3) Solar generation exceeds metered energy use

This condition is easily met on low rise buildings as they have a high ratio of roof area to energy use.

Just 10 solar panels would be sufficient for the house to generate as much electricity as it uses over a year. Energy generation could triple if the building is oriented East-West and the roof is fully utilised.

Discussion on other PV layouts

For houses facing to the South, energy generation per panel would be higher, but the Northern roof would not be useful for installing panels. Up to 24 panels could be fitted by moving the roof ridge slightly to the North, making the South roof plane large enough for a third row of panels.

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

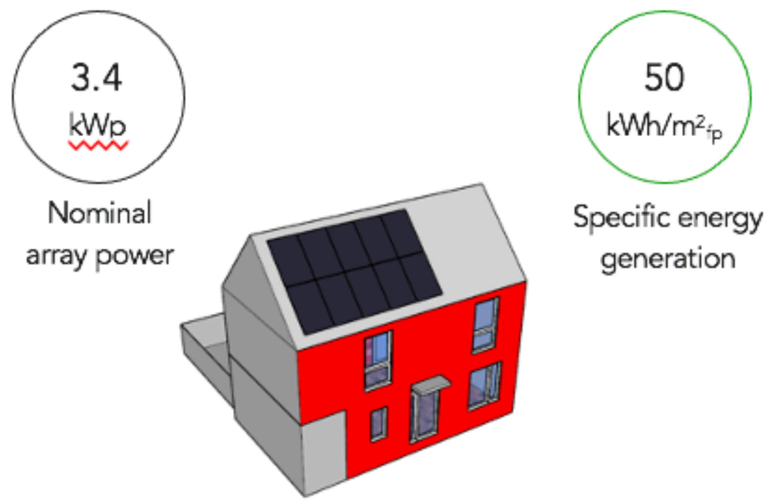
Ensuring residents benefit from solar

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.

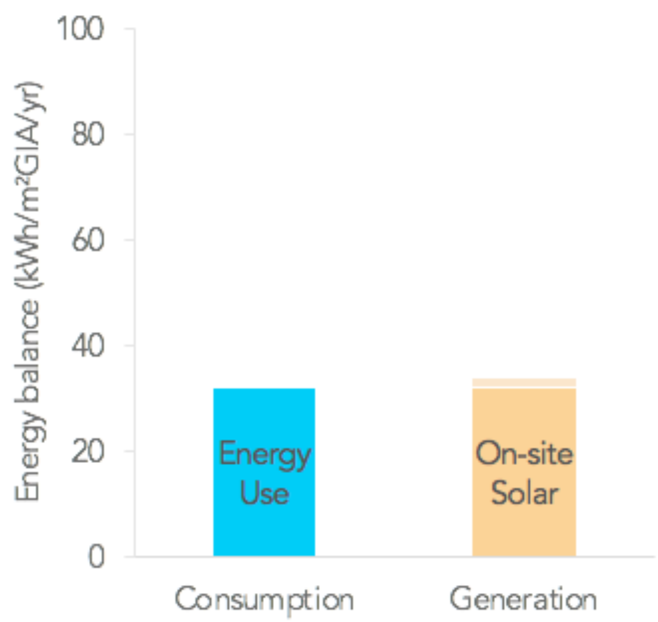
Typically, homes consume around 15-30% of solar energy directly, though 50-70% is possible with smart control of space and water heating. Energy efficient building fabric enables better use of smart heating controls as the building is better at retaining heat so the heating can be run when solar energy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

Surplus electricity could also be used for charging an electric vehicle, which typically require around 2,500 kWh per year. This could increase self-consumption of solar electricity above 70%.

Minimum solar for Net Zero Carbon

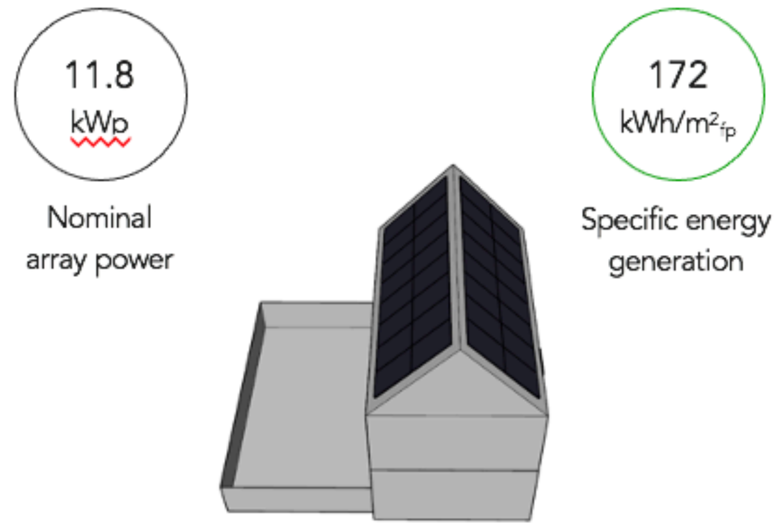


10 x 340W solar photovoltaic panels would be sufficient to generate 34 kWh/m2/yr and therefore achieve Net Zero Carbon.

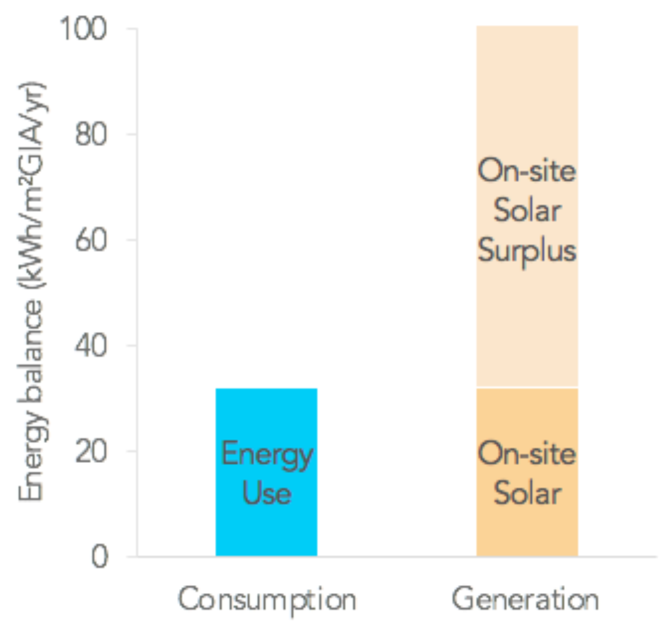


Net zero energy balance: *The house can generate as much solar electricity as it consumes with an East facing 10 panel solar array..*

Maximum solar potential



32 x 370W solar photovoltaic panels (16 on each side of the roof) would enable the house to be energy positive. Solar generation would be 374% of annual energy use.



Net zero energy balance: *The house is a net producer of clean electricity with East and West facing solar arrays.*

Net Zero Carbon definition for this type

Net zero carbon can be achieved with:

1. Metered energy use of 35 kWh/m$^2_{GIA}$/year or less
2. No fossil fuel combustion on site
3. Solar generation that exceeds energy use on site

This page focuses on building fabric and ventilation and their contribution towards (1). It is based on PHPP energy modelling.

(1) Metered Energy Use < 35 kWh/m$^2_{GIA}$/yr

Efficient building fabric is the foundation of a net zero building. The fabric and ventilation systems summarised on this page comfortably achieve a best practice level of space heat demand: 15 kWh/m²/yr.

This level of performance requires an efficient form and reasonable window proportions. 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.

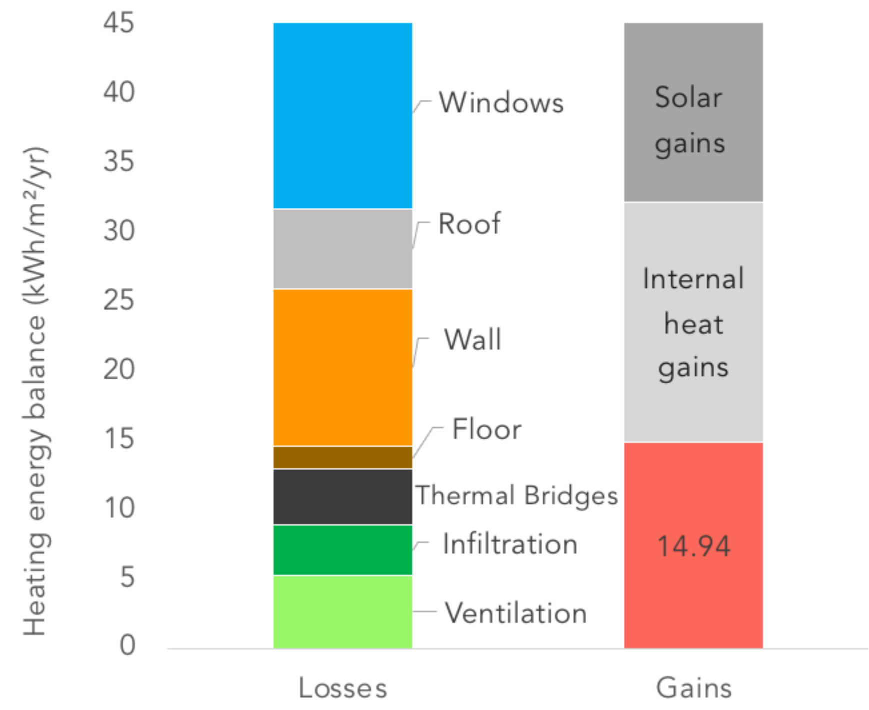
The baseline building was not designed to be a low energy building, however as it has a good form factor it is possible to achieve a low space heat demand without relying on excessively high specification materials or products.

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.

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 balance solar gains.

- 2833 sqm TFA
- 1094 sqm building footprint
- 1806 sqm external walls
- 552 sqm windows/doors/rooflights
- Form factor: 1.76

Building modelled: *A typical block of flats based on a development to the East of Cambridge has been modelled.*



Space heating demand: *The building 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	0.25 W/m²K	0.16 W/m²K	200mm Graphite EPS insulation
Wall U-value	0.25 W/m²K	0.16 W/m²K	200mm Blown mineral wool with AAC block internal leaf
Roof U-value	0.20 W/m²K	0.15 W/m²K	220mm EPS insulation
Soffit U-values	0.20 W/m²K	0.18 W/m²K	170mm Mineral wool board
Window U-value	1.40 W/m²K	0.90 W/m²K	Triple glazing. Low-e coating. Warm edge spacers
Thermal bridging	8 kWh/m²/yr	4 kWh/m²/yr	Thermally broken parapets, balconies, lintels and wall ties. Thermal break at base of wall, and insulation overlap at head of ground floor walls to unheated. Insulated soil vent pipes.
Ventilation	Continuous extract vent SFP < 0.24Wh/m³	MVHR 88% heat recovery SFP < 0.45Wh/m³	Zehnder Comfoair 160 with pre-insulated rigid ducting
Airtightness	<5m³/m²h	<0.65m³/m²h	Airtight layer, tape and service grommets

Building fabric and ventilation specifications: *A summary of key attributes of the building assumed for the PHPP and cost modelling*

Bioregional Etude Currie & Brown

This page focuses on how low carbon heating can deliver net zero requirements (1) and (2).

(1) Metered Energy Use < 35 $kWh/m^2_{GIA}/yr$

The low carbon heating systems most likely to be specified for net zero flats are an ambient loop air (or ground) source heat pump, or direct electric.

- The flats would achieve metered energy use of 26kWh/m^2_{GIA} /yr with an ambient loop air source heat pump
- The flats would achieve metered energy use of 41kWh/m^2_{GIA} /yr with direct electric heating

(2) No fossil fuel combustion on site

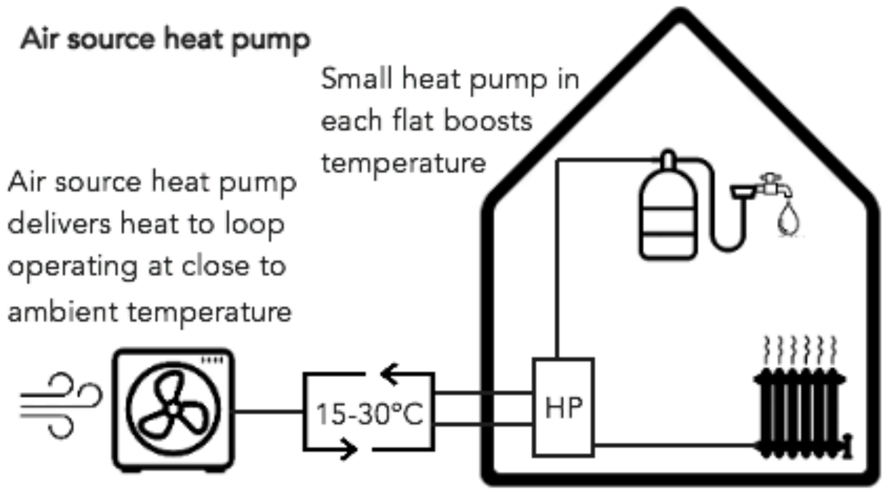
This condition will be met as long as the flats are not heated by an individual gas or oil boiler, or by a communal or district-scale heating system using gas.

This is unlikely to represent an additional cost as it is set to become a baseline requirement for new buildings, based on Climate Change Committee guidance that: '*from 2025 at the latest, no new homes should be connected to the gas grid, with ultra-low energy houses and flats using low carbon heat instead*'

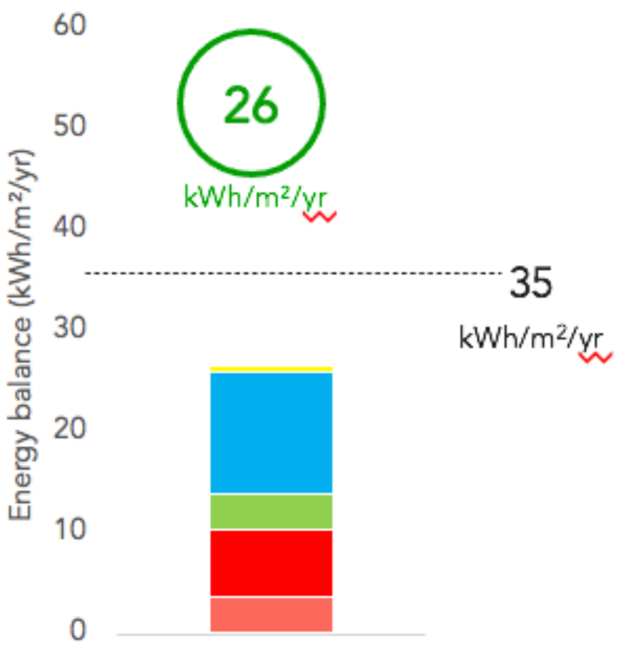
Discussion on other heating systems

There are several other types of heat pump that could be used to achieve net zero carbon. Options include: Air-air heat pumps, which are lower cost but provide space heating and cooling only. Ground source heat pumps, which are usually higher cost but longer lasting. 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 a limited amount of space heating.

Air source heat pump

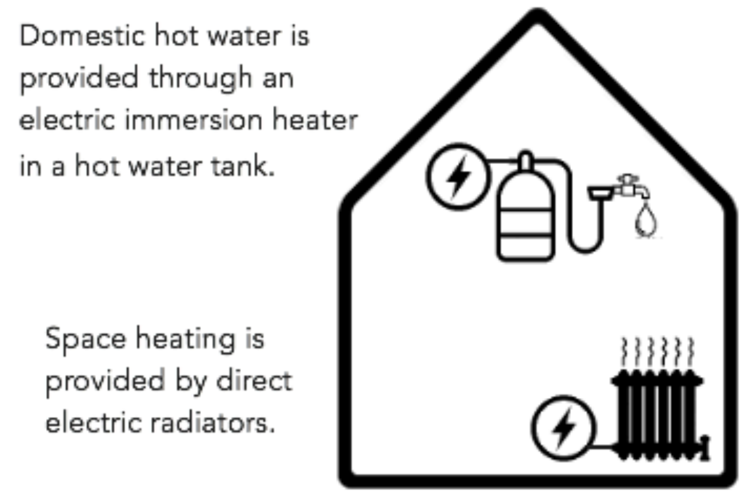


Heating system	Air source heat pump with ambient loop	e.g. Glen Dimplex Zeroth
Hot water cylinder	150 litres with losses < 1.0 kWh/day	e.g. Heat pump cylinder
Emitters	Wet heating system 2 radiators	e.g. Stelrad Softline K2

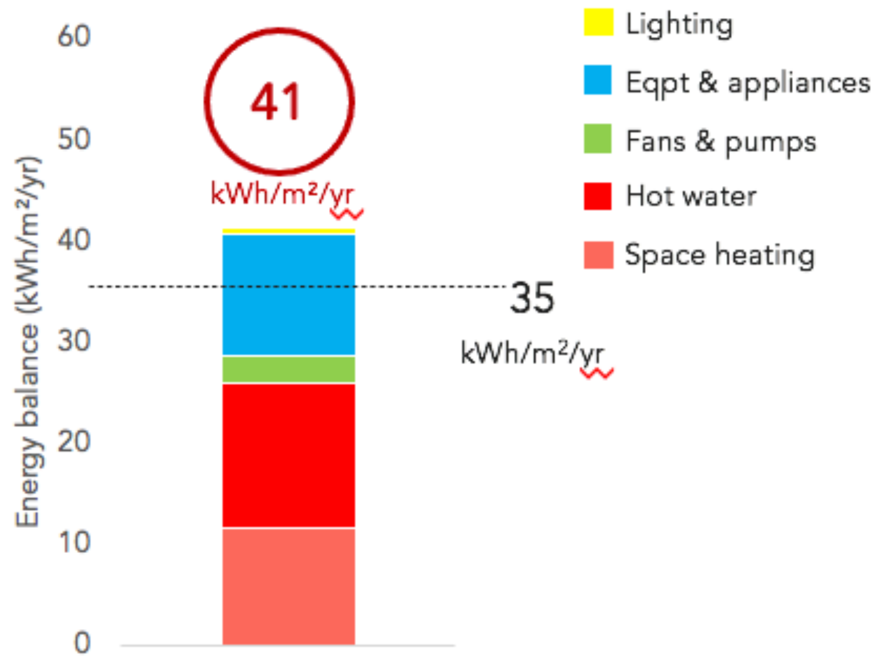


*With an **air source heat pump,** the flats achieve metered energy use of 26 kWh/m²/yr, compliant with Net Zero Carbon*

Direct electric heating



Heating system	Direct electric heating	
Hot water cylinder	100 litres with losses < 0.8 kWh/day	e.g. Dimplex ECSd
Heat Emitters	3 panel heaters	



*With **direct electric heating,** the flats achieve metered energy use of 41 kWh/m²/yr, exceeding 35 kWh/m²/yr. It could still achieve Net Zero Carbon if enough solar panels are installed.*

(3) Solar generation exceeds metered energy use

This condition is easily met on low rise buildings as they have a high ratio of roof area to energy use.

328 solar panels would be sufficient for the flats to generate as much electricity as they use over a year. Generation could double if the roof is fully utilised.

Discussion on other PV layouts

Monopitch solar arrays, rather than concertina type East-West arrays, enable even higher solar panel density and can also increase energy production per panel. Specific energy generation could exceed 200kWh/m$^2_{fp}$ with this approach.

The main risks to being able to install sufficient solar capacity to achieve net zero is through roof design with excessively high parapets, or cluttered with services that prevent installation of solar panels.

Ensuring residents benefit from solar

The greatest benefits are typically offered by setting the building up as a microgrid. Flats receive a blend of solar and grid electricity, maximising self-consumption of solar energy.

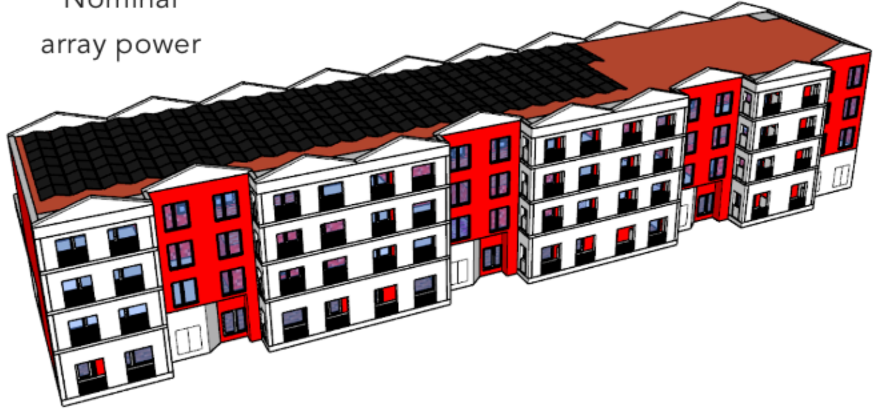
The building's total bill only reflects energy bought from the grid. This will be significantly reduced due to solar self-consumption. The balance owed is divided between each flat based on their energy consumption, measured by privately owned electricity meters.

Revenue from solar export tariff payments can be divided equally between flats and either issued as an annual solar dividend to occupants, or used to offset energy bills. Billing can be handled by a non-profit entity or other third party.

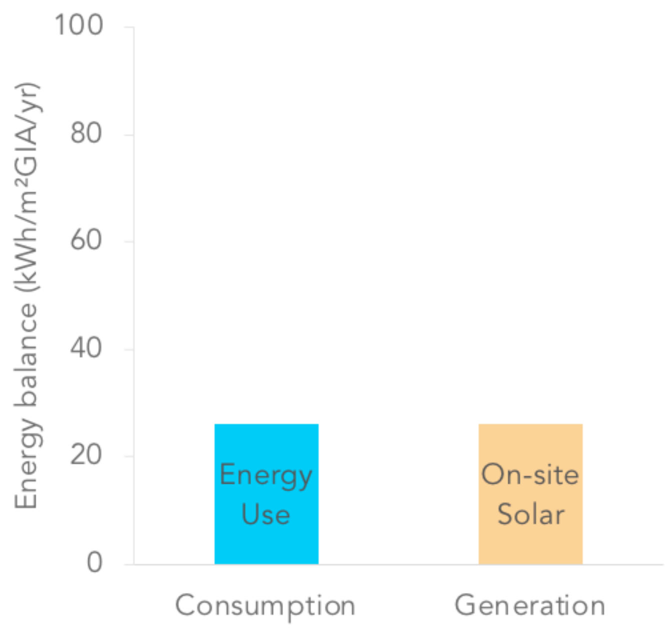
Minimum solar for Net Zero Carbon

112 kWp — Nominal array power

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



328 x 340W solar photovoltaic panels would be sufficient to generate 26 kWh/m2/yr and therefore achieve Net Zero Carbon

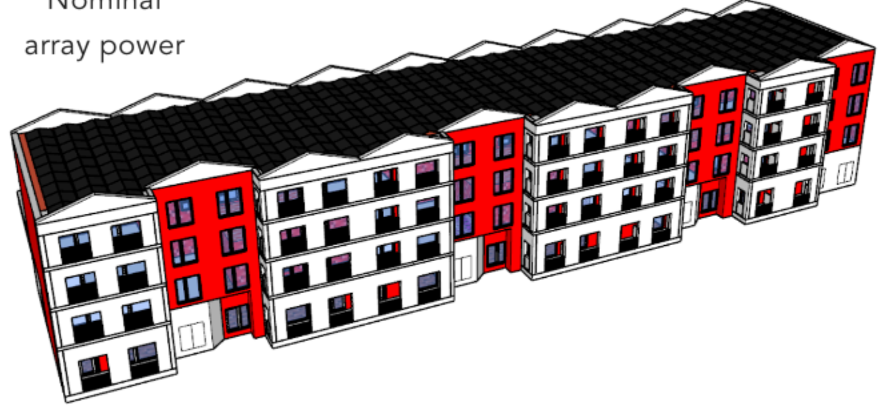


***Net zero energy balance:** The block of flats can generate as much solar electricity as it consumes with an East-West facing 328 panel solar array.*

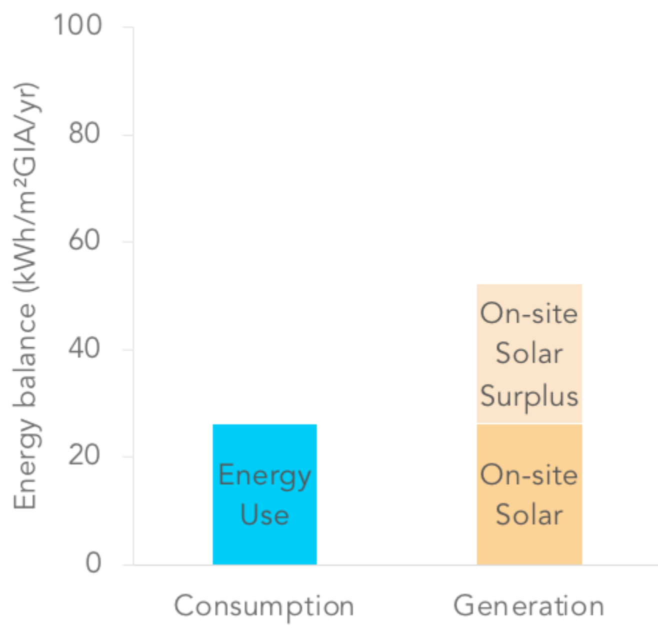
Maximum solar potential

221 kWp — Nominal array power

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



596 x 370W solar photovoltaic panels would enable the block of flats to be energy positive, generating 200% of annual energy use.



***Net zero energy balance:** The block of flats is a net producer of clean electricity with East and West facing solar arrays.*

Net Zero Carbon definition for this type

Net zero carbon can be achieved with:

1. Metered energy use of 55 kWh/m^2_{GIA}/year or less
2. No fossil fuel combustion on site
3. Solar generation that exceeds energy use on site

This page focuses on building fabric and ventilation and their contribution towards (1). It is based on PHPP energy modelling.

(1) Metered Energy Use < 35 kWh/m^2_{GIA}/yr

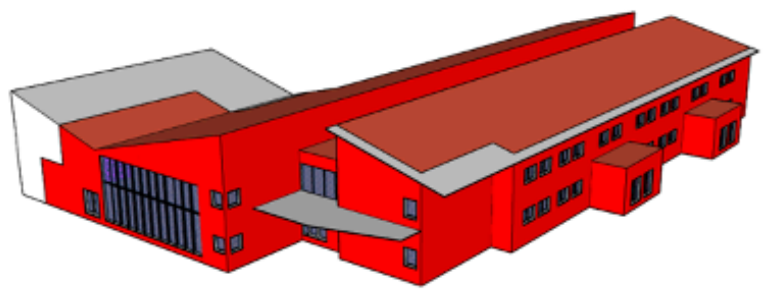
Efficient building fabric is the foundation of a net zero building. The fabric and ventilation systems summarised on this page comfortably achieve a best practice level of space heat demand: 15 kWh/m²/yr.

This level of performance requires an efficient form and reasonable window proportions. 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.

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.

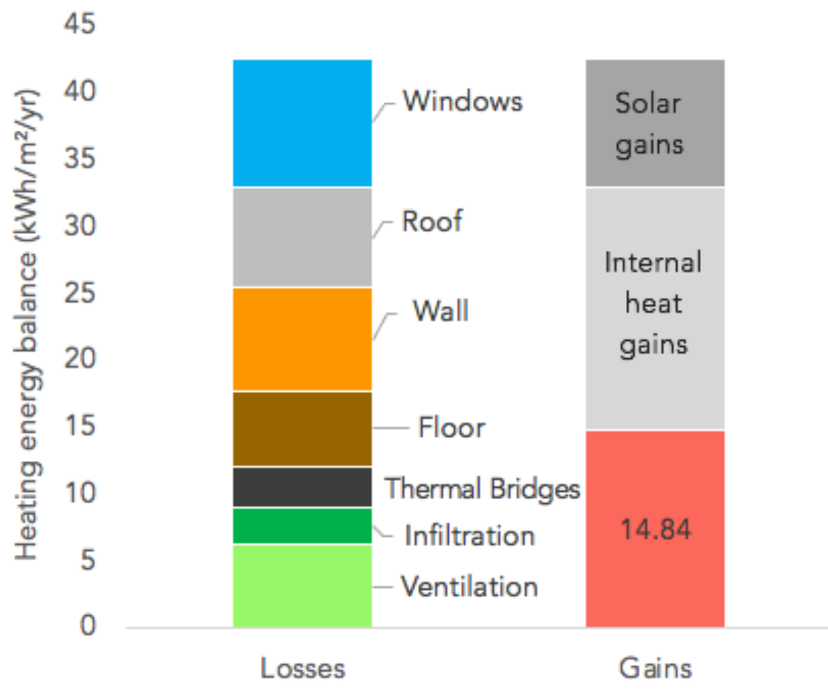
Better design could maintain current performance but reduce cost. For example, reducing glazed areas on Northern facades or combining split windows into single windows would reduce heat loss, improving energy performance.

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.



- 2630 sqm TFA
- 1940 sqm building footprint
- 1828 sqm external walls
- 281 sqm windows/doors/rooflights
- Form factor: 2.32

School modelled: *A typical school building based on Darwin Green Primary School has been investigated.*



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 vent 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

Building fabric and ventilation specifications: *A summary of key attributes of the School assumed for the PHPP and cost modelling*

This page focuses on how low carbon heating can deliver net zero requirements (1) and (2).

(1) Metered Energy Use < 55 $kWh/m^2_{GIA}/yr$

The low carbon heating systems most likely to be specified for a net zero school are an air (or ground) source heat pump.

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

(2) No fossil fuel combustion on site

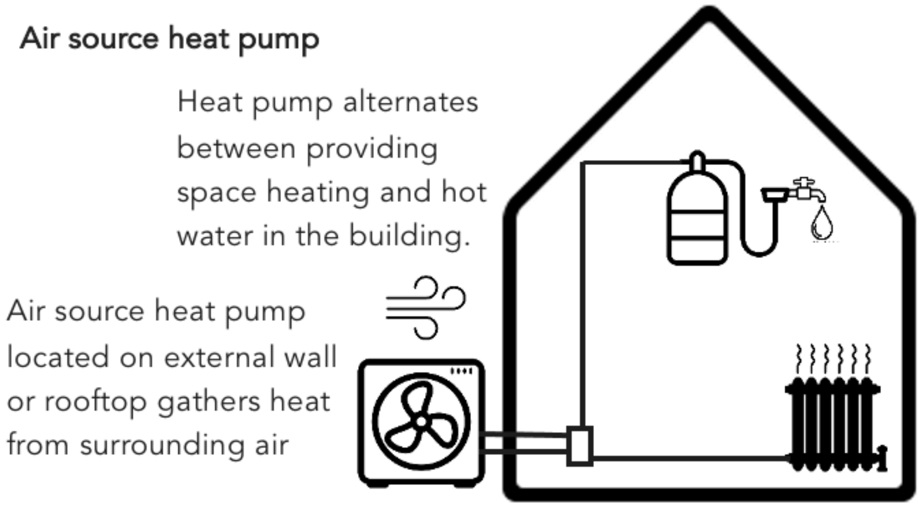
This condition will be met as long as the school is not heated by an individual gas or oil boiler, or by a communal or district-scale heating system using gas.

Discussion on other heating systems

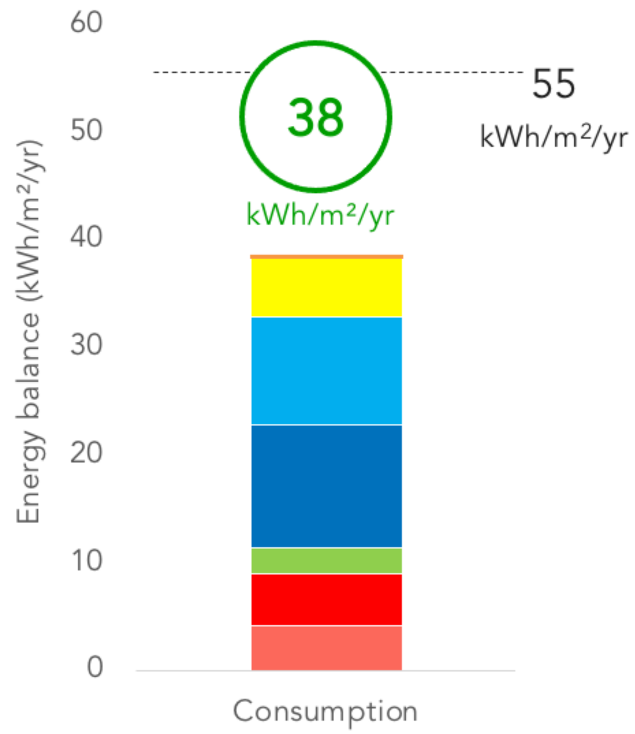
The main other type of heat pump that could be used to achieve net zero carbon is an air-air heat pump, commonly known as VRF air conditioning. These can efficiently shuttle heat between different parts of the building and provide cooling as well as heating.

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

Air source heat pump

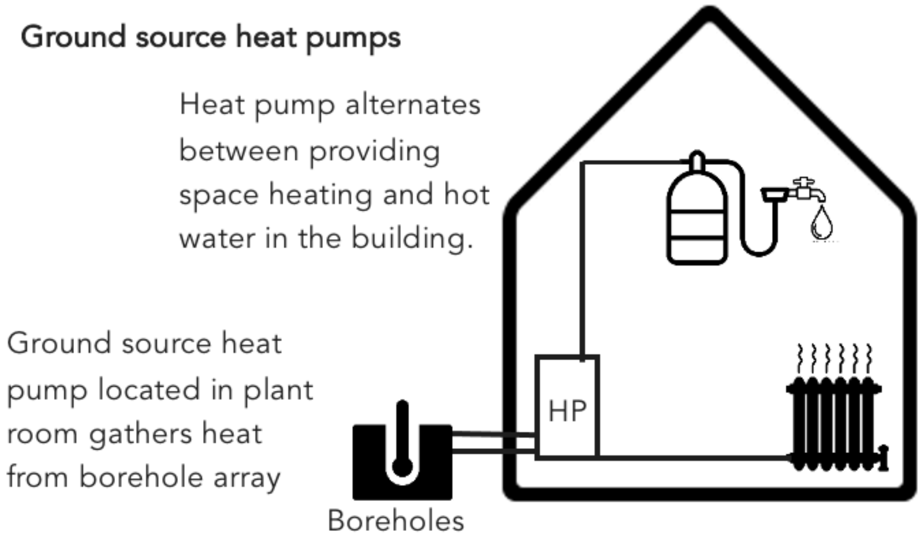


Heating system	Air source heat pump	e.g. 2 x 14kW Mitsu Ecodan
Hot water cylinder	2 x 250 litres with losses < 1.6 kWh/day	e.g. Heat pump cylinder
Emitters	Wet heating system 40 x radiators	e.g. Stelrad Softline K2

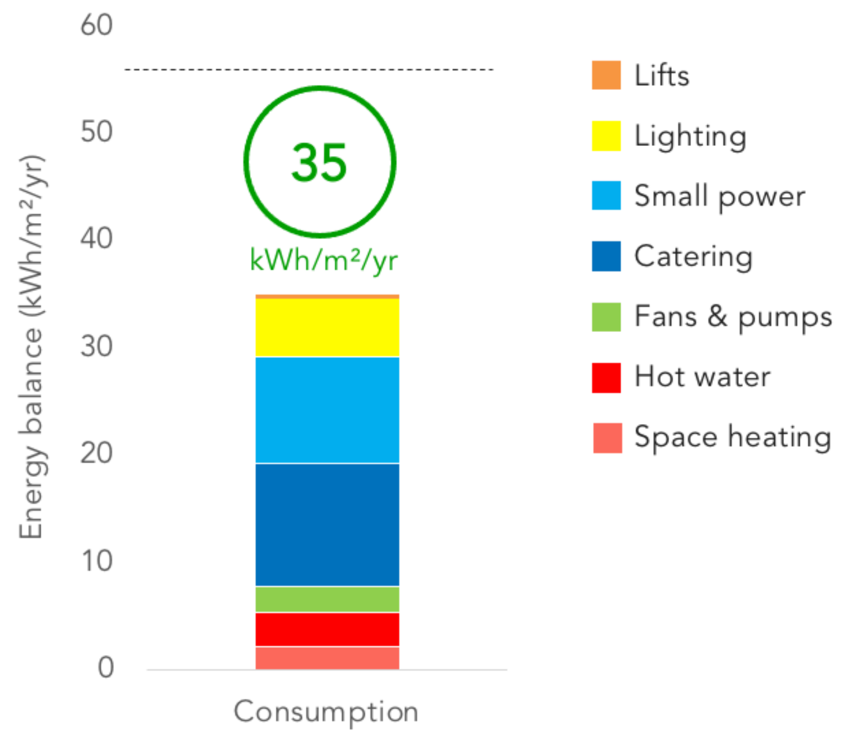


*With an **air source heat pump,** the school would achieve metered energy use of 38 kWh/m²/yr, compliant with Net Zero Carbon*

Ground source heat pumps



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



*With a **ground source heat pump,** the school would achieve metered energy use of 35 kWh/m²/yr, compliant with Net Zero Carbon*

(3) Solar generation exceeds metered energy use

This condition is easily met on low rise buildings as they have a high ratio of roof area to energy use.

376 solar panels would be sufficient for the school to generate as much electricity as it uses over a year. Generation could double if the roof is fully utilised.

Discussion on other PV layouts

The school's main roof faces to the South West. If it faced directly to the South, energy generation per panel would be slightly higher, but it would only be sensible to have solar panels on the Southern roof plane. Orientating the building to face East/West would enable the installation of hundreds of additional solar panels.

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

Ensuring the school benefits from solar

Schools with solar panels on the roof benefit from direct consumption of solar electricity and from export tariff payments for exported electricity.

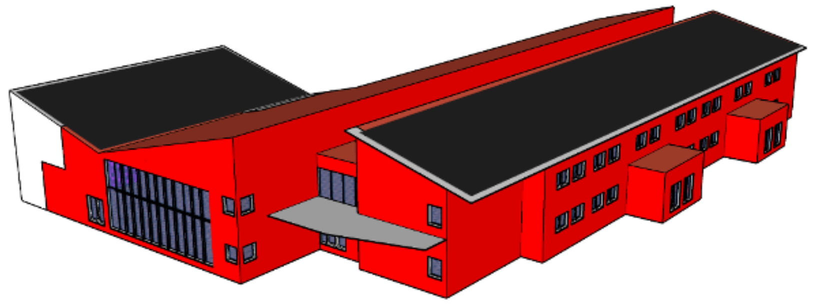
Direct consumption of solar electricity in schools can be highly variable, depending on how the building is managed and used both within term time, and at other times of the year. Smart control of space and water heating offers the potential to maximise direct consumption. Energy efficient building fabric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

Surplus electricity could be used for charging staff owned electric vehicles, which typically require around 2,500 kWh per year.

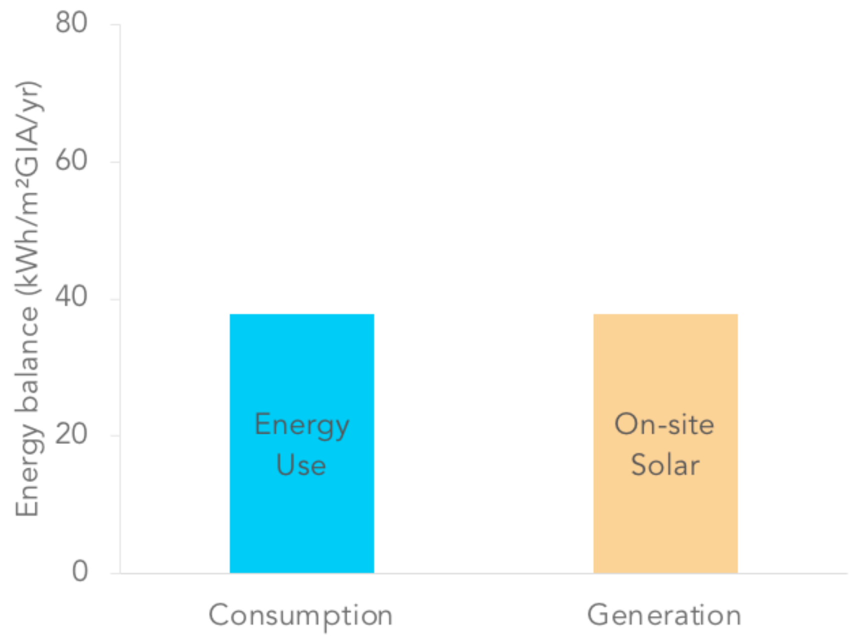
Minimum solar for Net Zero Carbon

128 kWp — Nominal array power

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



376 x 340W solar photovoltaic panels would be sufficient to generate 38 kWh/m2/yr and therefore achieve Net Zero Carbon

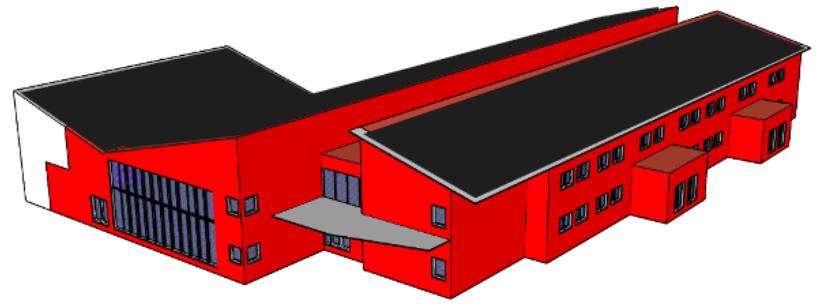


Net zero energy balance: *The school can generate as much solar electricity as it consumes with a South-West facing 376 panel solar array.*

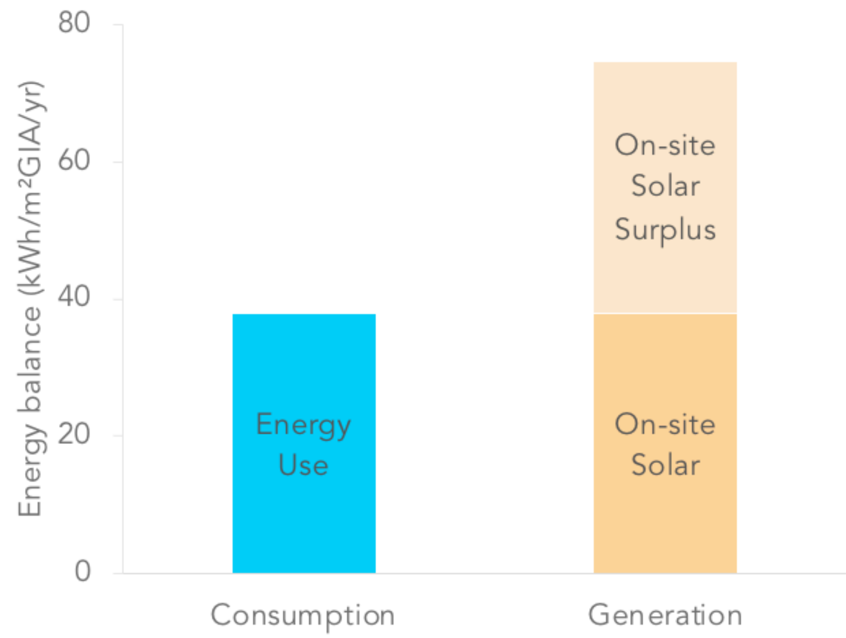
Maximum solar potential

279 kWp — Nominal array power

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



754 x 370W solar photovoltaic panels would enable the school to generate 215% of the annual energy it will consume. This assumes the building is rotated so the arrays face East/West.



Net zero energy balance: *The school is a net producer of clean electricity with East and West facing solar arrays.*

Task D
Technical Feasibility
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.

Technical Feasibility I Case Studies and Design Principles

Introduction

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

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

Offices

Residential Towers

Student Accommodation

Small Retail Units

Light Industrial Units

Leisure Centres

Research Facilities

Existing Buildings

There are a wide variety of building types in Greater Cambridgeshire beyond the four we have modelled for this evidence base. © Cambridge Science Park

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.

Net Zero Carbon for an office | Technical summary and recommendations

1 - Type specific considerations

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

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.

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

3 - Heating System

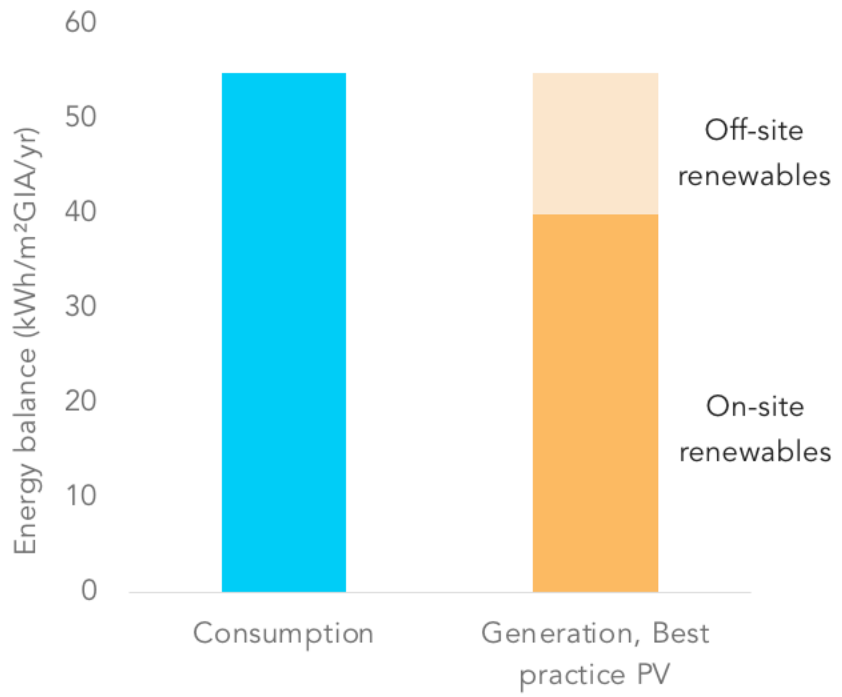
Heat pumps – whether ground or air source – or a Variable Refrigerant Volume system, if a low Ozone Depletion Potential and low Global Warming Potential refrigerant can be used.

4 - Renewable Energy

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

5 - Net Zero Carbon Feasibility

2-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.



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

Provisional Targets

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

Total energy consumption

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

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

1 - Type Specific Considerations

A 10-storey block of flats may be similar in form to the 4-storey block of flats, but there will be two main differences:

- The form factor will be reduced (there will be a smaller area of external building envelope to floor area).
- The roof area per flat will be smaller.

2 - Building Fabric

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

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

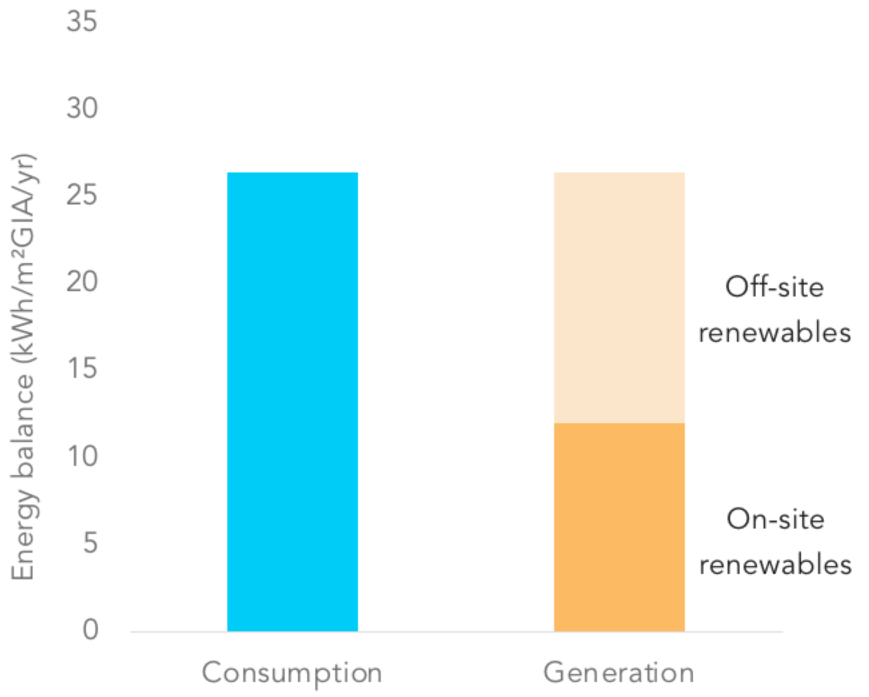
Communal air or ground source heat pumps are good candidates for medium to high density residential buildings to provide low carbon heat. Ambient Loop configurations reduce distribution losses and can support active cooling on sites where overheating may be an issue.

4 - Renewable Energy

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

5 - Net Zero Carbon Feasibility

These building types may find it difficult to achieve net zero carbon on site due to the limitation on the amount of renewable energy that can be installed on-site relative to the energy demand.



Typical net energy balance for a tall 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

1 - Type Specific Considerations

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

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

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.

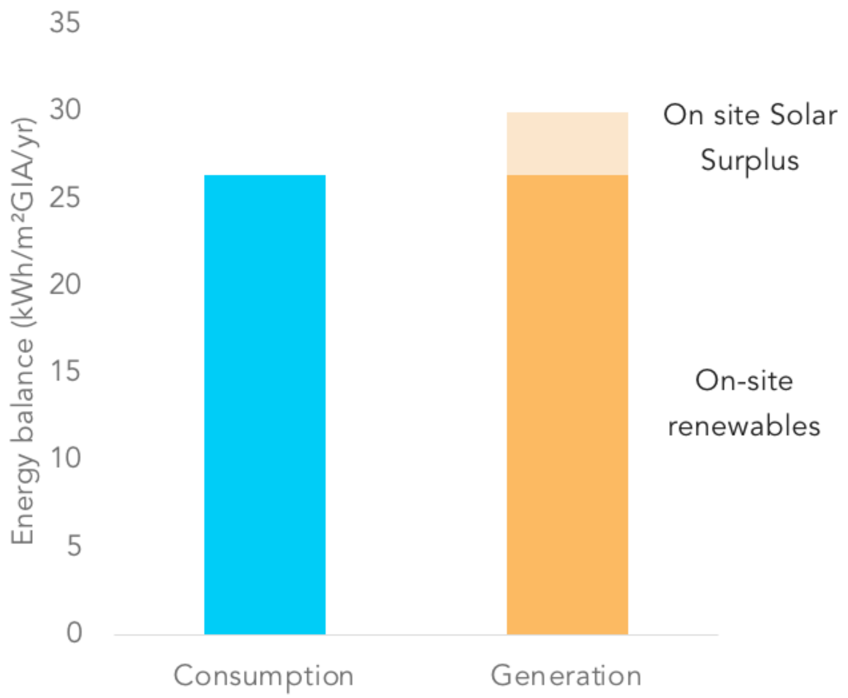
Hot water generation is a key issue in these buildings. Centralised 'hotel' type strategies may provide the best approach but distribution losses will be critical and the physical configuration of central stores relative to end uses should be analysed in detail on a per building basis.

4 - Renewable Energy

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

5 - Net Zero Carbon Feasibility

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.



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

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

1 - Type Specific Considerations

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

Building fabric performance should target a space heating demand of 15-30kWh/m².
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.

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

3 - Heating System

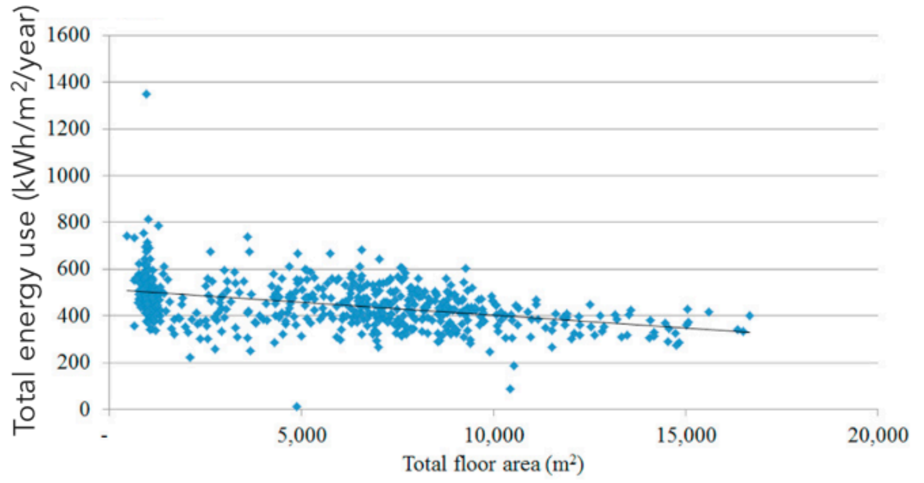
Heat pumps with low Ozone Depletion Potential and low Global Warming Potential refrigerants both for space heating and cooling, and for refrigeration of food.

4 - Renewable Energy

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

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.



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 Germnay 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

Net Zero Carbon for light industrial units | Technical summary and recommendations

1 - Type Specific Considerations

Typically lightweight, usually steel framed structures with metal cladding. Uses vary widely from warehousing to factory spaces and retail units. Many of these units are built speculatively without an end user identified.

2 - Building Fabric

For speculative development, the building fabric performance for retail should be based on limiting space heating cooling to 15 to 20kWh/m^2 (PHI recommendation) for an internal ambient temperature of 19 to 25°C. If the unit is being purpose built for a specific occupant whose normal operation lies well outside this range, then a specific energy balance analysis should be carried out.

Very good levels of air tightness can be achieved and thermal bridges can be minimised with the relatively simple construction techniques and materials traditionally used in this building type.

3 - Heating System

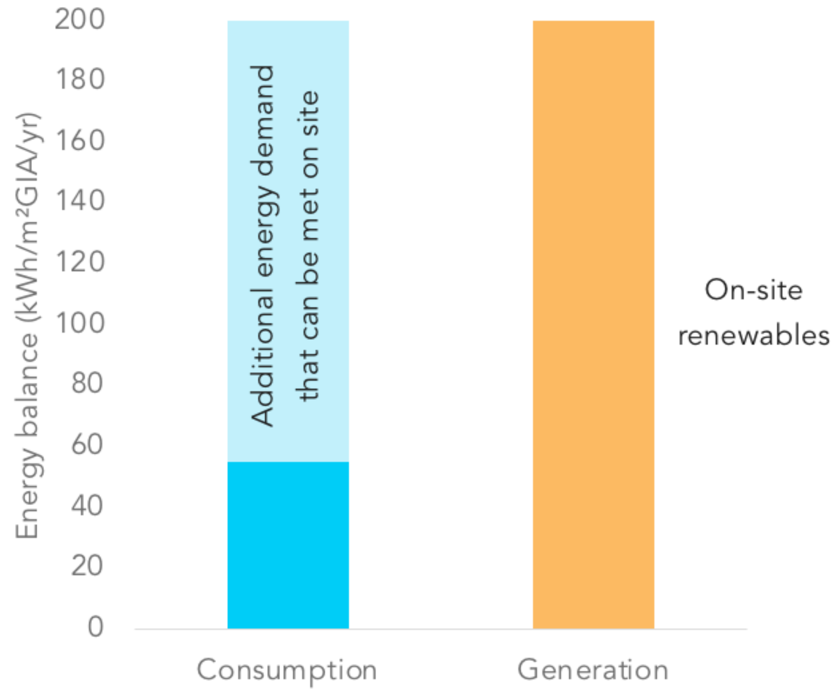
Heat pumps for retail units. Limited use of electric radiant heating in staff areas of warehouse units.

4 - Renewable Energy

Solar photovoltaic arrays up to 180kWh/m^2/yr are likely to be appropriate and achievable for buildings with higher energy demands. These buildings typically have large monopitch roofs with little rooftop plant that are easy to access.

5 - Net Zero Carbon Feasibility

Net zero carbon should be straightforward to achieve providing there are no particularly energy intensive industrial processes.



With best practice solar generation, a single storey building could meet a basic final energy demand of 55 kWh/m²/yr on site and still have enough surplus energy to achieve net zero with another 145 kWh/m²/yr of energy demand.

Provisional Targets

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

Total energy consumption

<180 kWh/m$^2_{FP}$/yr

Solar generation

Case study examples

Eco Business Centre – 1000m^2 Passivhaus certified small business and co-working space located in Bicester .

BC Passivhaus Factory – 1500m^2 factory located in Pemberton, British Columbia, Canada. While not a certified Passivhaus, the factory represents a successful application of Passivhaus principles to a large industrial building.

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

1 - Type Specific Considerations

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

2 - Building Fabric

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.

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

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

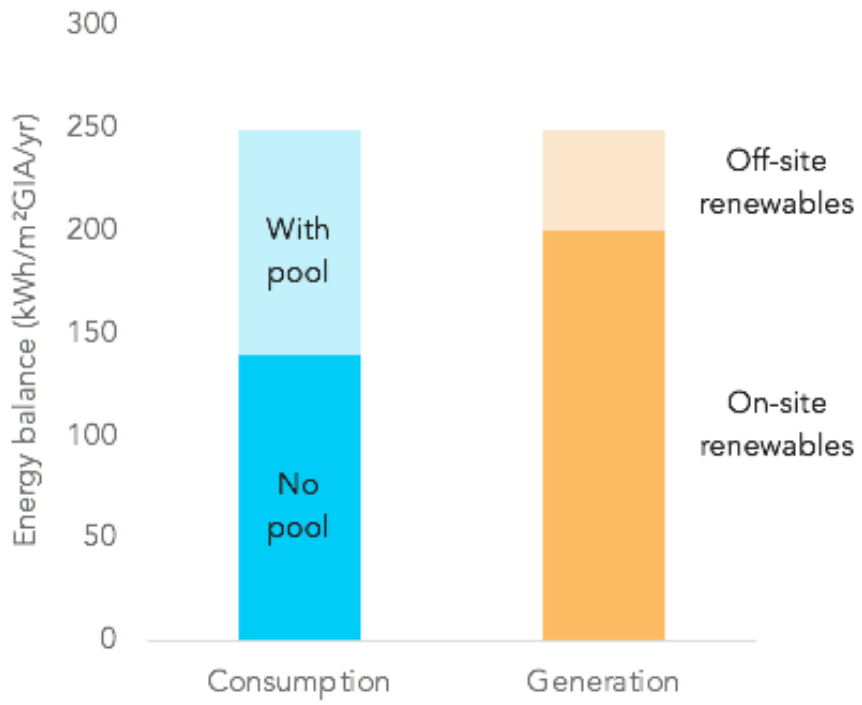
The temperatures at which swimming pools operate are a particularly good match for waste heat recovery applications.

4 - Renewable Energy

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

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



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/m²$_{GIA}$/yr — *Final energy Consumption (with pool)*

<200 kWh/m²$_{FP}$/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 4,850m² leisure centre in Exeter is aiming to be Passivhaus certified.

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

1 - Type Specific Considerations

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

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.

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

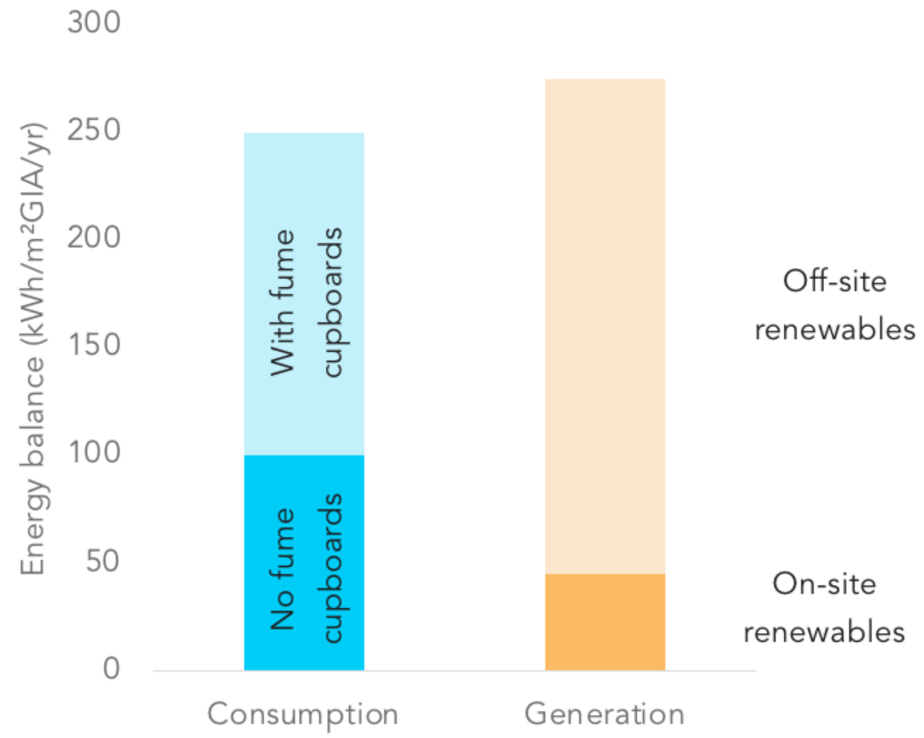
Heat pumps – whether ground or air source – or a Variable Refrigerant Volume system, if a low Ozone Depletion Potential and low Global Warming Potential refrigerant can be used.

4 - Renewable Energy

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

5 - Net Zero Carbon Feasibility

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



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/m²$_{GIA}$/yr

Total energy consumption

<180 kWh/m²$_{FP}$/yr

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.

Net Zero Carbon for existing buildings | Technical summary and recommendations

1 - Type Specific Considerations

'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

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

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

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

5 - Net Zero Carbon Feasibility

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 D

Technical Feasibility

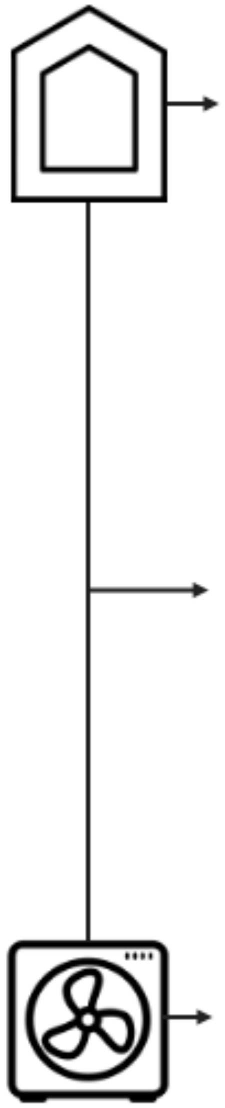
Policy for net zero carbon

This section explores the implications of technical feasibility on policy for Greater Cambridge.

What does the feasibility analysis tell us?

Informing net zero carbon policy

The results from our analysis show that building to net zero carbon standard is feasible in Greater Cambridge, at least for the modelled typologies which all met the criteria for net zero carbon onsite. Our case studies have suggested that other building typologies may need a level of offsite renewable energy generation. 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 following elements:



Space heating

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, terraced and flats) could achieve a space heating demand close to 20 kWh/m^2/yr or less without improvements in form and glazing proportions.

For commercial buildings the heating load depends on the use of the space and the extent of internal gains. Depending on the typology, a space heating target may be less relevant for commercial development.

Energy Use Intensity

This presents the overall energy efficiency of the building and has implications for the heating system choice and renewable energy generation.

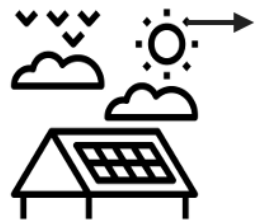
With an air source heat pump the modelled dwelling typologies all had an EUI of less than 35 kWh/m^2/yr, which is a recognised indicator of net zero carbon performance in the UK. With direct electric heating the EUIs varied from 40-55 kWh/m^2/y

The school had a modelled EUI of 35-40 kWh/m^2/yr.

Low carbon heat

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 Committee on Climate Change has set out the recommendation that **'from 2025 at the latest, no new homes should be connected to the gas grid'**[05]



Renewable energy generation

This should meet total energy consumption, either on a building by building basis or collectively across the new building stock.

All typologies modelled were low-rise and had the ability to generate surplus energy if PV space on the roof was maximised in specific orientations. Conversely, case studies of other building types suggested that many of these would require a proportion of off-site generation to reach net zero carbon.

Policy for renewable generation on new builds could mandate that generation should equal consumption, based on modelled EUI values, allowing offsetting for typologies that cannot meet this. Alternatively, a generation target per square metre of building footprint could be set. This would avoid penalising development with high density and could be used to encourage net export on low-rise development.

Optimising the design

Our technical analysis did not consider the potential benefits of designing for net zero carbon from inception. Optimised buildings would have improved shape, orientation and window proportions, as well as an asymmetric roof to help maximise the number of PV panels.

Adopting this approach would mean that more buildings could comfortably meet net zero onsite with high specification materials, the excellent fabric performance (15 kWh/m^2/yr) and low carbon heating system. Many buildings could easily be net energy positive, with the ability to export renewable energy or provide charging for electric vehicles. 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

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 on the following pages.

Elements of net zero carbon new building policy

Space Heating

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)

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

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 be 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

Policy must ensure predicted energy/carbon performance is achieved in practice. The performance gap and options to address this are discussed in later pages on assured performance.

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

Policy options for a space heating target

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

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

A space heating target of 30 kWh/m^2/yr is a good improvement on existing building regulations (new buildings typically achieve approximately 70 kWh/m^2/yr).

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

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)).

"15 kWh/m^2/yr" policy

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 5-7% above a standard build can be expected.

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

Policy options for an energy use intensity target

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.

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

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.

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 above a standard build (assuming gas boiler baseline) of approximately 2-3%. 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.

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.

Non-residential

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.**

Our modelling of a school shows that these targets are reasonable. 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

Policy options for a solar generation target

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 – not recommended.

Enough to match EUI

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.
- A renewable energy credit 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).

For the residential models our analysis indicated that matching EUI increases build cost by 1-3%.

A generation target depending on building footprint (e.g. 120 kWh/m^2/yr)

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 Greater Cambridge 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

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/m^2/yr
Other (e.g. renewable requirement of Passivhaus premium)

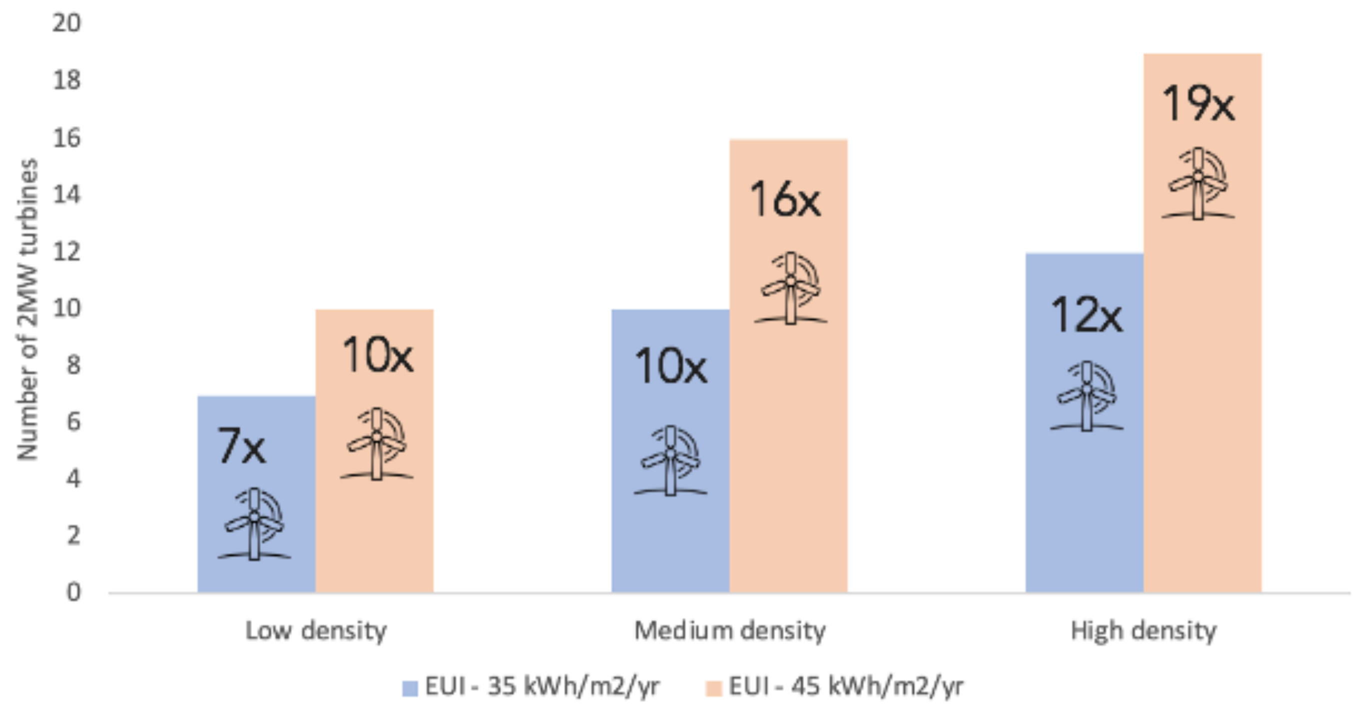
Off-site renewable energy

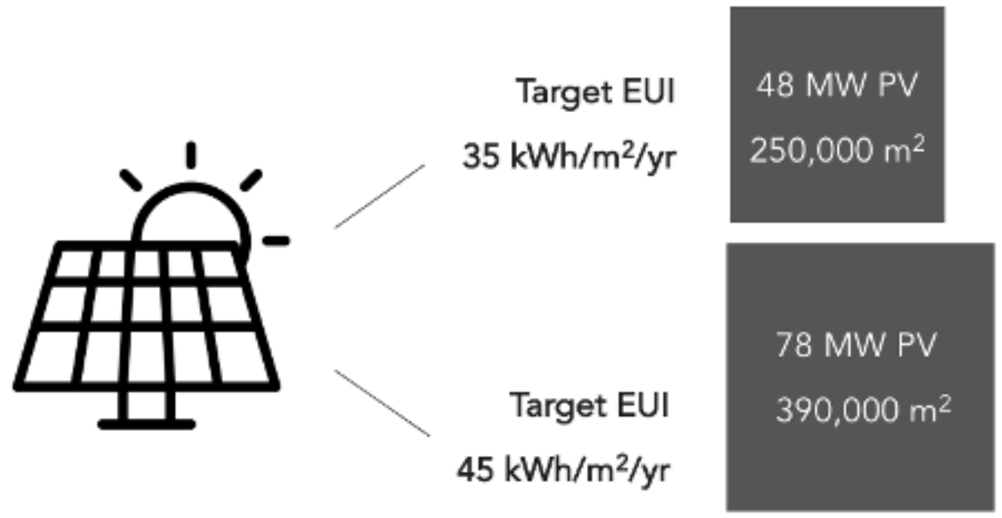
Off-site

- 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.
- Tall buildings, or those with higher energy demands, will find it challenging or impossible to generate enough energy to be "zero carbon" on-site.
- In our work on Offsetting (Task F), 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.
- We have tested different policy options for the cumulative impact on the amount of off-site renewables required across all projected new builds in Greater Cambridge over the life of the local plan:
- 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 Greater Cambridge, and we compare a EUI requirement of 35 vs 45 kWh/m^2/yr, we can see that we would need 160% more installed wind turbine capacity to satisfy the deficit.

A policy option that would not required off-site renewables

- 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 Greater Cambridge 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 (see the Appendices for details).
- 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 an offset fund or third party financing mechanism could be used to fund anything over and above matching the EUI of the building.





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 or area of photovoltaic panel.

Net zero carbon policy package

Our recommended package of policies to deliver net zero carbon is 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.

This policy package entails a total cost uplift of 3-13% (from improved fabric, choice of heating system, and inclusion of PV) depending on building typology. See Appendix E for a summary of costs and "Task E – Cost Implications" report. Operational fuel costs are lowest for this policy option – representing an 60% 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/m²/yr	60 kWh/m²/yr	100 kWh/m²/yr	Enough to match EUI	Uplift to SAP / SBEM requirements
20 kWh/m²/yr	45 kWh/m²/yr	65 kWh/m²/yr	120 kWh/m²/yr	Bespoke Greater Cambridge process
15 kWh/m²/yr	35 kWh/m²/yr	55 kWh/m²/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

Estimated impact of proposed policies on construction costs: residential

What is the baseline construction cost used?

The report "Task E – 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.

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.

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.

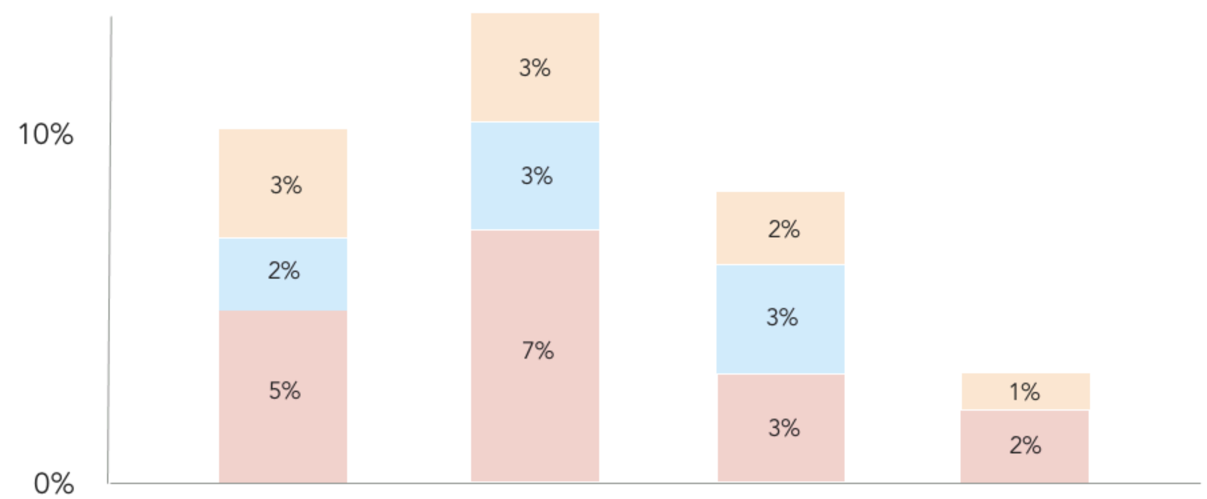
What is the impact of the proposed policies on construction costs?

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%.

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%.

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.

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.



	Semi-detached house	Terraced house	Flats	School
Total capital cost uplift	**10%**	**13%**	**7%**	**3%**
Building fabric and ventilation	5%	7%	3%	2%
Heating system	2%	3%	2%	0%
Renewable energy generation with PVs	3%	3%	2%	1%
Running costs/yr	-68%	-63%	-58%	-63%

Figure 5.2 - Summary of modelled cost uplifts for 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 D

Technical Feasibility

Delivering Net Zero

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

Compliance methods

Selecting the right compliance method

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.

Regardless of the calculation tool used to predict net zero carbon compliance , a rigorous quality assurance process is required to ensure the "as built" performance meets the "design". Quality assurance throughout design and construction is embedded in the Passivhaus certification process. 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).

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

Utilising existing standards

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
Passivhaus is a leading comfort and energy efficiency standard.

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
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 self-certify the project.

SAP & SBEM calculation
SAP and SBEM calculations are 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
CIBSE published TM54 "Evaluating Operational Energy Performance of Buildings at the Design Stage" in 2013 to help tackle the performance gap of low energy buildings. It provides guidance on how to calculate the total energy consumption of a new building more accurately at design stage. The guide suggests heating and cooling analysis should be done with dynamic simulation modelling. It also provides methodologies for calculating other areas of energy consumption using steady state calculations.

Assured Performance

The Performance Gap

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

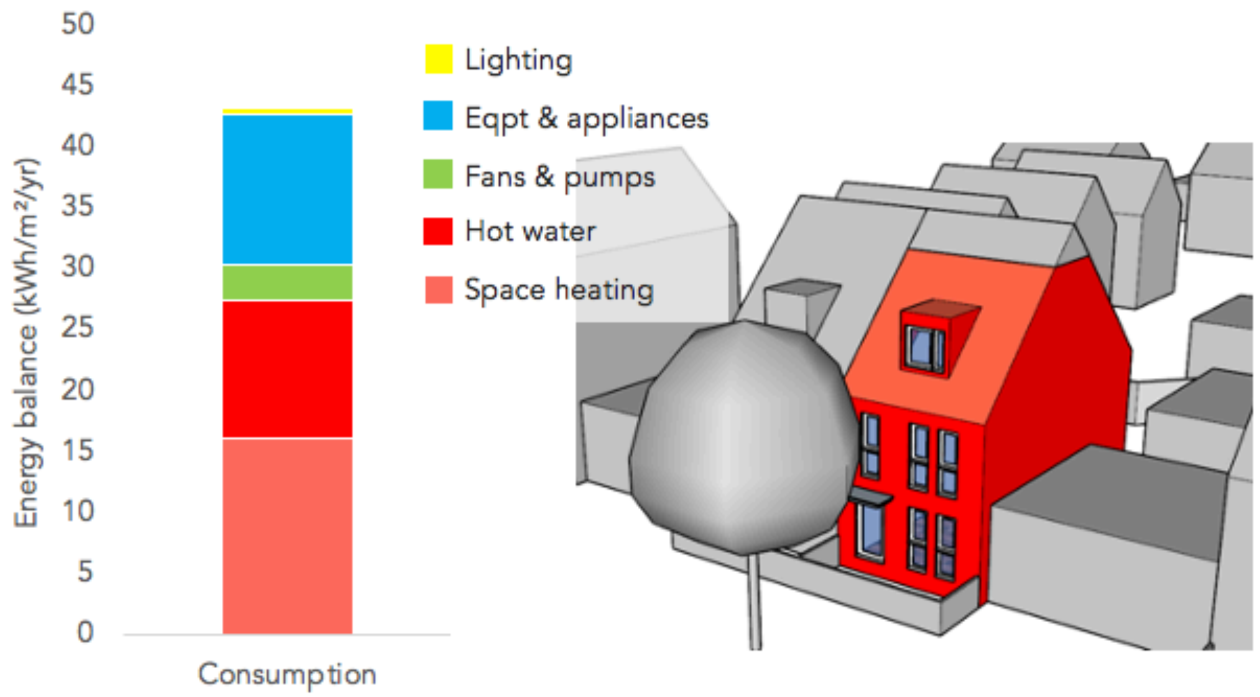
Modelling to predict the energy performance of buildings is most often carried out in order to demonstrate regulatory compliance. Calculations for regulatory compliance do not account for all energy uses in buildings. There are calculation and modelling platforms that are more comprehensive, most notably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

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.

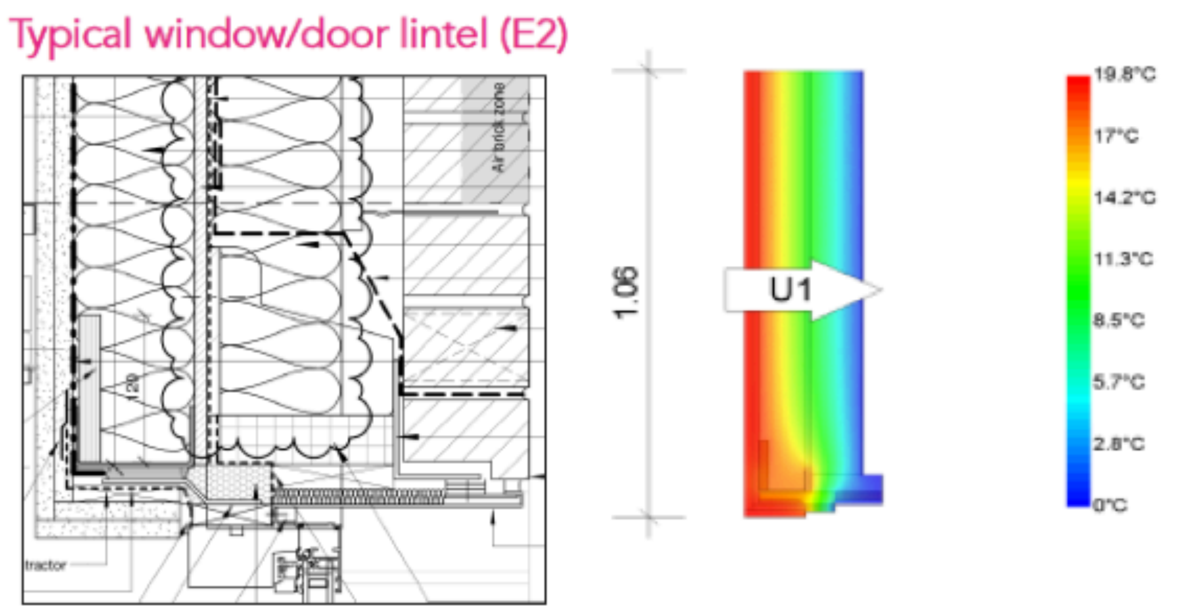
Future development of SAP may begin to address this concern, and if so, the degree of uplift, or the need for any uplift at all, can be reviewed.

Construction Quality Management

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.



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



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

Assured Performance

Assured Performance Schemes

Adoption of an assured performance scheme is required but the choice of which scheme can be left open, to suit each project and the capability of the project team.

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 for residential development.

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.

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

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

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]

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.

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 D
Technical Feasibility
Appendices

Appendix A1: Key issues raised in during the stakeholder workshop – general concerns raised

Question or issue raised	Response
Has a technology neutral approach been considered?	A technology neutral approach is assumed for delivery of the building fabric. Technology neutrality is not an appropriate mechanism for renewable energy as it is not guaranteed to deliver the electricity generation mix that is technically optimal at a national scale.
Is embodied carbon included in the definition of 'net zero carbon'?	No. Much embodied carbon is already accounted for in national carbon budgets for the country of manufacture. Including it in this analysis could result in double counting.
Can increased water efficiency be used to deliver greater carbon savings?	Yes, reasonable shower head flow rates in line with the AECB Water Standards and wastewater heat recovery are sensible measures and should be considered/encouraged.
What Seasonal Coefficient of Performance (SCOP) has been assumed for heat pumps?	The SCOP is calculated within PHPP based on heat pump test data under known conditions, the proportion of space heating vs water heating, the external temperature at the time of heat generation and the flow temperature. Typical SCOP's calculated in PHPP were 2.4-2.5. This is relatively low and is due to much of the heat output being used to provide domestic hot water.
Has energy storage been considered and is it required to deliver net zero carbon buildings?	Energy storage will be required in a net zero carbon energy system. Thermal storage using the thermal mass of the building and domestic hot water storage are likely to be sensible measures in most new buildings. It is not currently clear whether there will be a long term widespread requirement or financial case for behind the meter battery storage.
Does additional insulation increase building footprint?	In some cases yes, however this will depend on the form factor, build ups and type of insulation assumed in the baseline vs net zero carbon scenario. For example, improvements to a building's form could offset the need for some additional wall insulation, as could specification of a higher performing insulation.
Will external moveable shading or active cooling be required?	This has not been assumed in our modelling, but may be required in some cases.
Does each room still require a heat emitter in the net zero carbon scenario?	No, the level of fabric efficiency in the net zero carbon scenario means that not all rooms will require heat emitters.
Have lower heat emitter flow temperatures been accounted for in radiator areas?	Yes, heat emitter areas for the baseline and net zero carbon scenarios are based on the peak heat load and flow temperature.
Are any subsidies such as the Renewable Heat Incentive included in the cost calculations.	No. Exported solar electricity is assumed to be worth 5.5p/kWh based on market rates under the Smart Export Guarantee.
Has overheating analysis been performed for any of the buildings?	PHPP performs a single zone overheating analysis relative to a recommended frequency of under 5% of the year. The frequency of overheating was 1.6% for the semi-detached house, 25% for the terraced house, 3.1% for the block of flats and negligible for the school. Reductions in overheating risk on the terraced house could be achieved by reducing glazed areas, which would reduce cost.
What assumptions have been made for the cost uplift?	Assumptions will be outlined separately in the cost report.
Which end uses of energy are included in your net zero energy balance calculations?	Our calculations include a reasonable baseline allowance for all energy use. In dwellings this includes electricity used by appliances, small electronics, cooking, lighting, pumps, fans, domestic hot water and space heating. In schools this includes a typical basket of end uses.

Appendix A2: Key issues raised in during the stakeholder workshop – focus on solar photovoltaics

Question or issue raised	Response
Has a technology neutral approach been considered?	A technology neutral approach is assumed for delivery of the building fabric. Technology neutrality is not an appropriate mechanism for renewable energy as it is not guaranteed to deliver the electricity generation mix that is technically optimal at a national scale.
Is embodied carbon included in the definition of 'net zero carbon'?	No. Much embodied carbon is already accounted for in national carbon budgets for the country of manufacture. Including it in this analysis could result in double counting.
Can increased water efficiency be used to deliver greater carbon savings?	Yes, reasonable shower head flow rates in line with the AECB Water Standards and wastewater heat recovery are sensible measures and should be considered/encouraged.
What Seasonal Coefficient of Performance (SCOP) has been assumed for heat pumps?	The SCOP is calculated within PHPP based on heat pump test data under known conditions, the proportion of space heating vs water heating, the external temperature at the time of heat generation and the flow temperature. Typical SCOP's calculated in PHPP were 2.4-2.5. This is relatively low and is due to much of the heat output being used to provide domestic hot water.
Has energy storage been considered and is it required to deliver net zero carbon buildings?	Energy storage will be required in a net zero carbon energy system. Thermal storage using the thermal mass of the building and domestic hot water storage are likely to be sensible measures in most new buildings. It is not currently clear whether there will be a long term widespread requirement or financial case for behind the meter battery storage.
Does additional insulation increase building footprint?	In some cases yes, however this will depend on the form factor, build ups and type of insulation assumed in the baseline vs net zero carbon scenario. For example, improvements to a building's form could offset the need for some additional wall insulation, as could specification of a higher performing insulation.
Will external moveable shading or active cooling be required?	This has not been assumed in our modelling, but may be required in some cases.
Does each room still require a heat emitter in the net zero carbon scenario?	No, the level of fabric efficiency in the net zero carbon scenario means that not all rooms will require heat emitters.
Have lower heat emitter flow temperatures been accounted for in radiator areas?	Yes, heat emitter areas for the baseline and net zero carbon scenarios are based on the peak heat load and flow temperature.
Are any subsidies such as the Renewable Heat Incentive included in the cost calculations.	No. Exported solar electricity is assumed to be worth 5.5p/kWh based on market rates under the Smart Export Guarantee.
Has overheating analysis been performed for any of the buildings?	PHPP performs a single zone overheating analysis relative to a recommended frequency of under 5% of the year. The frequency of overheating was 1.6% for the semi-detached house, 25% for the terraced house, 3.1% for the block of flats and negligible for the school. Reductions in overheating risk on the terraced house could be achieved by reducing glazed areas, which would reduce cost.
What assumptions have been made for the cost uplift?	Assumptions will be outlined separately in the cost report.
Which end uses of energy are included in your net zero energy balance calculations?	Our calculations include a reasonable baseline allowance for all energy use. In dwellings this includes electricity used by appliances, small electronics, cooking, lighting, pumps, fans, domestic hot water and space heating. In schools this includes a typical basket of end uses.

Appendix B: The vital role of solar photovoltaic technology

International Context

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

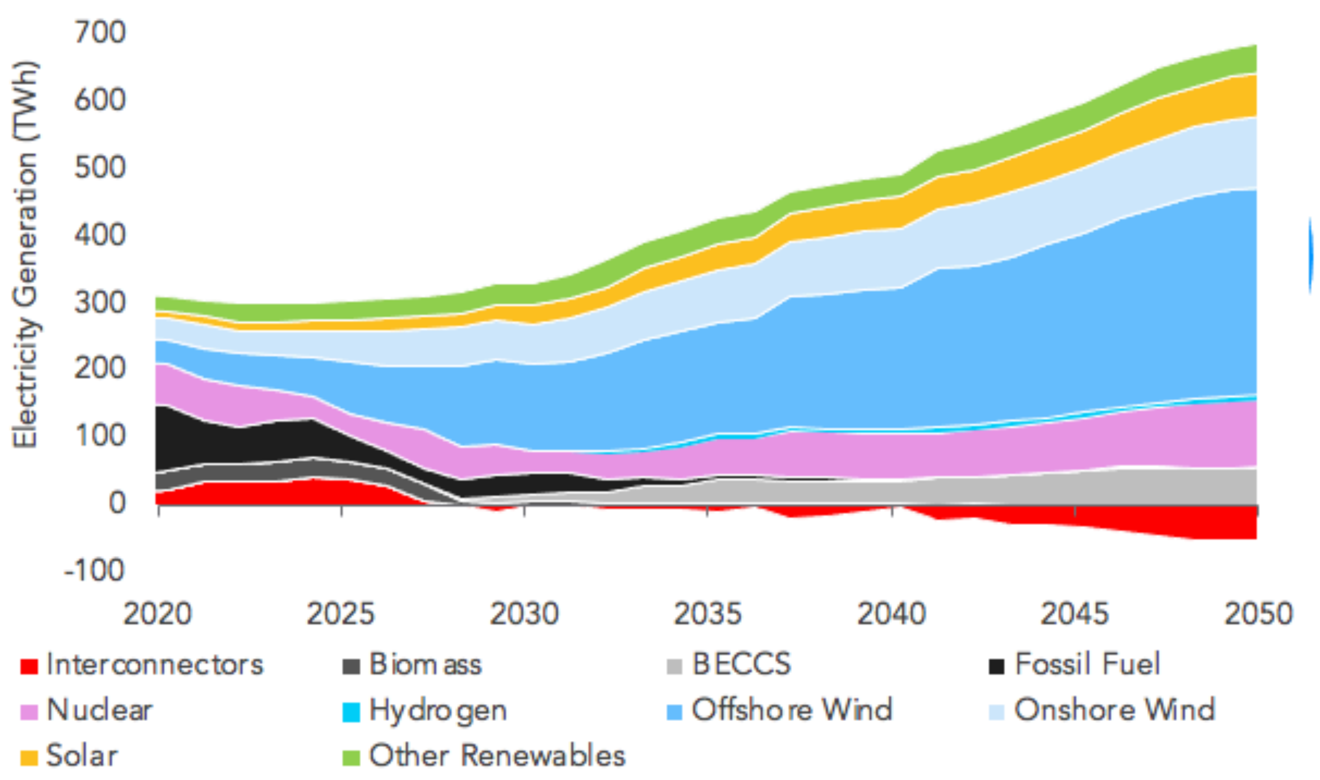
The National Grid produces a set of future scenarios for the UK's electricity generation mix each year. Three out of four of the most recent scenarios are currently compliant with limiting global warming to less than 2˚C: 'Consumer Transformation', 'System Transformation' and 'Leading the Way'. These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

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.

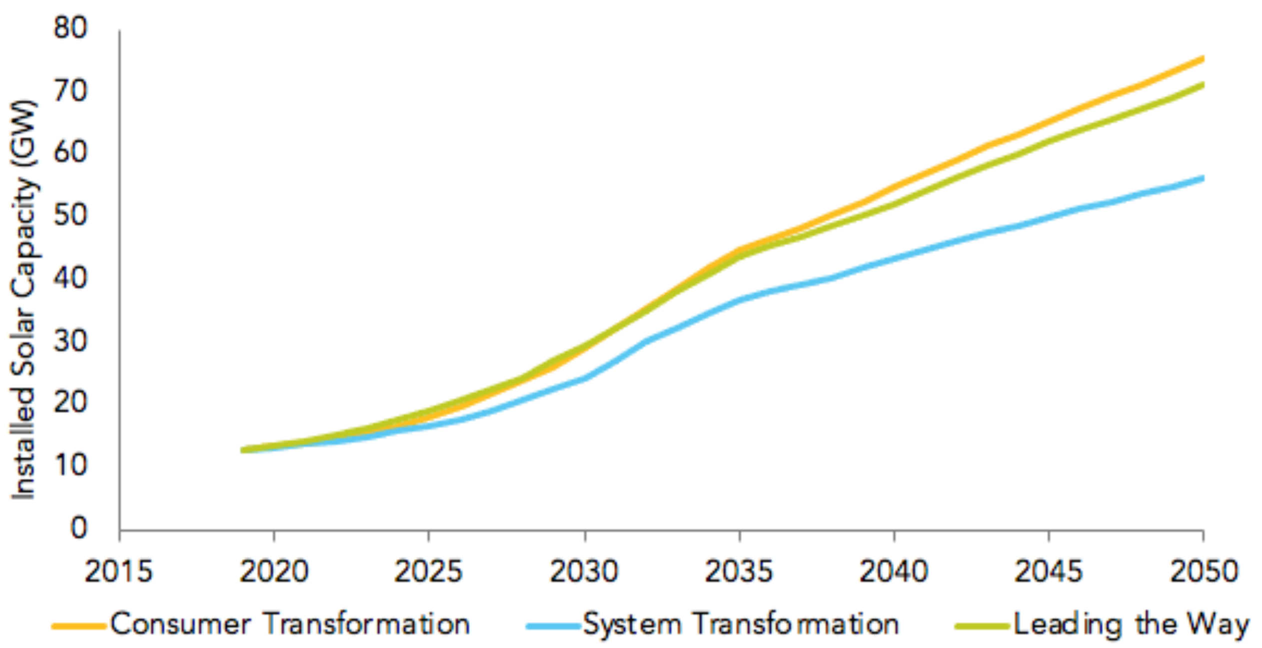
All of the two degree compliant scenarios require an increase of installed solar capacity in the UK by a factor of four to over five times within the next few decades. As shown in the figure below, this represents a substantial increase over current capacity of around 13GW.

Location: Buildings, Infrastructure or Fields?

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.



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)



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 C: Solar energy and the Electricity Grid

The National Grid

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.

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

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

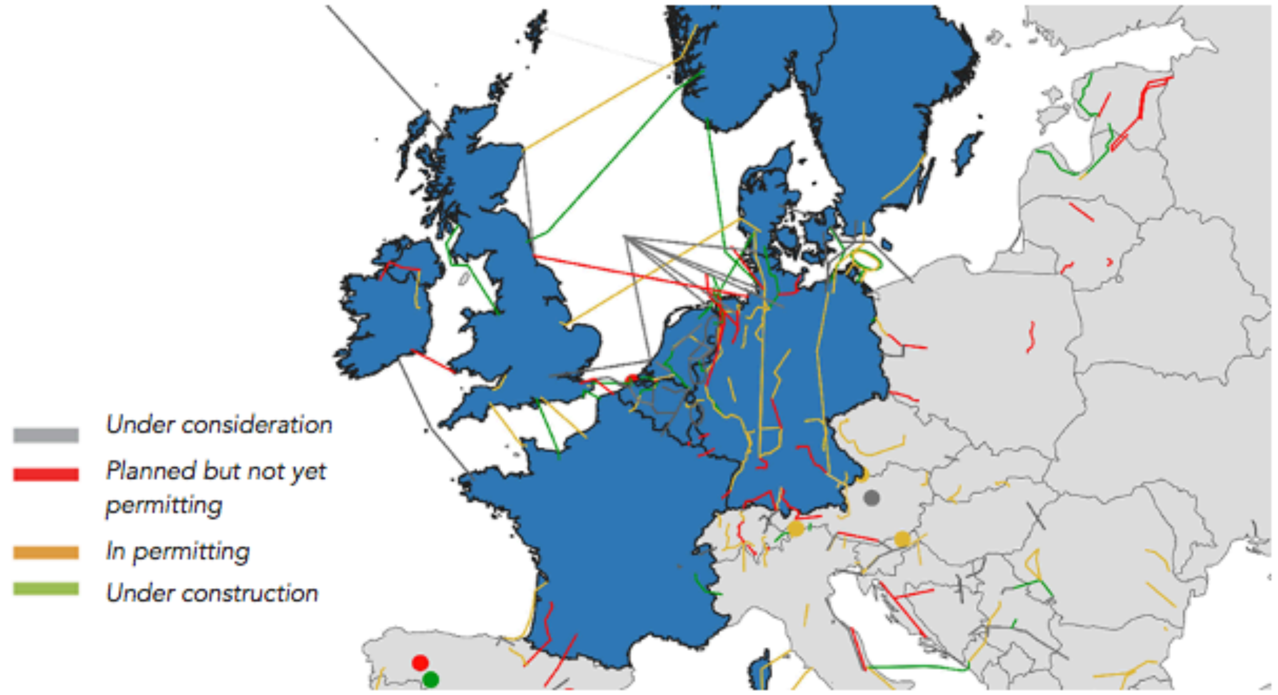
The following strategies will facilitate significant expansion of the UK's solar capacity:

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.



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.

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 D: Is solar generation in phase with energy demand?

Why time of generation is important

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.

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.

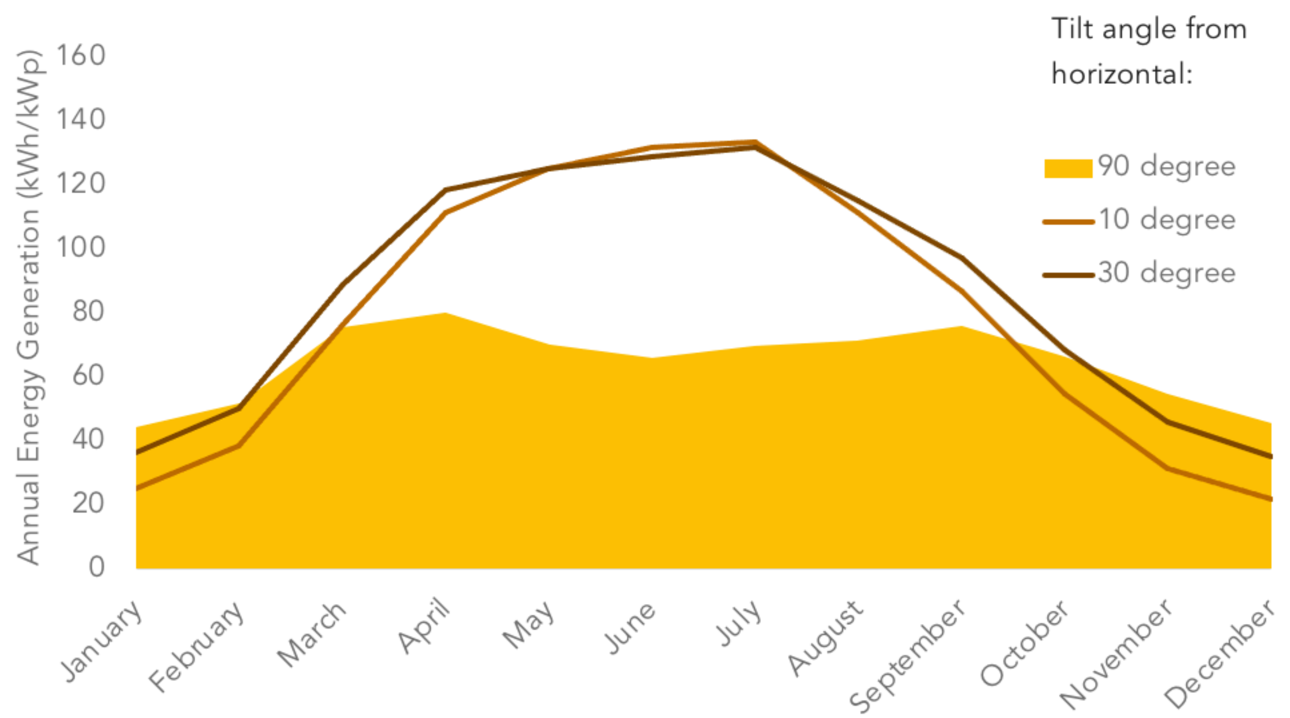
A traditional perspective: Is solar generation in phase with energy demand?

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.

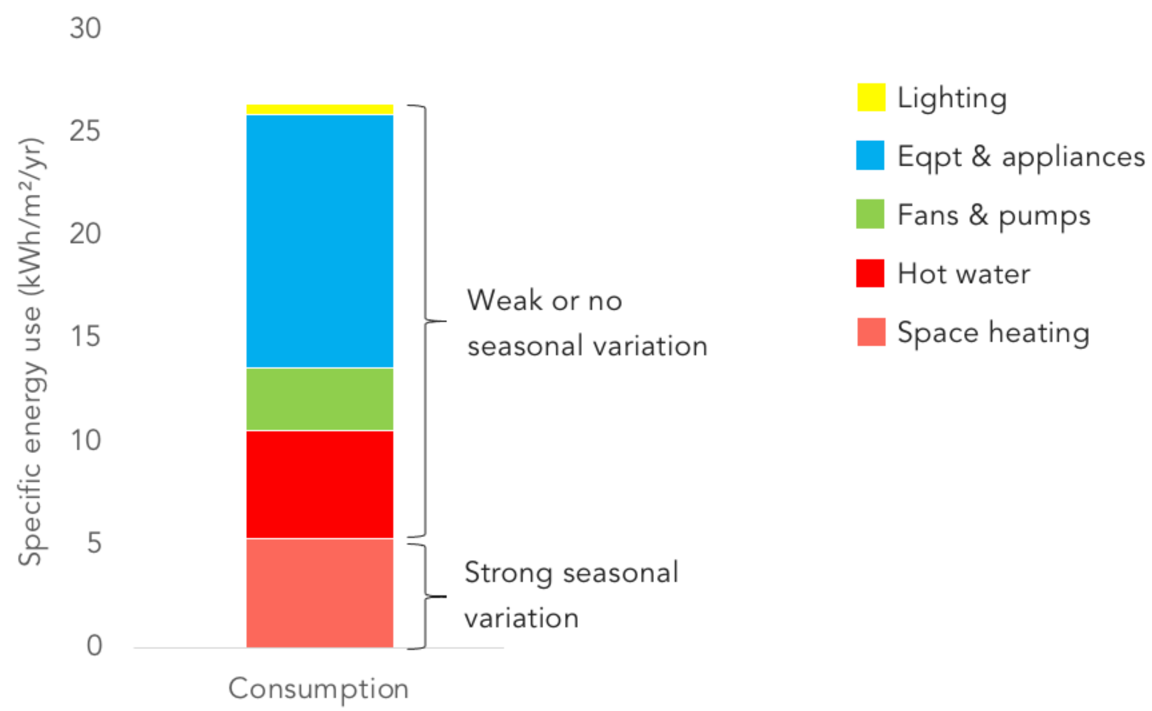
Many end uses of energy in a net zero carbon building are likely to be steady throughout the year. This is shown in the lower adjacent figure, where energy use for lighting, equipment and appliances, fans and pumps, and hot water generation are expected to exhibit a weak or no significant season variation. 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?

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.



Variation in monthly solar generation for Cambridge – South facing wall mounted systems generate 26% 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)



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 E: Embodied carbon of solar photovoltaics

Historical Trends

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

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).

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.

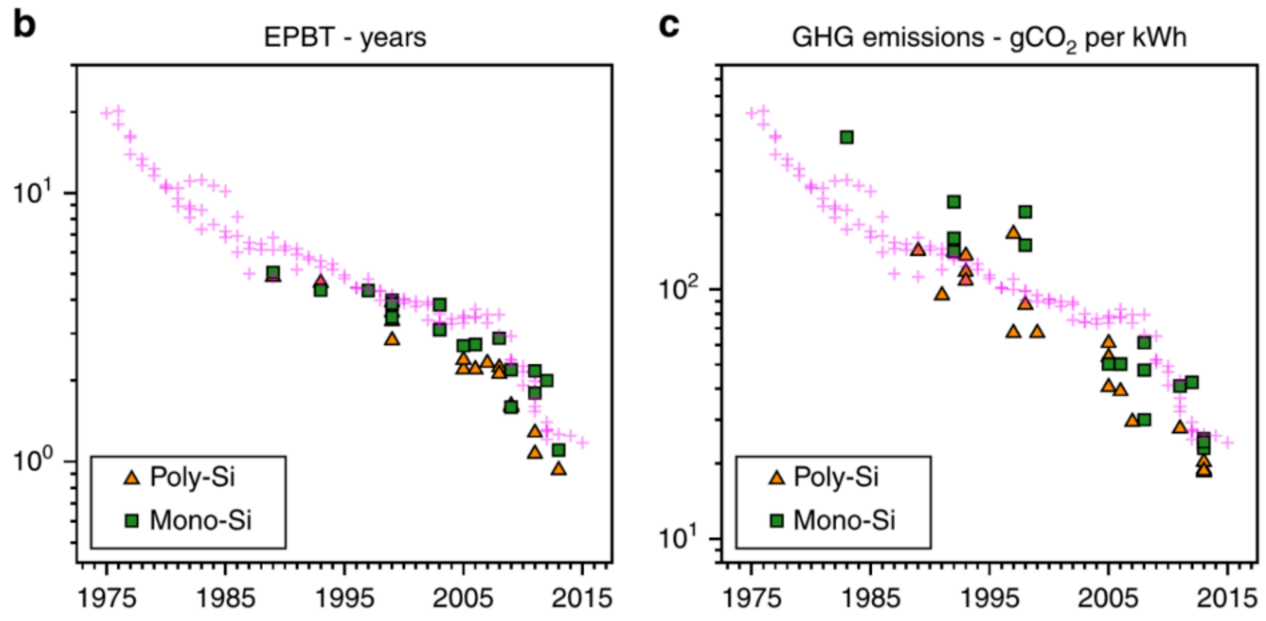
Why 'Carbon Payback' is not a Sensible Metric

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.

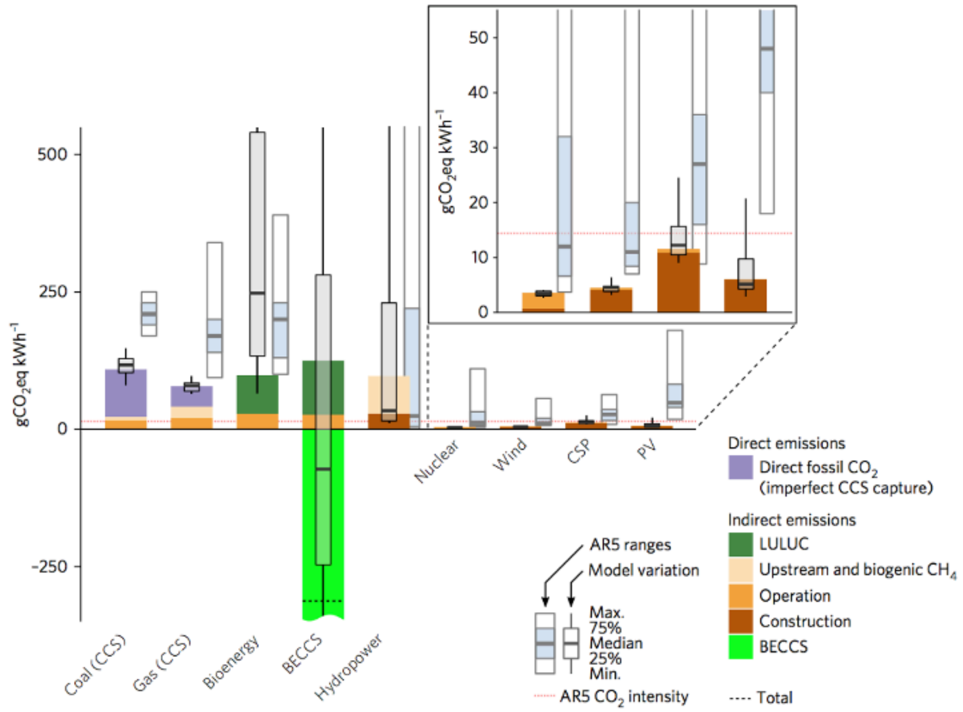
Additionally, as the grid decarbonises (due to the deployment of solar and wind technology) the calculated carbon payback period will trend toward infinity. Even when the grid is, for practical purposes, completely decarbonised, new solar photovoltaic systems will still be required to replace existing 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 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.



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)



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)

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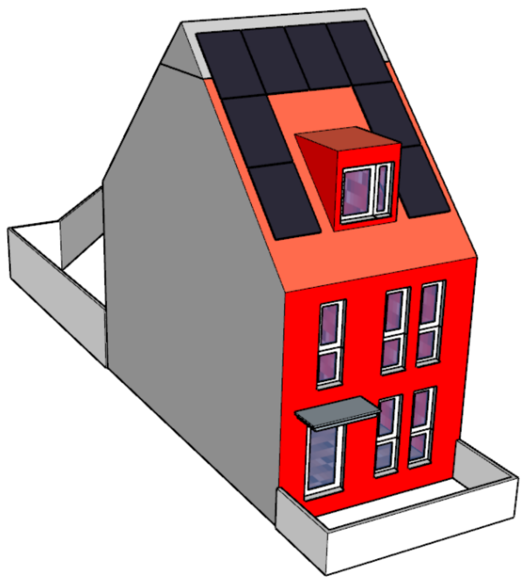
Appendix F: The effect of orientation on solar generation

Overview

The orientation and design of a building affects both the number of solar panels that can be installed and the amount of energy generated per panel. All of the building types modelled for this study could achieve net zero in any orientation.

The most challenging type is the semi-detached house due to the presence of a dormer window and rooflights. These limit available area for solar panel installation, and the dormer window creates some shading. The use of microinverters or DC optimisers is important for this building to limit the impact of shading and to maximise energy generation per panel. As the analysis on this page shows, while energy production per panel reduces for the East/West orientation, the amount of panels that can be installed increases.

Solar generation figures on this page were calculated using the EU Joint Research Centre's PVGIS tool for the proposed location of this house in Cambourne West. The PVGIS-SARAH solar radiation database was used, losses were reduced by 8% to reflect the use of microinverter s or DC optimisers.

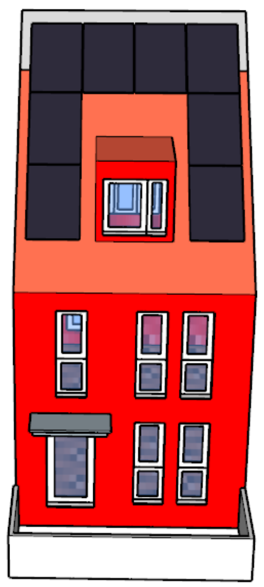


South East

This is the most challenging orientation as there is only space for eight panels to be installed on the dormer roof and irradiation is reduced relative to a South orientation.

Use of eight 380W panels with microinverters or DC optimisers is required for the house to achieve net zero with generation of 2,910kWh/yr, assuming 5% shading.

Modest changes to the roof design such as an asymmetric ridgeline or moving the dormer roof down could enable the installation of another two solar panels. This would allow use of a wider range of lower power panels to achieve net zero.

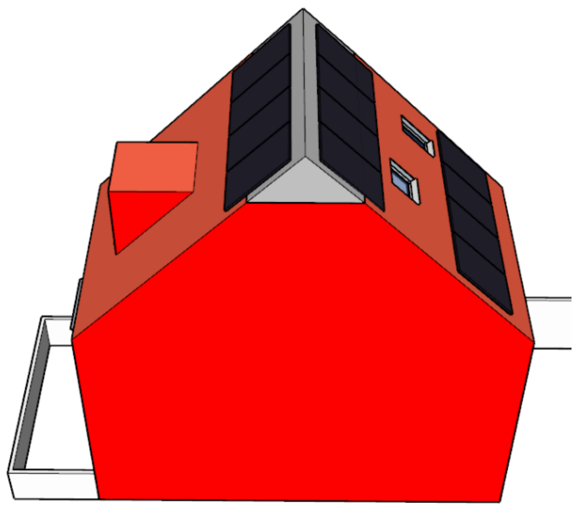


South

The best orientation for maximising energy production per panel in the UK, however not always the best orientation for maximising energy production for a given building. In this case, because it only allows for installation of up to eight solar panels.

Use of eight 360W panels with microinverters or DC optimisers is required for the house to achieve net zero with generation of 2,990kWh/yr, assuming 5% shading.

Modest changes to the roof design such as an asymmetric ridgeline or moving the dormer roof down could enable the installation of another two solar panels. This would allow use of a wider range of lower power panels to achieve net zero.



East / West

Although energy production per panel is reduced for this orientation, it allows installation of more panels on the roof. The impact on cost is expected to be modest as the marginal cost of additional panels is typically low.

Use of twelve 340W panels with microinverters or DC optimisers is required for the house to slightly exceed net zero with generation of 3,190kWh/yr, assuming no shading.

Modest changes to the roof design such as an asymmetric ridgeline, moving the dormer roof down, or moving the rooflight could enable the installation of more solar panels. This would allow use of a wider range of lower power panels to achieve net zero.

Appendix G: Solar photovoltaic design precedents

Real world solar design

All precedents shown in these slides have been built to completion showing they are not just design concepts but are feasible in reality. Each design selected shows the different ways in which designers and architects have thought about the use of solar photovoltaics.

Frameless semi-transparent solar modules can be integrated with roof gardens to deliver biodiversity gains and low carbon generation, as shown for this rooftop solar garden in Vienna, Austria.

High levels of solar generation are achieved in this medium rise residential building in Frankfurt through the use of a monopitch rooftop array and vertical solar arrays on the southern façade. © HHS Planer + Architekten

The Parc Eirin development by Sero Energy and Tirion Homes shows net zero homes are already being built at development scale in the UK. © Pobl Living

Carrstone House demonstrates it is possible for solar coverage to match the building footprint. Excess energy is used for EV charging or sold to the grid. © Eco Design Consultants

Appendix H1: Cost analysis summary by Etude

Greater Cambridge 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 E - Cost Implications", by Currie and Brown.

Semi-detached, Standard

	Fabric efficiency	Heating system				Construction cost uplift over baseline				Running cost/yr	
	15-20	Heat pump	v	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from
Baseline	-	-	-	-	-					818	-
Zero carbon	x	x	26	2.9	Yes	£6,830	£2,805	£3,245	£12,880	340	-58%

Terrace

	Fabric efficiency	Heating system				Construction cost uplift over baseline				Running cost/yr	
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline			?		-					793	
Zero carbon	x	x	32	3.4	Yes	£7,335	£3,035	£3,165	£13,535	300	-62%

Flats

	Fabric efficiency	Heating system				Construction cost uplift over baseline				Running cost/yr	
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Cost/yr	% change from baseline
Baseline			?		-					23090	
Zero carbon	x	x	26	112	Yes	£154,032	£94,723	£83,980	£332,735	9600	-58%

School

	Fabric efficiency	Heating system				Construction cost uplift over baseline				Running cost/yr	
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Cost/yr	% change from baseline
Baseline			?		-					21979	
Zero carbon	x	x	38	112	Yes	£126,330	(£13,135)	£95,670	£208,865	8170	-63%

Appendix H2: Cost analysis summary by Etude

Greater Cambridge 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 E - Cost Implications", by Currie and Brown.

Semi-detached, Standard

	Fabric efficiency	Heating system				Construction cost uplift over baseline					
	15-20	Heat pum	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from
Baseline	-	-	-	-	-					818	-
Zero carbo	x	x	26	2.9	Yes	5%	2%	3%	10%	340	-58%

Terrace

	Fabric efficiency	Heating system				Construction cost uplift over baseline					
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline			?		-					793	
Zero carbo	x	x	32	3.4	Yes	7%	3%	3%	13%	300	-62%

Flats

	Fabric efficiency	Heating system				Construction cost uplift over baseline					
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Running Cost/yr	% change from baseline
Baseline			?		-					23090	
Zero carbo	x	x	26	112	Yes	3%	2%	2%	6%	9600	-58%

School

	Fabric efficiency	Heating system				Construction cost uplift over baseline					
	15-20	Heat pump	EUI	PV, kWp	Net zero carbon?	Fabric	M&E	PV	Total	Cost/yr	% change from baseline
Baseline			?		-					21979	
Zero carbo	x	x	38	112	Yes	2%	0%	1%	3%	8170	-63%

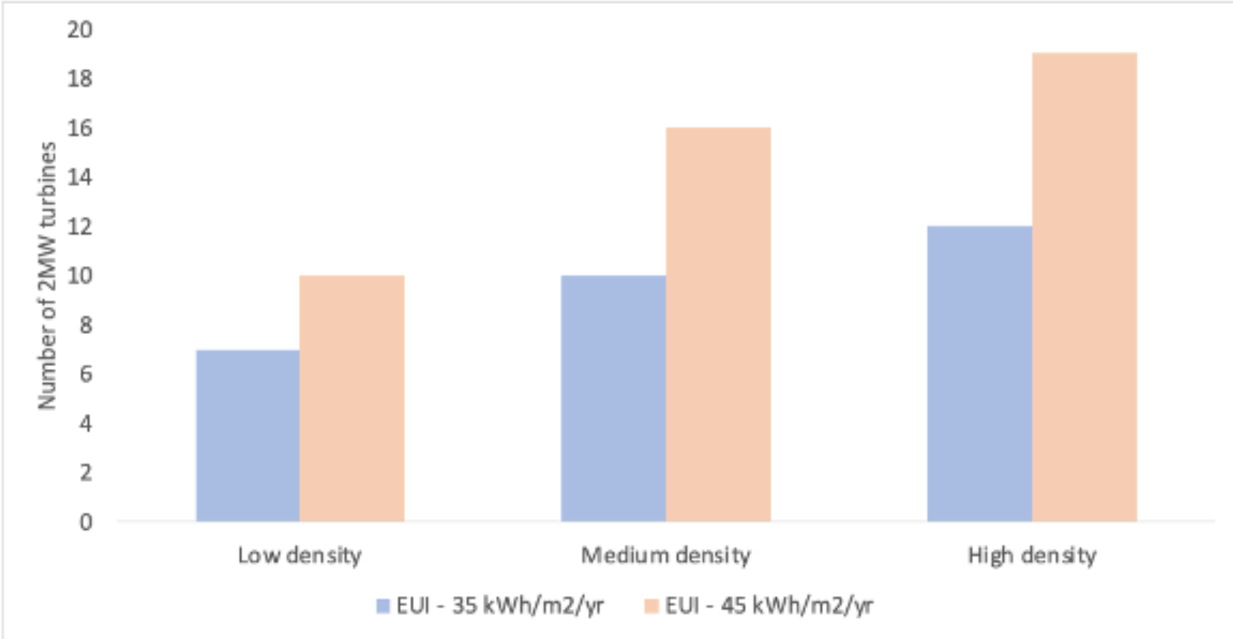
Appendix I1: Energy balance calculations

Project	Greater Cambridge 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	Apr-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/m^2GIA)	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 Greater Cambridge at different densities (see density assumptions) and different EUI targets

Scenarios

Density	EUI (resi)	PV policy	Net generation on new buildings	To make up deficit: No. 2MW wind turbines	To make up deficit: MW large scale PV	% difference between capacity requirements
L	35	match EUI	-30600	7	35	
L	45	match EUI	-30600	10	49	140%
M	35	match EUI	-33200	10	48	
M	45	match EUI	-55000	16	78	163%
H	35	match EUI	-40400	12	61	
H	45	match EUI	-81800	19	97	159%

Appendix I2: Energy balance calculations: density assumption, 1/2

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

	Pre-set densities				
	Low	Medium	High	Building type and height	
	5%	0%	0%	Bungalows	Residential houses
	45%	20%	5%	2-storey house	
	40%	25%	10%	3-storey house	
	0%	20%	20%	4-storey house	
	0%	0%	0%	2-storey blocks	Residential flats
	10%	20%	24%	3-storey blocks	
	0%	10%	25%	4-storey blocks	
	0%	5%	10%	5-storey blocks	
	0%	0%	2%	6-storey blocks	
	0%	0%	2%	7-storey blocks	
	0%	0%	2%	8-storey blocks	
	0%	0%	0%	9-storey blocks	
	0%	0%	0%	10-storey blocks	
	100%	100%	100%		Total residential
	0%	0%	0%	1-storey office	Offices
	20%	10%	0%	2-storey office	
	58%	30%	10%	3-storey office	
	15%	30%	40%	4-storey office	
	5%	20%	35%	5-storey office	
	2%	10%	15%	6-storey office	
	0%	0%	0%	7-storey office	
	0%	0%	0%	8-storey office	
	0%	0%	0%	9-storey office	
	0%	0%	0%	10-storey office	
	100%	100%	100%		Total offices
	80%	80%	80%	1-storey light industrial	Light industrial
	20%	20%	20%	2-storey light industrial unit	
	100%	100%	100%		Total light industrial
	20%	40%	60%	Small retail units (groui	Retail
	60%	45%	30%	1-storey large out of town retail units	
	20%	15%	10%	2-storey large out of town retail units	
	100%	100%	100%		Total retail

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	
	3	1	0	1-storey Primary schoo	Schools
	0	2	0%	2-storey Primary school	
	0	0	3	3-storey Primary school	
	1	0	0	2-storey seconary school	
	0	1	0	3-storey secondary school	
	0	0	1	4 storey-secondary school	
	4	4	4		Schools total
	25%	10%	0%	2-storey teaching facili	HE Teaching Facilities
	45%	40%	30%	3-storey teaching facilities	
	30%	45%	60%	4-storey teaching facilities	
	0%	5%	10%	5-storey teaching facilities	
	100%	100%	100%		Total HE teaching facilities
	0%	0%	0%	1-storey research facili	Research facilities
	25%	15%	5%	2-storey research facilities	
	55%	45%	35%	3-storey research facilities	
	20%	40%	60%	4-storey research facilities	
	0%	0%	0%	5-storey research facilities	
	100%	100%	100%		Total research facilities
	100%	100%	100%	1-storey sports hall	Leisure
	0%	0%	0%	2-storey leisure centre with pool	
	100%	100%	100%		Total leisure
				1-storey hotel	Hotel
				2-storey hotel	
				3-storey hotel	
	100%	100%	100%	4-storey hotel	
	100%	100%	100%		Total hotel

Appendix I3: Energy balance calculations: density assumption, 2/2

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
	90%	70%	40%	2-storey GP Surgery
	10%	30%	60%	Mixed-use, ground floor (no roof)
	100%	100%	100%	Total GP surgery
				2-storey hospital Hospital
	50%	50%	50%	3-storey hospital
	50%	50%	50%	4-storey hospital
	100%	100%	100%	Total hospital
	0%	0%	0%	1-storey student accon Student accommodation
	0%	0%	0%	2-storey student accommodation
	40%	40%	0%	3-storey student accommodation
	60%	60%	60%	4-storey student accommodation
	0%	0%	40%	5-storey student accommodation
	0%	0%	0%	6-storey student accommodation
	0%	0%	0%	7-storey student accommodation
	0%	0%	0%	8-storey student accommodation
	0%	0%	0%	9-storey student accommodation
	0%	0%	0%	10-storey student accommodation
	100%	100%	100%	Total student accommodation

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