Net Zero Carbon Toolkit

July 2021

Please attribute: Levitt Bernstein, Elementa, Passivhaus Trust and Etude commissioned by West Oxfordshire, Cotswold and Forest of Dean District Councils, funded by the LGA Housing Advisers Programme.

How to adapt and use this toolkit

For local authorities:

In line with the intention of the LGA Housing Advisers Programme grant, please feel free to adapt this toolkit in any way you wish, to make it specific to your Authority, geography or other circumstances.

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Introduction

This chapter sets out why this toolkit has been produced and how it can be used.

It also defines Net Zero carbon buildings and puts them in the context of the wider electricity revolution.

Foreword and commitment

The Forest of Dean, Cotswold and West Oxfordshire District Councils have a shared and collective ambition to deliver Net Zero as the standard of all new housing and in the retrofit of existing homes.

Achieving the UK's legally binding target of Net Zero is no small task, nor is it one that any single person or organisation can achieve alone. It requires everyone to come together, to work collectively, to share in their experiences and to build on their successes along the way.

As local planning authorities, we are dedicated to supporting individuals, businesses and communities on this pathway to Net Zero. This is why our three councils have partnered in the production of a Net Zero Carbon Toolkit: a practical and easy-to-navigate guide on how to plan your Net Zero housing project.

Whether you are a small or medium-size house builder, an architect, a self-builder or a consultant advising clients, this Toolkit will help you. With local planning policy expected to strengthen requirements for Net Zero in development terms, this Toolkit explains how this can be delivered through construction.

Our leading technical experts from Etude, the Passivhaus Trust, Levitt Bernstein and Elementa Consulting have produced a resource that contains the very latest design approach and good practice within the field of Net Zero buildings. This Toolkit is the output of funding from the Local Government Association (LGA) Housing Advisers Programme which is designed to support councils seeking to innovate in meeting the housing needs of their communities.

We hope you find technical value, as well as inspiration and motivation, to achieve the best housing design possible.

WEST OXFORDSHIRE DISTRICT COUNCIL

COTSWOLD DISTRICT COUNCIL

Forest of Dean DISTRICT COUNCIL

Introduction

In 2018, the Intergovernmental Panel on Climate Change (IPCC) showed the world there would be only 12 years to prevent irreversible catastrophic damage from a changing climate.

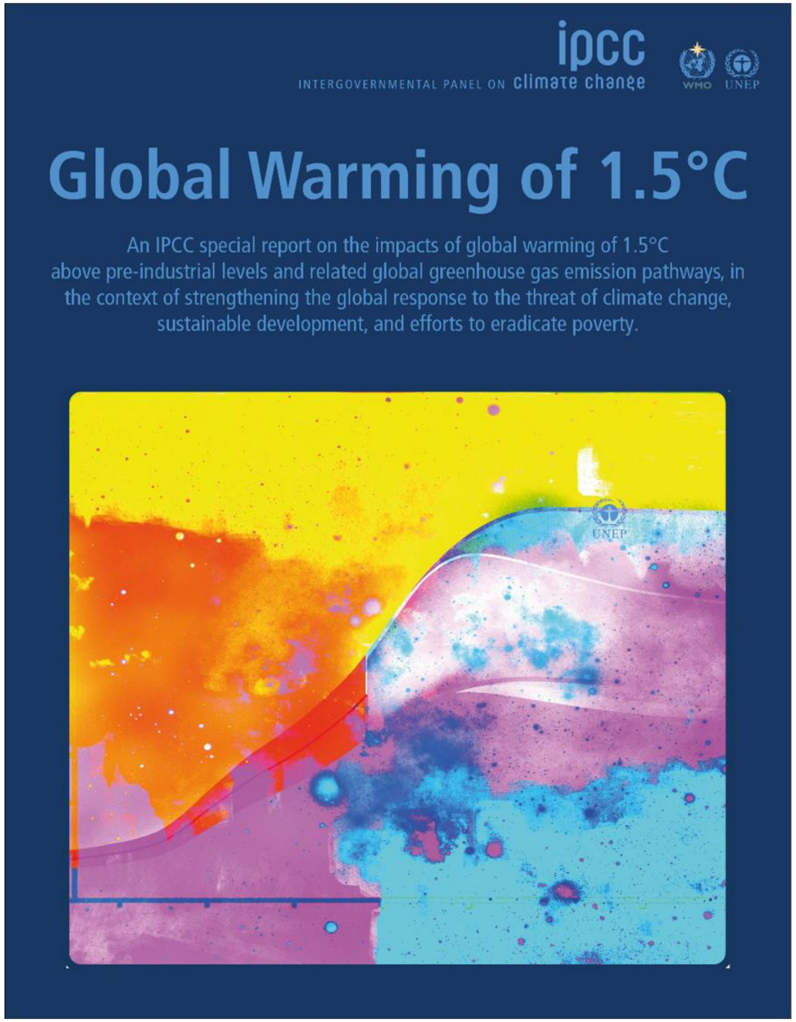
Any temperature increase above 1.5°C would trigger far worse effects than previously thought, in terms of drought, flood, poverty for many people, and catastrophic biodiversity loss.

The Forest of Dean, Cotswold and West Oxfordshire District Councils, along with other local planning authorities across the country, declared a climate and ecological emergency to deliver local action in response to a global issue.

Each of our three Councils has since taken strides in setting their own targets and pathways for achieving carbon neutrality by 2030. Looking across the districts, there is a significant role to play in ensuring new housing and retrofits adopt and achieve the highest possible standards of energy efficiency, low carbon and Net Zero building design.

The Net-Zero Toolkit is designed to assist in the planning, design and construction of a new build or retrofit housing project.

It provides a technical, go-to guide on what to consider in the very early stages of design; how to achieve fabric energy efficiency; what systems to include; where to go for expert advice; and what to consider once you have finished your housing project and you are handing over to occupants.



This Net Zero Carbon Toolkit

Who is it for?

This toolkit has been created to make Net Zero carbon new build and retrofit more accessible. It has been created for building professionals (developers, contractors, architects and engineers) and is also relevant to self-builders, planning officers and other housing professionals. Although it can be used by homeowners, it is aimed at those who already have some knowledge or experience of construction.

Both new homes and retrofit

The toolkit tackles new build homes and the retrofit of existing homes in separate chapters. So whatever your project, you will find relevant information here.

Small to medium scale housing

The primary focus is on small to medium scale housing projects, but the principles are generally applicable to projects of any scale.

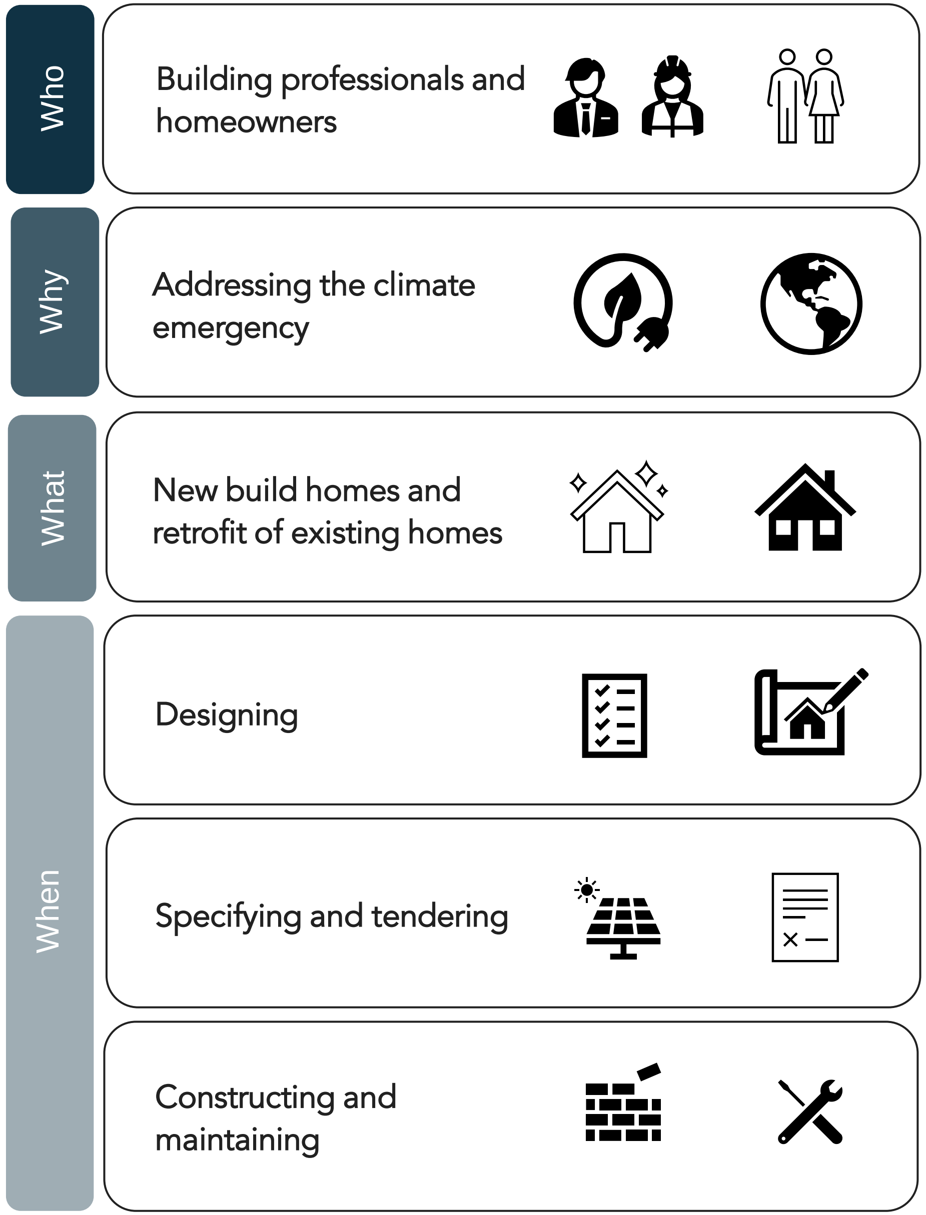
From site selection to construction to operation

It covers all stages of building design and construction, including maintenance and operation.

Understanding the complete picture

The toolkit aims to build the awareness and confidence of people implementing low or zero carbon projects and generally seeks to answer the following questions:

- Why?
- What to do and how to bring it all together?
- What does "good" look like?
- What to specify and how to choose products?



Core principles of Net Zero carbon buildings

Net Zero carbon buildings in operation are supported by three core principles: energy efficiency, low carbon heat and renewable energy.

Energy efficiency

Buildings use energy for heating, hot water, ventilation, lighting, cooking and appliances. The efficient use of energy reduces running costs and carbon emissions. It also reduces a building's impact on the wider energy supply network, which is also an important consideration.

There are different metrics we use to measure the efficiency of a building, including Space Heating Demand and Energy Use Intensity (both measured in $kWh/m^2/yr$). These are described on the next page.

Low carbon heating

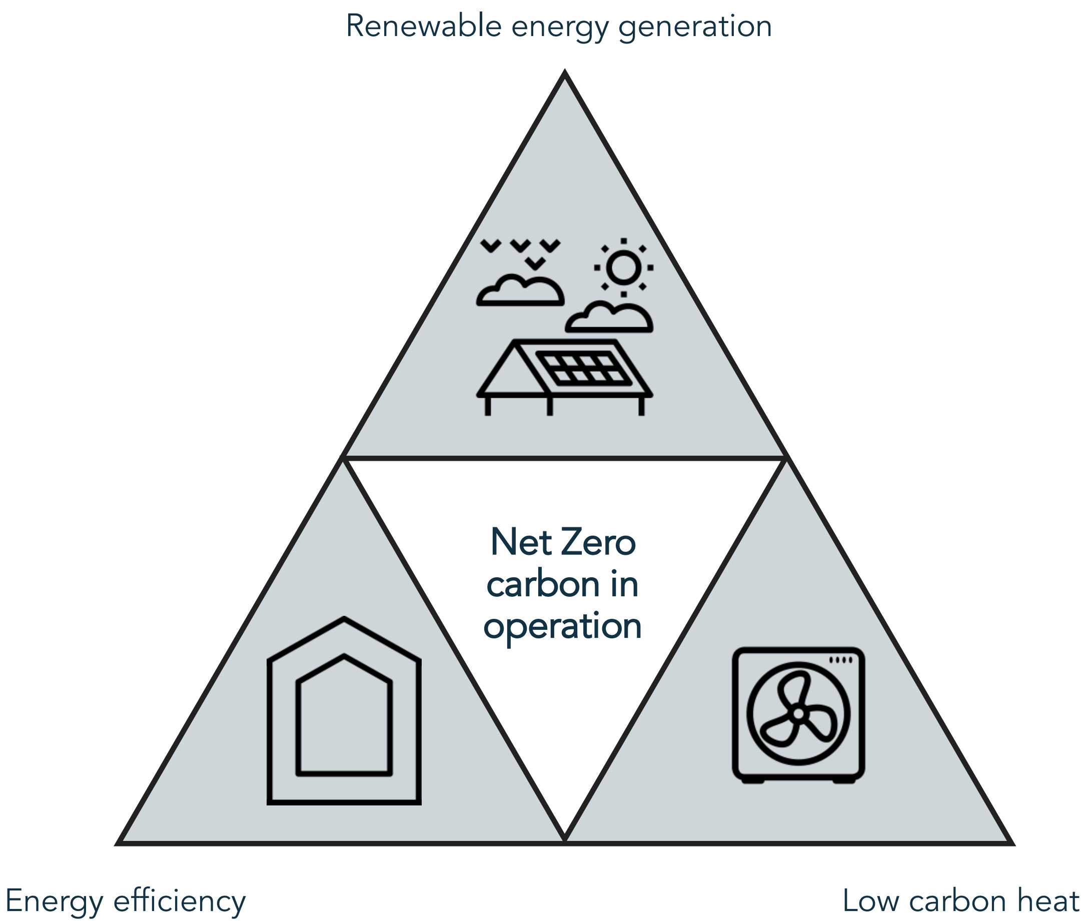
Low carbon sources of heat are an essential feature of Net Zero carbon buildings. All new buildings should be built with a low carbon heating system and must not connect to the gas network. Existing buildings need to transition away from gas and oil now.

Renewable energy generation

In new buildings, renewable energy generation should be at least equal to the energy use of the building on an annual basis for it to qualify as Net Zero carbon in operation. This is straightforward to achieve on site for most new homes through the use of solar photovoltaic (PV) panels. The roofs of existing homes should also be utilised for PV panels, to support the increased demand for renewable energy.

Embodied carbon

Operational carbon is only part of the story. Net Zero buildings should also minimise embodied carbon in materials.



The three pillars of a Net Zero carbon building in operation

Introduction to energy targets and Key Performance Indicators (KPIs)

What energy targets should I aim for?

We recommend the operational targets for new homes set out on this page, which are consistent with the *LETI Climate Emergency Design Guide*. Energy use targets are more transparent and robust than carbon reductions targets and are the best way to ensure zero carbon is delivered in practice.

What is an ultra low energy home?

An ultra low energy home is one which has a very low space heating demand. This requires a fabric efficiency and airtightness equivalent to that of a new Passivhaus home.

What is the most efficient form of heating system?

Heat pumps are considered the most efficient low carbon heat source keeping energy use to a minimum, while not using fossil fuels on site. Gas or oil boilers must not be used anymore.

Why set a renewable energy target?

Net Zero carbon in operation can only be achieved by increasing renewable electricity generation. Solar PVs represent a mature and easy to use technology.

Reducing the embodied carbon of a building

Limit the embodied carbon or emissions associated with the manufacture, transport, construction, repair, maintenance, replacement and deconstruction of building elements. This can be achieved by making informed design decisions based on quantified carbon reductions.

	KPIs New housing	KPIs Retrofit housing
Ultra low energy homes	Space heating demand 15 kWh/m²/yr	Space heating demand 65 kWh/m²/yr* *on average (range of 20-120 kWh/m²/yr)
Energy use and efficient heating	Energy Use Intensity 35 kWh/m²/yr	Energy Use Intensity 60 kWh/m²/yr *on average
Renewable energy	Electricity generation intensity 120 kWh/m^2_{fp}/yr m^2_{fp} : m² building footprint	Electricity generation intensity 120 kWh/m^2_{fp}/yr m^2_{fp} : m² building footprint
Embodied carbon	Embodied carbon benchmark 500 kgCO_{2e}/m²/yr	-

CIBSE TM59
Compliance with guidance on overheating risk

AECB
Good practice water standard

In-use performance
Collect data for the first 5 years

The electricity revolution: a greener grid and the future of heat

Towards a decarbonised and smarter electricity system

The carbon content of electricity has fallen over the last few years. It is now three times less than ten years ago and already lower than natural gas on a per kWh basis. It is forecasted to continue to reduce even further over the next 20-30 years. This explains the current energy revolution and why the electrification of transport and heat is the best strategy to move away from fossil fuels. It is also considered unlikely that hydrogen will play a significant role in heating our homes.

In order for this electricity revolution to be successful and as cost effective as possible it is very important to reduce energy use so that energy demand is not more than renewable and nuclear energy generation by 2050. If electricity demand is more flexible, it can also be matched to times of high renewable energy generation. Electric vehicle charging from homes will also create additional demand for electricity*.

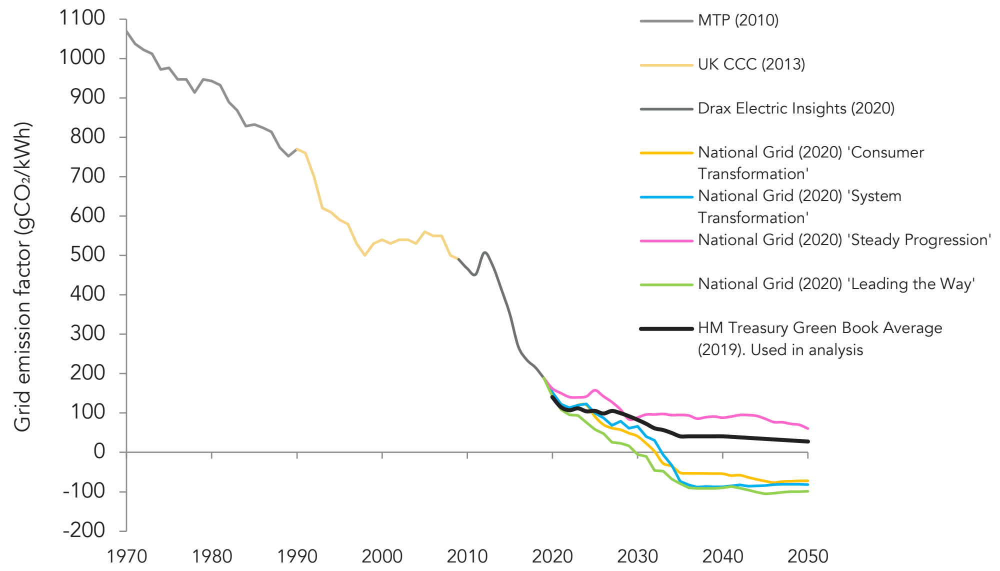
The impact on buildings

The electrification of heat (e.g. the replacement of gas boilers by heat pumps) is widely considered as one of the main priorities of decarbonisation. New gas or oil boilers should not be installed in buildings anymore, in new or existing homes.

Energy storage (e.g. hot water tank) and management (e.g. smart controls) as well as smart meters for Time of Use (ToU) variable electricity tariffs are all likely to become increasingly important.

In summary, electrification and digitalisation provide the backbone of decarbonisation for buildings.

** Electric vehicle charging is not currently covered by the Net Zero carbon home definition. It is captured in the assessment of transport emissions.*



Long-term variations in emission factor of grid electricity show the rapid historical reduction in emission factors *© Etude based on data from Market Transformation Programme, UK Committee on Climate Change, Drax, National Grid and HM Treasury.*

Note: *The National Grid Future Emissions Scenarios (FES) show that if the power sector removes CO_2 from the atmosphere by the growth of biomass and captures it when it is used in power stations, it could be carbon negative. This would rely on the use of Bioenergy with Carbon Capture and Storage (BECCS). Carbon Capture and Storage is a process in different steps: CO_2 produced is captured, transported away and isolated from the atmosphere in long-term storage in geological formations or for use in industrial processes). When more carbon is removed from the atmosphere and stored by a process than is emitted into the atmosphere, emissions are negative. BECCS features prominently in three of the four scenarios modelled in FES.*

The cost of Net Zero homes

There is a (small) cost premium

Achieving Net Zero as a society will have a cost. For some sectors it will require investments in Research and Development (R&D) as technological innovation is required. For others Net Zero compliant solutions exist but currently have a very high cost premium which needs to be reduced to be acceptable at scale.

New buildings are comparatively less challenging: technologies, techniques and processes required to deliver Net Zero carbon buildings in operation are already available and will only lead to a small cost premium compared with a Part L 2021 compliant house or block of flats, i.e. 2-6% additional capital cost.

Lowering the embodied carbon of new buildings will be more challenging and requires both material and procurement innovations. However, this does not have to lead to a significant cost premium either.

A good deal for residents

Net Zero carbon homes are not only good for the planet: they will also be much cheaper to run than a standard new build house. This is due to the combined effects of a lower energy demand alongside greater flexibility of energy use during the day and of solar electricity generation and self consumption.

Avoided costs for society as a whole

All new buildings built to poor levels of energy efficiency and fitted with gas boilers will have to be retrofitted in the next 20-30 years in order to achieve Net Zero. The cost of future retrofit is significantly higher than the cost of 'getting it right now'. There are also wider off-site benefits in terms of reduced infrastructure costs as less renewable energy generation will be required.

1. Energy efficiency	2. Low carbon heat	3. Solar generation	4. Demand flexibility
Better insulation Triple glazed windows Airtightness Mechanical Ventilation with Heat Recovery …	e.g. heat pump system	Roof mounted solar PVs	Hot water storage Smart controls

Additional costs of Net Zero carbon buildings in operation can be split up into four key categories

- 50%

Estimated savings on energy costs compared with a Part L 2021 compliant home

- No additional retrofit cost required later to achieve Net Zero
- Lower infrastructure costs

Savings on energy costs for residents and other savings for wider society

New housing

This section explains what can be done so that new housing forms part of the solutions to climate change, instead of adding to the problem.

The list of subjects it covers can be found on the following page.

Why? Key reasons for and benefits of Net Zero carbon new homes

Our buildings produce a lot of carbon – and are expensive to run

The emissions from our buildings account for 26% of the UK's total emissions. 18% of this total is from our homes. This is not only bad for the planet, it is bad for the occupants. It is therefore important for new homes to be designed and built to use significantly less energy which also means they would cost a lot less to run.

It is clear that a Net Zero UK means that we will have to significantly reduce energy use and carbon emissions from all buildings and, in particular, our homes. Even today, most new homes are being fitted with gas boilers and these will continue to emit carbon for perhaps 20 years and also degrade local air quality.

We haven't made any progress on this

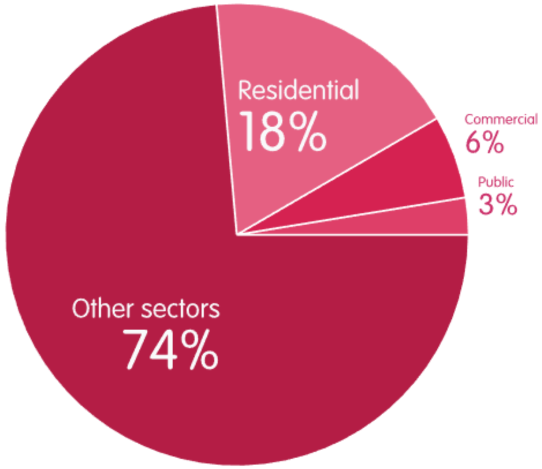
Despite rapid decarbonisation in many other sectors, the withdrawal of the Zero Carbon Homes target in 2016 has seen the energy performance of new homes remain almost constant over the last ten years. We need to do much better.

Heating is an important energy demand which can be reduced

Space heating during the winter months accounts for around 65% of the total energy demand in a new home. Space heating is an excellent proxy for the fabric efficiency of the building – i.e. the insulation in the walls, floors and roofs; the windows/doors and the ventilation system. This is why we need to concentrate on a 'fabric first' approach.

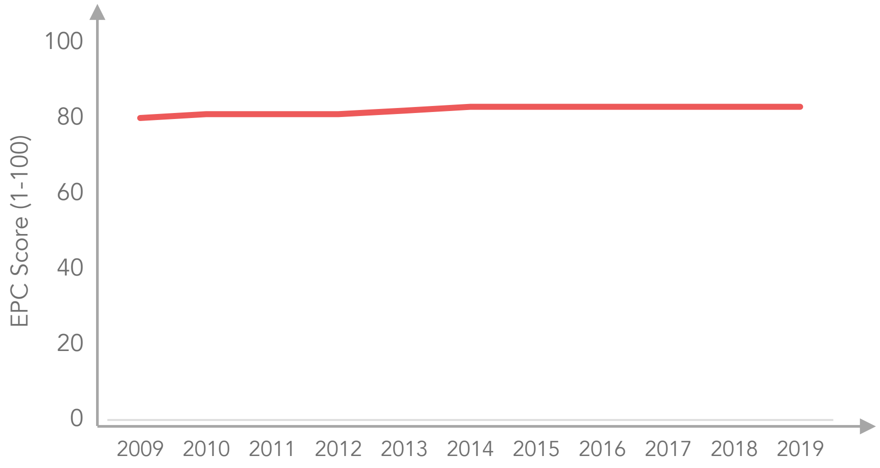
In summary

A Net Zero carbon home in operation is very energy efficient and has an ultra low level of space heating demand. It does not use any fossil fuels on site and therefore improves air quality. It also generates renewable energy on-site and is cheap to run.



UK CO_{2e} emissions, 2017

Source: UKCCC Net Zero – Technical Report, May 2019. Includes direct (at the building) and indirect (at the power station) emissions.



The EPC Score of new dwellings shows little improvement in the last 10 years

Source: Live tables on Energy Performance of Buildings Certificates, MHCLG, Jan 2020

Key Performance Indicators (KPIs) and recipe for Net Zero carbon homes

Setting the right brief and targets is key

To achieve Net Zero carbon in reality, it is important that the brief and targets reflect this ambition from the start. A strong brief provides tangible guidance on how targets can be achieved. Best practice KPIs for new homes are listed in the table and all KPIs must be met for a home to be Net Zero carbon.

Getting the right team

Delivering Net Zero carbon relies on the effective and successful coordination of a shared vision. Therefore, getting the right team on board at the right time is critical. The early appointment of an energy consultant with a specialism in Passivhaus or ultra low energy design, as well as early consideration of embodied carbon are recommended. A 'Net Zero carbon kick-off workshop' can be used to ensure the wider consultant team are clear on the targets and objectives.

Consider Passivhaus certification

Passivhaus certification is considered a robust means to meet the space heating demand and Energy Use Intensity KPIs. It also drives quality assurance during construction. This involves the early appointment of a Passivhaus 'designer' to steer the design from concept stage and carry out PHPP (Passivhaus Planning Package) modelling. A Passivhaus 'certifier' will be required to act as an impartial quality assurance check on predicted performance during design and to carry out site inspections.

Is energy modelling required?

Using accurate energy modelling is always the recommended route, however it is possible to target best practice by setting the right specification and design requirements as part of the project brief though. Please refer to the 'How it all comes together' pages.

	KPIs New housing
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CIBSE TM59
Compliance with guidance on overheating risk

AECB
Good practice water standard

In-use performance
Collect data for the first 5 years

What to do when? Timeline for design and construction

PRE-PLANNING		PRE-CONSTRUCTION	CONSTRUCTION	HANDOVER AND USE

Setting the brief and getting the right team

- Include Key Performance Indicators (KPIs) requirements in the brief
- Appoint the relevant consultants
- Require the assessment of embodied carbon particularly for medium to large scale developments.

Design considerations

- Optimise building form, orientation and window proportions
- Define building fabric performance e.g. U-values
- Allow sufficient thickness for all insulated walls, roofs and floor
- Incorporate Mechanical Ventilation with Heat Recovery (MVHR)
- Define airtightness strategy
- Consider low carbon heating options e.g. heat pumps
- Design roof to maximise renewables i.e. solar panels
- Carry out embodied carbon assessment

Detailing, specification and choosing the right products

- Include KPI requirements in the tender
- Detail build ups of all external elements including thickness and conductivity of all materials and contact suppliers for confirmation of U-values
- Identify all thermal bridges and conduct thermal bridge calculations
- Define airtightness testing requirement for contractor
- Specify high performing solar panels
- Agree scope of post-occupancy evaluation.

On-site quality inspections

- Run an ultra low energy workshop on site. Encourage contractor and team training to all attend.
- Review alternative materials or products proposed by the contractor and ensure these meet performance requirements to achieve KPIs
- Attend regular site visits and develop site quality tracker to assess against KPIs
- Witness commissioning of ventilation and heating systems.

Handover and use

- Provide building user guides and instructions e.g. sticker on MVHR for filter replacement routine
- Carry out lessons learnt review
- Carry out post occupancy evaluation (POE) during the first five years of use to verify KPIs have been met
- Ideally, publicise performance against all KPIs and POE reports e.g. on a company website

Best Practice Route

- Appoint Passivhaus consultant
- Energy (PHPP) modelling carried out by Passivhaus consultant to accurately predict energy use
- Detailed U-value calculations and thermal bridge analysis
- Regular inspections on-site by Passivhaus certifier
- Clear responsibility for airtightness and several air testing to meet requirements
- Passivhaus certification
- Final as-built energy (PHPP) model provided at hand-over

Refer to design checklist in Appendix for a more comprehensive list of actions.

Getting the design right from the start is key

Making informed decisions at an early design stage is key to delivering energy efficiency in practice. A building's form, orientation and window proportions are all aspects that do not add extra construction cost, but if optimised within the design can significantly improve the building's efficiency. For more details refer to the Passivhaus Design Easi Guide.

What should the building form look like?

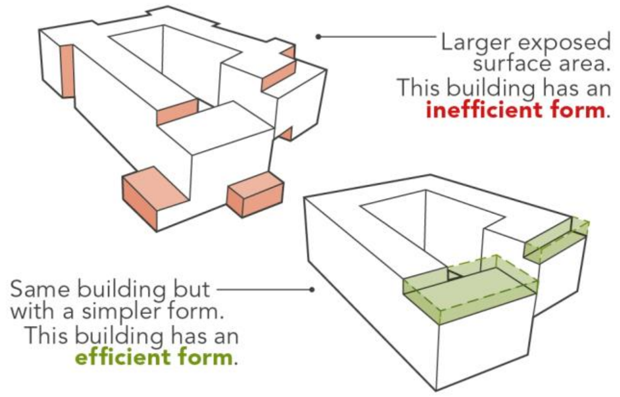
The building form should be as simple and compact as possible. This will reduce the exposed surface area for heat loss. Avoid or limit the use of stepped roofs, roof terraces, overhangs and inset balconies as these features will decrease the building's energy efficiency.

Which direction should the building face?

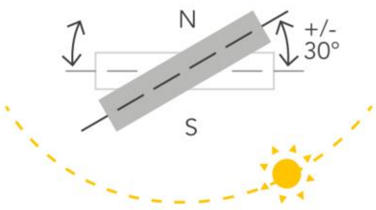
The orientation and massing of the building should be optimised if possible to allow useful solar gains and prevent significant overshadowing in winter. Encourage south facing dwellings with solar shading and prioritise dual aspect. Overshadowing of buildings should be avoided as it reduces the heat gain from the sun in winter.

How big should the windows be?

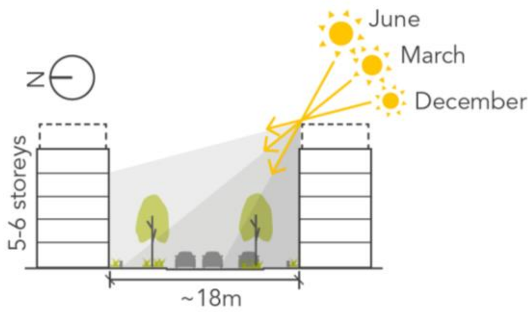
Getting the right glazing-to-wall ratio on each façade is a key feature of energy efficient design. Minimise heat loss to the north (smaller windows) while providing sufficient solar heat gain from the south (larger windows). It is much easier to design smaller windows facing access decks and larger windows facing balconies. Therefore, try to orientate access decks to the north and balconies to the south.



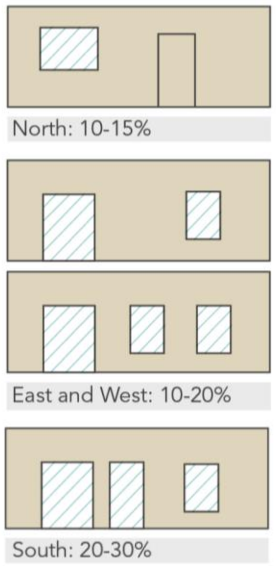
Designing the building to have an efficient form



Elevations facing +/- 30° south will benefit from useful solar gains in the winter



Allow a distance of 1-1.5 times the building's height between buildings



Recommended glazing percentages of each external facade

Construction methods and quality

Choosing a construction method

There are many different construction methods that could be utilised for building low energy residential dwellings: brick and block, timber frame, steel frame, structurally insulated panels, insulated concrete formwork, to name a few.

A low energy target need not dictate the construction method, but some methods of construction lend themselves better to the aims of ultra low energy buildings than others.

For example, closed panel timber framing may deliver a better quality and more thermally efficient structure than an open panel timber frame. Similarly, a solid, insulated masonry wall may be easier to control for airtightness than a cavity wall.

Achieving quality construction

The quality of workmanship on-site has a big impact on energy performance. Pitfalls to avoid include badly installed insulation which will reduce its effectiveness (e.g. compressed insulation, uninsulated gaps, or wall ties not being installed correctly), and site operatives cutting through air-tightness layers.

Ways to mitigate these risk include:

- Frequent checks on-site of insulation and airtightness measures by someone who knows what to look for, so problems can be addressed along the way rather then be covered up.
- Utilising off-site construction methods, where there is factory quality controlled manufacture can help.
- Using schemes such as Passivhaus or BEPIT (Building Energy Performance Improvement Toolkit) can provide assurances of better construction quality.

Left: an example of good Expanded Polystyrene insulation installation. Right: An example of poorly installed partial cavity installation, loosely fitting, and cement dropped atop and inside cavity.

A closed-panel timber frame, manufactured off-site with insulation, window and door frame included (© Vision Development).

Airtightness for new build

The importance of airtightness

Airtightness significantly improves energy efficiency and comfort, often for a relatively modest cost. New buildings must achieve an airtightness of at least 10m^3/h/m^2 as a minimum for building regulations, however new homes typically achieve levels of 3-5m^3/h/m^2. Best practice levels are considered to be <1m^3/h/m^2.

Start with a plan

Building airtight starts with a well thought through airtightness and ventilation strategy. Draw the airtightness line on plans and details, identifying which materials will form the airtight layer, and how they will be joined together. Identify challenging junctions, risks to airtightness, and consider how building services will interact with the airtight layer.

Use the right products

Experienced manufacturers of airtightness products such as Isocell, Isover, Pro-clima and Siga have developed their products to achieve airtightness that lasts for many decades. Specify good quality products and ensure that inferior substitutes are not used on site.

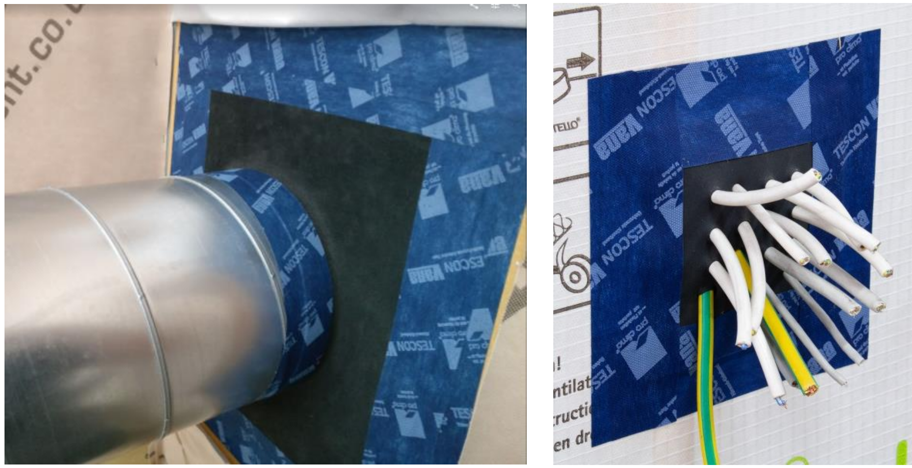
Stick to the plan on site

Once construction starts ensure the airtightness strategy is implemented precisely. Tradespeople should be briefed and the work regularly checked to ensure the airtight layer is being built correctly.

Test, then test again

Plan for at least two air tests. The first test should be completed as soon as the building is weathertight and while joints between different components in the airtight layer are still accessible so leaks can be repaired if necessary. The second test on completion.

A good airtightness strategy forms the basis of an airtight building. This is an excellent example of taped OSB, with a dedicated service cavity on internal walls. The service cavity means most wires and pipes will not breach the airtight OSB layer.



Services entries present a risk to airtightness, however proprietary grommets are available to ensure airtightness can be achieved. The image on the left is of a ventilation duct as a reminder that airtight buildings must have a robust ventilation strategy.

Ventilation for new build

Controlled air flow through good airtightness

The key to managing ventilation in new dwellings is being in control of where, when and how air flows through a building. This starts with very good airtightness, to limit any uncontrolled infiltration. Trickle vents should be avoided as they do not control infiltration.

Install a Mechanical Ventilation with Heat Recovery (MVHR) unit

To maintain good air quality, and to reduce heat losses within a home the use of an MVHR is critical. Not only does this unit supply air into living spaces, and extract air from kitchen and bathroom spaces, it does this using very little energy.

It is important that the unit is positioned as close as possible to an external wall to prevent heat loss from the ductwork that connects to the outside. These ducts should be accurately fitted with adequate insulation to prevent heat loss, and generally ductwork should avoid having sharp bends which could affect pressure loss and flow.

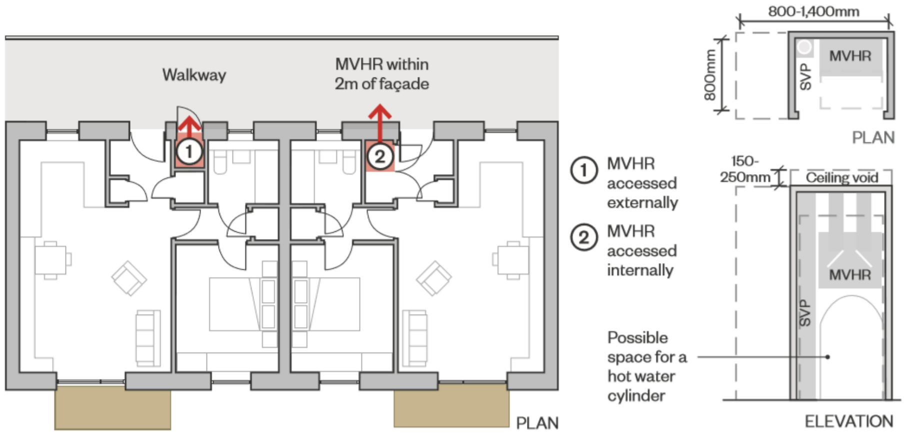
MVHR units include filters that must be changed regularly (usually at least once per year but check the manufacturer's instructions).

You can still open windows

There is a myth that 'sealing up' a building means you can no longer open the windows. This is not true. The benefit of an MVHR is that you do not have to open windows in winter for fresh air, letting the heat escape. Residents can open windows and use the homes normally.

Trust the controls

A common issue is a lack of understanding or trust that the unit is working correctly, and then it underperforms due to inappropriate user adjustments, or a user turning off the MVHR completely.



MVHR systems are an effective way of providing ventilation to airtight homes.

The unit should be located within 2m of the façade

Key requirements for a good MVHR system

Distance from external wall	<2m
Specific fan power	<0.85 W/l/s
Heat recovery	>90%
Thickness of duct insulation mm	>25mm
Certification	Passivhaus Certified
Maintenance	Easy access for filter replacement.

In order to have an efficient running MVHR, it is recommended to choose an MVHR that meets the above performance criteria

Avoiding overheating

Design out overheating from the start

Overheating is a known risk and can be reduced through good design:

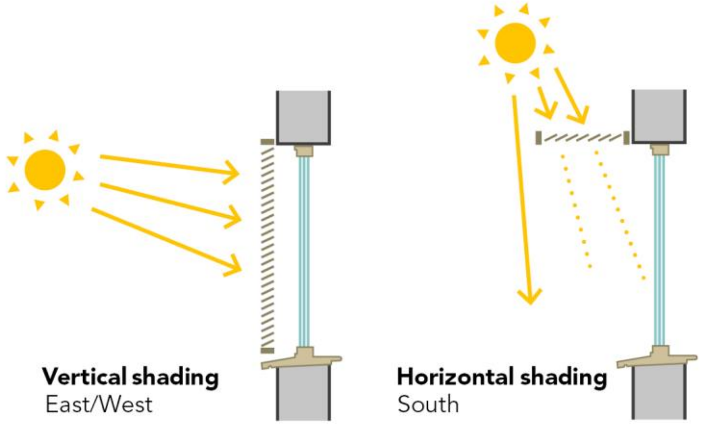
- Ensure glazing areas are not excessive i.e. not more than 20-25% of facade on south or west façades.
- Avoid fixed panes and maximise opening areas of windows. Side hung windows typically allow more ventilation than top hung.
- Favour dual aspect homes to allow cross ventilation.
- Provide appropriate solar shading. South façades should have horizontal shading over the window and the west façade should ideally have movable vertical shading e.g. shutters.
- Avoid relying on internal blinds, which can be removed by residents.
- Select a g-value (the solar factor indicating how much heat is transmitted from the sun) for glass of around 0.5 where possible.
- Use Good Homes Alliance overheating checklist for risk assessment.

Consider potential conflicts

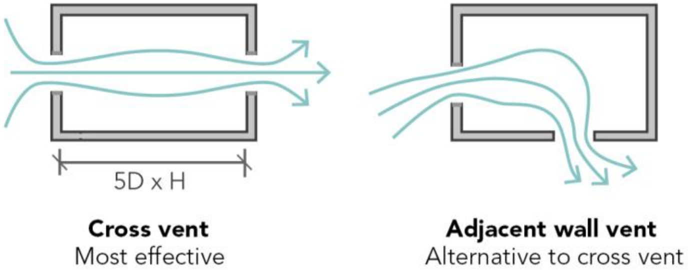
Daylight and acoustics design can conflict with overheating assessments. Use the Acoustics and Noise Consultants (ANC) Acoustics, Ventilation and Overheating Guide to determine an approach to acoustic assessment and seek to maximise daylight without significantly adding to the overheating risk.

Carry out overheating modelling

Dynamic modelling should be undertaken to identify more clearly the risk of overheating and how to mitigate it. Prior to any planning submission, checking compliance with CIBSE guidance TM59 is recommended. A statement should be produced as part of the assessment to demonstrate the strategies can be implemented.



Provide horizontal shading on the south facade (e.g. brise-soleil or deep reveals) and vertical shading on the east or west façade (e.g. shutters). Design solar shading to allow useful solar gains in winter and block solar gains in summer.



Design for dual aspect homes to allow for natural cross ventilation

Myth buster – a common myth is that ultra low energy design with airtight construction leads to overheating. It is true that any building which does not design in measures to address overheating effectively will be at risk of overheating (i.e. inadequate shading or insufficient openable windows etc.) but this is not a result of ultra low energy design.

The electricity grid has decarbonised and will continue to decarbonise, thus the most likely low carbon heat source for now and the future is electricity. This is done most efficiently, and has lower running costs, when using heat pumps.

What types of heat pumps are available?

There are lots of different types of heat pumps, broadly in two categories, individual heat pumps and communal heat pumps. Individual heat pumps are shown in the adjacent diagram. For more information on communal systems continue to the next page.

Designing heat pumps

Make sure that the heat pump is sized correctly to meet the heating and hot water load. Choose a heat pump with a refrigerant that has a low Global Warming Potential (GWP) - Propane is currently market best practice. Minimise pipe lengths to reduce the heat losses from distribution. Choose a heat pump with a high efficiency (often referred to as the Coefficient of Performance or COP).

Radiators might be larger

Heat pumps run best at lower temperatures (around 35-45°C degrees) this means that radiators may need to be slightly larger to emit the same amount of heat as a traditional radiator.

Commissioning and handover

Make sure it provides the right quantity of water and the right temperatures. Make sure the user understands how the heat pump works and why it is set to operate in a certain way.

	Heating	Hot Water
 Monoblock or split heat pump	✓	✓
 Ground source heat pump	✓	✓
 Heat pump integrated domestic hot water store	✗ Heating is provided by direct electric panel radiators	✓
 Exhaust air heat pump	✓ Provides some level of heating by heating air that is circulated through the home*	✓

This diagram above shows four types of individual heat pumps that can be installed in homes

** For ultra low energy homes this can provide the majority of the heating, but direct electric panel radiators may be needed for peak winter conditions or additional comfort*

What is a communal heating scheme?

Rather than each home having their own heat pump or boiler, in a communal heating scheme heat is generated in a central plant room, and distributed. Each home has a heat interface unit which heats up the water that the home needs. Traditionally fed by gas boilers, these systems now need to rely on heat pumps.

Heat is lost in distribution

Even with well insulated pipes, heat is lost when you transport hot water through pipes. For ultra low energy schemes that do not need much heat, more than 50% of the heat that is generated by the communal heating system can be lost through the distribution pipe work, this makes traditional communal heating very inefficient.

Communal heat pumps are not very efficient

The supply temperature for communal heating systems is generally between 60-80°C. However, heat pumps operate best at lower temperatures. This and the fact that so much heat is lost through distribution means that communal heat pumps are generally not recommended.

Ambient loops with heat pumps in every home

An ambient loop system is a totally different type of system, and is a hybrid between communal heating and individual heat pumps. A small 'shoebox' style water source heat pump per home, is connected to an ambient loop that usually fluctuates between 10-25 °C. The communal heat pumps upgrade the heat in the ambient loop to the temperature required for the home. The ambient loop is either a 'passive' loop coupled with the ground (a bit like a ground source heat pump) or an 'active' ambient loop connected to communal air source heat pumps.

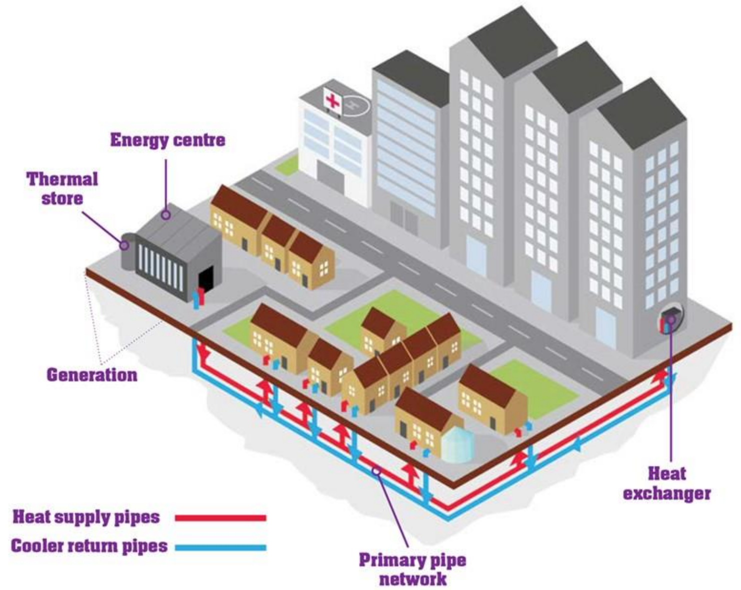


Diagram showing a traditional communal heating scheme connected to many homes from and energy centre containing the central plant (Source: E&T)

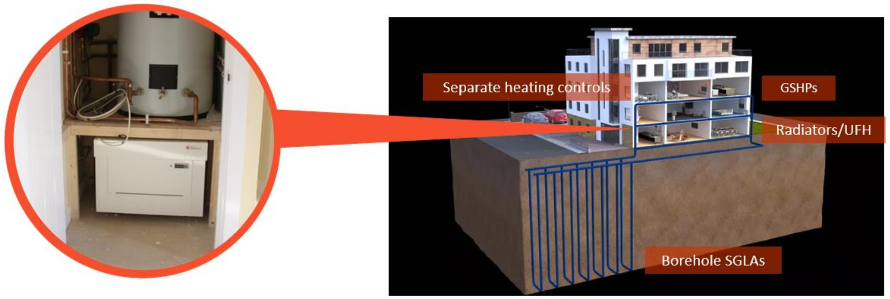


Diagram showing a passive ambient loop, with a small 'shoebox' style water source heat pump in each home connected to a ground array (© Kensa)

Which heat pump is best for me?

There are various types of heat pump options available for new homes. This page outlines which heat pumps are available and which to choose.

1 Which heat pumps are the best for new homes?

- Monoblock or split (air source) heat pump, generating heating and hot water
- A ground source heating pump system, generating heating and hot water
- Individual heat pump connected to an ambient loop

Why these heat pumps might not be suitable

- **Available space:** These heat pumps require space for indoor or outdoor units
- **Ground conditions:** Some ground conditions are not suitable for ground source heat pumps
- **Size of development**: an ambient loop is only really suitable when there are more than 30 homes

If these systems do not work

2 Which are next best for new homes with a low space heating demand?

- A heat pump integrated into a hot water tank. Heating is delivered through direct electric panel radiators
- An exhaust air heat pump (with direct electric panel radiators likely to be needed for winter peak conditions and/or additional comfort)

- An exhaust air heat pump provides comfort heating via an MVHR. This will only meet the heat demand in smaller dwellings (<60m^2) with a space heating <15kWh/m^2.year, Even then, it may need another form of top-up heating.

If these systems do not work

3 Communal heating systems fed by heat pumps (operating at around 60°C or less)

New homes with a high performing fabric need so little heat, that is it not recommended to use communal heating or district heating systems, as so much heat is lost through the distribution

If this system is not available

4 Consider direct electric heating and hot water

If there is not sufficient space to install a heat pump, then consider direct electric heating and hot water but make sure the energy efficiency KPIs are being delivered to avoid high running costs.

Water efficiency and domestic hot water

Reduce overall water consumption

Water efficiency is about reducing our use of mains water and the effect our buildings have on water resources. Water use should not exceed 110 litres per person, per day, ideally less.

Reduce hot water to reduce energy use

In very low energy buildings, the energy required for hot water can exceed the amount of energy required for space heating. Therefore optimisation of hot water systems is essential to ensure energy use remains low.

What can you do?

Reduce flow rates

- The AECB water standards (opposite) provide clear guidance on sensible flow rates for showers and taps in low energy buildings.

Reduce distribution losses

- All pipework must be insulated and designed to ensure there are no 'dead legs' containing more than 1 litre. Tapping points (e.g. taps, shower connections) should be clustered near the hot water source. Small bore pipework should be carefully sized based on peak demands, minimising the diameter where possible.

Insulate to minimise losses from hot water tanks

- The standby losses of hot water tanks are highly variable, and can have a significant impact on overall energy use. Target a hot water tank heat loss of less than 1 kWh/day equivalent to 0.75 W/K.

Install waste water heat recovery systems in shower drains

- A simple technology that recovers heat from hot water as it is drained. Vertical systems can recover up to 60% of heat more than common horizontal ones recovering 25-40%.

Consider water recycling

- This is the process of treating waste water and reusing it, it can be used for large portions of potable water use.

Appliance / Fitting	AECB Good Practice Fittings Standard
Showers	6 to 8 l/min measured at installation. Mixer to have separate control of flow and temperature although this can be achieved with a single lever with 2 degrees of freedom (lift to increase flow, rotate to alter temperature). All mixers to have clear indication of hot and cold, and with hot tap or lever position to the left where relevant.
Basin taps	4 to 6 l/min measured at installation (per pillar tap or per mixer outlet). All mixers to have clear indication of hot and cold with hot tap or lever position to the left.
Kitchen sink taps	6 to 8 l/min measured at installation. All mixers to have clear indication of hot and cold with hot tap or lever position to the left.
WCs	≤ 6 l full flush when flushed with the water supply connected. All domestic installations to be dual flush. All valve-flush (as opposed to siphon mechanism). WCs to be fitted with an easily accessible, quarter turn isolating valve with a hand-operated lever. Where a valve-flush WC is installed, the Home User Guide must include information on testing for leaks and subsequent repair.
Baths	≤ 180 litres measured to the centre line of overflow without allowing for the displacement of a person. Note that some product catalogues subtract the volume of an average bather. A shower must also be available. If this is over the bath then it must be suitable for stand-up showering with a suitable screen or curtain.

Refer to the full AECB document for more information.

Solar PV panels for houses

Solar PV panels are a simple, mature and reliable renewable energy technology. The majority of new homes have sufficient space on site to generate as much energy as they need on an annual basis. They are a particularly good match for heat pumps, where much of the solar electricity can be used to provide heating and hot water.

Can you save much with Solar PV?

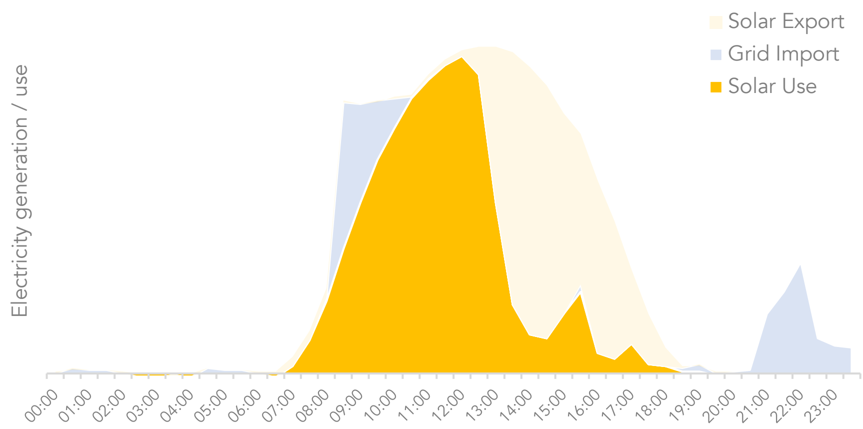
The lifetime cost of solar electricity in the UK is typically around half the price of grid electricity. Solar PV panels will therefore save money and carbon emissions by avoiding the need for your home to import electricity from the grid, and by exporting surplus energy back to the grid. Export tariffs typically pay around 5.4p per unit of electricity sold. Expect to use anywhere from 15%-50%+ of solar energy directly, depending on how well a home's consumption is matched to the sun.

Where to install solar PV panels

Solar PV panels are typically installed on roofs as these often provide unshaded locations facing the sun for much of the day. They can be installed on flat roofs, pitched roofs, and even on walls or pergolas. A solar installer can advise you as to the most suitable locations.

Choosing a good installer

Prices and installation quality vary between installers, so choose carefully. Small residential systems should typically cost around £1,500 per kW. The government regularly publishes *Solar PV cost data* if you want to check the latest prices. Look for a genuine and experienced Microgeneration Certification Scheme (MCS) certified installer that has a track record. Treat offers of 'free solar' with caution, these are typically financed systems, where you enter a long-term contract to pay a monthly fee. This can complicate selling or mortgaging your home.



This graph shows how solar works in practice on a sunny day. In the morning, solar energy is used to heat the home or a hot water tank, or charge an electric car. By early afternoon the hot water tank and electric car are both fully charged, so most solar energy is then exported. In the early morning and the evening, electricity is imported from the grid.

To maximise solar self-consumption, prioritise smart thermostats, solar hot water diverters, and solar electric vehicle charging. Residential batteries are expensive and can significantly increase the embodied carbon of solar energy, so avoid them unless absolutely necessary.

Solar PV panels for blocks of flats

In the UK it is generally possible for blocks of flats up to six stories in height to achieve a net zero energy balance on site through the use of rooftop solar PV arrays, heat pumps and efficient building fabric.

The value of solar PV panels

A key challenge for solar panels on multi-residential buildings is figuring out how to maximise the financial benefit to occupants. Exported solar energy is only worth about 5.4p per unit, whereas electricity typically costs about 16p per unit to buy. Savings are therefore greatest if solar electricity can be used directly, avoiding the need to buy grid electricity.

Connection options

The simplest option is to connect the solar PV panels to the landlord's supply, collect export tariff payments and issue a solar dividend to tenants, but this offers the lowest financial benefit.

A traditional approach to increase savings is to 'split' the array into many smaller arrays, and connect each one directly to each flat so the electricity can be used directly, however this can increase complexity and costs. A more elegant solution is the 'solar tenant model', pioneered in Germany. In this case, the building has a single electricity meter with the energy supplier and the landlord manages sub-meters to each flat. Bills are issued to tenants based on their share of the net consumption of the building from the electricity grid, maximising solar self-consumption.

Choosing a good installer

Large residential systems should cost under £900 per kW. Check government [Solar PV cost data] to make sure you get a good deal.

East/West facing concertina type solar arrays are usually the best solution for the flat roofs of blocks of flats. They generate less energy per panel than rows of south facing panels, but achieve much higher panel densities as they do not require large gaps between the rows to avoid interrow shading.

South facing solar facades produce around 15% less energy than an East/West concertina array, but generate more electricity than an East/West array in winter months. For buildings with heat pumps, this can be a great match.

Smart controls and demand flexibility

Intuitive and flexible energy use

Demand response or energy flexibility refers to the ability of a system to reduce or increase energy consumption for a period of time in response to an external driver (e.g. energy price change, grid signal). Energy storage allows these systems to consume, retain and release energy as required in response to specific energy demands. Smart controls respond to these external drivers and demands to manage our systems.

Maximise renewables and stabilise the grid

These measures can help maximise the utilisation of on-site renewables and help stabilise demand on the grid. Moreover it will help to decarbonise the grid: when renewable electricity generation is low, demand response measures reduce the load on the grid, reducing the amount of peak gas plant that must be switched on to meet the grid demand.

Smart controls and demand response measures in the home

What can you do?

Peak reduction

- Use passive measures and efficient systems to reduce heating, cooling and hot water peaks

Active demand response measures

- These measures reduce the electricity consumption for a certain period.
- Install heating and cooling set point control with increased comfort bands, controlled with smart thermostats or home energy management systems.
- Integrate thermal storage of heat into communal or individuals system within a building.
- Reduce lighting ventilation and small power energy consumption

Electricity generation and storage

- Use products that can generate electricity and feed into the grid, or power the building.
- Consider solar to water heat storage

Electric Vehicle (EV) charging

- It is generally accepted that there will be a large increase in electric vehicles, so it is essential to implement demand response to ensure grid stability.
- Charge EVs only when needed and allow the supplier to cut the charging short during peak times
- Install 'Vehicle to Grid' / 'Vehicle to Home' technology which allows the EV battery to be used to supply the home during grid peak periods.

Behaviour change

- Raise awareness of how people use electricity and the impacts.
- Consider incentives to reduce peak demand.
- Encourage responsible occupancy.

Microgrids

- Consider being part of a small semi-isolated energy network, separate from the national grid.

Embodied carbon

Embodied carbon includes the carbon emissions associated with the extraction and processing of materials, energy use in the factories and transport as well as the construction of the building and repair, replacement and maintenance. It also includes the demolition and disassembly of the building at the end of its life. Low embodied carbon design is not inherently more expensive or more complex, it just requires awareness and good design.

What can you do?

1 Refurbishment over new build
Only build new when existing homes cannot be reused or refurbished.

2 Lean design
Structural: Design structure for 100% utilisation. Use bespoke loading assumptions, avoid rules of thumb. Reduce spans and overhangs.
Architectural: Use self-finishing internal surfaces. Reduce the quantity of metal studs and frames.
Building services: Target passive measures (e.g. improved fabric) to reduce the amount of services. Reduce long duct runs, specify low Global Warming Potential (GWP) refrigerant (max. 150) and ensure low leakage rate.

3 Material and product choice
Prioritise materials that are reused, reclaimed or natural from local areas and sustainable sources and that are durable. If not available use materials with a high recycled content. Use the following material hierarchy to inform material choice particularly for the building structure;

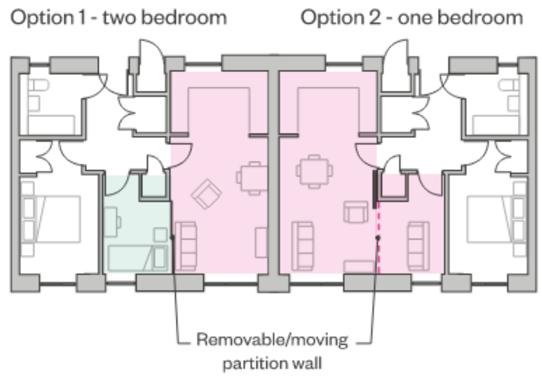
1. Natural materials e.g. timber
2. Concrete and masonry
3. Light gauge/Cold rolled steel
4. Hot rolled steel

Ask manufacturers for Environmental Product Declarations (EPD) and compare the impacts between products in accordance with BS EN 15804

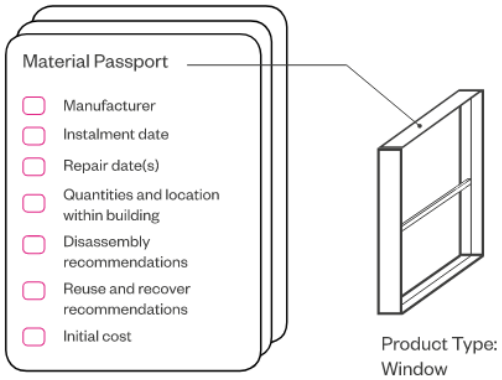
4 Housing adaptation & flexibility
Allow for flexibility and consider how a layout may be adapted in the future.

5 Easy access for maintenance
Maintained equipment will last longer.

6 Design for disassembly
Consider disassembly to allow for reuse at the end of life of the building. Create material passports for elements of the building to improve the ability of disassembled elements to be reused.



Design for adaptation using a flexible floor plan e.g. one bed flat can be converted to a two bed fat or a one bed fat with space for home working. Working to a regular grid with removable partitions will allow adaptation as well as creating soft spots in the structure



Create material passports for products: This will improve the ability of disassembled elements to be reused. A material passport provides identification of materials, components and technical characteristics with guidance for deconstruction and applicability of re-use. In this way the building becomes a material bank for future use.

How it comes together - new terrace house

Design checklist

Form efficiency

Ensure the building form is as simple and compact as possible

Window proportion

Follow recommended ratio of window to external wall

Mechanical ventilation

MVHR 90% efficiency

≤2m duct length from unit to external all

Airtightness

Airtight building fabric

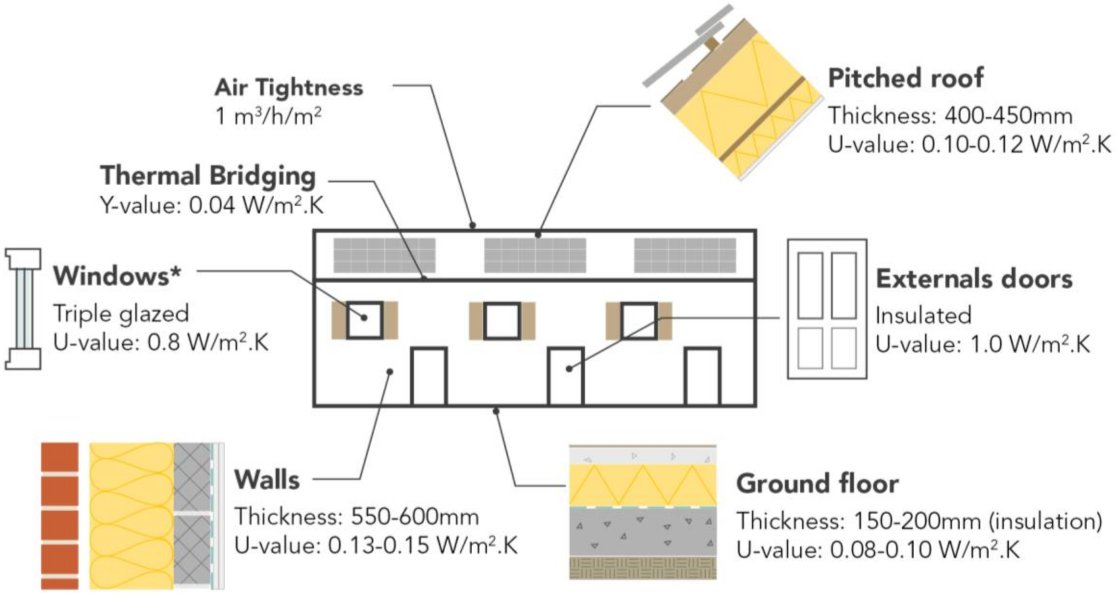
< 1 m³/h/m² at 50 Pa

Heating system

Choose a low carbon heating system e.g. heat pump

Design out overheating

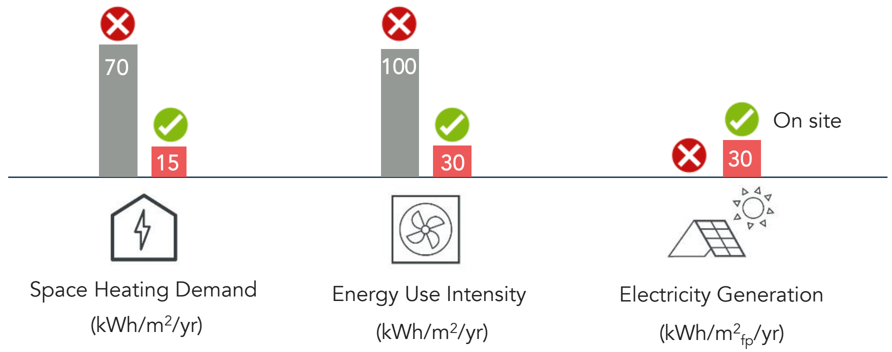
Carry out overheating analysis (as per CIBSE TM59 guidance) and reduce overheating through design e.g. external shading, openable windows and cross ventilation



Performance

As electricity generated on site with PVs is the same as the Energy Use Intensity (EUI) on an annual basis, the building is Net Zero carbon in operation.

- Typical terrace house built to comply with building regulations
- New zero carbon terrace house



How it comes together – small block of flats (6-8 units)

Design checklist

- **Form efficiency**

  Ensure the building form is as simple and compact as possible

- **Window proportion**

  Follow recommended ratio of window to external wall

- **Mechanical ventilation**

  MVHR 90% efficiency

  ≤2m duct length from unit to external all

- **Airtightness**

  Airtight building fabric

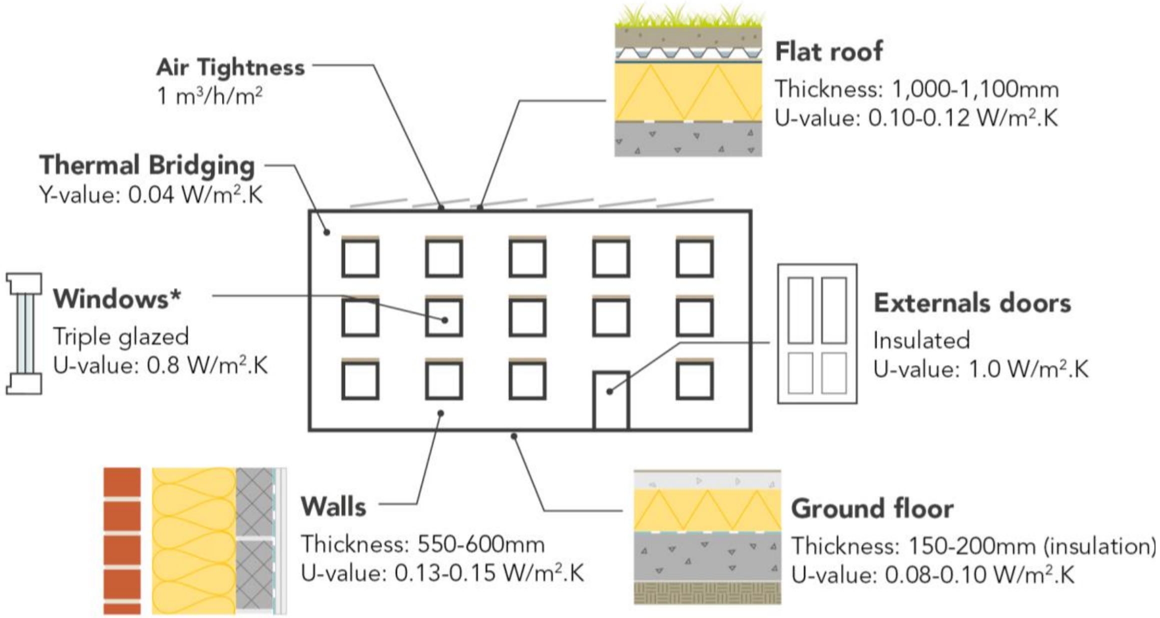
  < 1 m³/h/m² at 50 Pa

- **Heating system**

  Choose a low carbon heating system e.g. heat pump

- **Design out overheating**

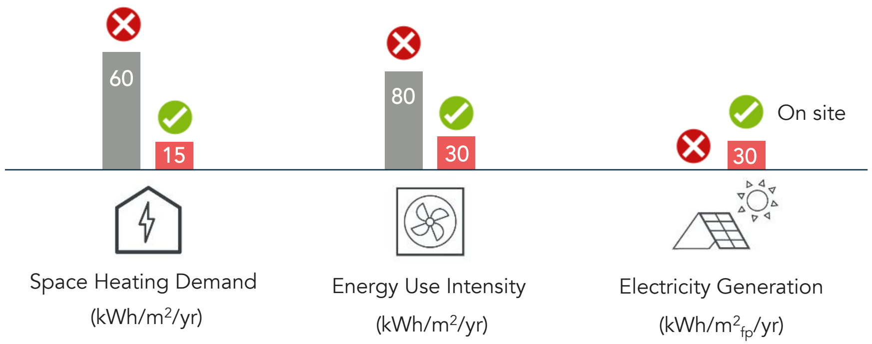
  Carry out overheating analysis (CIBSE TM59) and reduce overheating through design e.g. external shading, openable windows and cross ventilation



Performance

As electricity generated on site with PVs is the same as the Energy Use Intensity (EUI) on an annual basis, the building is Net Zero carbon in operation.

- Typical terrace house built to building regulations
- New zero carbon terrace house



Cost premium for a Net Zero new home

A 2-6% cost premium for Net Zero carbon in operation…

The cost premium for delivering a new Net Zero carbon home is estimated to represent approximately 2 to 6% compared with a Part L 2021 equivalent.

The majority of additional costs is associated with the energy efficient fabric and ventilation and in particular with triple-glazed windows, airtightness and MVHR, as well as additional PV generation. There is no significant additional cost for the heating system as Part L 2021 is already seeking to accelerate the transition to heat pumps.

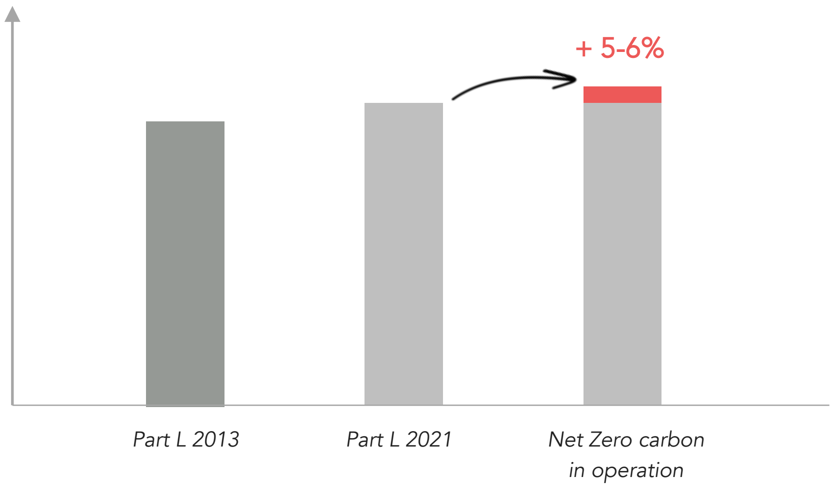
… and the potential to drive down costs

A significant advantage in committing to Net Zero new homes is that it is a sustainable standard for the future. This offers significant opportunities for clients, contractors and project teams to reduce their additional costs over time by improving processes (e.g. airtightness) or contributing to driving down the cost of key technologies. There has been a significant reduction in the cost of solar PVs in the last ten years and other reductions, albeit smaller, are expected for heat pumps and MVHR.

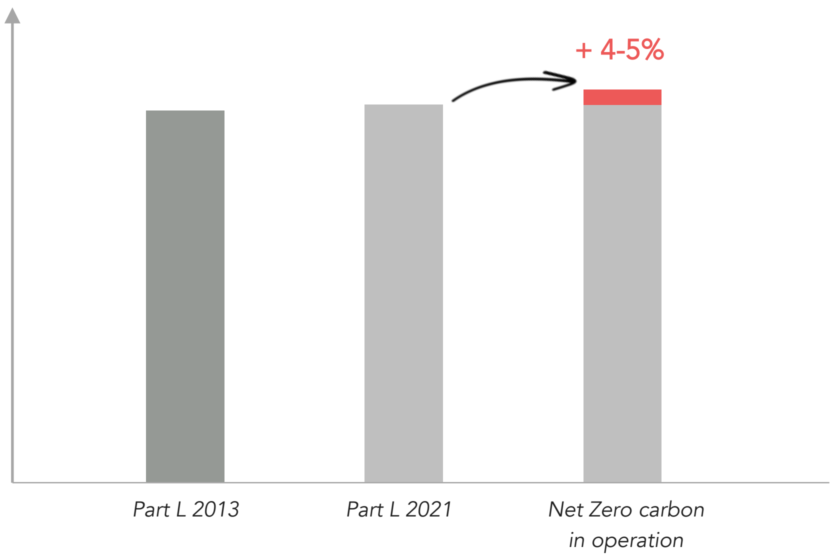
Significant cost savings for the residents

Using the same typologies as examples, a Net Zero carbon home is expected to lead to residents' energy bills which will be approximately 35-40% lower than compared to a Part L 2021 house.

For blocks of flats, an even greater level of reduction in energy costs appears to be possible, approximately 50%.



Estimated cost premium for a typical ***new terrace house***



Estimated cost premium for a typical ***new block of flats***

Don't do this! (new build)

The intention of this toolkit is to provide clear guidance on what you should do when designing and building a Net Zero carbon building. This page summarises some of the "Don'ts"…

Don't be misled by technologies and environmental schemes

When looking to build sustainable and low energy buildings, there are plenty of distractions. Many products, systems and technologies are suggested to be silver bullets in helping achieve Net Zero carbon buildings. Unfortunately, when put under scrutiny, many products or strategies do not achieve the desired outcome.

Additionally environmental assessment schemes for new homes are generally not sufficient to help the building achieve Net Zero carbon: a specific ambition is required.

Avoiding business as usual

There is an emerging consensus in the construction industry on how to achieve Net Zero operational carbon. For example, there are several key energy efficiency, heating and ventilation principles which need to be adopted which have been discussed in earlier sections. Taking a business as usual approach to construction is not sufficient because many traditional ways of heating and ventilating homes are not aligned with a Net Zero objective.

X *Do not install gas boilers.*

X *Do not install open fireplaces*

X *Do not install extract only ventilation systems*

X *Do not install domestic wind turbines.*

X *Do not rely on trickle vents to provide ventilation. MVHR should be adopted.*

X *Do not install double glazed windows: prefer triple glazed windows.*

Beyond energy

Considering the wider sustainability picture

Beyond energy, there are many design decisions that affect a home's impact on the environment and carbon emissions. Below are some things to consider and signposts to additional information.

The Home Quality Mark (HQM) is a certification scheme designed by the Building Research Establishment (BRE). There is a strong focus on sustainability, and the guides are available to download for free. They can be used to guide design decisions whether or not a developer decides to proceed with certification.

Choosing a site

There are many questions to consider when choosing a site:

- Is there an existing building that could be refurbished instead of demolished?
- What are the transport links like? Will occupants be dependant on using a car? (CO_2 emissions from local car use can represent a large proportion of a household carbon footprint).
- What biodiversity does the site support and how can the new development contribute to achieving biodiversity net gains over and above policy and legislative requirements and to creating new green infrastructure?

Facilitating sustainable transport

- Consider supplying properties with electric vehicle charging points – either shared or individual.
- Convenient and secure cycle storage is effective in encouraging journeys by bike – how can they be integrated into the design?
- Does the home support effective homeworking? Are there sufficient plug sockets and internet connectivity sockets? Should a home office be considered?

Resources

One Planet Living

Home Quality Mark

Transport

Cycle Stores

Ecology and biodiversity

Wildlife Trust: Homes for people and wildlife

Biodiversity Enhancement in New Housing Developments

Building with Nature

Supporting ecology and biodiversity

We are in an ecological emergency as well as a climate emergency, both of which are inextricably linked. Supporting and enhancing biodiversity and green infrastructure will benefit occupants, the wider community and economy with improvements to health, better water management, reductions in pollution etc as well as being of value to species and habitats.

Using water efficiently

It is little known that demand for water is projected to outstrip supply in future years. Therefore installing water efficient fittings is very important in new homes. It can also save energy and costs related to heating water. The AECB water standards provide guidance on water efficiency for all fittings.

Reducing flood risk through Sustainable Urban Drainage (SuDS)

Changes to our climate are predicted to result in increased rainfall and greater risk of flooding. Integrating SuDS into a development can greatly improve the site's ability to capture, absorb and effectively retain water as part of a comprehensive green infrastructure design. This will reduce surface water run-off and support local drainage networks to function effectively, reducing the risk of flooding.

Creating a healthy environment

Our homes are places that should support our health and wellbeing. Consideration to the materials chosen can have a beneficial effect on people's health. For example volatile organic compound (VOCs) content) can cause short term irritation for some people, and long term health problems. Ventilation and good indoor air quality are also discussed in this toolkit.

Resources

Water

- Developing Water Efficient Homes
- Advice on Water Efficient Homes for England
- AECB Water Standards

Sustainable Urban Drainage

- CIRIA Guidance

Healthy environment

- Good Homes Alliance: Healthy Homes

Case studies for new build

Ultra low energy design is fast becoming the new normal

The energy efficiency of new homes is increasing year on year. Many self builders and developers are choosing to go beyond building regulations for energy efficiency because it makes sense. Not only can low energy building be cheaper to run, they can be easier and cheaper to maintain and crucially, will not need further expensive retrofit in the future.

Beautiful and efficient homes

Lark Rise in the Chiltern Hills is certified to Passivhaus Plus standards. It is entirely electric, and generates 2.5 times as much energy as it consumes in a year. Careful optimised design has meant that it has a mostly glazed facade, minimal heat demand and stable temperatures over summer months.

Passivhaus/Ultra-low energy can be delivered at scale

Developers are building Passivhaus at scale. Example developments include Hastoe's development of 14 units – a mixture of houses and flats at Wimbish, Essex. The development is certified to Passivhaus standards, and average heating costs for the houses are £130/year. The development is operating as designed, and has effectively eliminated the 'performance gap'. Other examples include Springfield Meadows in Oxfordshire, Goldsmith Street in Norwich, Agar Grove in Camden and many other developments across the Country. Like Wimbish, they have an energy consumption of approximately less than half of that of a typical home.

Lark Rise, Chiltern Hills.

Passivhaus Plus certified.

© Bere:architects

Springfield Meadows

© Greencore construction with Bioregional

Wimbish

Passivhaus certified.

© Hastoe Housing Association.

Other typologies beyond housing (e.g. schools, offices, etc.)

Other building types tend to vary more widely than housing, making it more difficult to reliably determine generic forms, energy use or occupancy models. However, the RIBA, LETI, the UKGBC and other organisations have published relevant guidance on performance targets for space heating demand, total energy use and renewable generation. They are summarised below.

Schools

- Space heating demand of 15-20 kWh/m^2_{GIA}/year
- Total energy consumption of 65 kWh/m^2_{GIA}/year or less
- Solar electricity generation that exceeds metered energy use on site

Hotels

- Space heating and cooling demand of less than 30 kWh/m^2_{GIA}/year
- Total energy consumption of 55 kWh/m^2_{GIA}/year or less
- Solar electricity generation of at least 120 kWh/m^2_{GIA}/year

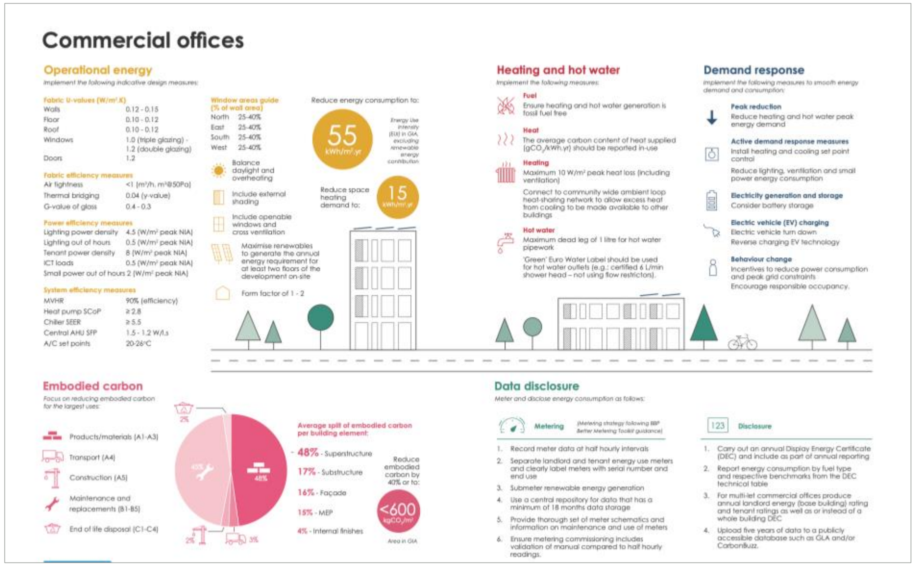
Offices

- Space heating and cooling demand of less than 15 kWh/m^2_{GIA}/year
- Total energy consumption of 55 kWh/m^2_{GIA}/year or less
- Solar electricity generation of at least 120 kWh/m^2_{GIA}/year

Light Industrial

- Space heating and cooling demand of 15-30 kWh/m^2_{GIA}/year
- Total energy consumption of around 55 kWh/m^2_{GIA}/year excluding specialist processes.
- Solar electricity generation of at least 180 kWh/m^2_{GIA}/year

Harris Academy Sutton: a large secondary school built to Passivhaus standards (© Architype)



The LETI Climate Emergency Design Guide provides guidance on non-domestic buildings

Retrofit

Putting our existing homes on track towards Net Zero is a challenge but it can be done. This section explains how. The list of subjects it covers can be found on the following page.

Retrofit | Contents

Why? Key reasons and benefits of a low carbon retrofit

Existing buildings are the real challenge

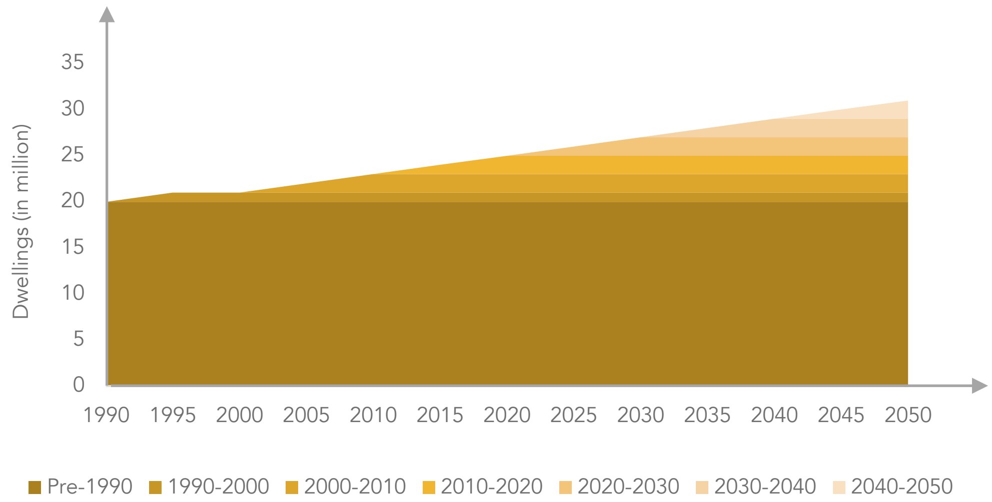
England currently has some 25 million homes. All of those will have to have some form of retrofit by 2050 while, in that time, we will have only built another six million homes. This means that 80% of the homes that will be present in 2050 have already been built. If we are to successfully decarbonise housing, retrofitting is where the real challenge lies: we need to increase their energy efficiency, change their gas or oil heating system for a low carbon heat system (e.g. heat pump) and generate more renewable energy on their roofs.

Reducing fuel bills alongside carbon emissions

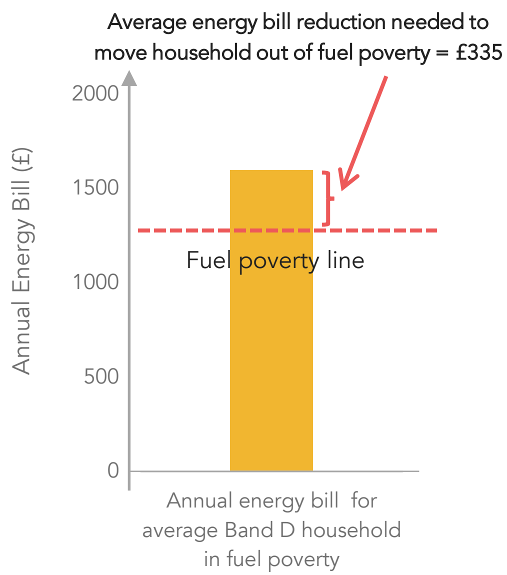
Whilst decarbonising homes is important to mitigate climate change, it is not the only reason to retrofit. In 2018, one in ten households in England were considered to be in fuel poverty. There is, unsurprisingly, a strong correlation between inefficient homes and fuel poverty with 88% of all fuel poor households living in properties with a Band D EPC or below. We can deliver lower bills as well as lower carbon emissions[1].

Health and wellbeing

Improving the energy efficiency of a home is also likely to increase thermal comfort (both in summer and in winter) and improve indoor air quality through better ventilation. This will have a positive impact on everybody, but especially small children, the elderly and those with respiratory conditions. The International Energy Agency (IEA) and the OECD suggest health improvements might account for 75% of the overall value of improving the energy efficiency of buildings [2].



England Housing Stock – 1990 to 2050 (Millions of dwellings)



Fuel poverty, health and wellbeing are all positive benefits of retrofit

[1] The average Band D annual energy bill is £1600 and the average reduction needed to bring these households out of fuel poverty is £335

[2] Separately, the BRE have estimated that poor quality housing costs the NHS £1.4 billion in avoidable treatments.

Energy targets and Key Performance Indicators (KPIs) for retrofit

Setting the right brief and targets is key

To achieve the most energy efficient outcome it is important that the brief and targets reflect this ambition from the start. A strong brief provides tangible guidance on how targets can be achieved. Best practice KPIs for retrofit housing are listed in the adjacent table and all KPIs must be met for a home to be Net Zero carbon.

Getting the right team

The success of the retrofit approach relies on the coordination of a shared vision. Therefore getting the right team on board at the right time is critical. The early appointment of an energy consultant with specialism in ultra low energy design and retrofit is recommended. Workshops at briefing stage can be used to establish the long term retrofit plan and ensure the wider consultant team are clear on the targets and objectives.

Consider energy modelling

Analysis of the design through energy modelling will ensure that the KPIs are met in practice. This involves the early appointment of an energy or retrofit consultant to steer the design from concept stage and carry out modelling using accurate tools such as the Passivhaus Planning Package (PHPP).

Without energy modelling

Using energy modelling is always the recommended route to ensure accuracy, however it is possible to target best practice by setting the right specification and design requirements as part of the project brief. Refer to the 'How it all comes together' for retrofit of a terrace house (including the case of a terrace house in a conservation area). The LETI Retrofit Guide can also be used for further guidance (www.leti.london).

	KPIs Retrofit housing
Ultra low energy homes	Space heating demand 65 kWh/m²/yr *on average (range of 20-120 kWh/m²/yr)
Energy use and efficient heating	Energy Use Intensity 60 kWh/m²/yr *on average
Renewable energy	Electricity generation intensity 120 kWh/m^2_{fp}/yr m^2_{fp} : m² building footprint

PAS 2035
Retrofit guidance (see next page)

TM59
Overheating modelling for compliance

AECB
Good practice water standard

KPIs in-use
Collect data for the first 5 years

PAS 2035 guidance should be followed on publicly funded retrofit projects.

The 'whole house' approach and PAS 2035

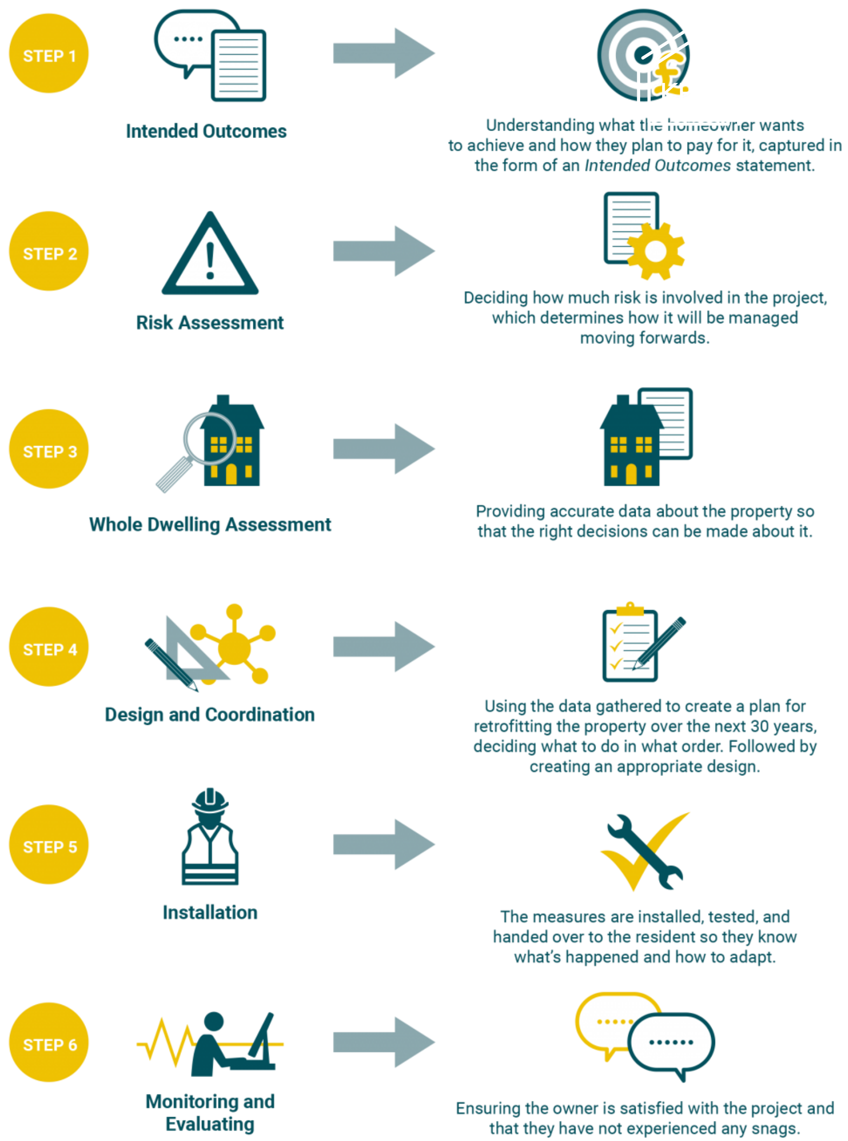
The importance of a 'whole house' approach

Successful retrofit relies on a structured process including adequate assessment, design, installation and monitoring to feed back into future work. These principles as well as the idea of whole house thinking and the role of retrofit coordinators have fed into the creation of PAS (Publicly Available Specification) 2035 the UK's first retrofit standard. This helps to deliver quality and manage risks associated with retrofit. It aims to ensure clients and homeowners get value for their investment. PAS 2035 follows two core principles:

1. A **'fabric first'** approach to reduce the heat demand of a building as much as possible and to ensure newly airtight homes are well ventilated and avoid issues with damp and humidity.
2. A **'whole house approach to retrofit'** to ensure retrofit plans for homes consider improvements to the fabric, services and renewable energy generation in a coherent way to minimise both risks and carbon emissions.

Who is a Retrofit Coordinator?

PAS 2035 requires an accredited Retrofit Coordinator to be appointed who will take responsibility for demonstrating compliance with the PAS 2035 standard. This is a relatively new role and different projects require input from different retrofit specialist depending on the risk category. The Retrofit Coordinator identifies whether the project falls into a low, medium or high-risk category and advises on appropriate steps to minimise risk. For more information, please refer here.



PAS 2035 recommends 6 steps to follow on a quality assured retrofit project

Changing a home's carbon dioxide pathway

How does a home produce carbon?

The vast majority (85%) of homes in the UK get their heating and hot water from a gas boiler and many other homes use other fossil fuels (e.g. oil). All the other energy uses in the home are drawn from the electricity grid. The emissions from the gas boiler are emitted on-site whilst the emissions associated with electricity use are emitted in a power station. Ten years ago, electricity was about 2.5 times more carbon intensive than gas, but things have changed a lot since then.

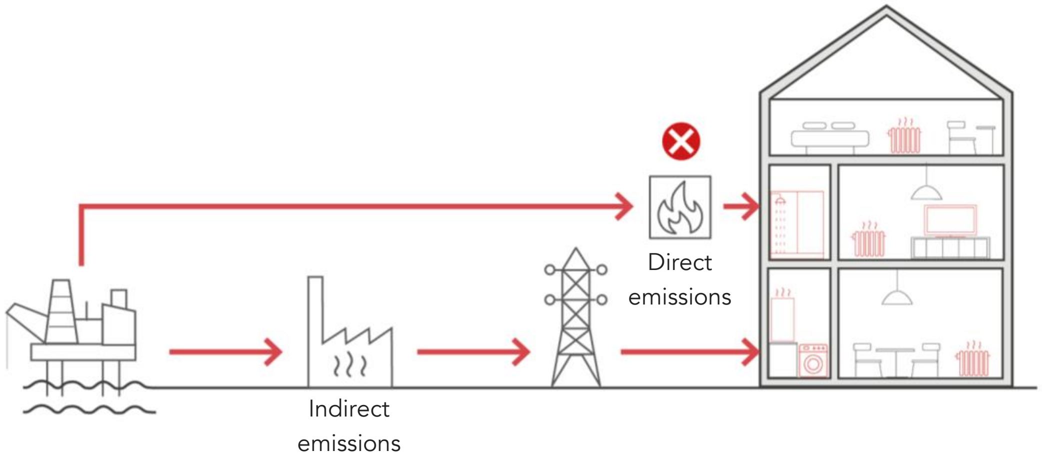
What has changed?

Over the past ten years, coal-fired power stations have been retired and the amount of renewable energy that feeds into our electricity grid has increased significantly. This means that the carbon intensity of our electricity has now dropped and is now about 30% lower than gas. As we add more renewables to our grid in the coming years, this will continue to drop until we approach a zero carbon grid.

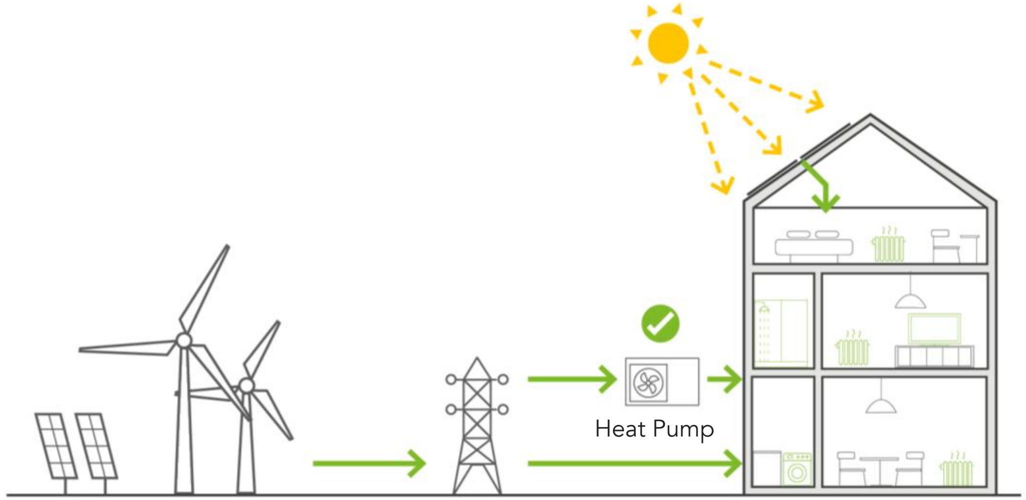
In contrast, a gas boiler installed today, will continue to emit carbon at the same rate until it is decommissioned – which could be another 25 years. This means that it has become a priority to move our homes away from gas to an electric-based system for heating and hot water.

Where do heat pumps fit?

Heat pumps will be discussed in more detail later, but they offer an excellent way of transitioning to electricity whilst reducing the load on the grid as they extract additional energy from the surrounding air or ground. Both the Government and the UK Climate Change Committee agree that they will form a major part of our future heating systems.



How most homes use energy now



How most homes should use energy now and in the future

Mapping to journey towards Net Zero

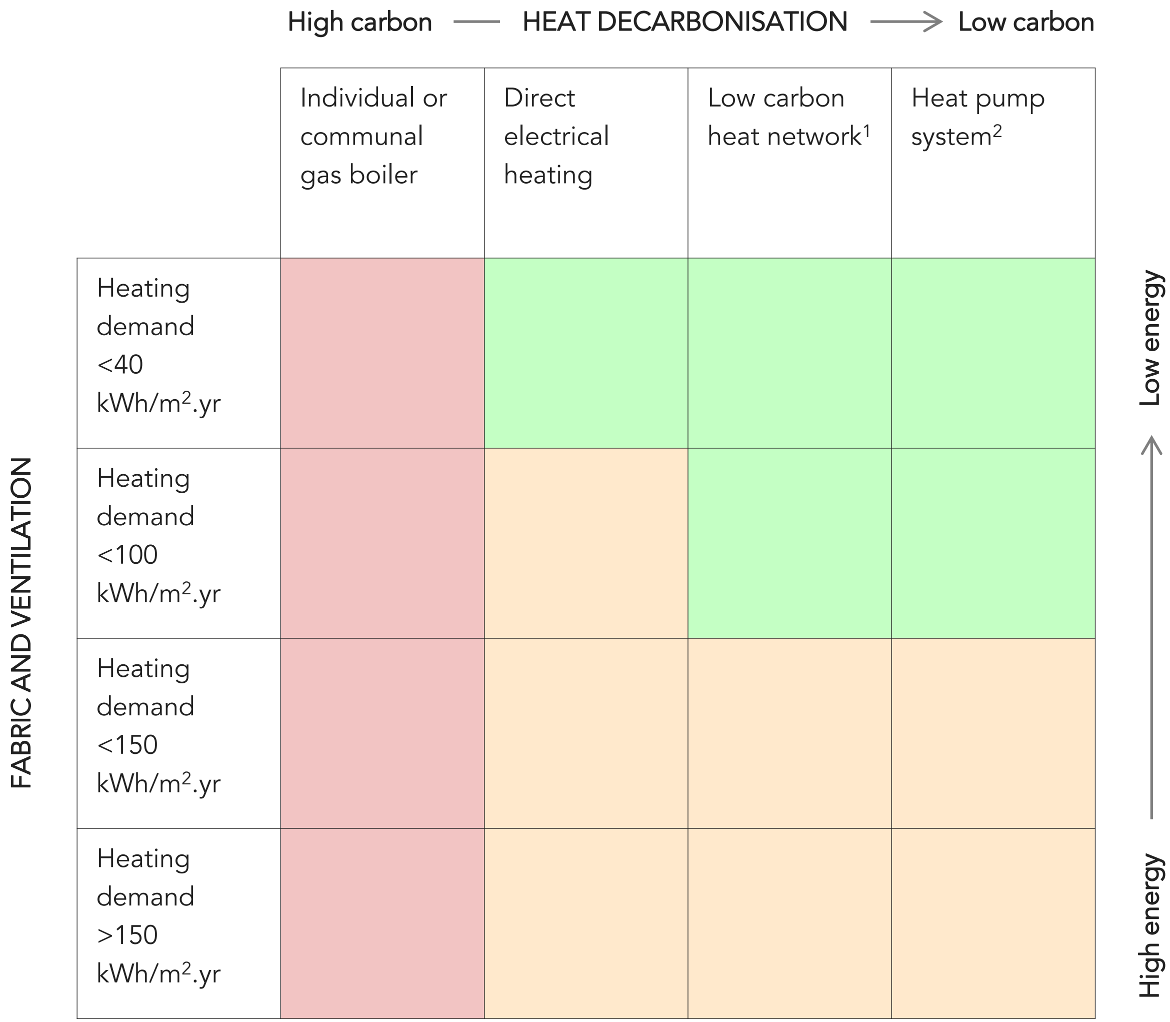
Each house or flat is different. They will have a different starting and final positions on the adjacent 'Retrofit Map' but ultimately, by 2050 (or earlier) all homes must be moved to one of the green squares.

The adjacent **Retrofit Map** could also be used to identify the buildings which should be most urgently retrofitted (in red) as they will be consuming most of the carbon budgets. Other factors (e.g. maintenance schedules, replacement opportunities, resident's appetite) may also influence the prioritisation.

Use of fossil fuels
Not compatible with Net Zero.
The heating system must be changed.

Low carbon heat but risk of high energy costs
A change of heating system may not be required but fabric, ventilation and system should be improved

Low carbon heat and sufficient level of energy efficiency
Compatible with Net Zero



[1] A heat network would qualify as 'low carbon heat network' for the purpose of this Retrofit Map only if it would have a lower carbon content of heat (per kWh delivered) than direct electric heating. Any system using fossil fuels and/or with high distribution losses is unlikely to qualify.

[2] Could be an individual or building level heat pump with low distribution losses.

A long term whole house renovation plan for a phased retrofit

An ambitious objective

The objective of a retrofit project should be to achieve Net Zero carbon by 2050 (or earlier). This means that:

- The home's energy efficiency is improved
- A low carbon heating system is installed
- Renewable energy is installed on-site
- The home is made smart ready

A whole house renovation plan is a useful tool to prepare and provides a pragmatic and coherent way to deliver this ambition.

Phasing improvements as part of coherent whole house plan

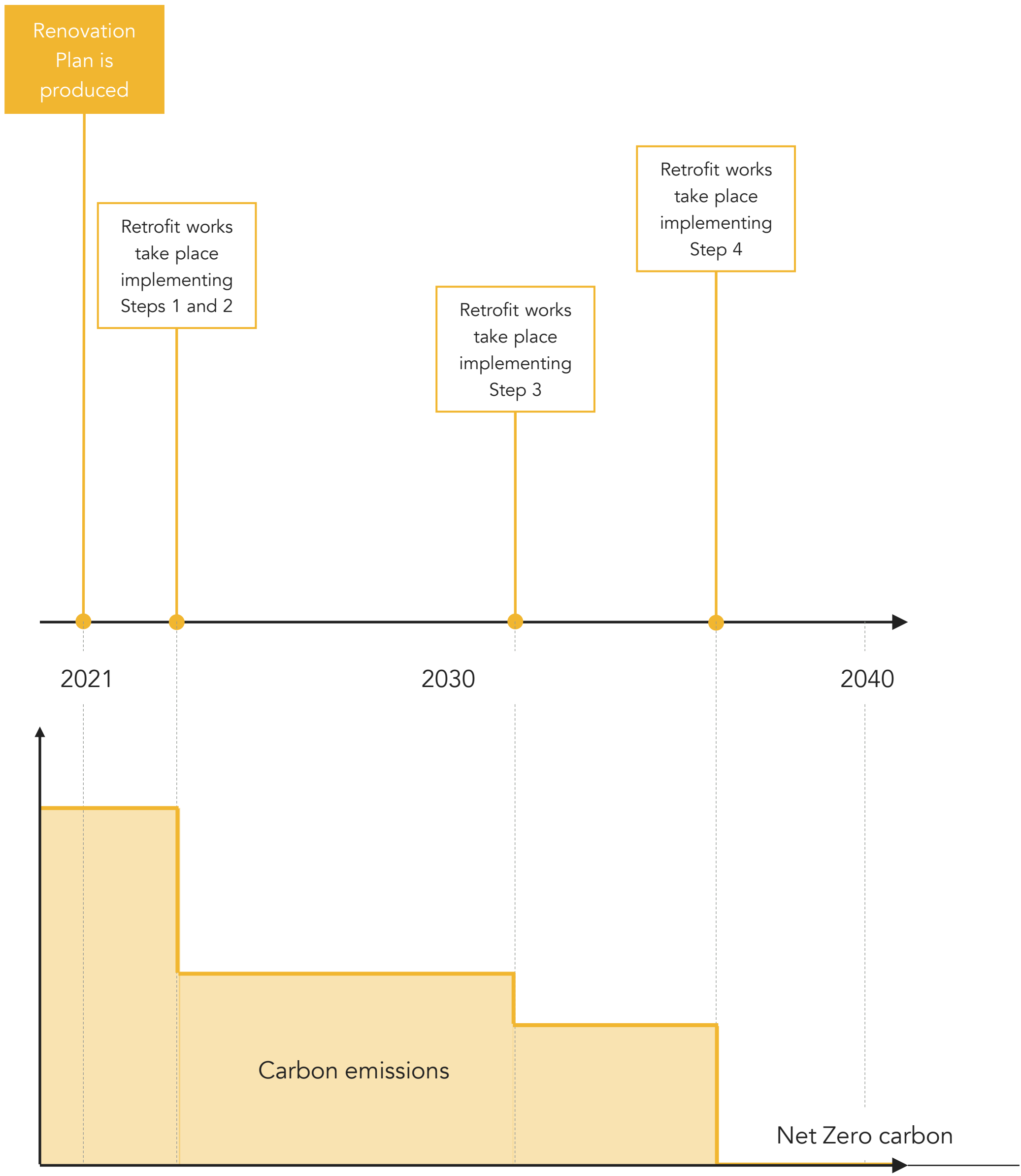
It may not be possible to implement all retrofit measures at once, but it is important to plan ahead so that packages of work are coherent and complementary. The preparation of a whole house plan is recommended to help in that planning.

This page shows how the measures can form part of a strategy for improvements. It would help landlord and residents to progressively save carbon and energy costs and avoid undertaking measures that conflict with planned future improvements.

A digital logbook

Alongside the whole house renovation plan, a building digital logbook can be developed to gather and retain all relevant information about the building.

Together, they form the **Building Renovation Passport**.



Note: the expected decarbonisation of the grid is not represented for simplicity but will also contribute to the reduction of carbon emissions over time.

Key retrofit risks and how to mitigate them

It's all about moisture …

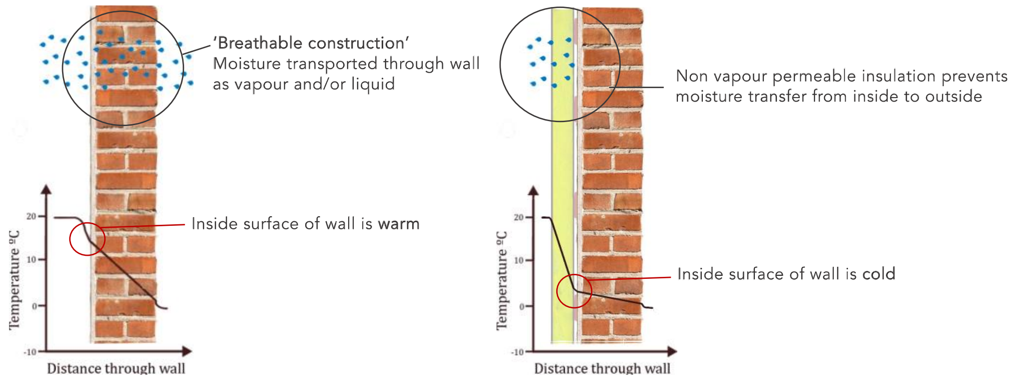
Our homes need to remain structurally sound, free from damp, mould and rot. Regrettably, many existing homes already suffer from excessive cold, damp, mould and condensation. A poorly planned and executed retrofit could actually make this worse. It is very important to understand this risk to mitigate and avoid it.

It may not be obvious, but our homes are constantly dealing with moisture. They are keeping out the rain and stopping the damp rising up from the ground. They are also dealing with the significant amounts of moisture that we generate inside the home from cooking, washing and breathing. Finally, if the building fabric does somehow get wet, they are designed to ensure that it will dry out without long-term damage. Interfere with any of these mechanisms, and we could end up doing damage to the health of both the building and its occupants.

Clear principles can address this risk

The risks of retrofit are well understood and can be overcome with sensible design and well-executed construction. Some key rules are:

- **No insulation without ventilation**. As you add insulation you are also likely to increase airtightness. This means less air moving through the building. You can counter this with opening windows and extract fans, but ideally by fitting a whole-house ventilation system like Mechanical Ventilation with Heat Recovery (MVHR).
- **External insulation is best**. Internal insulation means your external walls become cold and there is therefore a risk of condensation if the warm internal air reaches a cold surface. So, external insulation is preferred, but if internal insulation cannot be avoided, vapour open insulation (such as wood fibre) should be used. It is chemically fixed to the inside surface thus reducing the risk of condensation.



The risk of condensation with internal insulation

Installation of wood fibre insulation boards internally (© Back to Earth & ASBP)

What about heritage buildings and conservation areas?

Low carbon retrofit of heritage and traditional construction buildings in conservation areas is necessary and possible. There are a growing number of examples which show it can be done, and the PAS retrofit framework provides a suitable methodology.

Environmental and heritage conservation can go hand in hand

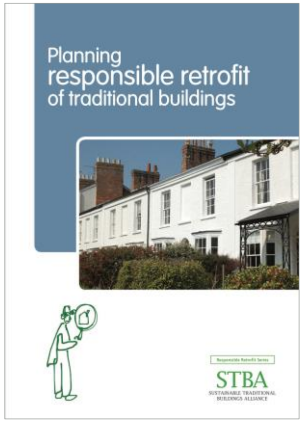
Heritage conservation is often given as an excuse to not improve energy efficiency and reduce carbon emissions. Proposals for those measures are sometimes refused by Local Planning Authorities particularly where they are not well thought through and do not form part of a whole building approach and therefore could cause damage to the structure of the building.

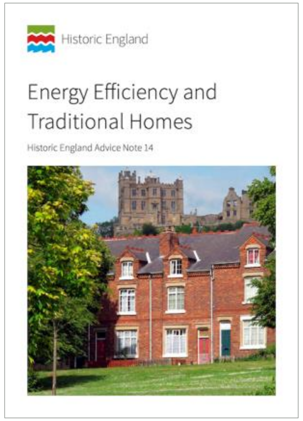
However, in addition to offering significant potential for carbon reductions, well-planned retrofit programmes can also contribute to conservation by incorporating maintenance and repair, and offering a new lease of life to buildings. They limit the risk of under-heating by occupants worried about energy bills, and associated risks of fabric degradation. By being more comfortable, buildings are also more likely to remain valuable and well looked after in the future.

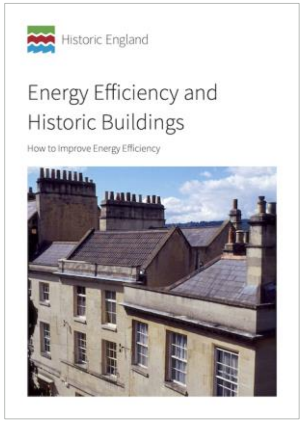
Identifying relevant solutions for the context

Upgrading existing windows, and/or installing replacement double/triple glazed windows (subject to planning officer's support) can reduce heat loss by up to 40%. Recent advances in windows technology such as evacuated glazing offer the possibility of recreating traditional windows forms but with only a fraction of the heat loss. This technique can in some cases be applied to listed buildings.

Emerging products such as insulating plasters also offer the opportunity to insulate walls in a sensitive manner.







There is a growing library of resources for responsible retrofit of traditional and historic buildings, including the above Sustainable Traditional Buildings Alliance (STBA) and Historic England guidance

Recent examples of exemplar retrofits with heritage considerations: Grade I listed Trinity Student Halls in Cambridge (left, credit to Max Fordham), and Grade II early Victorian home in Clapham, London (right, credit to Arboreal). Both include the application of internal insulation, with attention to moisture movement and monitoring of interstitial moisture level.

Grasping the opportunity

When considering the lifetime of a house, there are not many times when major improvements can be made. An extension is a fantastic opportunity to make a significant step towards Net Zero carbon and not locking in poor/high carbon decisions.

What to consider

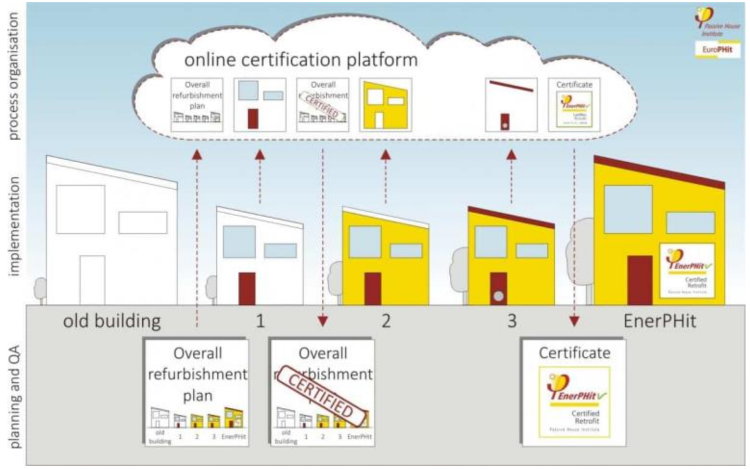
When considering the scope and costs of extending a home, the following opportunities should be considered:

1. Upgrading the heating system, and replacing the gas boiler with a heat pump.
2. Replacing existing windows with double or triple glazed windows
3. Upgrading the existing external fabric of the existing building (including both insulation and airtightness).
4. Installing Mechanical Ventilation with Heat Recovery (MVHR)
5. Installing solar PV panels to generate electricity

Staged retrofit – piece by piece

It is possible to undertake a staged retrofit when extending a home. A very useful resource and robust methodology is the EnerPHit Retrofit Plan. This scheme helps create a plan for taking a staged retrofit process, where the measures to improve the building fabric are put to a timeline. This allows the extension to be built and improvements to be made over time, and not just in a single phase. This can be an attractive and practical approach as often the capital costs of undertaking an extension and undertaking a major refurbishment all at once may not be affordable.

EnerPHit retrofit project with extension (Source: Passivhaus Plus)



EnerPHit staged retrofit improvement plan process (© PHI)

What are the low carbon heating options?

Heat pumps are the best option

The electricity grid has decarbonised and will continue to decarbonise, thus most likely low carbon heat source is using electricity. This is done most efficiently, and has lower running costs when using heat pumps. There are various types of systems available including, air-to-air and air-to-water heat pumps, ground source heat pumps, exhaust air heat pumps, heat pumps integrated into a domestic hot water store, and shoebox water-to-water heat pumps connected to an ambient loop. Hot water storage is required when using heat pumps.

What other options are available?

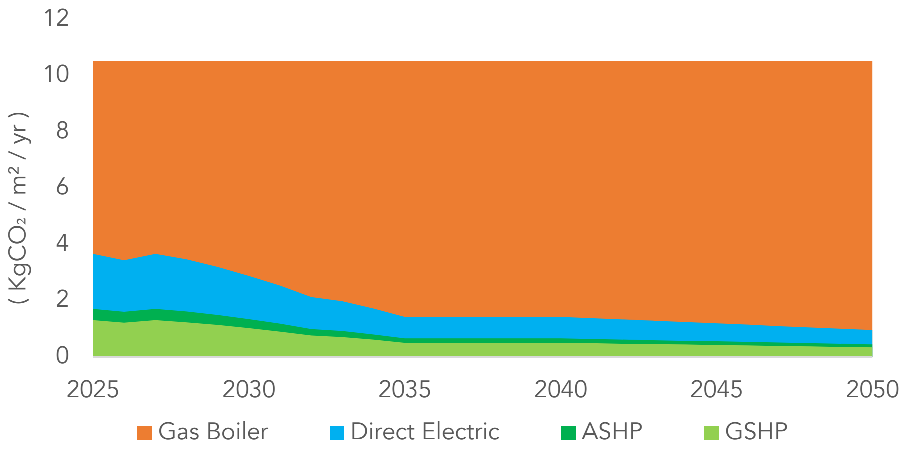
Direct electric heating, for example through panel radiators will become low carbon in the future, as the grid continues to decarbonise. However direct electric heating can lead to very high heating bills.

Hydrogen is very unlikely to be a solution for the majority of homes. 'Green' hydrogen from renewable power electrolysis is truly zero emissions. However, the UK gas supply industry advocates 'Blue' hydrogen manufactured from methane with carbon capture of its high emissions using yet to be proven at scale carbon capture and storage technology. Thus it is yet to be proven that hydrogen at scale is in fact low carbon and of an acceptable price.

Using woodburning stoves causes problems with air quality and involves burning raw materials, which should be avoided.

Is my home ready for low carbon heat?

If your home does not have a reasonable level of energy efficiency, particularly if it is a large house, using a heat pump can be quite expensive. In those cases, it is recommended to improve the fabric and airtightness, potentially over time.



This graph compares carbon emission associated with various heating systems over for a typical home. Emissions from a gas boiler stay constant, whereas emissions from direct electric systems and heat pumps reduce over time due to grid decarbonisation. Heat pumps have lower emissions than direct electric systems purely because they are more efficient.

Best → Worst

System	Carbon Emission Reduction	Running Cost	Capital Cost	Air Quality Neutral	Ease of Use & Maintenance
Ground source heat pump	✓✓	✓✓	✗	✓	✓
Air source heat pump	✓	✓	~	✓	✓
Direct electricity	~	~	~	✓	
Biomass/ wood burning stove	~	~	~	✗	✗
Hydrogen	✗	?	?	✓	✓

The table compares various low carbon heating options across different criteria

Key ✓✓ Very Good ✓ Good ~ Neutral / Dependant ? Unknown ✗ Bad

Which heat pump is best for me?

There are various types of heat pump options available for retrofitted homes. This page outlines which heat pumps are available and which to choose.

Most homes with a heat demand below 100kWh/m^2.year will be suitable for a heat pump, unless there is not sufficient space. At the higher end of this criteria larger radiator sizes or underfloor heating may be required.

1 Which heat pumps are the best for retrofitted homes?

- Monoblock or split (air source) heat pump, generating heating and hot water
- A ground source heating pump system, generating heating and hot water
- Individual heat pump connected to an ambient loop

Reasons why these heat pumps might not be suitable:

- **Available space:** These heat pumps require space for indoor and/or outdoor units
- **Ground conditions:** Some ground conditions are not suitable for ground source heat pumps
- **Size of development**: an ambient loop is only really suitable when there are more than 30 homes

If these systems do not work

2 Is the space heating demand < 100kWh/m^2.yr

No → It is recommended to retrofit the home such that the heat demand is as low as possible, as this reduces carbon emissions and fuel bills.

If the home cannot be retrofitted to below 100 kWh/m^2.yr heat demand then it is still recommended to install a heat pump, but assess the impact on energy costs.

Yes

3 Which are the next best heat pumps?

- A heat pump integrated into a hot water store (i.e. hot water heat pump). Heating is delivered through direct electric panel radiators
- An exhaust air heat pump with direct electric panel radiators are needed for peaks*

Reasons why these heat pumps might not be suitable

- **Available space:** These heat pumps require space for a hot water store
- **Ducting:** A heat pump integrated into a hot water store required ducting to the outside, in some homes there might not be space for this
- **Ventilation:** an exhaust air heat pump requires integration into an MVHR unit, MVHRs are highly recommended

If these systems do not work

4 Is the space heating demand < 40kWh/m^2.yr?

No → It is recommended to retrofit the home such that the heat demand is as low as possible, as this reduces carbon emissions and fuel bills.

If there is not sufficient space to install a heat pump, then consider direct electric heating and hot water.

Yes

5 Consider direct electric heating and hot water

*An exhaust air heat pump (compact unit) combined a heat pump and a MVHR. Some products can only meet the heat demand in smaller dwellings and/or this with a space heating <15kWh/m^2.year,

Why windows should be upgraded

Windows can lose more than ten times more heat compared to a well insulated external wall. Unless the current windows have been installed recently, it is very important to ensure that windows are replaced with high performing triple glazed windows (with a whole unit U-value calculated (U_w value) of less than 1.0 W/m^2K).

Detailing the window replacement

Where possible, the window should be replaced in line with the insulation layer of the external wall to continue the thermal line of the dwelling. The connection of the window to the external wall needs to be carefully considered as this is a weak spot thermally. It needs to be designed so that the risk of condensation between the external wall and window is reduced. A specialist consultant who can undertake thermal bridge modelling may need to consulted for project specific guidance. The use of low conductivity cavity closers and products like compacfoam can be a good way to reduce thermal bridging, and reduce the risk of condensation.

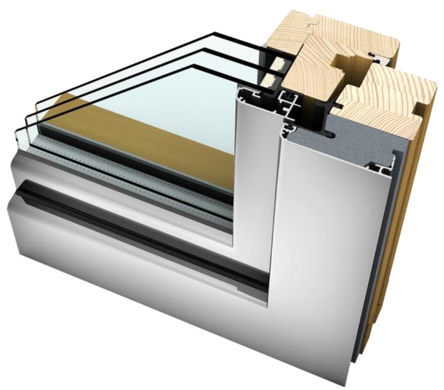


Photo of triple glazed aluclad timber window (© Internorm)

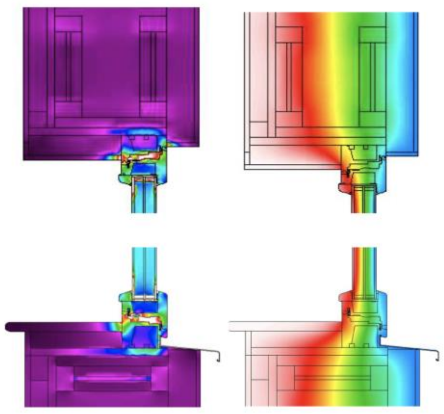


Photo of thermal bridge calculation of window install (© Warm)

Airtightness

When installing the windows, care should be given to the junction between the window frame and the airtightness layer of the external wall. High performance airtightness tape should be used to limit infiltration as the connection between windows and external walls can be leaky if not properly installed.

Replacement triple glazed windows (© Internorm)

Photo of window install in Enerphit retrofit (© Passivehouseplus)

Exceptions

Replacement windows may not always be appropriate in the context of a listed building, or some older buildings in conservation areas, and other methods of improving the energy efficiency of the existing windows may need to be considered as part of a more holistic 'whole house approach' (e.g. draught proofing or secondary glazing).

Insulating walls

Insulating externally or internally?

From a heat loss perspective, it is better to externally insulate as this allows the insulation to wrap around the building continuously and avoids the need to address weak points and junctions e.g. around floor joists. However, it will mostly come down to what is practical on the specific site: how much space there is available; the aesthetics preferences; whether the building has conservation or planning constraints that prevent external insulation; the level of disruption the installation will have to occupants; and the relative installation cost.

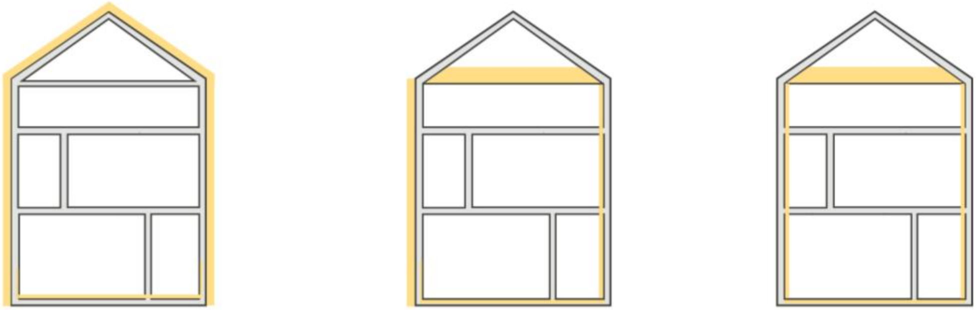
External insulation

External wall insulation is a good solution. It is very effective thermally, does not reduce internal space and generally enables residents to stay in the property when insulation is being fitted. The external appearance of a building will be affected, and roof eaves may require extending. Insulation can be easily covered in render but brick slips, pebbledash and cladding are also possible.

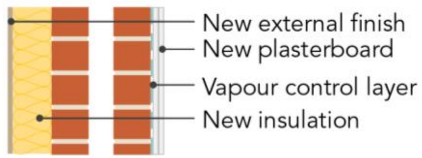
Internal insulation

Use breathable materials internally e.g. wood fibre insulation, hemp lime insulation. Avoid using non-breathable materials internally e.g. rigid insulation. Even though this can achieve a good thermal performance and is often cheaper, it can increase the condensation risk and make detailing around junctions more complicated. Consider the combustibility of insulation, natural products are likely to be combustible but can be used safely in the right application. Where space is limited internally consider using thin products such as aerogel insulation. Consider installing service voids for electrics to run outside of the insulation line.

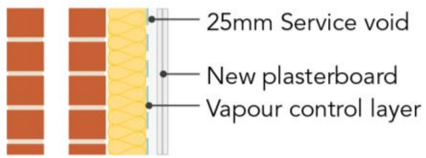
External Insulation Approach | Hybrid Approach | Internal Insulation Approach



In some circumstances, it may be beneficial to consider a hybrid approach e.g. internal insulation at the front to retain the architectural features of the front façade and external insulation at the rear. This maximises the insulation gains of using external insulation where it has less of a visual impact.

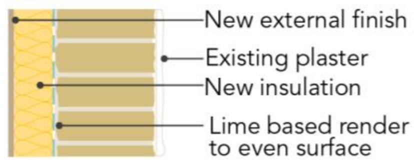


Externally insulated Brick Cavity

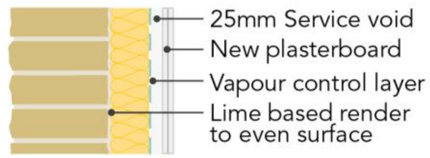


Internally insulated Brick Cavity

N.B. If considering cavity fill insulation ensures measures have been made to prevent condensation



Stone Wall



Internally insulated Stone Wall

Insulating floors and roofs

Consider floor-to-ceiling heights

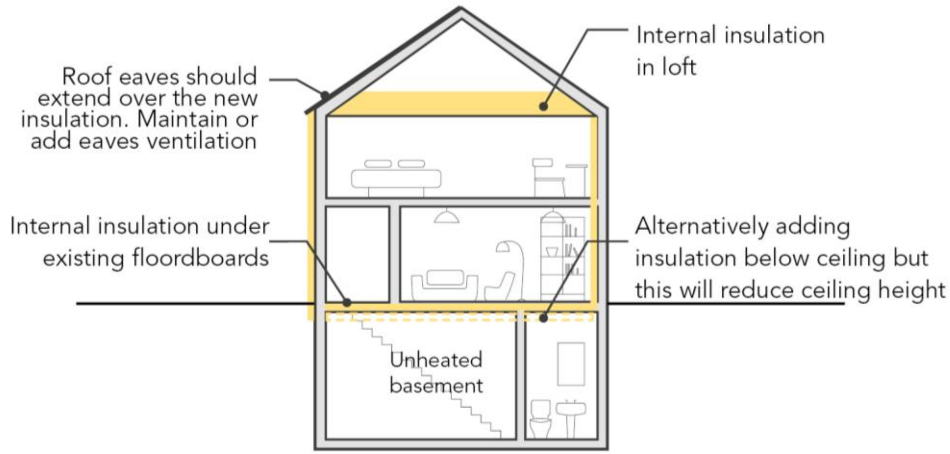
When insulating floors or ceilings be sure to check the floor to ceiling height. Insulating floors may require raising the floor level, so ensure you have considered the impacts e.g. steps at the entrances, door heights and consistent staircases levels.

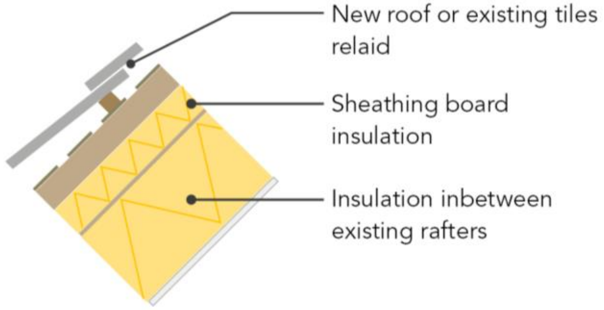
Extending eaves over external wall insulation

Where external wall insulation meets the roof consider extending eaves to cover the additional wall thickness. Also be sure to maintain or add ventilation at the eaves.

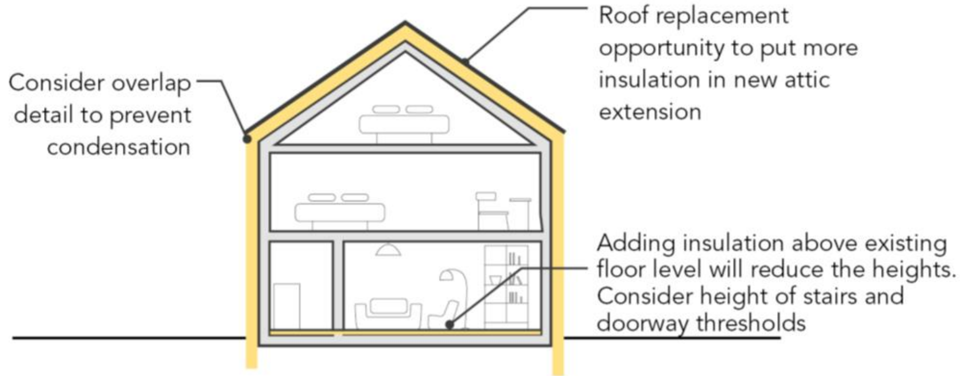
Insulating roofs

If you have an unheated attic space the simplest approach is to insulate the floor in the loft. Ideally relocate existing water services and tanks in the roof void or insulate them if not possible. If you require a heated and habitable loft, add insulation between rafters and apply insulated sheathing board over the rafters as shown in rafter detail below. Plasterboard can be fixed to the underside of the insulation. Consider fabric improvements in conjunction with any loft extension works.





Rafter insulation detail



Introduction to thermal bridges

Thermal bridges

A thermal bridge, or cold bridge, is a piece of material through which heat flows easily, relative to adjacent materials. For example, a concrete lintel that interrupts the wall insulation layer would be considered a thermal bridge. Thermal bridges should be avoided as they increase heat loss, and can cause cold spots that lead to condensation and decrease comfort for home occupants.

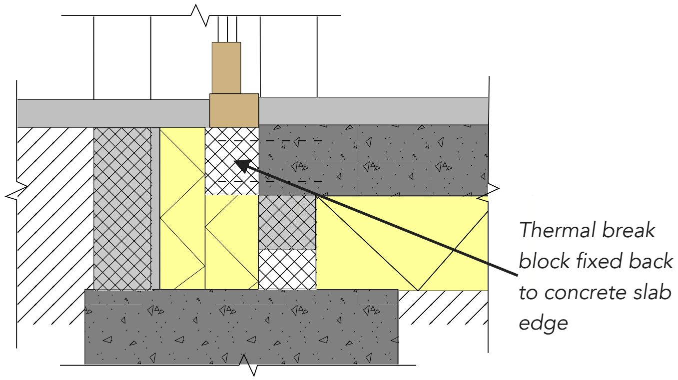
Identifying thermal bridges

A good approach to retrofit is to sketch out a cross section drawing of the building. Clearly identify materials that keep heat in, such as insulation, doors, and windows. Ideally, these should all connect together without insulation depth reducing by more than a third. Different materials should be butt jointed, or overlap, ideally for a distance equivalent to the thickness of the insulating element.

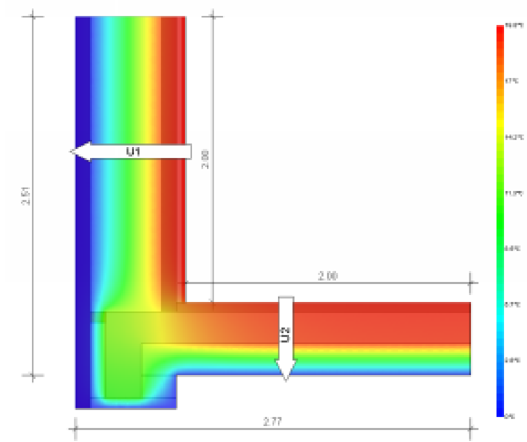
Tackling thermal bridges

There are many off-the shelf products available to avoid thermal bridging. Learn about these and use them where possible. Examples include thermally broken lintels, foam glass blocks, high density EPS foam, and specialist structural thermal breaks that can be cast into concrete, or used to fasten steelwork together.

In retrofit, there will be thermal bridges that cannot be avoided. In these cases, aim to increase the distance that heat must flow to escape the structure. For example, an insulation downstand or skirt could be applied around the external wall to ground floor junction of a building to reduce heat flow. Consider using thin pieces of higher performing insulation such as phenolic board or aerogel where depth is constrained.



Sketch out key junctions and ensure there is a continuous line of insulation that runs around the building. Try to ensure the insulation depth does not reduce by more than a third around any junction, and ensure window and door frames are in line with insulation.



Consider commissioning thermal bridge modelling for particularly challenging junctions to inform your strategy. Small changes to the position and type of material used in construction can have a big affect on the heat flow, a model will help to show this.

Junctions

Consider junctions carefully

Junctions which pose a weak point for heat loss, i.e. a thermal bridge, should be considered on a case by case basis. Key examples of such junctions are outlined below. Special care should taken to reduce the condensation risk posed at each junction. We strongly recommend engaging an architect or consultant who is able to produce a risk assessment and help design out condensation risk.

1 Roof eaves with external wall insulation

The space between the external wall insulation and roof insulation is a weak point for heat loss. This can be compensated by providing a strip of internal insulation at ceiling level.

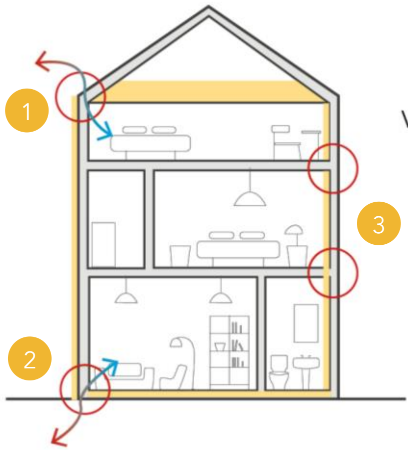
2 Foot of the façade with external wall insulation

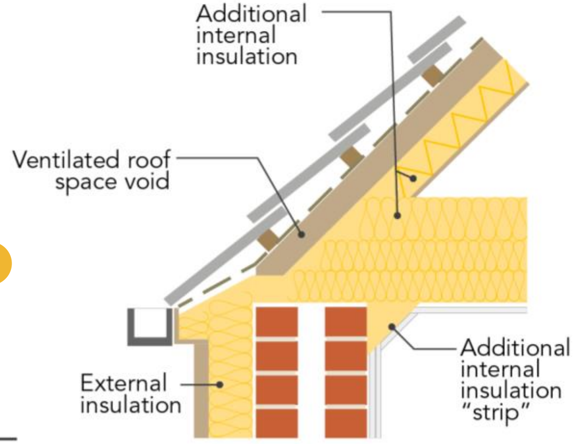
Avoid creating weak points for heat loss at the foot of the façade between external insulation and ground floor. Insulating externally down the wall below ground level as far as possible and provide some internal wall insulation up to counter top level.

3 Joist ends with internal wall insulation

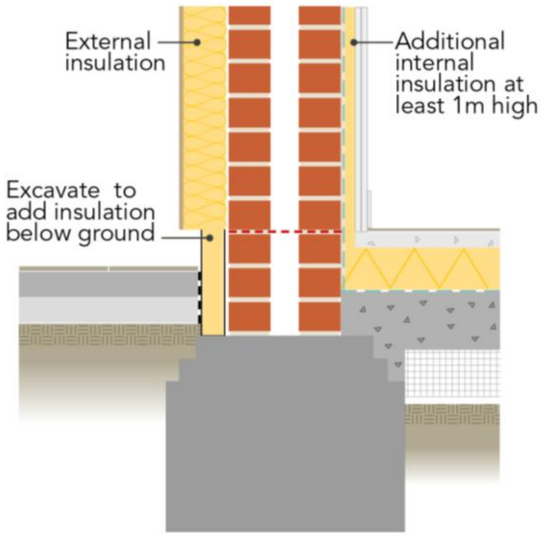
When applying internal insulation it is important to protect joist ends against thermal bridging and condensation risk:

- The most effective approach is to cut and rehang joists away from the external wall e.g. support them on hangers or by a beam between party walls. This allows for a narrow cavity of insulation to be inserted between the façade and end of joist.
- When insulating behind the joists is not possible, consider hanging the joists or wrapping the breather membrane around the end of the joist to prevent the build up of condensation.

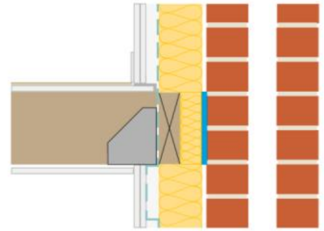




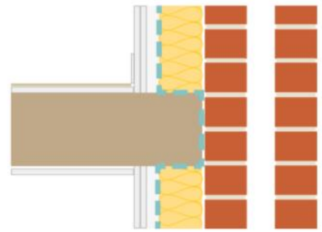
Detail for roof eaves and 'internal strip of insulation'



Measures to avoid thermal bridge at the foot of the façade



To avoid thermal bridge + condensation cut and rehang joist away from wall



To avoid condensation risk wrap joist (or add hanger)

Airtightness for retrofit

The importance of airtightness

The airtightness of existing homes varies hugely, however it is recommended that retrofit work targets a value of between 0.5 and $3m^3/h/m^2$, depending on the depth of retrofit and project limitations.

Start with a plan, investigate, then update the plan

Building airtight starts with a well thought through airtightness and ventilation strategy. Existing buildings conceal many secrets however, so expect to update the plan once you start stripping out the building. A key consideration in retrofit is managing moisture risk and minimising risk of warm humid indoor air coming into contact with cold surfaces.

Use the right products

Retrofits will use similar products to new build projects. Consider ordering a range of tapes, primers, membranes and parge coats in advance to test on parts of the building. It may be necessary to combine traditional building practices with modern airtightness products. Consider this carefully and contact manufacturers for advice if necessary.

Stick to the plan on site

Retrofit can be a bit chaotic, so ensuring the airtightness strategy is implemented properly is even more important than for new build. Expect setbacks and be ready to adapt your approach as necessary.

Test, then test again

Plan for at least two air tests. The first test should be completed as soon as the building is weathertight and while joints between different components in the airtight layer are still accessible so leaks can be repaired if necessary.

Achieving airtightness is possible in retrofit, but it is often necessary to strip back to the basic structure and perform basic repair work before methodically applying airtightness products and principles. Always consider risk of moisture and condensation.

Applying airtightness tape to joist ends is a common measure required to achieve good airtightness in existing buildings. Large gaps may need filling with mortar first, and remember to apply a suitable primer.

Retrofitting a ventilation system

Why is it important?

Existing buildings in the UK are generally leaky and naturally ventilated, leading to discomfort and large energy demands. Insulation, airtightness and new windows are often considered important but they generally should not be done without the retrofit of a controlled ventilation system. A mechanical ventilation and heat recovery (MVHR) system is often the best solution.

Mechanical Ventilation with Heat Recovery

The most efficient way to provide ventilation, is through a MVHR system. The equipment circulates air in a dwelling using a small fan, whilst recovering the heat from inside so it is not lost.

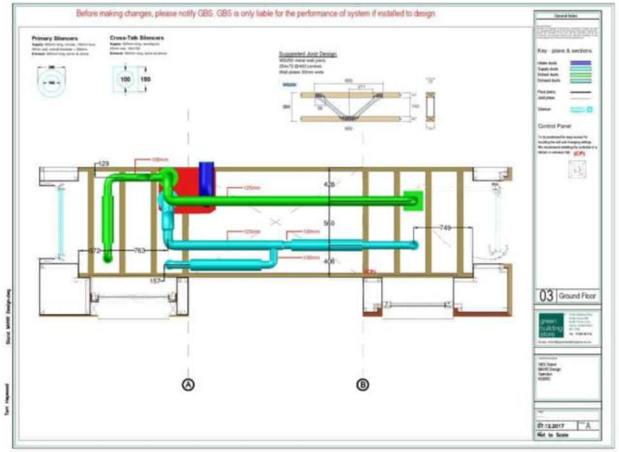
Designing and selecting the correct MVHR system

You will need a building services engineer and/or experienced subcontractor and/or a MVHR manufacturer/supplier to calculate the fresh air required, and design the MVHR system for your dwelling.

The MVHR unit should be sized and the system designed according to some specific requirements of the home and to achieve acoustic requirements. It is important to plan the space required for the MVHR unit and the associated ductwork and silencers. Rigid, insulated ductwork should be adopted where necessary. The MVHR unit should preferably be a Passivhaus Certified Unit.

Installing and commissioning the system

Historically the installation and commissioning of MVHR systems has been poor. To ensure the system works as planned, the system must be properly tested to ensure it is balanced, delivers the designed fresh air required and does not generate noise beyond what is expected.



MVHR system design for an existing dwelling (© Green building store)

Image of Zehnder MVHR unit being retrofitted into an existing house (© Bowtie construction)

Flow rate measurement: image of MVHR system being commissioned (© Fourwalls)

Water efficiency and domestic hot water

Reduce overall water consumption

Water efficiency is about reducing our use of mains water and the effect our homes have on water resources.

Reduce hot water to reduce energy use

In very low energy buildings, the energy required for hot water can exceed the amount of energy required for space heating. Therefore optimisation of hot water systems is essential to ensure energy use remains low.

What can you do?

Reduce flow rates
- The AECB water standards (opposite) provide clear guidance on sensible flow rates for showers and taps in low energy buildings.

Reduce distribution Losses
- All pipework must be insulated.

Insulate to minimise losses from hot water tanks
- The standby losses of hot water tanks are highly variable, and can have a significant impact on overall energy use. Target a hot water tank heat loss of less than 1 kWh/day equivalent to 0.75 W/K

Install waste water heat recovery systems in shower drains
- A simple technology that recovers heat from hot water as it is drained. Vertical systems can recover up to 60% of heat with more common horizontal ones recovering 25-40%.

Consider water recycling
- This is the process of treating waste water and reusing it, it can be used for large portions of potable water use.

Appliance / Fitting	AECB Good Practice Fittings Standard
Showers	6 to 8 l/min measured at installation. Mixer to have separate control of flow and temperature although this can be achieved with a single lever with 2 degrees of freedom (lift to increase flow, rotate to alter temperature). All mixers to have clear indication of hot and cold, and with hot tap or lever position to the left where relevant.
Basin taps	4 to 6 l/min measured at installation (per pillar tap or per mixer outlet). All mixers to have clear indication of hot and cold with hot tap or lever position to the left.
Kitchen sink taps	6 to 8 l/min measured at installation. All mixers to have clear indication of hot and cold with hot tap or lever position to the left.
WCs	≤ 6 l full flush when flushed with the water supply connected. All domestic installations to be dual flush. All valve-flush (as opposed to siphon mechanism). WCs to be fitted with an easily accessible, quarter turn isolating valve with a hand-operated lever. Where a valve-flush WC is installed, the Home User Guide must include information on testing for leaks and subsequent repair.
Baths	≤ 180 litres measured to the centre line of overflow without allowing for the displacement of a person. Note that some product catalogues subtract the volume of an average bather. A shower must also be available. If this is over the bath then it must be suitable for stand-up showering with a suitable screen or curtain.
Showers	6 to 8 l/min measured at installation. Mixer to have separate control of flow and temperature although this can be achieved with a single lever with 2 degrees of freedom (lift to increase flow, rotate to alter temperature). All mixers to have clear indication of hot and cold, and with hot tap or lever position to the left where relevant.

Refer to the full AECB document for more information.

Retrofitting solar PVs

Where to start

Contacting a local MCS certified solar installer is a great first step to retrofitting a solar Photovoltaic (PV) system. They can assess your property, provide information on solar panels and inverters, and provide a quotation indicating how much energy the system will generate. Quotations typically also include financial analysis such as annual savings and simple payback period. Prices can vary substantially between installers though, so obtain several quotes.

Planning work

Unless you live in a bungalow, scaffold will typically need to be erected to install solar panels. Consider whether this could provide opportunities to carry out other retrofit work such as wall insulation, replacing windows, or tackling a thermal bridge between your wall and roof insulation. Standard solar scaffolds may not include working decks on intermediate floors, so if you do plan to do other work discuss it with your installer.

Getting up and running

Once your system is installed, you will need to get registered for the Smart Export Guarantee to receive payments for exported solar energy. Check Solar Energy UK's league table to find an energy supplier offering a competitive rate. Most schemes require an MCS certificate from the solar PV installer and a smart meter or export meter that can record the amount of energy you are supplying to the electricity grid.

Over a million homes in the UK already have solar panels, many of which have been retrofitted. Notify your building's insurance provider if you are having solar panels fitted to ensure they are covered and your policy remains valid.

Products and processes have been specifically developed to securely fit panels to existing roofs. Example shows a stainless steel roof hook being mounted to a slate roof.

Smart controls and demand response

Intuitive and flexible energy use

Demand response or energy flexibility refers to the ability of a system to reduce or increase energy consumption for a period of time in response to an external driver (e.g. energy price change, grid signal). Energy storage allows these systems to consume, retain and release energy as required in response to specific energy demands. Smart controls respond to these external drivers and demands to manage our systems.

Maximise renewables and stabilise the grid

These measures can help maximise the utilisation of on-site renewables and help stabilise demand on the grid. Moreover it will help to decarbonise the grid: when renewable electricity generation is low, demand response measures reduce the load on the grid, reducing the amount of peak gas plant that must be switched on to meet the grid demand.

Smart controls and demand response measures in the home

What can you do?

Peak reduction

- Use passive measures and efficient systems to reduce heating, cooling and hot water peaks.

Active demand response measures

- These measures reduce the electricity consumption for a certain period.
- Install heating and cooling set point control with increased comfort bands, controlled with smart thermostats or home energy management systems.
- Integrate thermal storage of heat into communal or individuals system within a building.
- Reduce lighting ventilation and small power energy consumption.

Electricity generation and storage

- Use products that can generate electricity and feed into the grid, or power the building.
- Consider solar PV to water heat storage or battery storage.

Electric Vehicle (EV) charging

- It is generally accepted that there will be a large increase in electric vehicles, so it is essential to implement demand response to ensure grid stability.
- Charge EVs only when needed and allow the supplier to cut the charging short during peak times.
- Install 'Vehicle to Grid' technology which allows the battery of the EV to be used to supply the building during grid peak periods.

Behaviour change

- Raise awareness of how people use electricity and the impacts.
- Consider incentives to reduce peak demand.
- Encourage responsible occupancy.

Microgrids

- Consider being part of a small semi-isolated energy network, separate from the national grid.

Indicative costs of retrofit

How much does it cost to retrofit and what are the results?

Retrofit costs depend hugely on the baseline building's characteristics and condition. A rough guide for an average semi-detached home is £5-15k for a shallow retrofit which, if starting with a poor baseline, could save around 30% in carbon emissions, through to £45-55k for a deep retrofit which would include significantly improving the building fabric, changing the heating system to a heat pump and fitting roof mounted solar PVs. This level of retrofit could achieve an 80-90% reduction in carbon emissions – particularly in the future as the heat pump makes use of a lower carbon grid.

Seeing retrofit as an additional cost to maintenance?

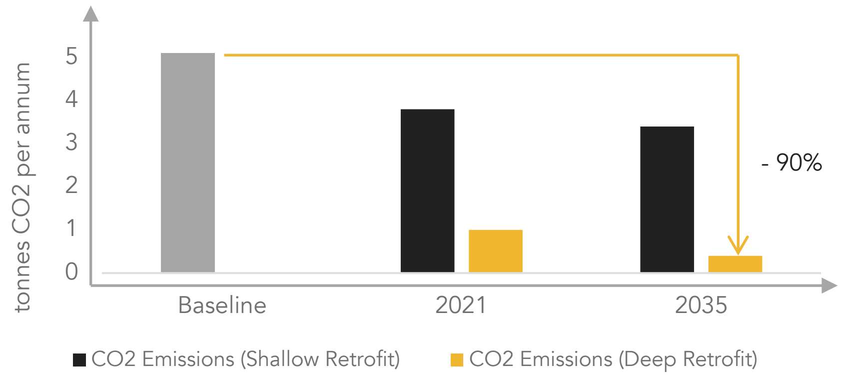
It is important to consider whether a measure is best undertaken as part of a planned or required maintenance activity. For example, re-rendering a wall would be an ideal time to apply external insulation and would mean the actual extra costs are just the insulation material and labour to secure the insulation to the wall.

And don't forget the co-benefits

Improved comfort, health and lower fuel bills are all valuable and important outcomes of retrofit. Prioritising measures using these different criteria is likely to produce a different order of priority for retrofit. For example, health and wellbeing is probably most improved by a Mechanical Ventilation with Heat Recovery (MVHR) system as this will dramatically improve indoor air quality and comfort. On the other hand, in most solid-walled dwellings, external wall insulation will offer the greatest net energy savings, and so the most significant reduction in fuel bills, despite being relatively expensive.

Measure	Shallow	Deep
Fit 100% low energy lighting	£ 20	£ 20
Increase hot water tank insulation by 50mm	£ 50	£ 50
Loft Insulation - add 400mm	£ 500	£ 500
Fit new time and temperature control on heating system	£ 150	£ 150
Improved draught proofing	£ 150	
100% draught proofing - improve airtightness		£ 2,000
Cavity Wall Insulation - 50mm	£ 600	£ 600
Floor Insulation - between & below suspended timber		£ 1,500
Insulate all heating and hot water pipework		£ 500
Fit Mechanical Ventilation and Heat Recovery (MVHR)		£ 7,000
Main Heating - High Efficiency Condensing Gas Boiler	£ 3,800	
Main Heating - Air Source Heat Pump and new HW tank		£ 9,000
Half Glazed Doors - Double Glazed (16mm argon)	£ 1,500	
Half Glazed Doors - Triple Glazed, High Performance		£ 2,000
External Wall Insulation - 160mm Expanded Polystyrene		£11,000
Double Glazing (16mm Argon Filled, Low E)	£ 7,000	
Triple Glazing (16mm Argon Filled, Low E)		£ 8,400
Photovoltaic Panels, 3kWp array, (21m^2 area)		£ 6,500
Miscellaneous and emabling works	£ 1,000	£ 5,000

Indicative retrofit costs for an unrenovated 90m^2 semi-detached dwelling



CO_2 reductions for an unrenovated 90m^2 semi-detached dwelling

Embodied carbon

Embodied carbon is the carbon emissions associated with the extraction and processing of materials, energy use in the factories and transport associated with the products used in the retrofit. It includes emissions associated with disassembly and disposal of these products at end of life as well as the construction of the building and repair, replacement and maintenance. It also includes the demolition and disassembly of the building at the end of its life. Low embodied carbon design is not inherently more expensive or more complex, it just requires awareness and good design.

What can you do?

1 **Use re-used or reclaimed materials**
Prioritise materials that are reused or reclaimed and that are durable. If not available use materials with a high recycled content.

2 **Use natural materials**
Use natural materials where possible. Insulation choice is a good opportunity to reduce embodied carbon.

3 **Lean design**
Finishes: Use self-finishing internal surfaces.
Building Services: Target passive measures such as improved fabric to reduce the amount of services needed. Reduce the need for long duct runs, specify low Global Warming Potential (GWP) refrigerant (max. 150) and ensure low leakage rate.

5 **Encourage EPDs**
Ask manufacturers for Environmental Product Declarations (EPD) and compare the impacts between products in accordance with BS EN 15804 (2019).

6 **Easy maintenance and use**
Consider maintenance & access requirements, maintained equipment will last longer.

7 **Design for disassembly**
Consider disassembly to allow for reuse at the end of life of the building, this is key to creating a circular economy. Create material passports for elements of the building to improve the ability of disassembled elements to be reused.

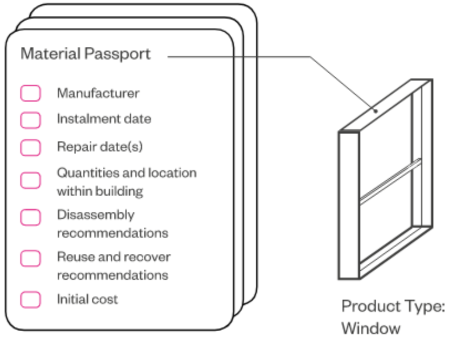
Sheep wool insulation

Cellulose- made from recycled paper

Cork insulation

Hemp insulation

Some insulating materials like straw bale, hempcrete, and wool store (sequester) carbon and have negative emissions



Create material passports for products: A material passport provides identification of materials, components and technical characteristics with guidance for deconstruction and applicability of re-use. In this way the building becomes a material bank for future use.

Design checklist

Heating System

Replacing the heating system e.g. adding a heat pump can significantly improve efficiency

Mechanical Ventilation

MVHR 90% efficiency

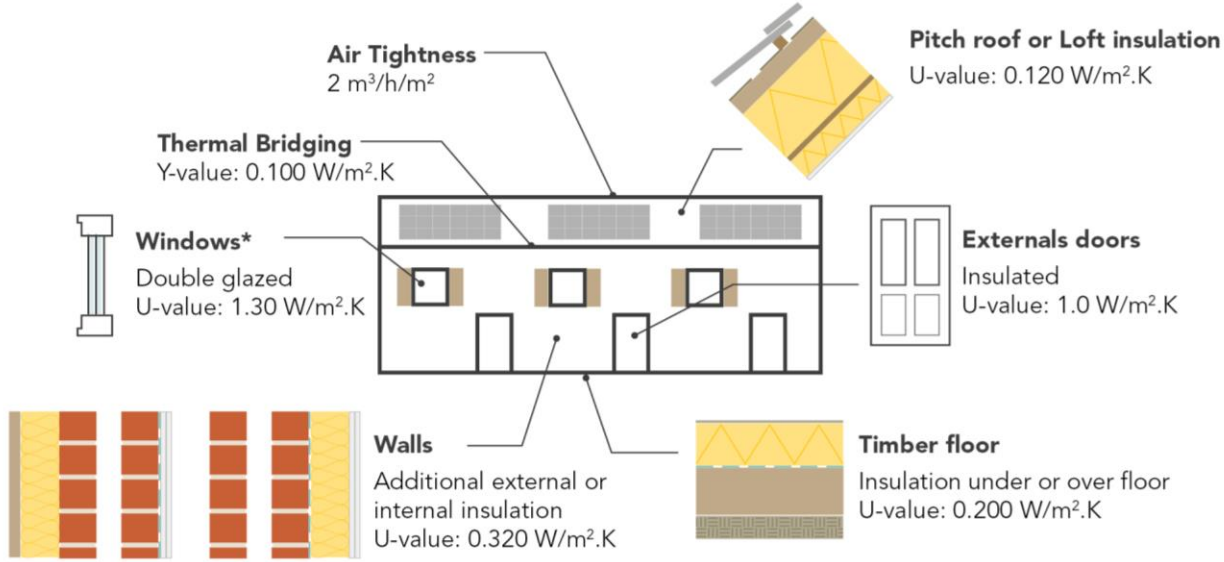
≤2m duct length from unit to external all

Airtightness

An extremely airtight building fabric of 2 m3/h/m2 at 50 Pa.

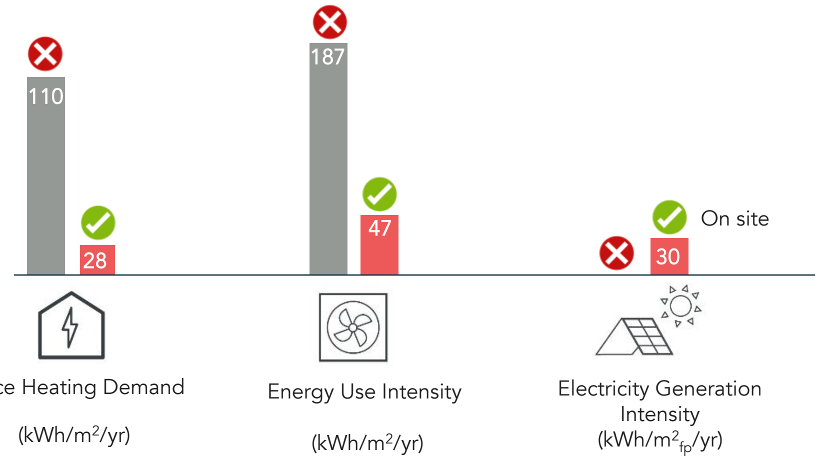
Improve fabric efficiency

Add insulation externally or internally to improve fabric efficiency



Performance

As the Energy Use Intensity (EUI) is the same as the electricity generated on site that means that the building is net zero carbon.



- Typical terrace house built to building regulations
- New zero carbon terrace house

How it comes together - Retrofit of a terrace house in a conservation area

Working with constraints

A retrofit of building within a conservation area or with other heritage constraints can be challenging. It is therefore important to weigh up the options and "do the most where you can". It should be noted that these constraints do not apply to the majority of the houses in the U.K. and only a select few. It is advisable to bring on board a heritage consultant early to understand the constraint and work together to find appropriate solutions.

Consider a hybrid approach

Consideration to the placement of additional insulation to work with the building's aesthetics using a combination of internal and external insulation. For example, if a building has a decorative frontage which contributes to character of the street, it may be better to use internal insulation on this façade. Whereas the rear of the property may be seen as less significant and therefore external insulation could be applied here.

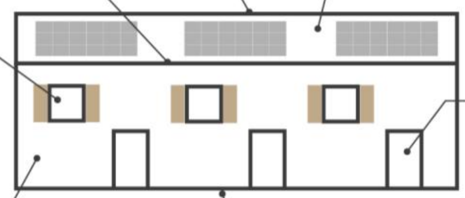
Breathable materials

In older stone wall construction that are more prone to damp, consider natural breathable materials (hydrophobic insulation) such as hempcrete which will not trap moisture.

Finding opportunities for renewables

Consider placement of solar panels on non prominent roofs that do not impact any constrained aesthetics. Also consider the orientation of solar panels to ensure they working efficiently i.e. avoid placing on shaded and north facing roofs.

Diagram illustrating a hybrid retrofit approach with internal and external insulation.



Recommended U-values to target net zero carbon for a constrained property.

Don't do this! (retrofit)

The intention of this toolkit is to provide clear guidance on what you should do when retrofitting a building to be Net Zero carbon. This page summarises some of the "Don'ts"…

Don't be misled by technologies and environmental schemes

When looking to build sustainable and low energy buildings, there are plenty of distractions. Many products, systems and technologies are suggested to be silver bullets in helping achieve Net Zero carbon buildings. Unfortunately, when put under scrutiny, many products or strategies do not achieve the desired outcome.

Additionally environmental schemes for existing homes may not all by themselves help the building achieve Net Zero carbon.

Avoiding business as usual

There is an emerging consensus in the construction industry on how to achieve Net Zero operational carbon. For example, there are several key energy efficiency, heating and ventilation principles which need to be adopted which have been discussed in earlier sections. Taking a business as usual approach to construction is not sufficient because many traditional ways of heating and ventilating homes are not aligned with a Net Zero objective.

Do not forget about the risk of moisture and condensation

One of the major risks associated with low energy and Net Zero carbon retrofit is creating areas where moisture condenses leading to mould growth. This typically happens when applying wall insulation, or where thermal bridges (e.g. around windows) are not treated to reduce the risk of condensation. It is extremely important to not forget about moisture as part of the retrofit process, and specialist advise should be sought to advise in order to mitigate this risk.

X *Do not replace the gas boiler. Heat pumps should be considered*

X *Do not leave open fireplaces.*

X *Do not install extract only ventilation systems. MVHR should be adopted.*

X *Do not install domestic wind turbines.*

X *Do not rely on trickle vents to provide ventilation. MVHR should be adopted.*

X *Do not install double glazing windows. Install triple glazed windows.*

Case studies for retrofit

There are many examples

A lot of examples of successful retrofits are now available. The adjacent images illustrate different typologies and examples but there are many more.

Key lessons learnt

Successful retrofit relies on a structured process including adequate assessment, design, installation and monitoring as set out within the Publicly Available Specification (PAS) 2035. It is underpinned by the idea of a retrofit coordinator who will help lead the process from start to finish.

Opinion has varied on how far to go over the last 30 years. Schemes like the Green Deal did not set an end goal or a metric but used 'pay back rules' which tended to undermine whole house thinking and quality. Consensus is now emerging that whole house plans are an appropriate way to take into account the specific characteristics of a house while providing a flexible path to the end goal for homeowners and landlords. For example this would enable them to coordinate retrofit with their ongoing maintenance/extension and other life plans.

It can be done: the Technology Strategy Board "Retrofit for the Future" programme, undertaken over 10 years ago, delivered 80% carbon reductions on 37 pilot homes.

This included 11 pre-1919 homes which demonstrated that heritage sensitive retrofit measures can deliver the scale of carbon reduction we need to see happening more.

(© Marion Baeli, Paul Davis and Partners)

Shepard's Barn, County Durham

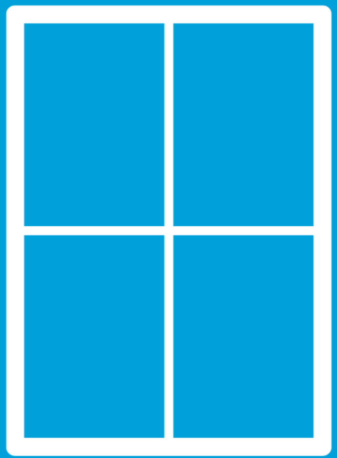
Passmore Street, London

Ernley Close, Manchester

Wilmcote House, Plymouth

Grove Road, London

Akerman Road, London



Products

Achieving Net Zero on new and existing homes also relies on good quality products.

This section explains the level of performance to require from products which will help to reduce energy use and generate renewable energy.

Windows

Window types

Window performance will vary greatly and is not always immediately apparent from their external appearance – or even price.

Key selection criteria

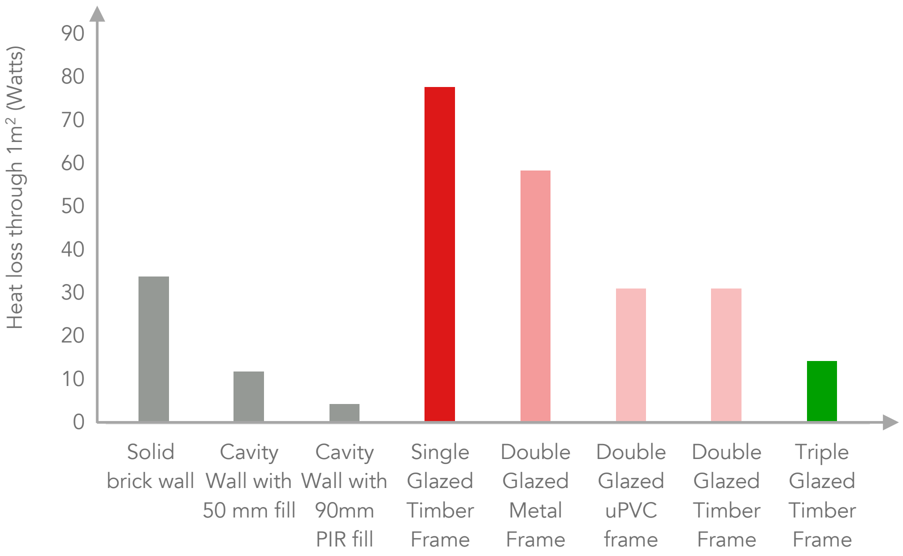
Glazing U-value - This is an indication of the ability of the glazing itself to retain heat. For double glazing, this should be 1.3 W/m²K or lower. For triple glazing you should expect 0.6 W/m²K or lower.

Frame type - The frame is an important part of the window's thermal performance. Generally, it is best to avoid metal frames unless they have a dedicated thermal break. Timber frames offer good levels of performance and are a good option in most cases and can be clad in aluminium if required. If you can find out the frame U-value, it should be ideally less than 1.6 W/m²K.

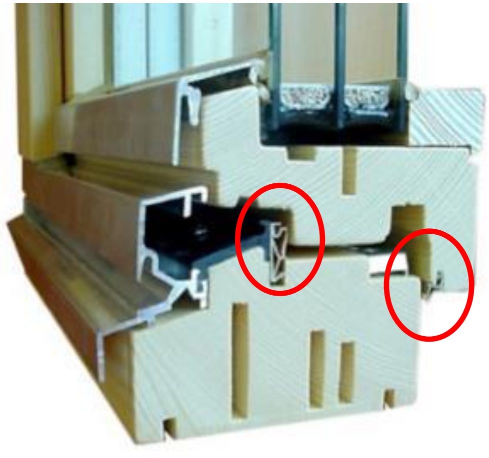
Whole window U-value - Sometimes, manufacturers do not provide a separate glazing and frame U-value and will only provide a U-value for the whole window. If this is the case, aim for <1.4 W/m²K for double glazed and <0.85 W/m²K for triple glazed.

Window design - For most types of frame, the frame performance will be worse than the glazing performance. This means that we should try and minimise the amount of frame – including mullions and transoms – to make the window as efficient as possible. This will also improve the amount of daylight entering the building.

Airtightness - The way in which the window's closing mechanism works, combined with the design of the opening sash sections will influence how good the window will be at keeping out draughts. Look for a multi-point mechanism with two separate seals – this will help with security as well as airtightness. Ask if the window has an air-permeability test rating – if it does, it should be Class 4.



Heat loss through 1m² of various wall and window types (with 0°C external temperature)



Triple glazed opening sash – timber frame with aluminium cladding and two seals.

Multi-point locking mechanism

Doors

This page summarises some of the key selection criteria when reviewing which doors to purchase.

Key selection criteria

U-value – This describes the thermal performance of the door product. Consideration should be made to the U-value of the whole door unit. A U-value of 1.0 W/m^2K should be used as a guideline.

Glazed doors – If the door is glazed, then the glazing properties need to be considered. The g-value as well as the U-value needs to be considered as these impact energy performance and solar gains.

Airtightness rating – The airtightness rating of the doorset systems should be reviewed, and high performance systems specified.

Embodied carbon – The amount of carbon dioxide equivalent emissions generated in the production and manufacture of the door unit material should be considered.

Security – Consideration should be made to the security ratings when selecting the doors.

Performance ULTRA insulated timber door - Green building store

Triple glazed timber doors - Green building store

Internorm triple glazed balcony door

Garage Door - Hormann LPU67 Thermo M

Find High Performance Door Products

The *Passive House Institute Component database* is a fantastic way of searching for high performing door products.

Insulation materials

There are many types of insulation products which are appropriate based on their application. Insulation, and the systems used to support them are key to achieving low U-values. The following considerations should be made when selecting Insulation:

Key selection criteria

Area for use – Where will the insulation be used (e.g. external wall, roof, floor).

Thermal conductivity – How much heat the material conducts. The lower the conductivity, the better performing the product.

Moisture and air permeability – Some insulation products allow water vapor and/or air to pass through them, and some don't. It is important to understand their hygroscopic properties, particularly when retrofitting a pre-1919 building.

Thickness – The thickness should be considered to ensure it achieves the required U-value and aligns with building setting out. For external walls, it is important to ensure that the products used to support insulation are available in the length required.

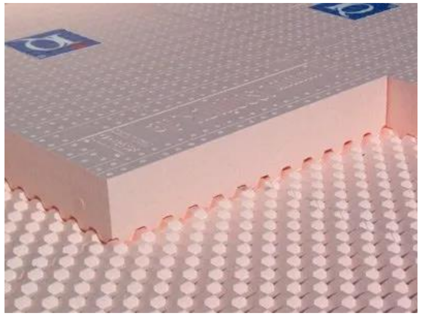
Physical properties – Insulation can be rigid or not, and there are advantages to both. Consideration should be made for insulation installation on site and methods of construction.

Fire rating – The building regulations associated with fire rating and insulation should be consulted to ensure safe and compliant products are used in the correct areas.

Compressive strength – Some insulation may require a degree of compressive strength, and this should be considered (usually floors).

Embodied carbon – The amount of carbon dioxide equivalent emissions generated when producing the insulation material should be considered.

Knauf Dritherm Mineral Wool Insulation



ISOQUICK® insulating foundations

Foamglas Perinsul - structural insulating material

Finding High Performance Insulation Products

The *Passive House Institute Component database* is a fantastic way of searching for high performing insulation products.

Airtightness products

Main building elements

The main building elements that form the airtight layer are the floors, walls, roof, windows/rooflights and doors.

Concrete surfaces such as a floor or roof slab can usually be considered airtight. Masonry walls built from blockwork are not airtight, but can be made so with a suitable parge coat and wet plaster. Timber framed structures such as walls and roofs can use airtight OSB boards or specialized airtight membranes to create an airtight building element.

Connections

Most connections between airtight elements of the building are made airtight through the use of specialist airtight tapes. These are designed and manufactured to last for many decades and should never be substituted for other construction tapes. Many different versions are available for different applications, for example fleece backed tapes that can be plastered over, double sided tapes for window frames, tapes for below ground use. Certain surfaces require application of a primer before taping, so make sure you know where these are on your project. Some sealants are also available for situations where tapes are not suitable.

Services

Building services such as cables, pipes and ducts can be sealed with airtightness tapes, or specialised grommets that come in a range of sizes and styles. While grommets are more expensive, they can reduce the amount of labour required to achieve airtight service entries.

Large airtight surfaces within buildings are typically created from airtight OSB, parge coat and wet plaster applied over blockwork, concrete castings, or specialised airtight membranes. Do not use cheap polythene membranes, as these are fragile and lack the rigidity to tape without creases that cause leaks.

Components of the airtight layer are primarily connected together with tapes. Appropriate primers should be applied to certain surfaces before taping to ensure adhesion. Airtightness grommets and specialised long-life sealants are also available to assist with more specialist junctions in construction.

Ventilation units

Mechanical Ventilation with Heat Recovery (MVHR)

There are many MVHR units available on the market. In practice, a building services engineer or professional will often be involved in helping you to select an appropriate unit. Key selection criteria to consider are:

Air volume flow rate (litres per second) – This must be high enough to meet requirements in Part F of the building regulations, and to mitigate overheating risk.

Pressure drop (pascals) – This is how much pressure the MVHR can overcome and will influence your ductwork design.

Noise rating (dB) – This needs to be low enough at the design duty not to cause a nuisance. In a utility space NR35-40 may be appropriate, however if it is near living space or sleep accommodation NR25 or lower should be targeted.

Size – MVHR units come in varying sizes and shapes, some are more suited to cupboard installation and some are longer and flatter suited to a ceiling void. A key consideration for size is selecting a unit to suit the space available that allows for the filter to be easily changed.

Specific Fan Power (Watts per litre per second) – This is critical to the energy efficiency of the ventilation system. A value of 0.9 or lower is recommended.

Heat recovery efficiency (%) – This defines how much heat can be recovered from the exhaust air. For best practice a minimum of 90% efficient should be targeted.

Summer bypass – This automatically bypasses the heat exchanger so heat is not recovered when using the ventilation unit for cooling.

Certification – Choose an MVHR unit that is Passivhaus certified to ensure quality and performance

A range of Passivhaus certified MVHR units are available in both wall and ceiling mounted designs. The performance of Passivhaus certified units has been independently verified, which can be a good indication that a manufacturer is motivated to demonstrate the energy performance of their product.

Pre-insulated MVHR ducting is available from a range of manufacturers in both rectangular and round format. These systems can simplify duct installation between the MVHR unit and outdoor air terminals, improving energy efficiency. Combined intake/exhaust terminals are also available, which often help to minimise duct length, also increasing efficiency.

Waste Water Heat Recovery Systems

Waste water heat recovery systems recoup heat

Waste water heat recovery (WWHR) systems recover heat from shower or bath water as it is drained, this is used to warm the incoming mains water. The systems are very simple, and typically come in two forms, vertical or horizontal.

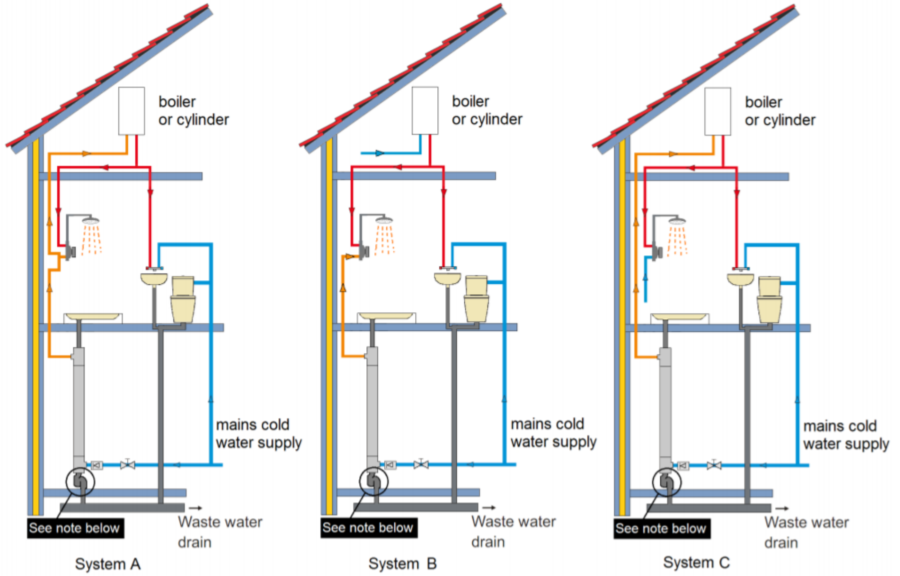
WWHR systems can be included in retrofit

Although WWHR units are far easier to install for new housing, this does not mean they cannot be installed as part of retrofit. As long as there is access to the pipework serving the shower and suitable pipework lengths, a unit can be installed.

Key selection criteria

Efficiency of recovery unit (%) – This represents the percentage of heat recovered by the MVHR system compared to actual heat required for the shower. The efficiency is greater for showers with lower flow rates. For vertical units, target greater than 55% and for vertical units, target greater than 25%.

Other key considerations during selection and installation include shower flow rates, pipework connection sizes for the mains water and waste water, and water pressure. Manufacturer guides will provide acceptable ranges and details for their products.



System A	- WWHRS outlet connects to water heater inlet AND shower cold inlet
System B	- WWHRS outlet connects to shower cold inlet ONLY
System C	- WWHRS oulet connects to water heater ONLY

A diagram of installation configurations for waste water heat recovery.

Heat pumps

Selecting the right heat pump

Sizing a heat pump is never simple. There is no one-size-fits-all as the heating demands of every property and family is unique. To get air source and ground source heat pump size right, the following things should be considered.

- Type/size of property
- Level of insulation/heat loss
- Size of radiators/underfloor heating
- Desired indoor temperature
- Seasonal outdoor/ground temperatures in your area

Key selection criteria

Maximum heating capacity (kW) - Heat pumps are given output ratings in kilowatts (kW) which represent how powerful a heat pump is. For heat pumps, bigger is not always better though: they should be sized according to the peak heating demand. Max heating capacity tends to range from 4 kW and 16 kW.

Minimum heating capacity (kW) - The minimum capacity of the system selected is as important as the maximum. A good heat pump has adequate turn-down to perform well during low-load conditions as well as peak conditions

Coefficient of Performance, CoP – The efficiency of a heat pump is expressed as ratio of the heat energy produced to input electrical energy. For example, if a heat pump produces 4 kWh of usable heat for a home and requires 1 kWh of electricity to do so, it has a COP of 4.

Seasonal Coefficient of Performance, SCoP - This is an average coefficient of performance taken across the entire heating system, and the main metric used to define the performance of a heat pump.

Maximising heat pump efficiency

The efficiency of heat pumps increase as the temperature difference between the heat source and system temperatures. To increase efficiency consider:

Lower system temperatures - Whereas radiators typically require a minimum water flow temperature of 45-55˚C, underfloor heating can operate as low as 25-35˚C. Lower system temperatures also mean lower losses in conversion, storage and distribution of heat.

Heat source - The temperature of the ground is roughly 10–13˚C all year round, so a ground source heat pump remains consistently efficient, unaffected by seasonal changes. An air source heat pump on the other hand is subject to fluctuating air temperatures. In the colder months, when there is the greatest demand for heating, they are at their least efficient.

Maintenance and warranty

When correctly installed, heat pumps should require little maintenance and last for at least 20-30 years. If something does go wrong, it can lose efficiency fast, but this underperformance should be noticeable. Most heat pumps come with a 5-10 year warranty on parts and labour.

	Heat Pump Type	Standard CoP	Best Practice CoP
Heat Pump - Space Heating	ASHP	2.50	3.50
	Closed GSHP		4.50
	Open GSHP		5.50
Heat Pump - Domestic Hot Water	ASHP	2.0	2.50
	Closed GSHP		2.50
	Open GSHP		3.00

Air source heat pumps (ASHPs)

Efficient and fossil fuel free

Air source heat pumps (ASHPs) absorb heat from the outside air, from temperatures as low as -15°C, to provide space heating and hot water. They run on electricity but are far more efficient at generating heat than conventional systems and therefore require less energy. Unlike gas and oil boilers, heat pumps tend to deliver heat at lower temperatures over much longer periods.

The two main types

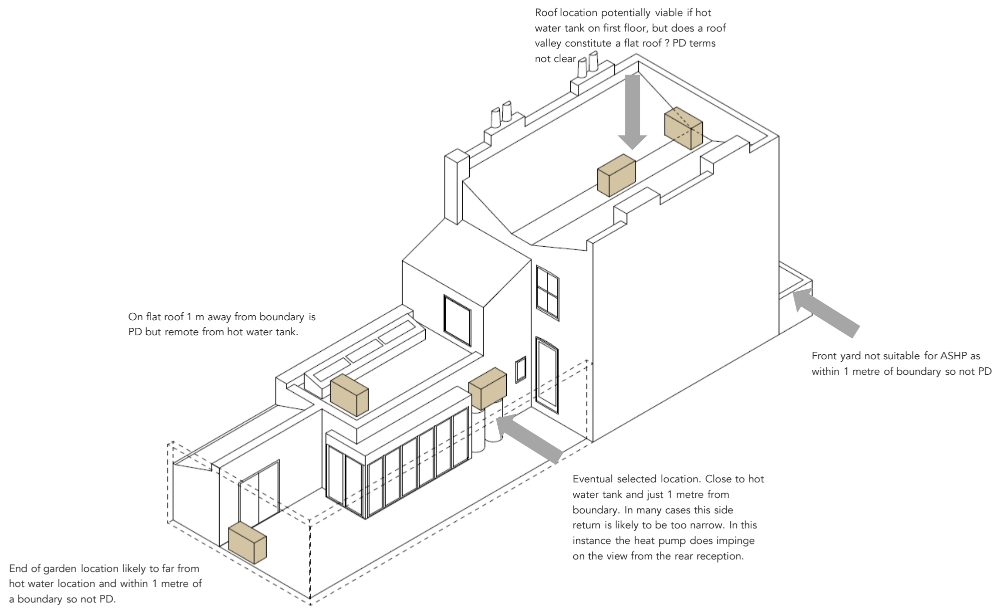
Air-to-water heat pumps are the most common and can be used with a wet central heating system. Because of the lower temperatures they work well with underfloor heating or larger radiators. Air-to-air heat pumps provide warm air directly to a room. They will not provide you with hot water as well.

Heat pumps need a home, and you may need planning permission

You will need a place outside the home where the external unit can be fitted to a wall or placed on the ground, with plenty of space around it for air flow. The external unit is often connected to an internal unit containing circulation pumps and hot water, which is usually larger than the average boiler. Although they might not take up much space, heat pumps may be visible. If permitted development rights cannot be used, a planning application may be required with a noise report.

Potential fuel bill savings

Installing a typical system costs around £5,000 to £11,000. It will most likely reduce fuel bills if replacing a conventional electric heating system, but you are unlikely to save much on your heating bills if you are switching from mains gas, unless other energy efficiency and fabric improvements are made.



Potential locations identified by the architect for a terrace house (© Prewett Bizley Architects)

Benefits

1. It could lower fuel bills if replacing conventional electric heating
2. It could provide an income through the UK government's Renewable Heat Incentive (only applies to air-to-water heat pumps)
3. Fossil fuel free and highly efficient therefore will reduce carbon emissions
4. It can provide hot water as well as space heating
5. It can be easier to install than a ground source heat pump

Ground source heat pumps (GSHPs)

Efficient and fossil fuel free

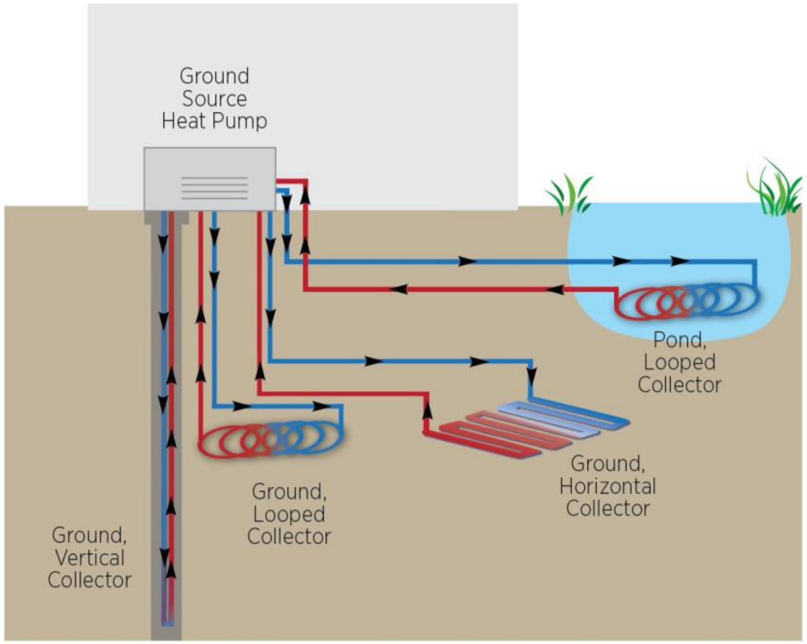
Ground source heat pumps (GSHPs) use a buried ground loop to extract heat from the ground which is then passed through a heat exchanger into the heat pump. This heat can be used to serve radiators, underfloor heating, warm air systems and hot water. Heat pumps run on electricity, but the heat they extract from the ground is renewed naturally. They are far more efficient at generating heat than conventional systems and therefore require less energy.

Space is required for the ground loop

The length of the ground loop required depends on the amount of heat needed. If there is enough space, the loop can be laid horizontally in a trench. Where there is not room to do this, you can drill vertical boreholes, typically between 90m and 160m deep, but this requires specialist machinery and may increase the cost of installation.

A potential source of income

Installing a typical system costs around £14,000 to £19,000. It will most likely reduce fuel bills if replacing a conventional electric heating system, but you are unlikely to save much on your heating bills if you are switching from mains gas, unless other energy efficiency improvements are made. If the system is part of a new development, combining the installation with other building work can reduce the cost of installing the system. You may be able to receive payments for the heat you generate using a heat pump through the [UK Government's Renewable Heat Incentive].



Different types of ground loop can serve the heat pump depending on the space available.

Benefits

1. It could lower fuel bills if replacing conventional electric heating
2. It could provide an income through the UK government's Renewable Heat Incentive
3. Fossil fuel free and highly efficient will reduce carbon emissions
4. It can provide hot water as well as space heating
5. Minimal maintenance required

Domestic appliances

White goods

The main energy consuming appliances to consider are dishwashers, clothes washers, clothes dryers, refrigerators, freezers and cookers. When purchasing from new, energy labels should be available. Compare these to best practice performance on the Top Ten UK site below, and choose the most efficient appliance that meets your needs.

If purchasing second hand appliances, energy labels can often be found by searching the model number of the appliance.

Consumer electronics

The energy consumption of consumer electronic devices is usually quite low. Possible exceptions include devices that produce heat, such as coffee makers with keep hot functions.

Audio visual

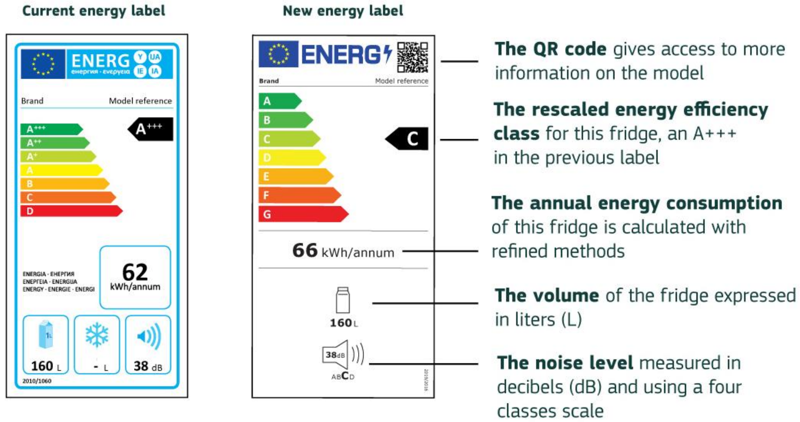
Most new televisions and stereos are relatively energy efficient, however energy labels are available, so follow the same advice as for selecting white goods. Games consoles have powerful processors that can use reasonable amounts of energy, so should be turned off when not in use.

Standby consumption

While electricity use in standby mode (also known as vampire load, or phantom consumption) used to be a significant concern, a series of increasingly stringent EU regulations over the past decade have effectively reduced it to negligible levels.

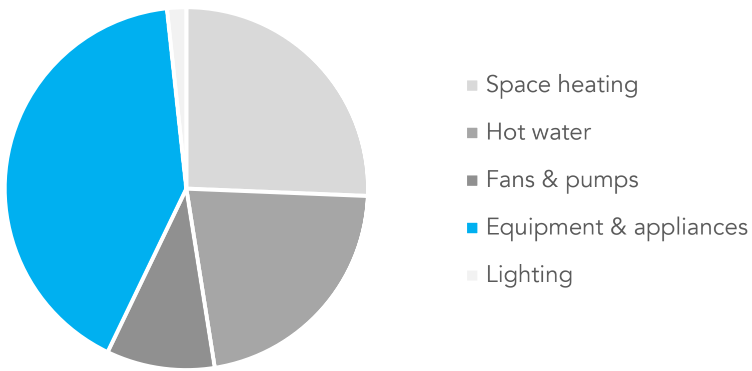
Resources

The Energy Saving Trust's 'Top Ten' is an excellent resource that lists the most efficient appliances currently available on the market.



The energy labels for a fridge without freezer

Most appliances for sale in the UK will continue to carry EU energy labels. These were rescaled in Spring 2021 to adopt the original A to G system, ending the use of A or higher ratings. Under the new scale, there are few A-rated appliances currently on the market – this is intentional, to allow room for future improvements to efficiency.*



Electricity used by equipment and appliances is likely to be the largest end use of electricity in many net zero energy homes, so it is important to choose the most energy efficient appliances you can. Data based on energy modelling for a net zero energy new build home.

Solar photovoltaic (PV) panels

Solar PV panels

Modern solar PV panels are a simple, mature and reliable technology. Most solar PV panels currently manufactured are based on wafers of monocrystalline silicon. Outdated polycrystalline technology is still available and should be avoided. Choose a panel with a 25 or 30 year linear power output warranty.

Sizes vary, but 1,730mm x 1,040mm is typical. Expect a power output of 360 Watts per panel, though up to 400 Watts or more is possible. It does not usually cost much more to specify a higher power panel, so this is often a good option to consider, particularly if you plan on using a heat pump or electric vehicle in the future.

Solar tiles are available, however standard format solar panels dominate the market for good reason. If you decide to install solar tiles, choose a company with a track record that will be around in the future to provide spare parts and support if required.

Specify monocrystalline silicon solar panels and microinverters for best long-term performance. Image shows a generic solar panel and an Enphase IQ7 microinverter.

Inverters

The inverter in a solar PV system conditions the electricity generated by the solar panels so it is safe to use in your home. Traditional systems used a single large inverter, however small 'microinverters' that mount behind each panel offer numerous benefits. They cost a little more than a single larger inverter, but can increase energy output up to 15% and are very reliable, with 25 year warranties available.

Batteries

In many cases, batteries cost more to buy and operate than they will ever save you, though there are exceptions. Batteries also increase the complexity and embodied carbon of a solar PV system. Consider smart thermostats, solar hot water diverters and solar EV charging to increase self consumption of solar electricity.

Power output warranties lasting 25 to 30 years are standard for solar photovoltaic panels. Look for a panel with a linear (rather than stepped) performance warranty for increased lifetime energy production.

How to Specify

Delivering homes that will perform well in reality (and not just on paper) relies on a quality assured construction or retrofit process.

This section provides guidance on how to specify key elements.

Approach to deliver Net Zero carbon buildings

Decide on your targets

From the very start of the project, you should be clear about the targets that you are aiming for. For both new build and retrofit, this should be expressed in Energy Use Intensity (EUI) and Space Heating Demand. Both of these should be modelled early on to see how your project matches up. Space Heating Demand is an excellent proxy for the fabric efficiency of the building. It will tell you how far you have gone down the fabric first approach. Exemplar values for homes are 15 kWh/m^2.year for new build and 25 kWh/m^2.year for retrofit, although retrofits can be challenging and a target of 50 kWh/m^2.year would be a significant achievement in most cases.

Do whatever it takes to move to electrical heating and hot water

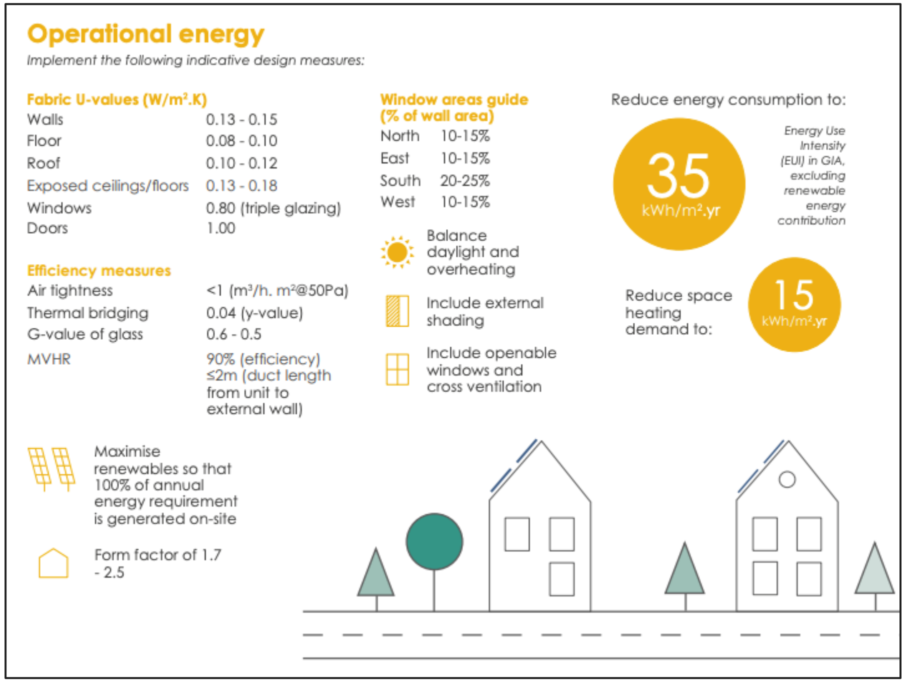
This guide has made it clear that fundamental to achieving Net Zero carbon homes is transitioning to electrical based heating and hot water to capitalise on grid decarbonisation. To avoid high running costs, this is best achieved by fitting heat pumps. Thus, make sure you design your fabric, heating and hot water strategy around the basic premise of a heat pump. For retrofit, even if you can not fit one straight away, put enabling measures in place so one can be fitted in the future.

Build the team's knowledge

Much of what goes in to a Net Zero homes, it not necessarily part of normal building practice. It is important to get the whole team on board from the designers, right through to the site team. Arrange regular tool box talks so that everyone understands the key principles that are being targeted like airtightness and eliminating thermal bridging.

Measure the results

How do you know it has worked? It is now cheap and easy to monitor energy use so put this in place as part of the project so you can see how it performs and, if necessary, make some improvements next time.



LETI Targets for new-build dwellings (LETI Climate Emergency Design Guide)

The AECB Retrofit standard sets a space heating demand target of 50kWh/m^2.year

Finding competent contractors

There is no substitute for experience

When looking for suitable contractors, find out if they have completed any low energy or Net Zero projects. Ideally, they will have completed a project which has been quality assured or certified in some way. A Passivhaus certified project (new build or retrofit), AECB self-certification with independent verification, or a self-declared LETI Pioneer project would all be good indicators. Failing that, any project which has good post-occupancy monitoring data showing its actual performance is also a good sign.

National schemes

PAS2035 sets out a framework for the design and management to ensure the safe and effective implementation of energy efficiency measures. PAS2030 set out the standards that must be achieved in installing these energy efficient measures. If you are embarking on anything more than a very minor retrofit, then it would be advisable to ensure that your design team includes a qualified Retrofit Coordinator who has met the requirements of PAS2035 and that your contractor has achieved PAS2030 certification.

Other trade bodies

For specific retrofit elements, there are also other trade bodies which you can ask whether your provider is registered with:

- *Cavity Insulation Guarantee Agency*
- *Solid Wall Insulation Guarantee Agency*
- *Microgeneration Certification Scheme (MCS) - for heat pump and Solar PV installations*
- *Trustmark*

PAS2030 and PAS2035

Agencies and schemes which protect consumers and require certain standards

Specifying airtightness requirements

This section summarises the requirements during construction in order to ensure that the airtightness target can be achieved.

Managing the airtightness risk

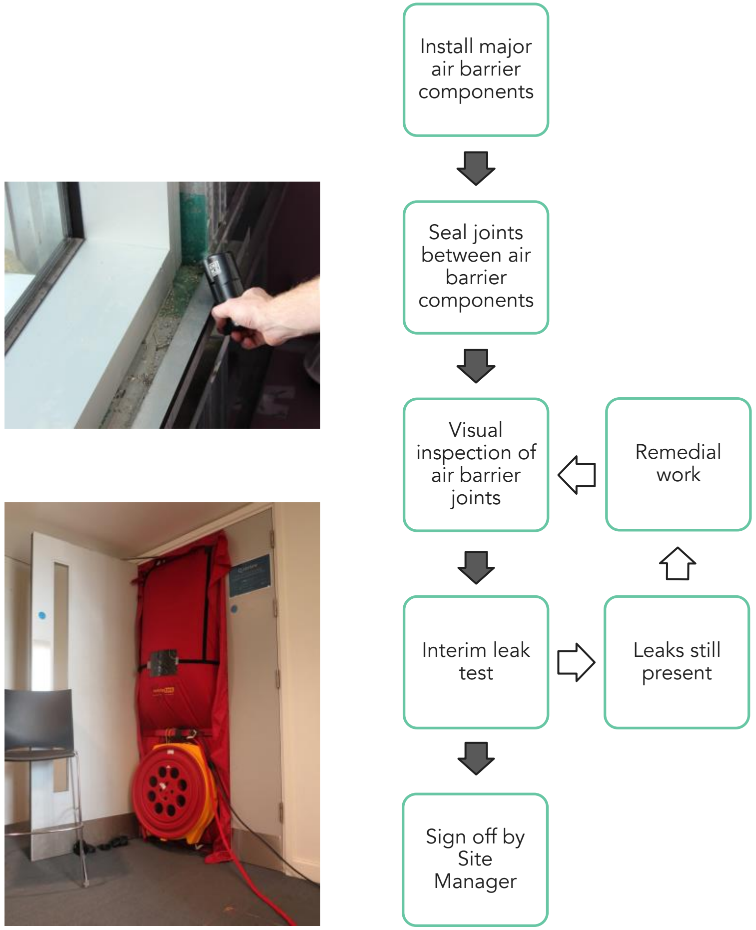
It is possible to robustly manage the risk of achieving the airtightness requirement on site. The contractor should take responsibility for delivering the airtightness and propose a robust strategy. A programme including interim leak tests, proposed materials and proposed responsibility will be required as a minimum. Early testing gives reassurance that the quality of construction is on course to meet the target, and allows any quality issues to be easily and cost effectively found and rectified. Leaving these issues to the end of the project is a far more risky and potentially costly approach and may lead to failing to meet the airtightness target.

The importance of interim leak testing

A phased leak testing strategy is recommended. Each dwelling should be tested for air leaks before the air barrier is covered or closed up.

- ✓ All air barrier parts should be installed and open to visual inspection.
- ✓ Using a blower door fan to negatively pressure areas undergoing internal investigation or positively pressurise areas for external investigation.
- ✓ Carrying out investigation on the air barrier side of the construction (internal for most of the building.)
- ✓ Using thermographic camera equipment, smoke pens, or feeling the joints to identify any air leaks.
- ✓ Remedying any leaks.

A section should be deemed to pass the leakage test when no leaks in the external fabric can be detected with reasonable effort.



Recommended airtightness process: visual inspection, leak finding and interim air testing are all required before the final air test

Commissioning of heat pumps and MVHR systems

Heat pumps

The commissioning of a heat pump is very similar to the commissioning of a boiler.

- Ensure the system is watertight – complete a standard test, first with pressurised air, then with water.
- Ensure the fuel source is safe – in this case check the electrical test certificate is in place.
- Ensure the unit is functioning correctly – check the flow volume and temperature (ideally at varying external air temperatures)
- Ensure the water pressure is inline with manufacturers recommendations.
- Ensure the user is trained – make sure any alarms are being generated correctly and that the user understands what protocols to follow for each alarm option.

MVHR systems

The following items should be checked on MVHR units

- Check filters are clean
- Inspect ductwork for any air leaks and seal where appropriate.
- Check that the ductwork is clean at the terminals
- Set the fan speed and balance the supply and extract flow rates
- Ensure the supply and extract rates to each grille are operating at the design air flow
- If there is a boost function make sure that this works correctly
- Ensure the user understands how to use and maintain the MVHR

Examples of Passivhaus certified MVHR units

Building performance delivery schemes

This page summarises several operational energy standards which would help achieve the levels of energy efficiency and construction quality required to deliver Net Zero carbon buildings.

New build standards

Passivhaus Classic, Plus and Premium - These schemes are facilitated by a designer and third party certifier to ensure the design and construction achieve best practice levels of energy efficiency and renewable energy generation (for Plus and Premium).

PHI low energy building standard - Similar to Passivhaus, this standard has slightly reduced energy efficiency targets.

Building Energy Performance Improvement Toolkit (BEPIT) – This scheme provides a practical framework through each stage of the project in order to deliver energy efficiency measures on site.

Retrofit standards

EnerPHit – Similar to Passivhaus, this scheme helps deliver exceptional levels of energy efficiency through deep retrofit and refurbishment.

AECB Low Energy Retrofit Standard – This standard is primarily focused on improving the building fabric but low carbon heat also needs to be considered.

Energiesprong – A model for retrofitting several homes at once. The up front costs of this scheme are financed through a payback based on savings to the tenants bills and an additional 'comfort charge'.

PAS 2035 – This code of practice published in 2019 seeks to provide quality assurance for retrofit. It focuses on the process, not the target(s).

New build standards

Retrofit standards

Standards summarised on this page help achieve the space heating and energy consumption levels of performance required to achieve net zero carbon buildings.

Some standards also address low carbon heat and renewable energy generation but they focus primarily on energy efficiency. Embodied carbon is not addressed by the above schemes and would require separate consideration

Building regulations and planning approval

When you need building regulations approval

Most building work (whether refurbishment, retrofit or new build) will need building regulations approval. Building Regulations is mostly concerned with ensuring homes are safe to live in.

In most cases your builder or tradesperson will be responsible for ensuring building regulations approval is obtained. However, you should check this at the beginning and be clear who is liaising with the building control body. The ultimate responsibility lies with the building owner, and fines may be issued where approval is not obtained.

You will need to use a building control body to check and approve work before, during and after construction. This can be through a local authority building control service (LABC) or through a private approved inspector. In some cases tradespeople can self certify, if they are registered with a competent persons scheme.

When you need planning

If you are altering the appearance or function of your building or site you may need to apply for planning permission from your local authority. This will be required if you want to:

- build a new home
- build an extension above a certain size
- change the use of an existing building for residential use.

To find out if you need planning permission, and how to apply for it, contact your local planning authority (LPA) through your local council.

Sources of information

The Planning Portal website and the Local Authority Building Control websites are both excellent sources of information on planning permission and building regulations approval.

	Building regulations approval	Planning permission
Objective:	To ensure the safety and health of people in or about those buildings.	To control the impact the development will have on the general environment.
Concerned with:	• Structure • Fire safety • Electrical safety • Access • Ventilation • Energy efficiency	• Appearance • Impact on neighbouring properties • Landscaping • Highways access
Through	• A building control body (through local authority or privately). • Competent persons scheme for some small works (e.g. repairs, replacement or maintenance.	• Local Authority planning department.
Find out more	• *Planning Portal* • *Local Authority Building Control*	• *Planning Portal* • *West Oxfordshire District Council* • *Cotswolds District Council* • *Forest of Dean District Council*

☑ Always check with your local authority whether you need either planning permission or building regulations approval.

☑ Are your tradespeople registered with the competent persons scheme?

☑ Check "right to light" laws when building, which are not included in the planning permission process, but a a legal right of neighbouring properties.

Communicating this to customers and clients

The industry is on a path to Net Zero carbon

We are in a climate emergency and it is important that we communicate this effectively to customers and clients to ensure immediate action is taken to meet our Net Zero carbon target. In 2019 the UK Government amended the Climate Change Act to adopt the recommendations of the Committee on Climate Change, and adopted a target for achieving net zero emissions by 2050. Delivering Net Zero carbon homes is an attainable target which can be achieved today and in recent years this has been clearly mapped out.

The future of housing

The Committee on Climate Change (CCC) report 'UK housing – fit for the future?' highlights the need to build new buildings with 'ultra low' levels of energy use. It makes a specific reference to space heating demand and recommends a maximum of 15-20 kWh/m^2.yr for new dwellings. Currently new domestic buildings can have a heating demand ranging anywhere from 40-120 kWh/m^2.yr. Buildings provide a significant opportunity for reducing emissions without impacting the quality of experience for those that use them. Targeting good practice design, such as Passivhaus for new homes, and well considered retrofit strategy will also ensure high construction quality and minimise defects on site.

Affordable and clean energy for residents

The transition to Net Zero carbon housing will also improve energy bills for residents, as well as local air quality. Moving away from fossil fuels and switching to low carbon heating is a necessary part of meeting Net Zero carbon.

The UK Government has committed to Net Zero emissions by 2050. Many regions and organisations are being put under pressure to improve on this. Over 1400 local jurisdictions, including Oxford, have declared a climate emergency.

Extinction rebellion and School Strikes for Climate protests showing strong public support for response to the Climate Emergency and action today. Greta Thunberg and the Schools strike movement have inspired the next generation of citizens Worldwide.

The importance of maintenance – Keep operating at Net Zero carbon

In order to for a building to operate at Net Zero it need to be maintained properly, particularly in the following areas.

MVHR

MVHR needs to be installed in an accessible location as filters need to be cleaned/changed every 3-6 months so that it operates efficiently.

Heat Pumps

Immersion heater should only be used as a back up to heat the water in the hot water store and only manually switched on if the heat pump is not working. If the Immersion heater is an automatic back up (might be the case for Exhaust air heat pump) – use of this Immersion heater should be closely monitored to make sure that it is not turned on more than it should be.

Airtightness layer

There is a continuous airtightness barrier around the building. It is important that this barrier is not broken, otherwise the airtightness of the building will get worse. Key watchpoints;

- Drilling into the wall – know where the airtightness layer in the building avoid damaging it by drilling through / perforating it.
- New penetrations for equipment such as washing machines, should be installed with airtightness grommets so that the water pipes do not increase the air permeability.

Solar PV

Every few months it is good to check the generation meter, to make sure that the panels are generating electricity and there is no fault. It is also important to clean the Solar PV panels every year, to make sure that they are operating as efficiently as they can.

Dirty filter

Clean filter

MVHR filters are easy to remove and clean, clean filters improve energy efficiency

Airtightness grommets need to be used so that service penetrations do not increase air permeability

PV panels need to be cleaned at least once per year

✔ Checklist for new build: design and construction

What to do when? Checklist for design and construction

RIBA Stage 2 - Concept Design	✓
Optimise building orientation to balance solar gain and increase south facing roof area. Design roof to maximise density of renewables.	
Calculate and report the building form factor for design options.	
Arrange embodied carbon workshops with design team to target lean design principles and reduce big tickets items e.g. structure.	
Identify design team members to carry out embodied carbon assessment. Carry out multiple embodied carbon calculations of key elements to demonstrate low carbon design choices.	
Mark-up insulation line on all plans and sections. Mark unheated external areas on plans.	
Allow sufficient wall construction thickness for all insulated walls, roofs and floors.	
Mark window openings for providing natural ventilation for summer comfort.	
Identify a location for the MVHR next to an external wall.	
Carry out preliminary overheating risk assessment using the Good Homes Alliance overheating checklist.	
Carry out initial PHPP model.	
For projects using Passivhaus certification this is a good time to consider an appointment.	

MVHR: Mechanical Ventilation with Heat Recovery

PHPP: Passivhaus Planning Package

This design checklist provides a list of key actions that should be carried out at each work stage to meet the KPI targets for new homes.

This should be shared with the design team to check off after each stage is complete.

RIBA Stage 3 - Spatial Coordination	✓
Review mark-up of insulation line on all plans and sections and carry out initial U-value calculations.	
Carry out heating options appraisal including a low carbon option.	
Hold a thermal bridge workshop. Include the structural engineer for review of columns, masonry support etc.	
Provide MVHR layout including duct distribution and measurement of intake and exhaust duct lengths to external walls for sample dwellings.	
Carry out full embodied carbon assessment of whole building and compare against embodied carbon target. Implement reductions where necessary.	
MEP consultant to review embodied carbon impact of services and reduce the amount of kit where possible. Use CIBSE TM65 embodied carbon in building services to assess impact.	
Carry out PHPP modelling alongside SAP calculations. List all model assumptions including U-values, thermal bridges and system specifications etc.	
Carry out overheating assessment and eliminate overheating through passive strategies where possible (TM59). Ensure all element assumptions match PHPP and SAP models.	
Calculate electricity generation intensity of PV arrays and review against KPI.	
Define airtightness strategy and identify airtightness line on plans and sections.	
Measure heating and hot water pipe lengths for sample dwellings. Minimise distribution or standing losses.	
Demonstrate distribution losses have been calculated and reduced.	
Prepare RIBA Stage 3 report and include predicted operational cost to tenant.	

What to do when? Checklist for design and construction

RIBA Stage 3+ - Early Technical Design (and tender)	✓
Detail build-ups of all external elements including thickness and conductivity of all materials.	
Detailed U-value calculations (including masonry support system, etc.).	
Identification of all thermal bridge junction types (e.g. parapet A, parapet B).	
Thermal bridge calculations for a selection of the most important junctions.	
Definition of airtightness testing requirements for contractor.	
Include requirements for Environmental Product Declarations (EPD) in the tender. Make EPDs obligatory for structural materials, primary façade and any other major materials.	
Include KPI requirements in the tender.	
Agree scope of Post-Occupancy Evaluation in tender. Identify level of participation from contractor and design team.	

RIBA Stage 4 - Technical Design (in addition to Stage 3+)	✓
Develop junction details for window and doors.	
Review airtightness line on each drawing and identification of airtightness requirements for service penetrations.	
Carry out a thermal bridge workshop to review thermal bridge lengths and calculate Psi-values for all junctions.	
Review MVHR layout including duct distribution and measurement of length of intake and exhaust ducts for all homes.	
Measure heating and hot water pipe lengths for all communal areas and homes.	
Carry out embodied carbon assessment of whole building using accurate Bills of Quantities.	
Specify high performing PV panels.	

RIBA Stage 5 - Manufacturing and Construction	✓
Run an introduction to ultra-low energy construction workshop on-site.	
Encourage site manager and team training on construction quality requirements covering insulation and airtightness.	
Prepare toolbox talk information for site team inductions on low energy construction quality.	
Review alternative materials or products proposed by the contractor. Ensure substitutions do not compromise the thermal performance or embodied carbon target.	
Carry out regular construction quality assurance site visits and reports (depending on the size of the scheme – at least six) in tandem with regular visits.	
Develop site quality tracker, assess against KPIs and update regularly.	
Require leak finding airtightness tests at first fix and second airtightness test pre-completion.	
Witness commissioning of MVHR systems and heating system.	
Carry out predicted in-use energy model of each building leading to the final 'as built' PHPP model.	
Consider recalculating embodied carbon using 'as built' information.	

RIBA Stage 6 - Handover	✓
Provide building and operational information to residents in the form of site inductions and simple building user guides and instructions (e.g. sticker on MVHR for filter replacement).	
Consider embodied carbon as part of the replacement and maintenance strategy and include in the O&M manual.	
Carry out post-occupancy evaluation during first 5 years of use and verify KPIs have been met.	
Lessons learnt project review with design team.	
Publicly report KPIs.	