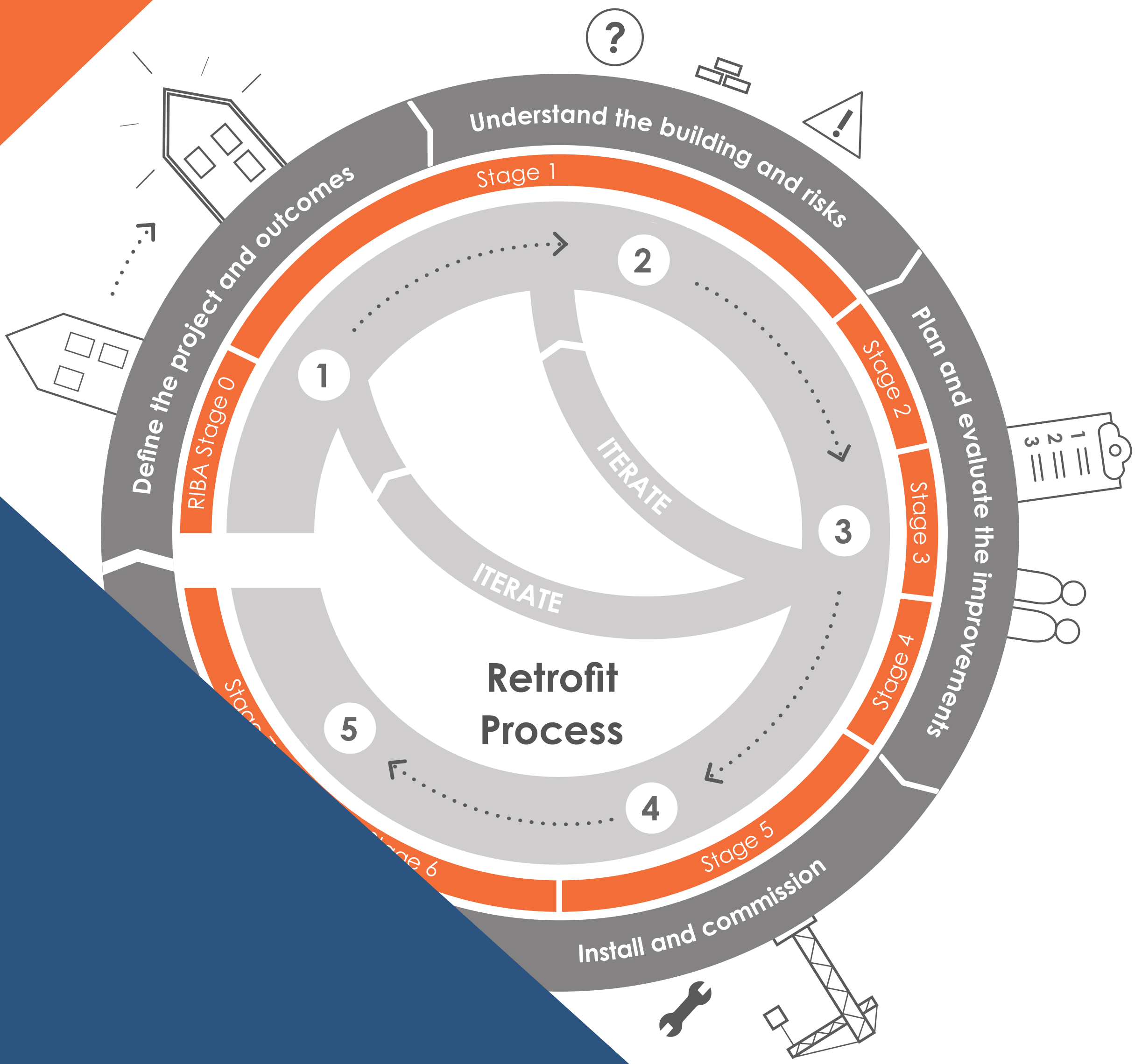
LETI Climate Emergency Retrofit Guide

How existing homes can be adapted to meet UK climate targets



With thanks to all who contributed to this guide:

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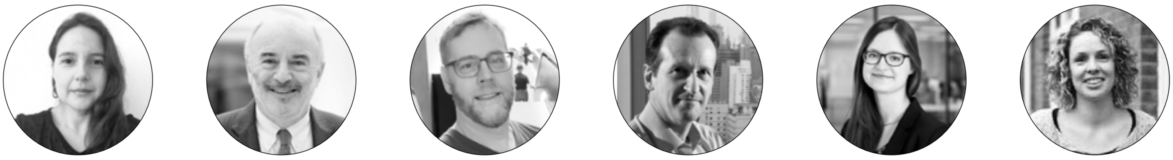

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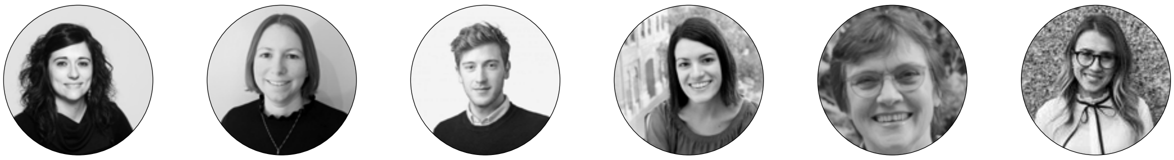

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About LETI

The London Energy Transformation Initiative (LETI) was established in 2017 to support the transition of the capital's built environment to net zero carbon, providing guidance that can be applied to the rest of the United Kingdom (UK).

We do this by:

→ Publishing guidance to support the built environment industry to meet the climate emergency;
→ Engaging with stakeholders to develop a robust and rapid energy reduction approach, producing effective solutions to the energy trilemma of security, sustainability and affordability;
→ Working with local authorities to create practicable policy alterations to ensure the regulatory system is fit for purpose, placing verified performance at its core;
→ Encouraging and enabling collaboration within a large, diverse group of built environment professionals; and
→ Providing technical advice to support exemplar developments, enabling leaders who want to deliver net zero carbon buildings.

LETI is a network of over 1,000 built environment professionals who are working together to put London on the path to a zero carbon future. The voluntary group is made up of dedicated and passionate developers, engineers, housing association professionals, architects, planners, academics, sustainability professionals, contractors, facilities managers and local authorities.

Over the last few years LETI has focused on providing guidance on defining what good looks like in the context of the climate emergency and LETI have published three key pieces of guidance: The Climate Emergency Design Guide; The Embodied Carbon Primer; and The Client Guide.

The LETI Climate Emergency Retrofit Guide was conceived to follow in the footsteps of the successful Climate Emergency Design Guide. Sharing knowledge on how to go about retrofit and setting targets. The information shared will inevitably be refined and evolve over time.

For more information on LETI, please see:
www.LETI.london

Supporting organisations

The following key organisations contributed to this guide by providing: key leadership team members; support on the guide; and advice as the guide progressed:

LETI would like to thank the European Climate Foundation who provided support for the archetype modelling that was required in this guide.

While every effort has been made to check the accuracy and quality of the information given in this publication, neither the Authors nor LETI accept any responsibility or liability for the subsequent use of this information, for any errors or omissions that it may contain, or for any misunderstandings arising from it. It will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

Contents

Executive summary

Why retrofit?

There is currently a climate emergency caused by greenhouse gases being released into the atmosphere and we emit huge amounts of carbon dioxide by heating and using hot water in our homes. What may not be as obvious is that our existing homes are by far the worst polluters in the housing sector.

Of all the operational emissions that come from buildings in the UK, 69% come from energy use in the domestic stock which alone is responsible for 18% of our annual national emissions[1,2].

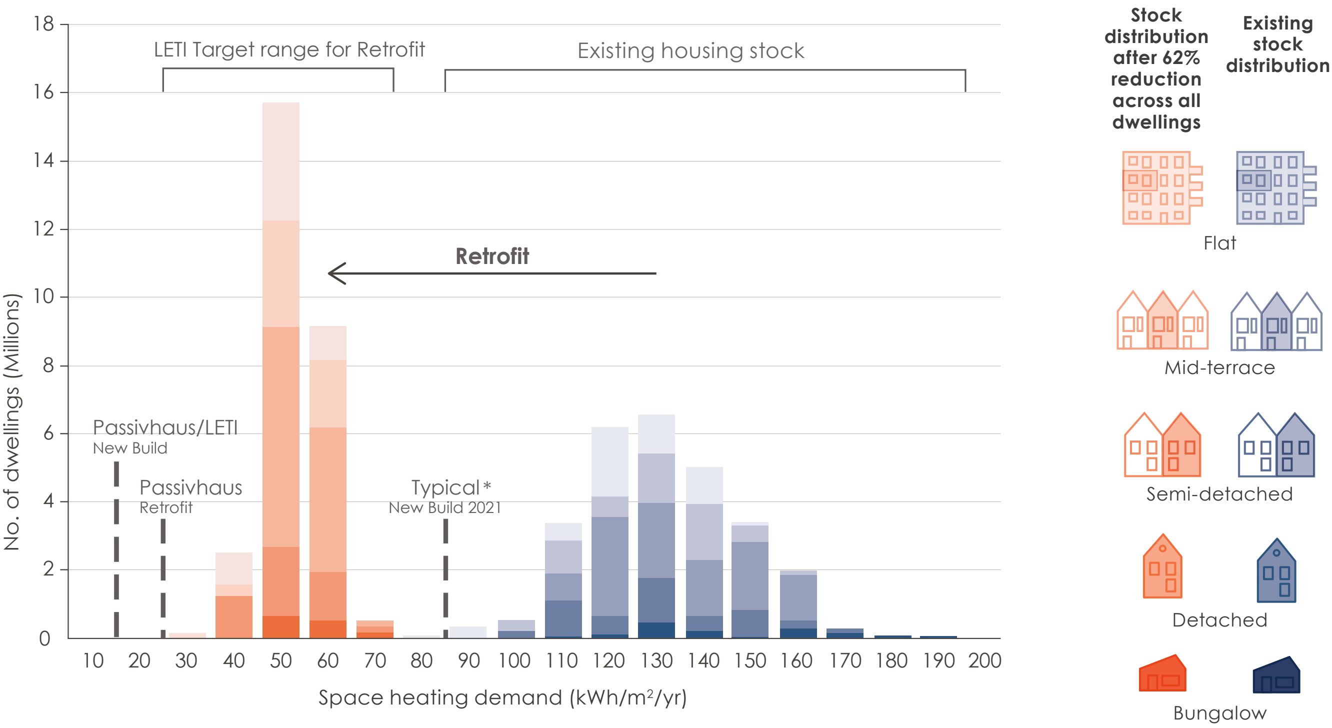
But retrofit isn't just about reducing carbon emissions. A best practice retrofit should reduce fuel bills and also improve health and wellbeing. Retrofit at scale would also generate significant employment opportunities and stimulate the economy.

How far should retrofit go?

The more we can reduce our demand for energy, the lower our emissions… but how much is enough?

The answer is different for different buildings, but in considering 'how much is enough?' We need to look holistically at the benefits of retrofit. This means considering: at what point health and wellbeing benefits are realised; the effect on fuel poverty; whole life costs; the costs to the nation (i.e. is it cheaper to generate more energy, or use less in the first place?) and the capacity of our electricity grid – now and in the future.

If we consider all these aspects, then it appears that a deep retrofit, with up to a 70% reduction in energy consumption, will have the most positive impact.



* Includes for an assumed performance gap

Figure 0.1 - Total number of UK dwellings broken down by their space heating demand, showing the transition required from existing levels of high demand to the LETI retrofit target range. Figure based on stock modelling carried out by LETI.

In contrast, a shallow retrofit with limited demand reduction could see neutral or even adverse effects.

LETI have produced a UK stock model to understand the scale of the challenge and also see what could realistically be achieved at a national level. If we consider that the space heating demand of a dwelling is a good indicator of the building's fabric efficiency, the modelling has shown us that a best practice level of retrofit could reduce our overall average space heating demand from 130 kWh/m^2/year down to about 50 kWh/m^2/year (Figure 0.1).

When fabric upgrades are combined with a heat pump, the potential reduction in average energy consumption is huge - around 75% - and approaches the levels that we could expect from even the most efficient new-build properties.

Retrofit – a risky business?

The UK has homes of many different types and ages which all require subtly different approaches to retrofit. All too often, poor retrofits can result in damage to the building fabric and a degradation in the internal living environment, with poor air quality and perhaps even damp and mould.

However, this should not be a barrier to retrofit, retrofit can be done well. With careful assessment and design, a best practice retrofit will protect the building fabric and, in most cases, significantly enhance the internal living environment.

To make sure you achieve a best practice retrofit, the impact of all the proposed retrofit measures needs to be carefully considered as a whole, with the building's fabric, ventilation and heating characteristics all designed to work in harmony with each other.

Choosing a heat source

This guide makes it clear that retrofit should focus on reducing the energy demand of a home. However, if we are looking specifically at how to reduce carbon emissions then the choice of heat source is also a critical part of the jigsaw.

Zero carbon energy will ultimately be delivered by the electricity grid and thus, at least in the short to medium term, we need to shift our buildings to produce their heating and hot water from a system that runs on electricity. In most cases this is going to be a heat pump of some form. We can't discount other technological solutions like low or zero carbon heat networks and hydrogen coming along, but most people agree that, for the vast majority of homes, heat pumps are the only viable option with the least uncertainty at this stage.

So, the key message is – if you do nothing else, make enough fabric improvements to switch to a heat pump and avoid putting in fossil-fuel systems at all costs.

LETI retrofit targets

LETI have set out best practice targets for retrofit, which we believe are achievable in the vast majority of UK dwellings. These targets are based on a combination of improved fabric efficiency and a heat pump to provide heating and hot water. We have also set out exemplar targets for buildings that can go further.

Space heating demand, hot water demand and Energy Use Intensity targets have been developed for when predictive energy modelling can be carried out. Fabric and system targets have been developed in tandem and these can be used when detailed energy modelling is not possible or financially feasible, for example on a small project.

Retrofit quick start guide

1 Use the six key principles for best practice retrofit

Principle 1: Reduce energy consumption

Principle 2: Prioritise occupant and building health

Principle 3: Have a whole building Retrofit Plan

Principle 4: Measure the performance

Principle 5: Think big!

Principle 6: Consider impact on embodied carbon

SIGNPOST *Chapter 2 - What is retrofit?*

2 Tailor the retrofit to the property type

Determine whether the home is constrained or unconstrained:

Heritage or visual appearance

Form factor (bungalow)

Space

Constrained

All other homes

Unconstrained

3 Make a whole house Retrofit Plan and follow the LETI Retrofit Process

The whole house Retrofit Plan must:

→ Set out key building information, constraints, risks, and opportunities.

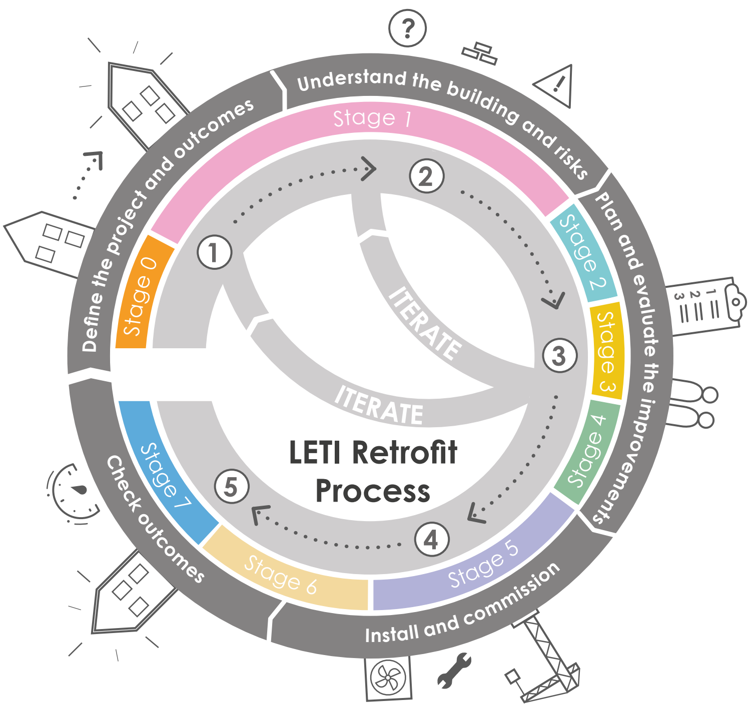
→ Set out the key works proposed along with related strategies and details.

→ Set out the sequence of work.

→ Be appropriate in its level of detail and intervention for the project.

→ Include a plan for monitoring and reporting energy consumption.

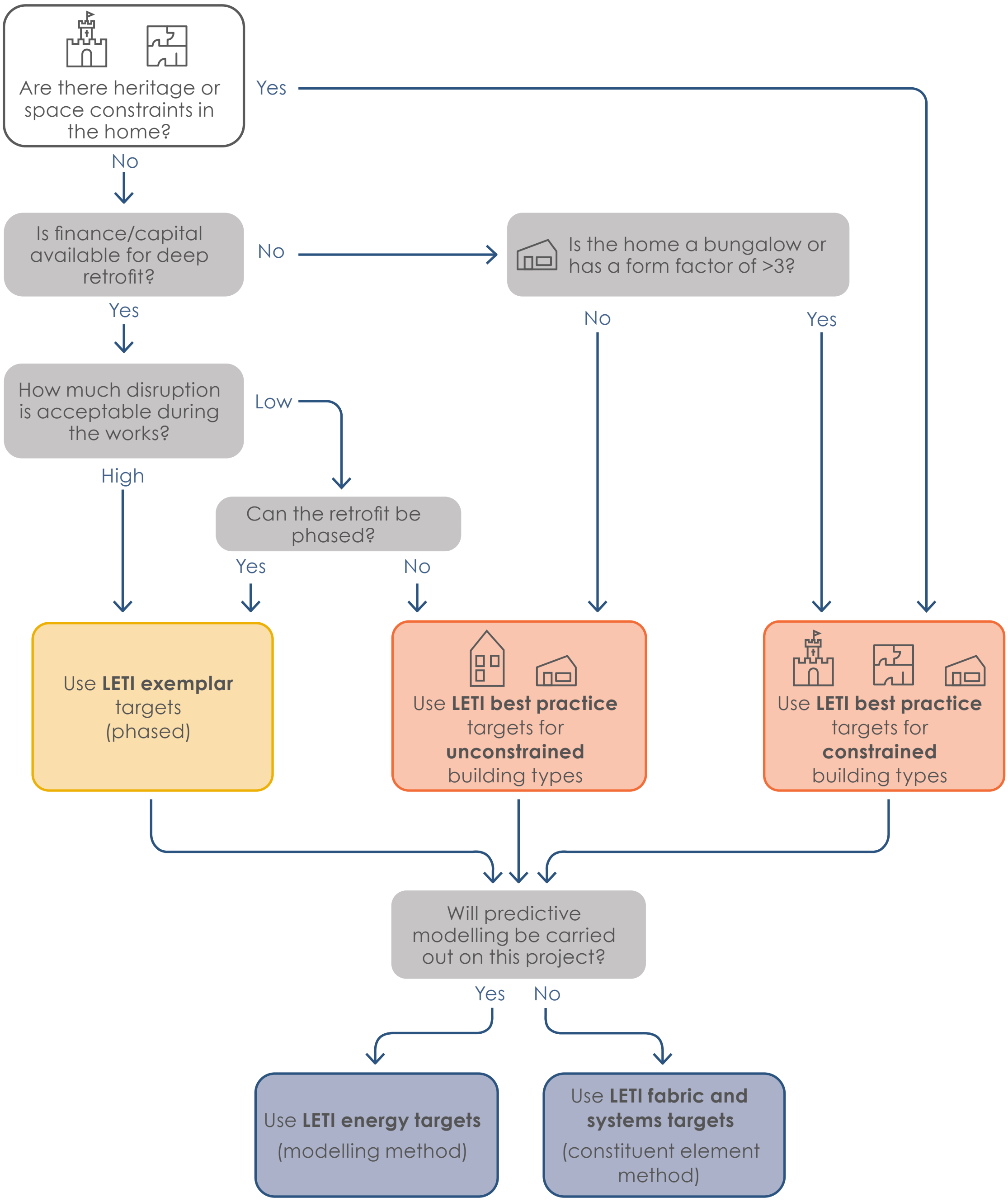
→ Stay with the building.



SIGNPOST *Chapter 5 - How do we do it?*

4 Use the flow chart to determine the appropriate LETI target and approach

The following flowchart sets out how to decide on the appropriate retrofit target for the project:



Notes:

→ If there are heritage or significant space constraints in the home, still try to reduce the space heating demand, hot water demand and Energy Use Intensity (EUI) as much as possible. Use the U-values recommended for the unconstrained retrofit wherever possible.

→ For any retrofit - independent quality assurance (QA) process is recommended for example for LETI exemplar use EnerPHit. Requirements for EnerPHit depend on the UK region, if following EnerPHit check the full requirements at the start of the project.

SIGNPOST *Chapter 4 - LETI home retrofit targets - 4.4 Using retrofit standards and guidance*

SIGNPOST *Chapter 3 - Where are we now and what can we achieve? - 3.2 Form factor*

5a LETI retrofit energy targets (modelling method)

Our analysis demonstrated that what LETI considers to be a pragmatic, affordable and realistic level of retrofit matches closely with the AECB Retrofit standard in terms of both space heating demand and final EUI. LETI considers this to be a **best practice** retrofit.

SIGNPOST *Chapter 4 - LETI home retrofit targets - 4.2 Modelling method*

The more demanding Passivhaus EnerPhit retrofit standard achieves further reductions and is aligned with LETI's **exemplar** targets in terms of retrofit ambition.

Use of either energy target requires detailed energy modelling to be carried out.

LETI best practice retrofit

Fossil fuel free
Fossil fuel free home

Energy Use Intensity
50 kWh/m²/yr
+10 kWh/m²/yr
Additional allowance for constrained retrofit

Space heating demand
50 kWh/m²/yr
+10 kWh/m²/yr
Additional allowance for constrained retrofit

Hot water demand
20 kWh/m²/yr
+5 kWh/m²/yr
Additional allowance for homes <75m²

Renewable energy
40% of roof area covered in PV panels
0% Constrained retrofits may not be able to accommodate PV
Maximise renewables where conditions are suitable to support solar generation

LETI exemplar retrofit

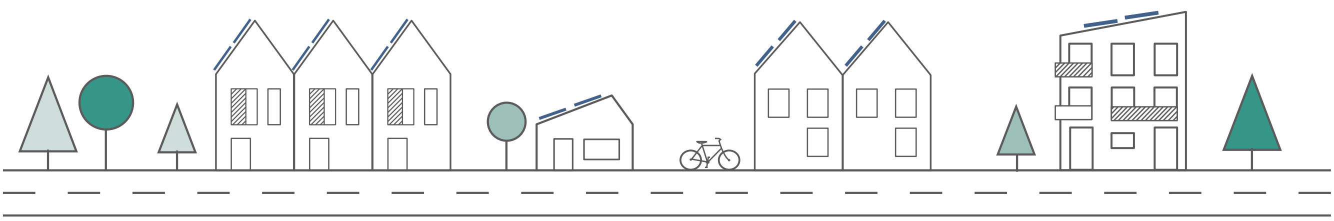
Fossil fuel free
Fossil fuel free home

Energy Use Intensity
40 kWh/m²/yr

Space heating demand
25 kWh/m²/yr

Hot water demand
20 kWh/m²/yr
+5 kWh/m²/yr
Additional allowance for homes <75m²

Renewable energy
40% of roof area covered in PV panels
Maximise renewables where conditions are suitable to support solar generation



SIGNPOST *Chapter 4 - LETI home retrofit targets - 4.5 LETI typical house archetype examples*

5b LETI retrofit fabric and system targets (constituent element method)

This constituent method can be used where detailed energy modelling is not possible or financially feasible on a small project.

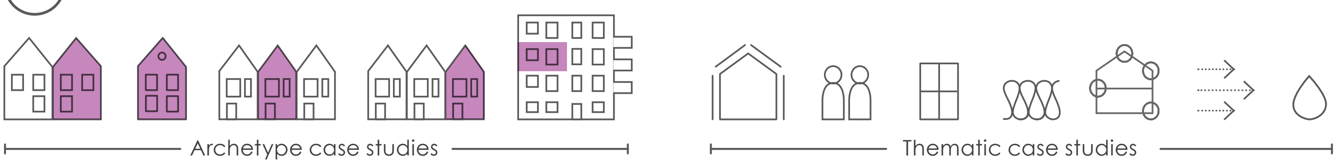
The fabric and system components of the retrofit works should achieve the target parameters set out below.

SIGNPOST *Chapter 4 - LETI home retrofit targets - 4.3 Constituent element method*

Building element		Retrofit actions	LETI best practice: Constrained retrofit	LETI best practice: Unconstrained retrofit (cool temperate climate)	LETI exemplar: All retrofit types
Walls	Cavity	External, cavity or Internal insulation	0.24 W/m².K	0.18 W/m².K	0.15 W/m².K
	Solid uninsulated	External or Internal insulation	0.32 W/m².K	0.18 W/m².K	0.15 W/m².K
	Timber frame	External or Internal insulation	0.21 W/m².K	0.18 W/m².K	0.15 W/m².K
Roofs	Cold	Insulate	0.12 W/m².K	0.12 W/m².K	0.12 W/m².K
	Warm/flat	Insulate	0.22 W/m².K	0.12 W/m².K	0.12 W/m².K
Floors	Suspended timber	Insulate between joists	0.20 W/m².K	0.18 W/m².K	0.15 W/m².K
	Solid uninsulated	Excavate and insulate below	0.80 W/m².K	0.15 W/m².K	0.15 W/m².K
Windows and doors	Windows	Replace	1.30 W/m².K	1.00 W/m².K	0.80 W/m².K
	Doors	Replace	1.00 W/m².K	0.80 W/m².K	0.80 W/m².K
General envelope	Thermal bridging	Mitigate where possible	0.10 W/m.K	0.10 W/m.K	0.08 W/m.K
	Airtightness	Draught proofing, sealing of chimneys and vents	3.0 ach@50Pa	2.0 ach@50Pa	1.0 ach@50Pa
Systems	Systems and appliances	Fossil fuel free home	Fossil fuel free	Fossil fuel free	Fossil fuel free
	Ventilation type	Install and remove extract fans	MVHR*	MVHR	MVHR
	Lighting power	Replace lamps and fittings	50 lm/W	100 lm/W	100 lm/W
Hot water	Hot water tank	Increase insulation or replace	1.5 W/K	1.5 W/K	1.5 W/K
	Primary pipework	Insulate all pipework	90% of pipework insulated	90% of pipework insulated	90% of pipework insulated
	Shower demands	Low flow fittings	16 litres/pers.day	16 litres/pers.day	16 litres/pers.day
	Other demands	Low flow fittings	9 litres/pers.day	9 litres/pers.day	9 litres/pers.day
Renewables	Photovoltaic generation	Rooftop installation	0 % of roof area covered in PV panels	40 % of roof area covered in PV panels	40 % of roof area covered in PV panels

* If not possible use demand control dMEV or demand control cMEV

6 Case studies



SIGNPOST *Chapter 6 - Case studies*

1

Why retrofit?

1.1 Introduction

This document is aimed primarily at construction sector professionals - architects, designers, clients and contractors to help them understand the size and scope of the domestic retrofit challenge as well as set out some sensible parameters and practical guidance to achieve a successful retrofit project. Public and private sector sustainability professionals may also find it useful to help define the scope of what can be achieved in decarbonising our housing stock. Individual homeowners embarking on their own retrofits may also find this guide informative.

This guide sets out what a best practice and exemplar retrofit looks like. It suggests a combination of pragmatic, realistic and affordable measures which, when undertaken as a coordinated Retrofit Plan, will deliver a comfortable, healthy and efficient home with a greatly reduced carbon footprint that supports our national transition to net zero. It looks specifically at the UK's residential housing stock[1.1].

This document does not seek to define Net Zero retrofit, however LETI advocates the following hierarchical approach to be followed:

1. Reduce the space heating demand and Energy Use Intensity as far as is practicable for the building/situation.
2. Remove fossil fuel heat sources and replace with low carbon alternatives. LETI believes that the main option for this over at least the next decade will be heat pumps.
3. Generate renewable energy on site wherever feasible – but do not pursue this at the detriment of items 1 or 2 above.

The only way the UK will achieve a net zero balance is to match the proportion of national renewable energy generation that can be realistically allocated to buildings against the energy that buildings use. We know that this will only be possible if we significantly reduce demand, but we also need to be realistic and pragmatic about what can be achieved. LETI believes that reducing space heating demand and Energy Use Intensity in line with this guide will give us the best chance of achieving net zero.

A building meeting the targets set out in this guide is considered by LETI to be a net zero compliant retrofit, when the above hierarchy is followed and when there is no gas or oil boiler in the home.

Structure of this report

→ **Chapters 1 to 3** set out the imperatives for retrofit, the current level of efficiency of our housing stock, and derive a level of retrofit that LETI is suggesting is appropriate and achievable.

→ **Chapter 4** sets out the LETI home retrofit targets which is derived from the modelling in Chapter 3.

→ **Chapter 5** describes how the LETI home retrofit targets from Chapter 4 can be achieved in practice.

→ **Chapter 6** offers illustrative case studies.

In summary, if you are interested in the theory, read Chapters 1 to 3, whilst if you just want to focus on practice, then jump to Chapters 4 and 5. Throughout this report the SIGNPOSTS below are used to guide you to related sections in the document.

Theory

SIGNPOST *Chapter 1 - Why retrofit?*

SIGNPOST *Chapter 2 - What is retrofit?*

SIGNPOST *Chapter 3 - Where are we now and what can we achieve?*

Practice

SIGNPOST *Chapter 4 - LETI home retrofit targets*

SIGNPOST *Chapter 5 - How do we do it?*

SIGNPOST *Chapter 6 - Case studies*

Figure 1.1 - Structure of LETI Retrofit Guide

1.2 Retrofit and the climate emergency

The energy needed to run the UK's buildings accounts for 27% of our annual carbon emissions with 18% alone coming from our domestic housing stock[1.2], see Figure 1.2 below.

Our progress in decarbonising the grid has masked the fact that the energy our buildings use has changed very little over the past 10 years[1.3], see Figure 1.3. If we are to meet our national net zero trajectory, we will need to significantly reduce the energy demand from our buildings.

Our existing building stock is, by far, the biggest problem. 80% of the homes that will exist in 2050 have already been built[1.4]. Furthermore, as our new-build standards are still not in-line with net zero, even the homes we are building now will need to be retrofitted before 2050. Retrofit is therefore critical in supporting our transition to net zero.

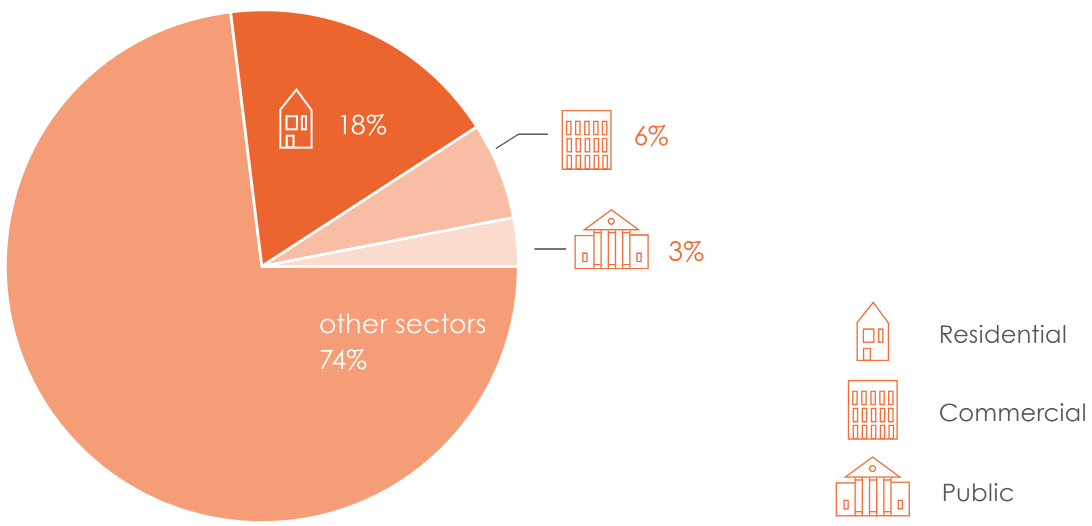


Figure 1.2 - United Kingdom buildings CO_2e emissions, 2017. Includes direct and indirect emissions. Source: UKCCC, Net Zero-Technical Report, May 2019. Note: 'other sectors' include power, industry and transport[1.2].

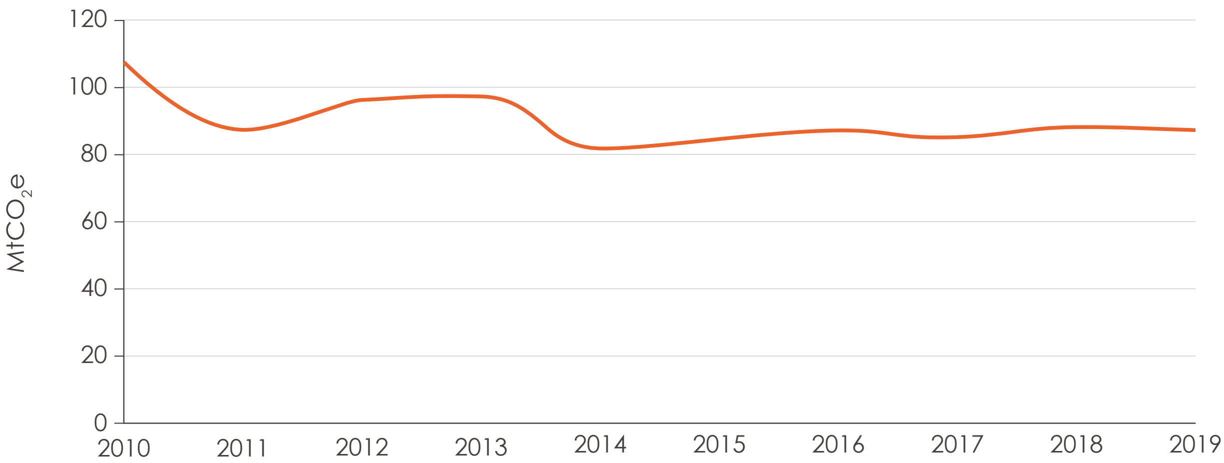


Figure 1.3 - Total annual emissions (direct and indirect) from UK buildings, 2010 to 2019, in $MtCO_2e$. Source: UKCCC, Progress Report to Parliament, June 2020

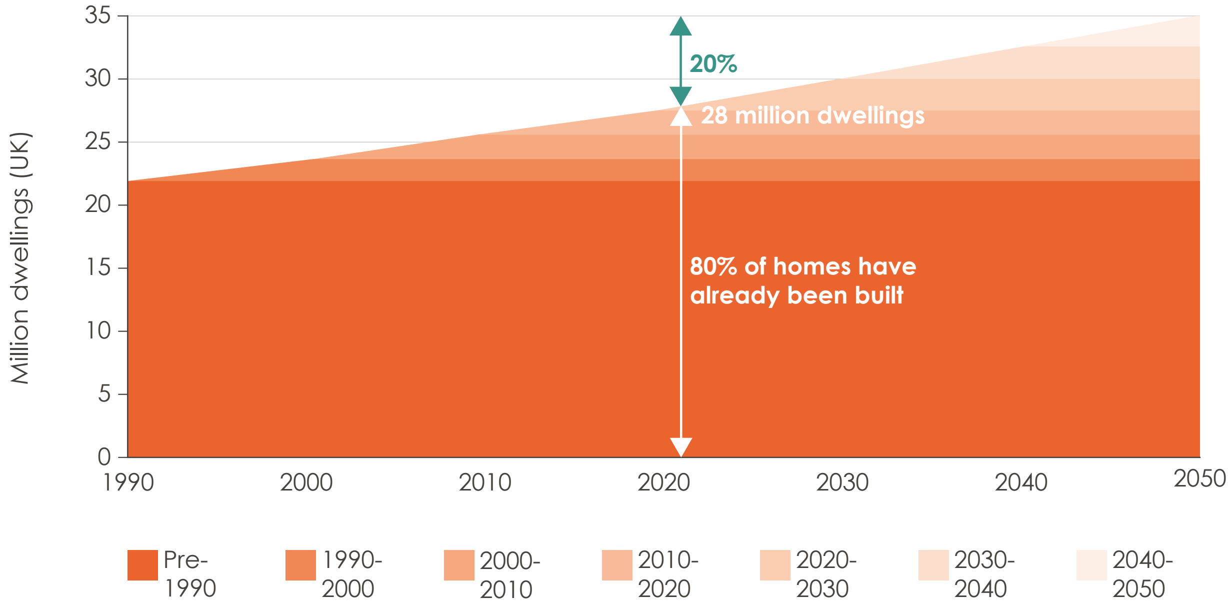


Figure 1.4 - Millions of dwellings built in the UK from pre-1990 to 2050. Note: demolition has been ignored in this table as the relatively small amount of domestic demolition is usually followed with replacement.

1.3 Retrofit and health

Many properties in the UK – and not just the old ones – already suffer from serious problems beyond energy inefficiency: uncomfortable draughts, leaking gutters, rising damp, cracked pointing, damp, mould, rot, poor ventilation, internal condensation.

The Housing Health and Safety Rating System (HHSRS) is a measure of poor housing used in England, Wales and Northern Ireland. Scotland uses the Scottish Housing Quality Standard (SHQS). The table below shows the proportion of dwellings that failed to meet their relevant national standards between 2015 and 2017[1.5].

England	Scotland	Northern Ireland	Wales
11%	40%	9%	18%

Figure 1.5 - Proportion of dwellings failing to meet relevant standards.

Within the HHSRS, there is an excess cold assessment which indicates that over 900,000 dwellings across the UK are likely to see internal temperatures which could adversely affect the health of the occupants[1.6]. Public Health England suggest that up to 10,000 people a year die as a result of cold homes[1.7]. Overall, the BRE estimate that the annual cost of poor housing is over £20Bn[1.3].

	England	Wales	Northern Ireland	England, Wales and Northern Ireland
% poor condition (HHSRS Category1)	11%	18%	9%	11%
Total cost of mitigation works per annum	£10,072m	£584m	£305m	£10,961m
Annual treatment cost to NHS per annum	£1,413m	£95m	£40m	£1,548m
Full annual health cost of poor housing per annum	£18,667m	£1,031m	£401m	£20,099m

Figure 1.6- Table reproduced from The Housing Stock of the United Kingdom Report, BRE Feb 2020.

1.4 Retrofit and fuel poverty

Whilst exact definitions of fuel poverty vary between nations, in general a household is considered to be in fuel poverty when they need to spend more than 10% of their disposable income on heating their home.

Over 11% of households in the UK, some 3.3M homes, are considered to be in fuel poverty[1.8].

There is a strong correlation between fuel poor households and people living in homes with poor energy efficiency ratings. For example, in England, 88% of all fuel poor households live in properties with a Band D EPC or below. These households have an average annual fuel bill of £1590 which would need to be reduced by £334 to take them out of fuel poverty[1.9].

A reduction of, say, 50% in heating demand for these households would result in a reduction of approximately £390 in their overall fuel bill - which would take millions of households out of fuel poverty[1.10].

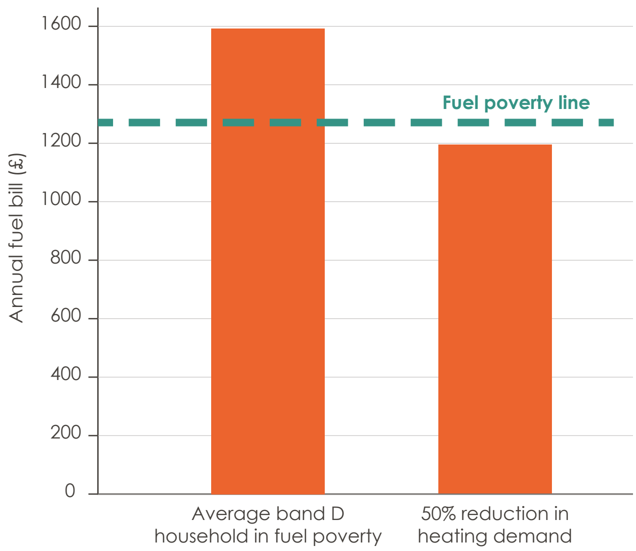


Figure 1.7 - Annual fuel bills of average band D household in fuel poverty and with 50% reduction in heating demand.

1.5 Retrofit and society

Retrofit also has broader societal implications. People who live in warm, comfortable homes are happier as well as being healthier. This means they are more productive at work, and are less likely to commit crime or engage in anti-social behaviour.

The Housing Associations' Charitable Trust (HACT) have developed a Social Value calculator which identifies the broader social value relating to improvements in housing. The calculator notes significant benefits from improvements in EPC bands, rectification of condensation/mould issues and rectification of damp[1.11].

More broadly, large scale retrofit projects can also be the stimulus for the regeneration and renewal of whole areas which will bring multiple long-lasting benefits.

A Social Return on Investment analysis for the Passivhaus retrofit Erneley Close, a large multi-residential development in Manchester, calculated the overall benefit to society to be in the region of £11.1M with only £407k of that relating to energy bill savings[1.12] . These societal benefits included improved mental wellbeing, reduced anti-social behaviour, greater disposable incomes and a notable increase in the economic activity of the surrounding areas.

SIGNPOST *Chapter 6 - Case studies*

1.6 Retrofit and employment

A large-scale programme of retrofit to significantly improve the performance of the UK's 28 million homes would see a huge increase in the amount of construction work in this sector. This would provide hundreds of thousands of additional jobs, support small builders and stimulate local economies across the country. The Construction Leadership Council have recently published a national retrofit strategy[1.13] which suggests that a retrofit programme could result in 500,000 new jobs by 2030 alongside a £309bn boost to the economy.

1.7 The benefits of retrofit - summary

Retrofit's multiple benefits bring substantial financial advantages, but for too long we have considered only the simple pay-back on energy bills. Consequently we have struggled to make retrofit pay for itself, because retrofit tends to have a high capital cost, be time-consuming and disruptive. However, if one considers whole-life value and broader financial benefits to both the individual and society, the business case for retrofit starts to look a lot stronger.

All numbers shown on this page are based on the average UK building stock.

SIGNPOST *Annex J - References and further information*

Energy efficient

Best practice retrofit will reduce peak heat demand, enabling homes to shift to zero carbon electric heating.

Our peak gas demand for heating and hot water is currently 170GW on the coldest day. However, our electricity grid can only provide 60GW now and perhaps 95GW in 2050. We need to reduce demand significantly to achieve the shift to clean electricity.

£££

Improving energy efficiency is key to reducing bills, especially as electricity is more expensive then gas.

Over **3.3M** UK households live in fuel poverty, that's **11%** of all homes.

	Energy consumption	Emissions	Energy bills
Average UK home	214 $kWh/m^2/yr$	2,035 $tCO_{2\,eq}$	£1,156 £/ yr *(typically with gas boiler)*
Retrofitted home that meets LETI spec	50 $kWh/m^2/yr$	160 $tCO_{2\,eq}$	£829 £/ yr

Water efficient

Retrofit is an opportunity to reduce water consumption and the CO_2 emissions associated with supplying and heating water.

By 2030, the UK will suffer **annual water shortages** in many areas[1.14].

	Water use
Average UK home	142 l/person/day
2030 RIBA climate challenge	<75 l/person/day

Comfortable

Best practice retrofit can make warm homes more affordable, whilst addressing the risk of overheating.

Best practice retrofit can reduce noise ingress to healthy levels.

Over 28,000 excess winter deaths per year in the UK, of which perhaps up to **10,000** are due to cold homes. Annual cost of cold homes to the NHS around **£0.85 bn.**

More than **30%** of EU population is exposed to levels exceeding **55 dB(A)** at night. WHO guideline for maximum noise levels in bedrooms is **30 dB(A).** Noise impacts on sleep and cardiovascular health.

Healthy

Best practice retrofit can reduce NO_x emissions from buildings and improve internal air quality by filtering incoming air and tackling damp.

28,000-36,000 UK deaths per year due to long-term exposure to gas boilers and hobs. Air pollution causes heart disease, stroke, respiratory disease and lung cancer.

1 in 5 UK children carry inhalers for asthma. Almost **1 million homes** in the UK suffer from serious damp. Indoor mould and excess humidity contribute to asthma.

Resilient

Retrofit is an opportunity to mitigate flood risk to our homes, address overheating and become more resilient to storms and extreme cold weather.

Excess summer deaths are estimated to be around **2,000** per year currently and **5,000** per year by 2050. **20%** of existing homes already suffer from overheating.

Number of homes at risk of flooding

1 in 6 - 2020

1 in 3 - 2050

Protecting assets

Best practice retrofit can protect our heritage and improve building capital.

23%

23% of UK homes were built pre-1919 and there are **millions** of homes in the UK's 10,000 conservation areas.

80%

80% of the homes that will exist in 2050 have already been built.

Figure 1.8 - Benefits of retrofit

1.8 The financial benefits of retrofit

INDIVIDUAL AND BUSINESS

Lower energy bills if buildings are substantially more energy efficient.

Reduced maintenance costs

Higher asset value because buildings are more energy efficient, comfortable and durable.

Improved productivity because occupants live in healthier and more comfortable buildings.

Reduced rent arrears and void periods because tenants enjoy lower bills and more pleasant buildings.

Lower costs relating to carbon such as offsetting, carbon taxes and carbon capture because energy demand and peak loads have been reduced.

SOCIETAL

Less fuel poverty because energy bills are lower.

Lower health-care costs because occupants live in healthier buildings with good air quality and thermal comfort.

Lower energy generation and infrastructure costs because energy demand and peak loads have been reduced.

More local jobs because retrofit is a labour intensive activity that benefits the local economy.

Figure 1.9 - Financial benefits of retrofit.

1.9 How far should retrofit go?

The question of what depth of retrofit is appropriate, or required, is complex. What we do know is that achieving a net zero building is challenging even for new-build. For retrofit, it is likely to be more so. But individual net zero buildings are not necessarily the goal... what we need to achieve is a net zero UK. This means that we need to balance the supply of renewable energy against the demand at a national level.

Whilst renewable energy in itself is almost infinite (sun, wind, tide), our capacity to harvest it is not. Each solar panel or wind turbine has a cost, both in financial and embodied carbon terms, depletes our finite supply of rare earth materials, and must be maintained and then replaced over time. We therefore have a limited amount of renewable energy available even in the most optimistic of future scenarios.

All the UK's sectors (transport, industry, power and agriculture) also need to transition to use this renewable energy. Thus, if there is to be enough to go round, then we need to significantly reduce the demand from our 28 million homes whilst also maximising the opportunity to generate renewable energy from every site.

In trying to judge what level of retrofit might be appropriate, it is important that we look at retrofit holistically and consider these macro issues as well as the second order effects beyond the headline effect of reducing carbon emissions.

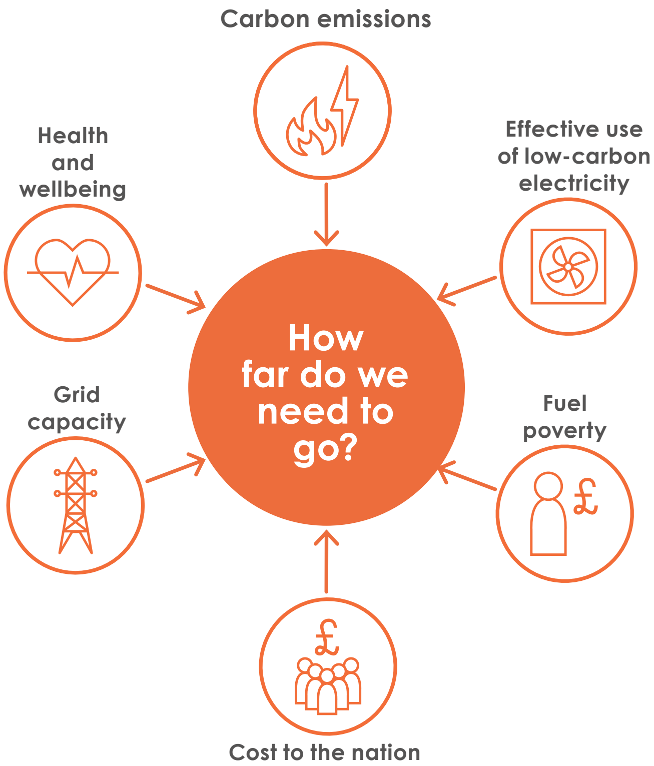


Figure 1.10 - How far should retrofit go.

Carbon emissions

If our primary, and perhaps sole, objective is to reduce and ultimately eliminate carbon emissions, then it is clear that we need to move to low (or zero) carbon sources of energy. With hydrogen for domestic heating looking unlikely anytime soon (see Chapter 2.3 Options for heating and hot water in homes for further detail), this leads us to the conclusion that electricity, coupled with heat pumps, is the most effective solution. Once a heat pump is providing heating and hot water for a building, its carbon emissions will reduce as the grid decarbonises. Ultimately, a low or zero carbon grid will mean almost zero emissions from that property. In fact, at that point, regardless of how much energy the property is using, it will still be zero carbon. This logic suggests that an extensive retrofit which significantly improves the building fabric (often called a 'deep retrofit') is actually not a prerequisite for net zero. This highlights the danger in looking at carbon in isolation rather than combined with energy consumption and demand. It also assumes that the UK is on track to support a net zero carbon grid with sufficient capacity to meet energy demand.

SIGNPOST *Chapter 1 - Why retrofit?*

SIGNPOST *Chapter 2 - What is retrofit?*

Grid capacity

As set out in section 1.9, our capacity to harvest renewable energy is not infinite and there is a financial and carbon and rare materials cost for all renewable technology. Hence there is a limit to how much renewable energy we will have in the future. Crucially, as renewable energy comes from naturally variable sources, there is also a limit to how much power we can use at any one time and there will also be a limit on how much storage we are able to provide. These are the three key capacity limitations: the amount of renewable energy we can generate, the maximum peak load we can meet and storage capacity available.

Peak load may be a critical constraint. It is estimated that the peak thermal load currently demanded by our homes and delivered by gas is 170GW[1.15]. The current electrical grid capacity is around 60GW and even by 2050 is projected to only be 100GW[1.16]. In 2050, all our sectors, particularly transport, will be drawing from this source of low carbon energy and thus the share that can realistically be allocated to our buildings will be a small fraction of that. Thus, demand reduction and management is going to be needed to enable us to stay within peak load limits.

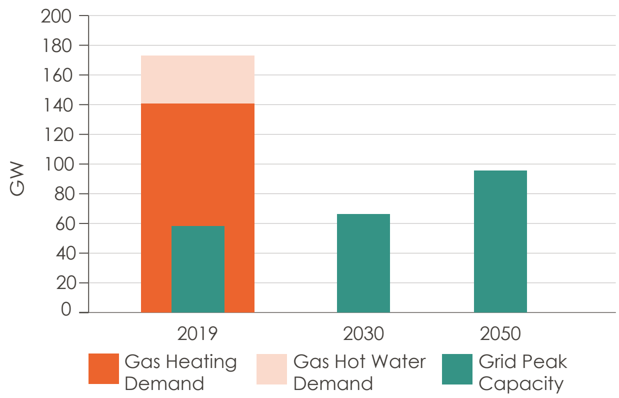


Figure 1.11 - Gas heating demand and gas hot water demand compared to electrical grid peak capacity.

Effective use of low-carbon electricity

Getting heat pumps to provide our heating and hot water is a priority (see Chapter 2.3 Options for heating and hot water in homes for further detail). However, in existing buildings, this presents several challenges. Heating systems designed to operate with gas boilers work at flow temperatures of around 70°C. Most heat pumps work most effectively at around 35°C or below. Some newer models are able to deliver higher temperatures with reasonable efficiencies - but still below traditional gas boiler temperatures. Making a building suitable for a heat pump is likely to involve some level of demand reduction - i.e. reducing heat loss, combined with measures such as increasing radiator sizes to enable greater heat distribution. The greater the reduction in demand, the more efficient the heat pump will become. If we don't reduce demand, then we could end up with cold homes which cost more to heat than they did with a gas boiler. Higher costs to achieve lower carbon emissions might be acceptable for some people, but for most, a retrofit would be expected to result in lower fuel bills.

SIGNPOST *Chapter 2 - What is retrofit?*

Fuel poverty

Fuel poverty is a significant issue in the UK. Our efforts to achieve net zero shouldn't make this worse. Electricity is currently around four times more expensive than gas[1.17]. Whilst switching to an electrical-only building will eliminate the gas standing charge, this still means that a seasonal coefficient of performance (SCOP) of around three will need to be achieved from a heat pump system to ensure running costs remain the same as for a gas boiler. This level of SCOP is currently typically only achieved using low flow temperatures which, again, implies lower heat demand. Furthermore, a lower heat demand also reduces fuel bills. Getting this wrong would not only push more people into fuel poverty, but would discourage any large-scale take up of heat pumps from the public in general.

Cost to the nation

Even if the capacity issues set out above are resolved, every MWh of energy demand that we do not reduce via retrofit will need to be generated from a renewable source. That energy source (e.g. a wind turbine) has a cost to design, finance, produce, store, deploy, distribute, manage, maintain and decommission as well as consuming our finite natural materials. This cost can be calculated per MWh generated over the lifetime of the source and is known as the levelised cost of energy (LCOE). In contrast, the cost of saving energy is the cost to design and implement the retrofit measure - which then delivers that saving for perhaps another 40 to 60 years.

Health and wellbeing

Poor quality homes can have a detrimental impact on our health. Many of our existing dwellings are too cold in winter, too hot in summer and suffer from poor indoor air quality. These issues impact our health and wellbeing, affecting in particular, the very young, elderly and those with respiratory conditions or compromised immune systems. However, these issues can be addressed with best practice retrofit. These issues also have real financial impact. The IEA and the OECD suggest health improvements might account for 75% of the overall value of improving the energy efficiency of buildings[1.18]. Achieving warm homes and good indoor air quality is unlikely to be achieved by a small number of minor retrofit measures. In fact, a poorly executed retrofit can result in moisture and condensation issues which actually exacerbate health risks.

Overall, these arguments would suggest that achieving net zero, improving health and also the best value option is to retrofit more deeply.

Deep retrofit

→ Reduced carbon emissions
→ Reduced renewable energy demand
→ Reduced peak load
→ Less grid storage required
→ Significantly lower energy bills
→ Improved health and comfort
→ Effective heat pumps

Shallow retrofit

→ Reduced carbon emissions
→ Large renewable demand
→ Large peak demand
→ More grid storage required
→ Little change in energy bills
→ Limited health benefits
→ Sub-optimal heat pump performance

Figure 1.12 - Comparison of percentage of energy demand reductions and associated co-benefits from shallow and deep retrofits.

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2

What is retrofit?

2.1 Definition of retrofit

For the purpose of this document we use the term 'retrofit' to refer to "the upgrading of a building to enable it to respond to the imperative of climate change"[2.1]. Retrofit may involve repair, renovation, refurbishment and/or restoration of the building. The aim is to both mitigate against climate change and ensure the building is well adapted for our changing climate.

Retrofit can be deep, achieving significant reductions in energy consumption, or shallow, achieving only minimal energy use reductions. Retrofit can also be good, successfully reducing energy consumption and carbon emissions, whilst improving health and comfort. However, retrofit can unfortunately be poor, failing to realise the anticipated energy, carbon and financial savings and increasing the risks of problems like damp, fire and overheating.

Best practice retrofit takes a whole building approach, where the consequence of every retrofit measure is fully understood and the building is considered as a whole. Best practice retrofit is fabric first, improving fabric energy efficiency before introducing low carbon technologies. Best practice retrofit can be carried out in one go, or phased according to a well considered Retrofit Plan.

By contrast, poor retrofit often involves single measures installed in a building in a piecemeal way leading to a host of unintended consequences. Poor retrofit is also unstructured, resulting in missed opportunities and abortive work.

***"If done correctly, the change we are about to go through could save residents money whilst improving their safety, health and wellbeing; if done poorly and in an unmeasured way, the opposite will be true." Unlock Net Zero*[2.2]**

2.2 Avoiding the risks of retrofit

"Retrofit isn't rocket science, but it is complicated." Rick Holland, Innovate UK

Unfortunately, there have been many instances of bad retrofit that not only fails to improve a building or achieve its aims, but exacerbates or creates new problems where none existed previously. No retrofit can be deemed successful-even if energy savings are achieved-if it results in an unhealthy, uncomfortable or unsafe environment for its occupants or an unhealthy building fabric prone to defects and decay.

Figure 2.1 illustrates the sorts of risks we face if we carry out poor, piecemeal, ill-considered, single-measure retrofit. It also notes how all these risks can be minimised if one takes a well planned, whole house approach set out in a whole house plan. This approach is championed by many including the AECB and Passivhaus Institute and is laid out in "*PAS 2035:2019 Retrofitting dwellings for improved energy efficiency – Specification and guidance*" and explained in greater detail in Chapter 5.

SIGNPOST *Chapter 5 - How do we do it?*

Annex H contains further information on moisture risks - including the imperative to maintain the existing moisture balance of a building, whether it's generally 'vapour-open' or 'vapour-closed'.

Refer to Annex D for further information on ventilation options.

SIGNPOST *Annex H - Moisture risks and how to avoid them*

SIGNPOST *Annex D - Retrofit ventilation strategies*

Single-measure retrofit...

Draught-proofing

New windows and doors

Insulation

Heat pumps

PVs and solar hot water

Hot water tank and pipework insulation

... can lead to unintended consequences ...

Insulation and draught-proofing reduce uncontrolled ventilation. If controlled ventilation isn't improved to compensate, **indoor air quality and risk of summer overheating** could get worse.

When insulation is installed or windows upgraded, more heat is lost through thermal bridges than before - resulting in cold spots prone to condensation and mould and lower reductions in **energy consumption** than expected.

Insulation that is poorly detailed, incompatible with the existing fabric or installed on already damp structure can lead to excessive trapped moisture, mould and rot - resulting in poor **indoor air quality** and reduced **building durability.**

Some types of insulation and electrical equipment are a fire hazard, reducing **fire safety,** if not well detailed and considered as part of a robust fire strategy.

Heat pumps use electricity and require lower flow temperatures. If heat demand isn't reduced, **energy bills** can increase. If radiators aren't sized properly, **thermal comfort** is affected.

Low and zero carbon technologies may need different size hot water tanks, operating at different temperatures and with different size pipes. Poor planning can lead to abortive work, missed opportunities and additional costs in the future.

... but these risks are minimised with a **whole house approach.**

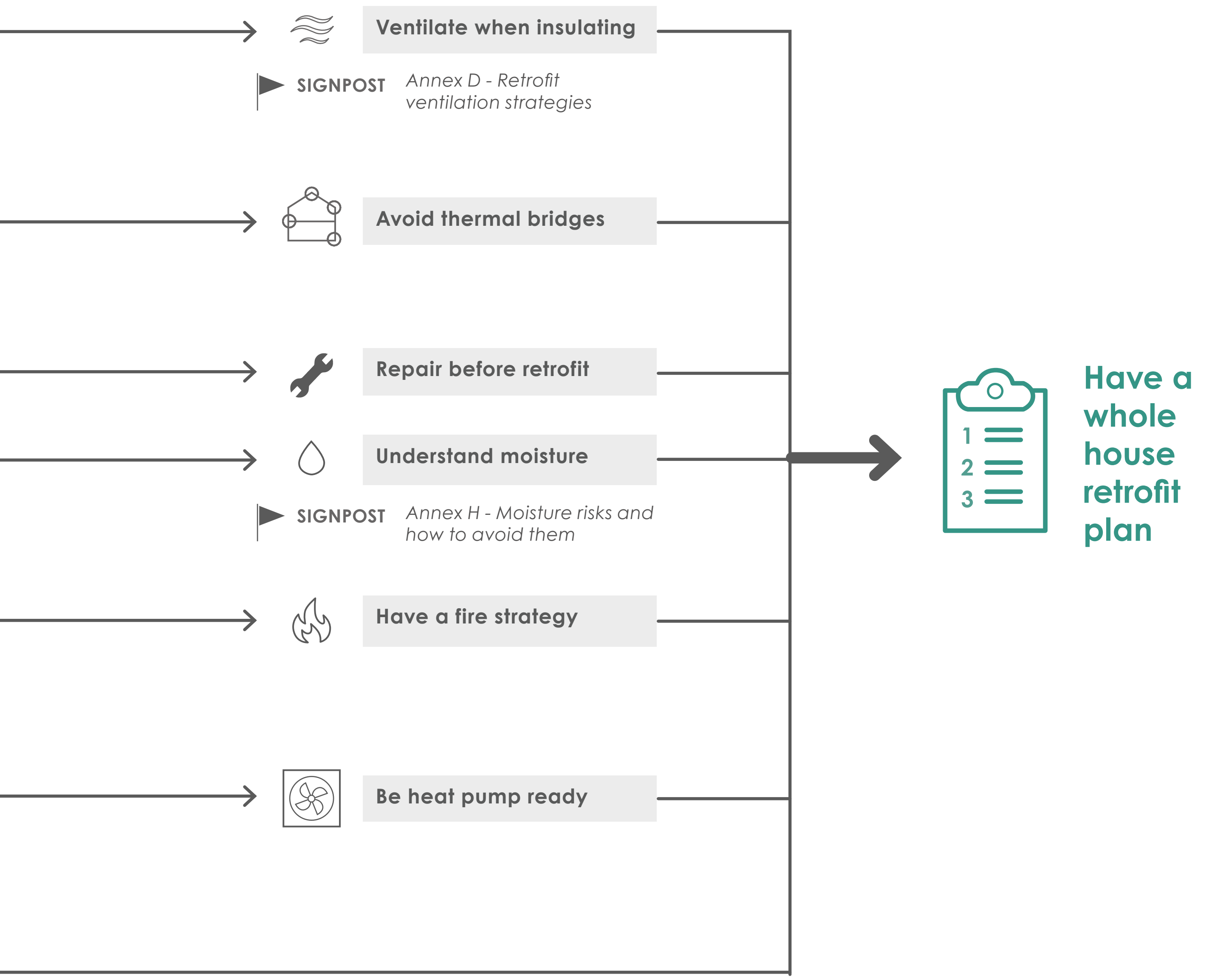


Figure 2.1 - Overcoming retrofitting risks - a whole house approach.

2.2 Avoiding the risks of retrofit *(cont'd)*

To summarise, best practice retrofit can bring multiple social, environmental and financial benefits. Many of these go hand in hand, allowing multiple needs to be achieved with one deed. However - with poor retrofit that is not thought through - some of these impacts become potential risks. These risks can be minimised and the benefits maximised by following six simple principles:

Principle 1: Reduce energy consumption. Minimising energy consumption can aid energy security, reduce bills and improve comfort as well as making national decarbonisation possible. This will ensure a host of benefits beyond reduced carbon emissions alone.

Principle 2: Prioritise occupant and building health. This is essential if we are to retrofit buildings that are fit for the long-term. To create healthy, durable and resilient buildings we must adapt for climate change and take a whole building approach.

Principle 3: Have a whole building Retrofit Plan. This will help you minimise risks and the performance gap, maximise opportunities and avoid disruptive, abortive work.

SIGNPOST *Chapter 5 - How do we do it?*

Principle 4: Measure the performance. This will help you understand whether you've achieved what you set out to do, learn from the successes and mistakes, and build business cases for future projects.

Principle 5: Think big! We are facing a climate emergency and must be zero carbon by 2050. We cannot afford to do the bare minimum. Otherwise we'll have to re-retrofit buildings only a few years later. We need to plan strategically for 2050, whilst identifying what can be done today.

Principle 6 - Consider impact on embodied carbon. Embodied carbon of retrofit can be significant, and needs to be minimised, through eliminating new materials where not needed and using durable, low embodied carbon materials. It is important to understand however that measures that improve the thermal performance have the potential to increase the embodied carbon. This balance should be studied. For more guidance see section 2.3.

Figure 2.2 lists the potential benefits of best practice retrofit and illustrates how, if the above principles are followed, multiple needs are achieved with one deed.

Diagram key

Elements that best practice retrofit addresses

- Focus on energy to reduce carbon emissions, peak loads and bills.
- Prioritize building and occupant health to improve health and comfort, protect heritage and ensure long term durability.
- Have a plan to maximise all these benefits, minimise cost and disruption and the performance gap.

Potential benefits of best practice retrofit

- Economic
- Environmental
- Social

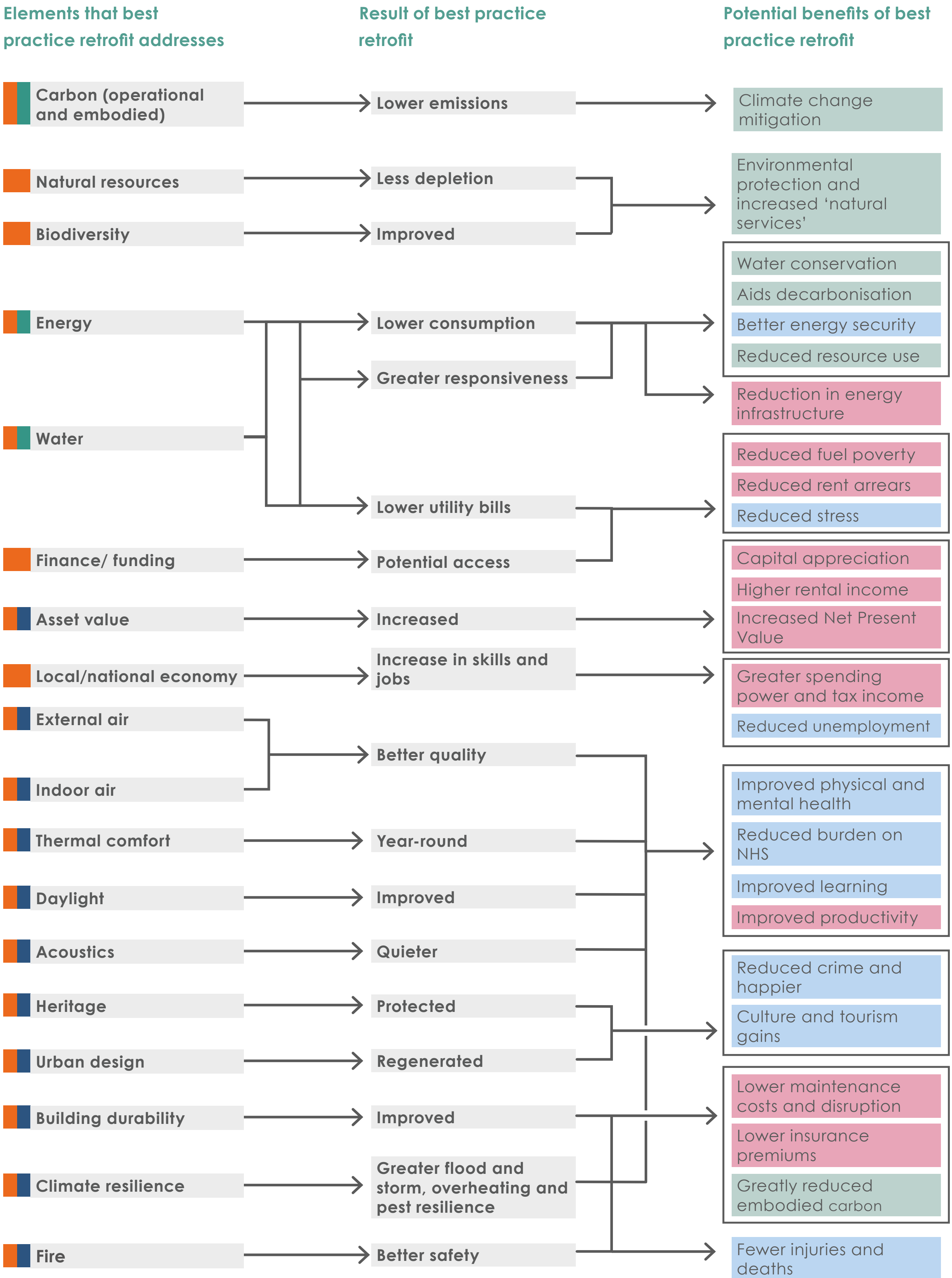


Figure 2.2 - The multiple benefits of best practice retrofit, filling many needs with one deed.

2.3 Embodied carbon

When carrying out retrofit it is important to consider the embodied carbon impact. This page outlines some strategies that help to reduce the embodied carbon impact of retrofit. For more information see the LETI Embodied Carbon Primer.

Retrofit best practice to reduce embodied carbon by element

Structure (sub and super structure)	→ If structural modifications are needed, seek the input of a retrofit-experienced structural engineer, ideally who is sympathetic to low-embodied carbon design. → Consider the likely loads and consider challenging safety factors to limit introduction of unnecessary additional structure. → Seek to limit the introduction of heavy elements wherever possible to limit the need for additional structure or strengthening. → Specify maximum embodied carbon targets by structural element/material. Targets can be achieved through low carbon concrete mix design, low carbon materials and using recycled/re-purposed materials. The impact to procurement must be considered early in the project programme.
Envelope (facade and roof)	→ Consider the embodied carbon of the entire retrofit solution for facade/roof systems during early design stages and compare carbon impacts of different options. → Remember that it is the hidden parts (for example metal secondary framing) of a build up that often contain the most embodied carbon. Where metals are used, seek to be as efficient in use as possible and incorporate recycled content, and ensure metals can be removed and recycled at end of life. → For new windows, consider timber frames to minimise embodied carbon impacts. Design windows to be efficient in terms of glazing to frame ratio. → Where possible specify natural insulation materials.
Mechanical, Electrical and Plumbing (MEP)	→ The fabric improvement measures, required for the LETI best practice and LETI exemplar retrofit specification, reduce the amount of heating equipment required, thus reducing the embodied carbon impact of new services. → For any new MEP systems, seek to limit lengths of ductwork and be as efficient as possible in the layout. Typically, fewer and simpler systems will reduce embodied carbon. → Avoid over-provision of plant - a detailed load assessment must be undertaken. → Consider maintenance and access requirements, maintained equipment will last longer. → Design for deconstruction and recycling as MEP is typically replaced 2-3 times during the lifespan of a building. → Specify refrigerants with low Global Warming Potential (i.e. <10) and ensure refrigerant leakage is as low as possible and carefully considered in the whole life carbon analysis.
Finishes and Furniture Fixtures and equipment (FF&E)	→ Consider eliminating materials where not needed e.g. by exposing services. → Utilise self-finishing internal surfaces like timber. → Consider the cleaning and maintenance regime to be undertaken. → Carefully compare products based on EPD data, recycled material and also avoidance of harmful chemicals like formaldehydes and VOCs. → Consider the replacement cycle and specify for longevity and end of life. → Choose products that do not rely on adhesives so fabrics or finishes can be replaced. → Be wary of trends that are likely to date and require early replacement.

Figure 2.3 - Retrofit best practice to reduce embodied carbon by element

Retrofit principles to reduce embodied carbon

Build light	→ Look for opportunities to re-use and re-purpose existing materials and systems where possible. Consider the full life carbon benefit of replacing with new. Ensure that the required logistics (e.g. storage on site) can be made avaliable. → Seek to simplify the design - simple designs usually means less embodied carbon.
Build wise	→ Carry out a material efficiency review - are all materials proposed necessary? Can some layers of the building serve a dual purpose? → Prioritise materials that are reused or reclaimed and that are durable. If not available, seek to use materials with high recycled content and naturally renewable building materials. → Ensure longevity of material and systems specifications, particularly in consideration of a changing climate to limit future re-retrofits. → Review material efficiency options like designing to standard building sizes or for a repeating module to limit offcuts and waste wherever possible. → Consider locally sourced material options, reducing transport to site. At smaller scales of construction, transport emissions can be significant as part of the total whole life impact of the works, particularly if sourcing a product with only marginal embodied/operational carbon savings. → Consider approaching unconventional suppliers or sources for lower embodied materials or re-purposed materials, e.g. local reclamation yards, specialised material stockists
Build low carbon	→ Reduce the use of high embodied carbon materials. → Identify 'Big ticket Items' and focus on the big wins first (e.g. new MEP, insulation, cladding, any new structural elements) → Consider natural and renewable materials - for retrofit, consider natural insulation although bear in mind the required build-up thicknesses for meeting U-value targets in early design stages - the earlier natural materials are accommodated for the better. → Seek EPDs for new elements being introduced and compare the impacts between products in accordance with BS EN 15804 (2019).
Build for the future	→ Ensure future uses and end of life are considered and adaptability is designed in. → Consider maintenance & access requirements - well-maintained equipment and products will last longer. → Consider soft spots in the structure (for flexibility in the future e.g. adding in risers). → Consider future-proofed risers and plant space. → Mechanically fix systems rather than adhesive fix so they can be demounted and re-used or recycled, supporting a circular economy. → Explore methods of creating longevity for materials without additional coatings, as they can reduce the recyclability of the material. → Create material passports for elements of the building to improve the ability of disassembled elements to be reused - including data on best practice for products/ materials recycling and end of life strategy at time of construction.
Build collaboratively	→ Solutions must involve the whole design team and the client. → Use 'rules of thumb' data to drive decision making in meetings, especially in the early stages of design. → For larger projects engage design team and contractor for smarter BIM-driven ordering and procurement to limit over-ordering and limit wastage in construction. This can also limit need for remedial works on site with higher carbon materials.

Figure 2.4 - Retrofit principles to reduce embodied carbon

2.4 Options for heating and hot water in homes

As we look towards a net zero future, it is clear that the ways in which we heat and provide hot water for our homes will need to change. Currently, over 85% of UK homes have gas boilers[2.3]. These gas boilers emit around 240g of CO_2 for every kWh of energy that they deliver to the home[2.4]. The average UK home uses 12.5MWh/year for heating and hot water which results in 2.6 tonnes of CO_2 being emitted annually[2.5].

Our electricity grid also uses gas to produce much of our electrical energy. The process of generation and distribution of electricity incurs losses and thus, historically, more CO_2 has been emitted for every kWh of electrical energy generated by gas than for a kWh of gas used for heating. However, as more renewable energy sources have been introduced, the carbon intensity of our electricity has reduced dramatically. The yearly average is now around 140gCO_2/kWh and is forecast to reduce to almost zero by 2035[2.6]. In contrast, our gas boilers will continue to emit at the same rate until they are decommissioned[2.7].

This decarbonisation of the electricity grid has a critical influence on the aims of retrofit. A deep retrofit which leaves a gas boiler in place will, over the lifetime of that gas boiler, probably emit more carbon than a shallow retrofit[2.8] of the same property which includes a switch to electrical heating and hot water. Whilst there are many other benefits of deep retrofit, see Section 1.7, from a decarbonisation perspective alone, our priority must be to enable a low carbon heat source.

SIGNPOST *Chapter 1 - Why Retrofit?*

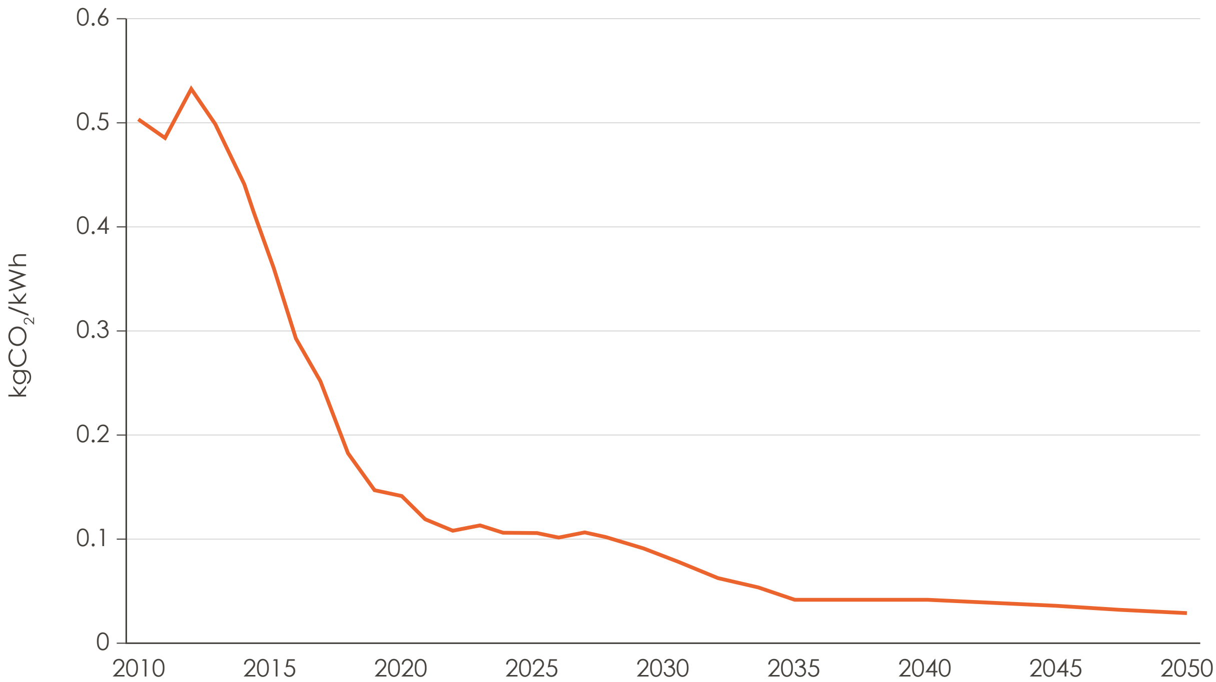


Figure 2.5 - Decarbonisation of the electricity grid.

Options for heating our homes in the future are summarised below:

Most encouraged

Air and ground source heat pumps	To be encouraged. Heat pumps use electricity from the gradually decarbonising grid, combined with the passive relative warmth of the ground or air, to produce heat. They are a proven and reliable technology but generally produce lower temperature water than gas boilers and thus the heat demand of the building, and the size/capacity of the heat emitters (e.g. radiators) must be carefully matched to ensure that the heat pump can deliver sufficient energy. Heat pumps will also need a hot water tank to provide hot water as they cannot match the instantaneous power provided by a gas combi boiler. Thus, there will be a requirement for additional space in smaller dwellings. Typically they produce 2 or 3 times as much heat energy than the electrical energy they use (this ratio is called Coefficient of Performance (COP). This is a useful rule of thumb for ensuring that we don't overload the grid and have sufficient renewable energy for all sectors to achieve net zero.
District heating networks	This type of distributed heating and hot water system is popular in some parts of the UK. However, many networks are powered by gas (e.g. boilers and combined heat and power (CHP)) and thus need a transition plan to move away from fossil fuels. If heat pumps are used as an alternative generation plant, the lower temperature of the hot water generated may present an issue and losses will need to be carefully modelled. It is also worth noting that networks can be expensive and/or unreliable in addition to suffering from significant distribution losses. Ambient loop systems have lower losses and greater efficiencies and should be considered where large-scale retrofit is taking place, for example as part of neighbourhood regeneration plans.
Direct electric	Direct electric heating systems use electric energy without any supporting mechanisms such as heat pumps e.g. an electric panel heater. Electric heating and hot water systems can be attractive due to their simplicity and typically lower capital cost when compared to a wet system. However, the building will be significantly more expensive to run compared to either a boiler or heat pump. Direct electric also results in higher peak loads and so is not desirable at scale, for the grid system. The use of storage heaters can help to mitigate both these factors, but, in general direct electric should only be considered where heat pumps are not feasible and where the heat demand is very low.
Hydrogen	There is a perception that hydrogen may offer a relatively painless option to transition away from gas without having to improve the fabric performance of our homes. However, there are many unknowns and uncertainties about this route. At this point, it would appear that hydrogen is unlikely to be a cheap and easy option for domestic heating and it should be discounted for any retrofits taking place in the short and medium term. LETI have produced a detailed analysis of the potential role of hydrogen and buildings which expands on this further[2.9].
Biomass	To be avoided. Wood burning stoves and boilers may seem like an attractive low-carbon option. However, even sustainable timber takes time to grow and also needs to be transported - so there is, at best, a short-term carbon penalty as soon as the biomass is combusted. Furthermore, there is also an adverse impact on air quality.
Gas and oil boilers	To be avoided/removed as soon as possible. Where the heat demand of the building during colder periods is too great to be met by a heat pump alone at this point in time, a hybrid system of boiler and heat pump can be considered - but only if there is a transition plan to improve the building fabric to a point where the boiler is no longer required.

Least encouraged

Figure 2.6 - Options for heating our homes in the future.

2.5 Metrics and Energy Performance Certificates

Energy Performance Certificates (EPCs) are the national method for presenting the predicted energy efficiency of a dwelling. However, they actually provide a cost index indicating how much it would cost to run the building under assumed occupancy levels and fixed heating patterns. As the grid has decarbonised, the link between running costs and carbon emissions has weakened as electricity remains significantly more expensive than gas. Thus, lower energy costs do not necessarily mean a more efficient building with lower carbon emissions. For example, achieving an EPC A or B could be achieved by a fabric inefficient building with gas heating and a large PV array rather than a very efficient building using a heat pump. SAP is used to calculate EPC ratings, however, in its current form SAP does not accurately predict the energy use of homes. LETI therefore consider that EPCs are not a good indicator of the actual energy performance of buildings.

So what metrics should we be using? To understand how a building is consuming energy, we actually need to look at several metrics. In most existing homes, heating will typically be the largest energy demand. After that, hot water and then appliances/ lighting. The energy needed for heating, known as the space heating demand (SHD) is an excellent proxy for the fabric efficiency of the building – i.e. how well (or badly) that building retains heat. Space heating demand is therefore a key metric if we are interested in fabric performance.

Whilst retrofit will tend to focus on the fabric of the building, there are also measures we can take as part of a retrofit to reduce our hot water demand. Thus, this is also a metric which we would wish to monitor.

Our heating and hot water requires some form of heat source (e.g. gas boiler or heat pump[2.10,2.11,2.12]) which will have its own specific efficiency. This means that the amount of energy delivered to (consumed by) the building will be different from the amount of energy actually required for heating and hot water - the demand. This means that we also need a metric which looks at the delivered energy to ensure that the heat source is efficient.

Finally, whilst a retrofit can't do much to control appliances, we do need to ensure that the overall amount of energy consumed by a building is not excessive and is commensurate with a net zero future. Adding together the energy delivered for heating, hot water, ventilation and appliances and lighting gives us the overall Energy Use Intensity (EUI) of the building.

How these various metrics relate is illustrated in Figure 2.7 for a house which uses a heat pump for heating and hot water. As the heat pump delivers more energy than it draws from the electricity grid, the EUI for heating and hot water is less than the original demand. For the appliance loads, the EUI is the same as the demand.

All these metrics are forms of energy and are expressed per m^2 of the building's internal area to allow us to compare different sized buildings. We also assess these energy uses over the course of a year, again to allow like-for-like comparison. Thus, the unit for all of them is kWh/m^2/year.

Annex A contains a more detailed explanation of demand versus delivered energy and why energy metrics are preferable to carbon metrics.

SIGNPOST *Chapter 3 - Where are we now and what can we achieve?*

SIGNPOST *Annex A - How do our homes produce carbon?*

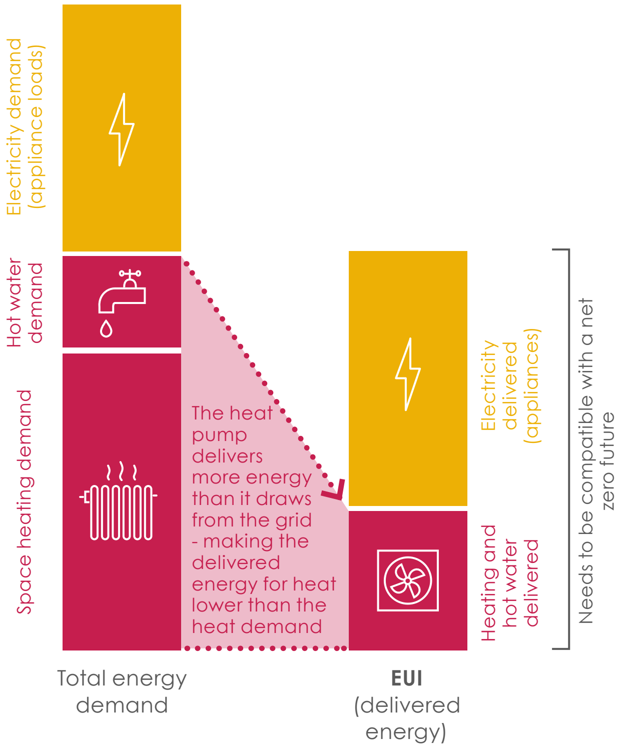


Figure 2.7 - Energy demand versus energy consumed/delivered

Summary of key metrics:

Space heating demand (SHD). The amount of energy needed over the course of a year to heat the building to a comfortable temperature. This is a direct proxy for the fabric performance.

Hot water demand (HWD). The amount of energy needed over the course of the year to provide hot water for use by the occupants.

EPC

EPC Energy Efficiency Rating (EER). A cost-based index which indicates the relative cost of energy for a home. A high (good) EPC score does not necessarily indicate a building with high levels of energy efficiency.

Energy Use Intensity (EUI) is the delivered energy (sometimes called energy consumption) per m^2 that is required by the building over the course of a year.

LETI believes that setting an EUI requirement for buildings is fundamental to meeting our climate change targets. It is a good indicator for building performance as the metric is solely dependent on how the building performs in-use; rather than carbon emissions, which also reflect the carbon intensity of the grid.

EUI is a metric that can be estimated at the design stage and very easily monitored in-use as energy bills are based on kWh of energy used by the building. This metric can be used to compare buildings of a similar type, to understand how well the building performs in-use. It includes all of the energy consumed in the building, such as regulated energy (heating, hot water, cooling, ventilation, and lighting) and unregulated energy (plug loads and equipment e.g. kitchen white goods, ICT/AV equipment). It does not include PV generation or the charging of electric vehicles. The EUI is not the sum of space heating and hot water demand. The actual energy used by the building for these purposes will be reduced by the coefficient of performance of the heat pump (consumption).

EUI can be expressed in GIA (Gross Internal Area), NLA (Net Lettable Area) or TFA (Treated Floor Area). In this document the EUIs are expressed in TFA unless specified. Delivered energy is used interchangeably with EUI in this document.

EUI should replace carbon emission reductions as the primary metric used in policy, regulations, and design decisions.

2.6 Floor areas

The energy calculations in this guide have been undertaken using the Passivhaus Planning Package (PHPP) which uses the Treated Floor Area (TFA) convention when considering the internal floor area of a building. TFA is effectively the 'liveable area' of a building and excludes internal walls and areas with little or no headroom (e.g. under stairs). Full details can be found in the PHPP user guide TFA must be measured accurately from drawings for energy calculations, but as a rough rule-of-thumb for comparison purposes, can be considered to be approximately 90% of a building's Gross Internal Area (GIA).

Throughout this guide the area specific energy figures – i.e. kWh/m²/year, use TFA as the floor area.

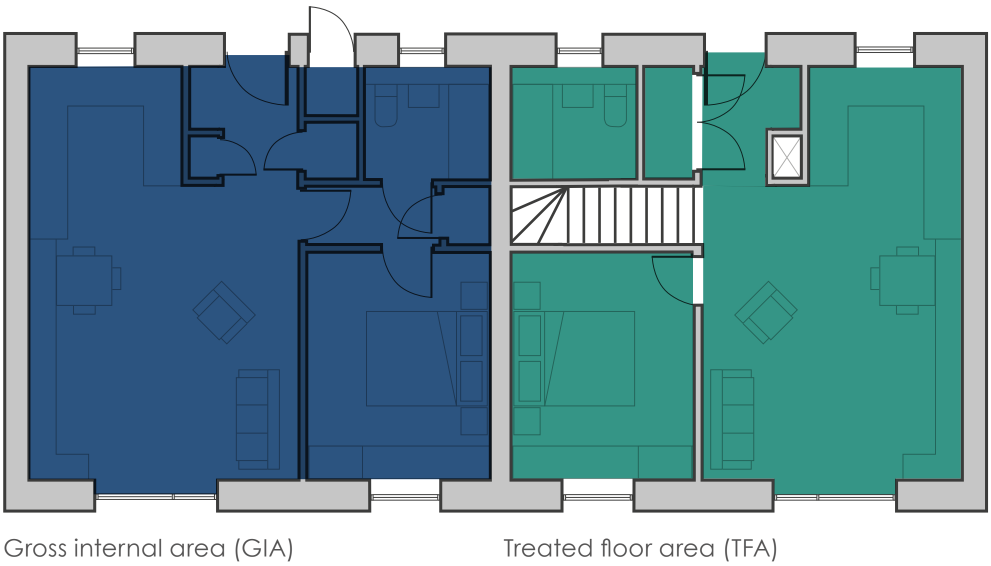


Figure 2.8 - Illustrative difference between GIA and TFA floor area measurements

2.5 References and footnotes

2.1 - Marion Baeli. Residential Retrofit 20 Retrofit Case studies. London: RIBA Publishing, 2013

2.2 - Unlock Net Zero, Aico Feature - Achieving Net Zero with Data and Collaboration [Online] Available from: https://www.unlocknetzero.co.uk/partner-content/aico-feature---achieving-net-zero-with-data-and-collaboration

2.3 - The Government, Energy Consumption in the UK [Online] Available from: www.gov.uk/government/statistics/energy-consumption-in-the-uk

2.4 - Bre Group, The Government's Standard Assessment Procedure for Energy Rating of Dwellings [Online] Available from: https://www.bregroup.com/wp-content/uploads/2019/10/SAP-10.1-01-10-2019.pdf

2.5 - National Grid, Future Energy Scenarios 2020 [Online] Available from: https://www.nationalgrideso.com/document/173821/download

2.6 - The Government, Energy consumption in the UK 2020 [Online] Available from: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2020

2.7 - A note on hydrogen: Hydrogen may at some point in the future be injected into the gas grid and contribute to decarbonising it to some extent, but this is currently very uncertain and is not expected for at least one decade, except possibly in small trial zones such as the "hydrogen villages. Although its also important to note that even if Hydrogen becomes viable at some point after 2030, we still need 600,000 heat pump installs annually by 2030, as otherwise we will have exceeded all our carbon budgets. See also ref. 2.9.

2.8 - If we assume a shallow retrofit reduces demand by 30% and a deep by 70%, using cumulative carbon emissions from HMT Green Book, a deep retrofit with a gas boiler will emit 1.6kgCO2/kWh whereas a shallow retrofit with heat pump will emit 0.5kgCO2/kWh between 2021 and 2050

2.9 - London Energy Transformation Initiative, Hydrogen: A decarbonisation route for heat in buildings? [Online] Available from: www.leti.london/hydrogen

2.10 - HVDH domestic heating guide, 2021, for individual homes installations

2.11 - MCS certification scheme, including how to find an installer and Domestic Heat Pumps - A Best Practice guide. [Online] Avaliable from: https://mcscertified.com/wp-content/uploads/2020/07/Heat-Pump-Guide.pdf

2.12 - CIBSE AM16, 2021 - Heat pump installations for multi-unit residential buildings

3

Where are we now and what can we achieve?

3.1 Great Britain housing stock

If we are to achieve retrofit at scale, we first need to understand the scope and nature of the problem.

When people discuss the difficulties of retrofit, we often hear assertions such as "But what about all those Victorian Terraces?". So, how many Victorian Terraces do we actually have? Figure 3.1 sets out the distribution of our housing stock, divided up by age, form/shape and original wall type. It shows us that the UK mainland currently has around 28M dwellings and whilst the UK has some of the oldest housing stock in Europe, in fact only 3.3M dwellings were built before 1900 and the majority (18.4M) were built after 1950.

Whilst many relatively modern homes have insulated cavity walls, many still have either solid uninsulated walls or uninsulated cavities. Double glazing is now very common, but there still remain a significant number of buildings which also have an element of single glazing. Also, much of that double glazing is now aging, performs very poorly and needs replacing.

Many of our buildings will have constraints on their external appearance which will affect the type of retrofit measures which we can use and also the level to which they can be applied. Whilst the proportion of listed buildings is very small, around 10% of our homes are in conservation areas and, overall, English Heritage estimate that up to 25% of our housing stock will have heritage features which would constrain retrofits. It is likely that this is most prevalent in our older building stock, with all pre-1919 stock exhibiting heritage features and then a diminishing number in more modern buildings.

However, heritage features are not the only constraint. Many non-heritage buildings that make up attractive street-frontages will also have external architectural features which owners will be reluctant to cover with insulation. Furthermore, over 11% of our buildings have an internal floor area of less than 60m^2, so in these buildings we may not have the freedom to reduce internal areas with significant thicknesses of insulation or to install a thermal store, as required to make a heat pump viable.

All this indicates that the number of 'space constrained' or 'appearance constrained' retrofits that we will need to take into account will be a significant proportion of the overall housing stock. However, these buildings are by no means a lost cause. There is still scope to achieve best practice levels of retrofit even in heritage constrained areas. In fact, these areas of our towns and cities could even provide opportunities for more efficient retrofits at scale. For example, in Conservation Areas, specific neighbourhood and typology guidance can be applied over larger areas. This neighbourhood level Retrofit Planning guidance would facilitate quicker retrofit implementation as it does away with repeat work of preliminary investigation on similar properties. It can even facilitate cheaper group or entire terrace multiple retrofit as there is more planning control available in Conservation Areas.

We should also ensure we don't become fixated on the difficult cases. Even if heritage constraints apply to 25% of our housing stock, 75% of our stock is therefore suitable for most retrofit measures and offers significant opportunity to reduce energy demand. Put simply, we should not hide behind the constraints of some of our building stock as an excuse not to retrofit.

Volume of UK mainland housing stock in millions

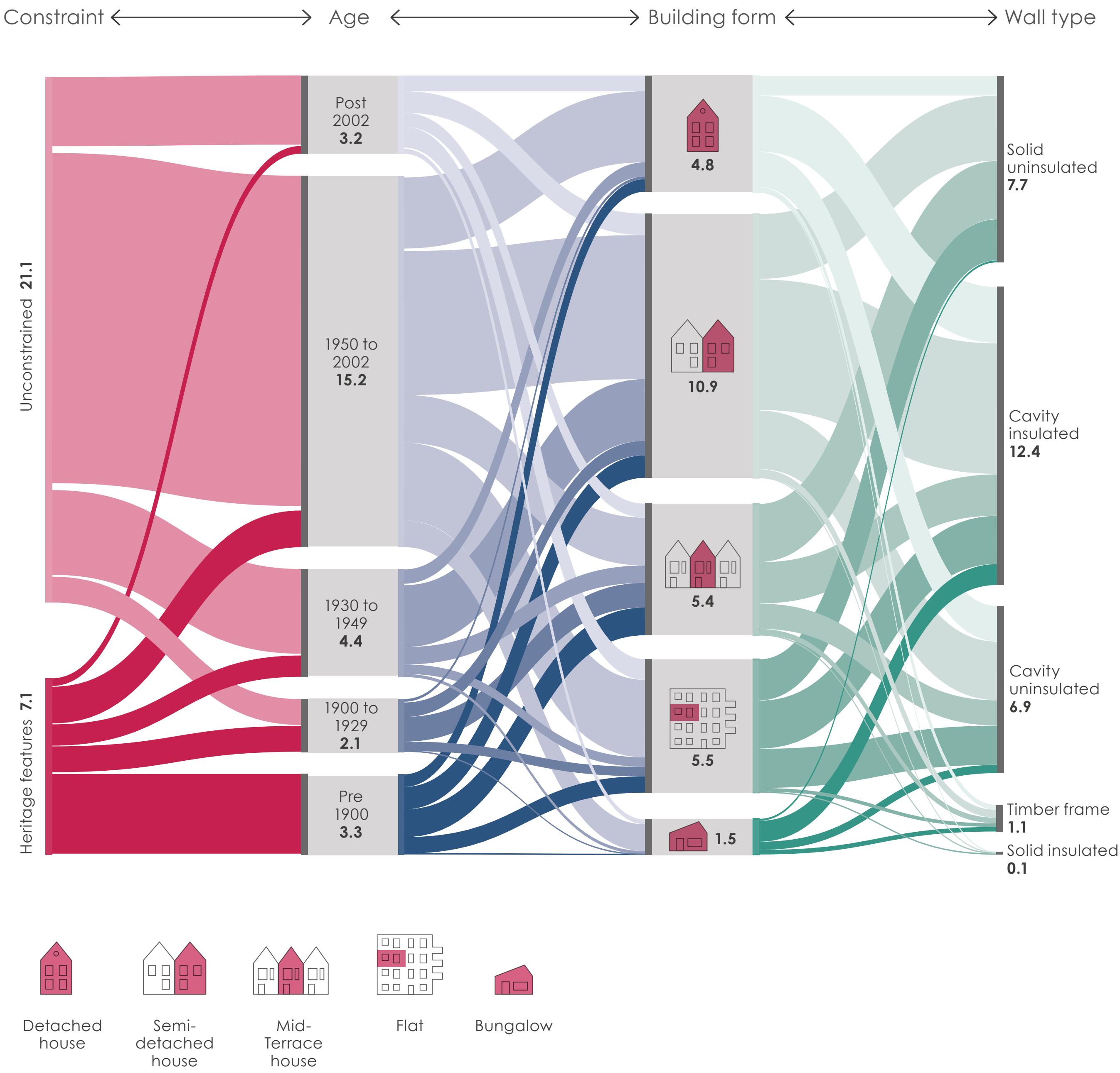


Figure 3.1 - UK mainland housing stock, by volume (millions of dwellings). Extrapolated data for 2018 (28 million dwellings).

How well do our existing dwellings perform?

Before considering by how much we might improve the performance of our homes, it is worth understanding where we are starting from. Unfortunately, this is far from clear as we have little national data which accurately describes our homes and how they perform.

The first step is therefore to build an accurate picture of our housing stock - a stock model. LETI has developed a detailed stock model representing the nation's 28 million dwellings which has been used to look at baseline energy demand and then to examine how this demand changes as we apply different levels of retrofit. Full details of how the stock model was constructed and calibrated against measured energy use are provided at Annex E.

SIGNPOST *Annex E - Stock modelling method and assumptions*

Figure 3.3 shows a breakdown of the baseline energy demand for heating and hot water and shows a slight shift away from the stock numbers themselves, demonstrating that the largest proportion of energy use is in our post 1950s buildings with semi detached and cavity uninsulated dwellings taking nearly a third of all energy use.

The stock model was used to demonstrate how our existing domestic energy use is spread across the different dwelling forms and also how this compares to new-build energy standards. Figure 3.2 shows that, overall, we currently have an average domestic Energy Use Intensity (EUI) of 214kWh/m^2/year (includes regulated and unregulated energy) compared to a target of 60kWh/m^2/year for a new-build dwelling built to the forthcoming 2021 English Part L standards and to just 35kWh/m^2/year for a building that meets LETI targets.

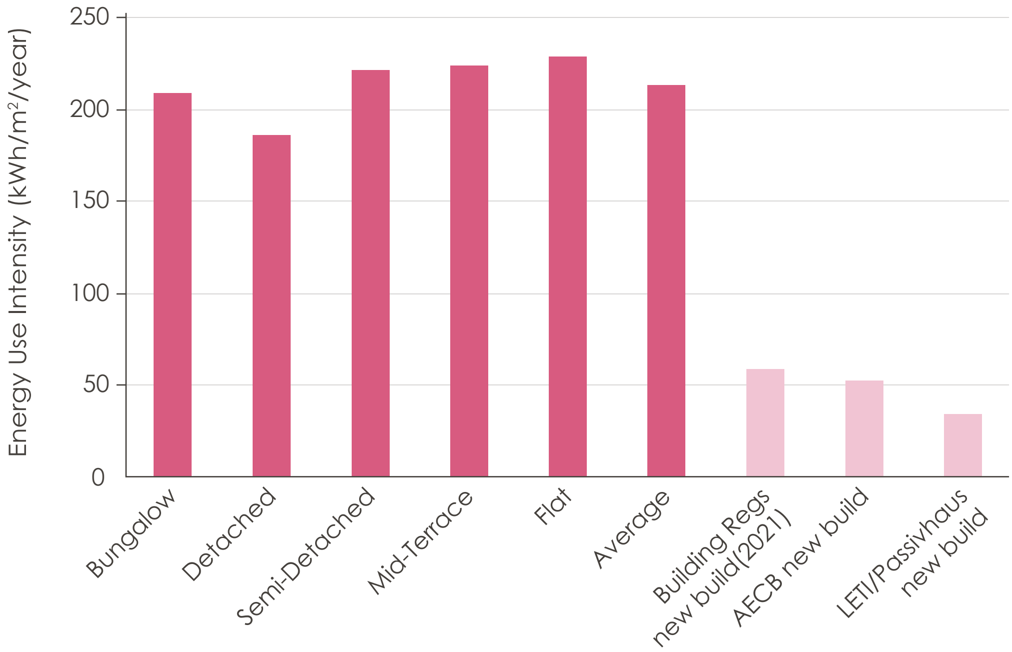


Figure 3.2 - As modelled Energy Use Intensity for existing dwellings by form factor and new build standards. See also discussion on page 50.

Annual heating and hot water demand in TWh/year

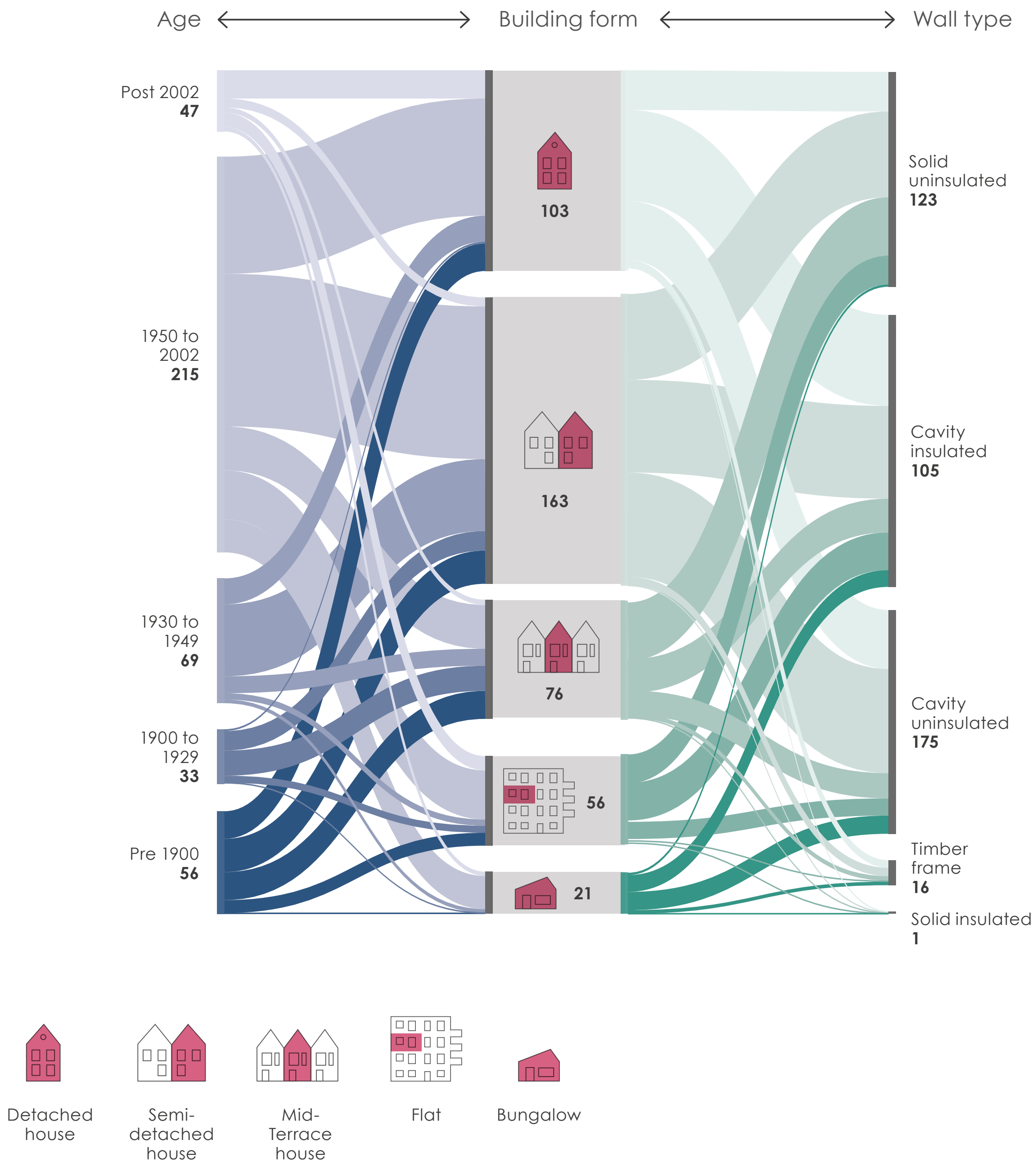


Figure 3.3 - Modelled baseline annual heating and hot water demand (TWh/year) by dwelling age, form and wall type (28million dwellings)

How well do our existing dwellings perform? *(cont'd)*

The significant drop in EUI between existing and new build is due in large part to the fact that the new-build standards have been modelled to have thermal energy delivered via a heat pump, whereas, for the existing stock, the default is assumed to be a gas boiler. However, there is also a significant difference in fabric efficiency between our existing dwellings and new build standards. The relationship between energy demand and energy delivered at the meter (EUI) where a heat pump is used is illustrated in Figure 3.4 and explained in more detail in Annex A.

SIGNPOST *Annex A - How do our homes produce carbon?*

A dwelling's space heating demand is a good proxy for its fabric efficiency and ventilation performance. It is therefore more revealing to look at the space heating demand derived from this modelling in more detail, we can see the distribution of efficiency across the entire housing stock. This is shown in Figure 3.5 below. It demonstrates a mean demand of around

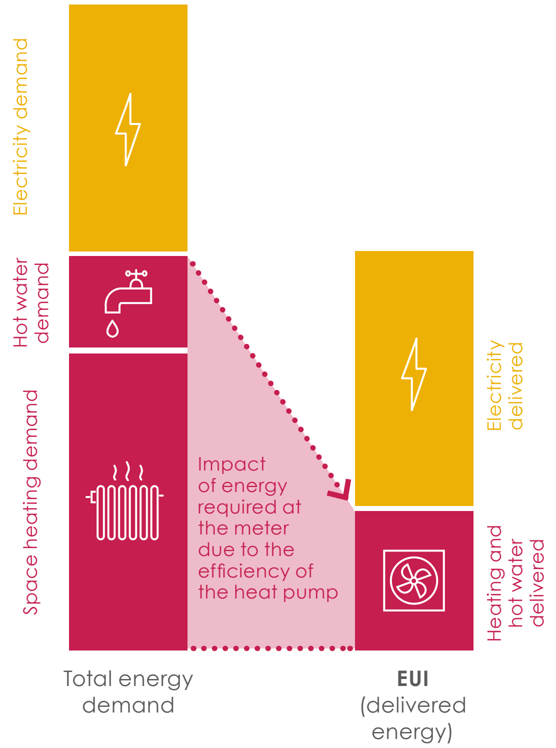


Figure 3.4 - Relationship between energy demand and EUI when using a heat pump.

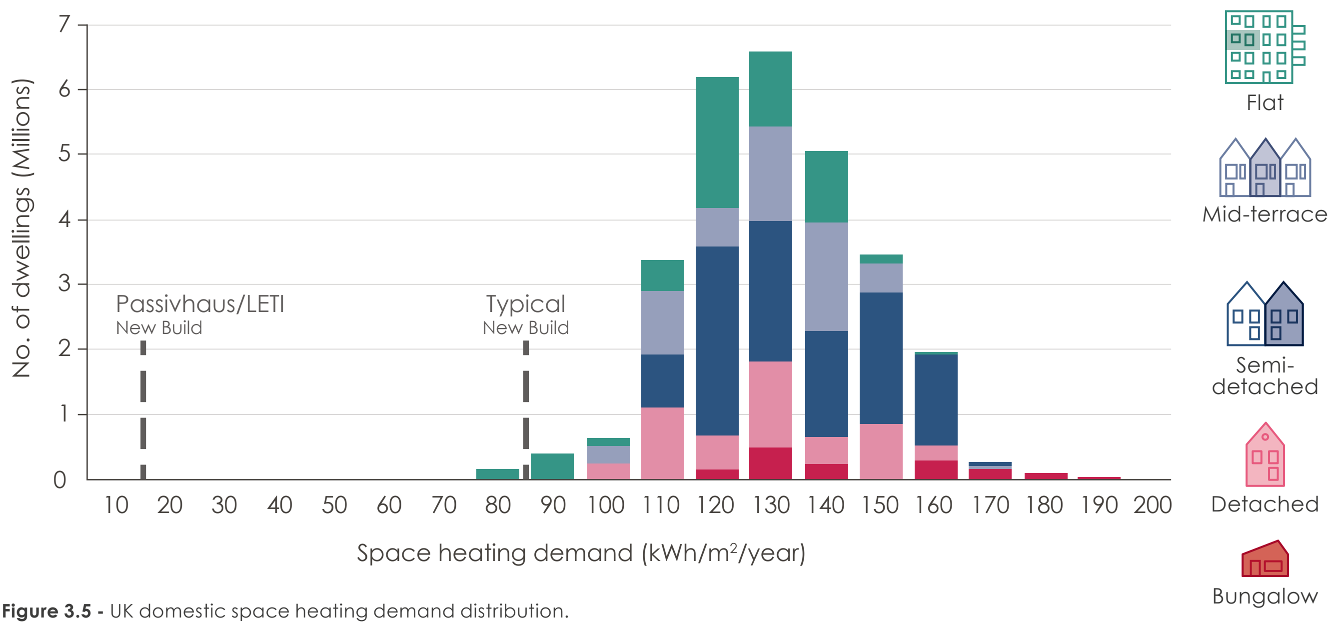


Figure 3.5 - UK domestic space heating demand distribution.

130 kWh/m²/year with a fairly typical normal distribution. As would be expected, the more compact buildings (e.g. flats) tend to have lower space heating demands.

Of note, a new build building regulations compliant dwelling (including the performance gap) is estimated to perform at 85 kWh/m²/year[3.1] and a new build Passivhaus at 15 kWh/m²/year. This is a significant difference and indicates the inefficiency of our existing housing stock compared to exemplar levels of performance.

Good levels of fabric performance - known typically as a 'fabric first' approach, not only reduce energy demand at source, but also offer increased levels of comfort and improved health by providing thermal comfort in both summer and winter as well as greatly improved indoor air quality. In contrast, achieving reductions in demand just by fitting heat pumps and solar PV alone will not result in these co-benefits.

Our main sources of energy

It is also important to understand how our energy is currently delivered. The majority of our existing housing stock (84%) uses natural gas to provide heating and hot water with the remainder mostly using electricity and a small fraction relying on oil and biomass. Overall, the domestic sector uses around 480 TWh of energy annually (29% of the country's total energy consumption) with the majority of that energy going towards heating and hot water[3.2]. Clearly, if we are to take advantage of a decarbonised electricity grid, we have to move away from fossil fuel heating and hot water.

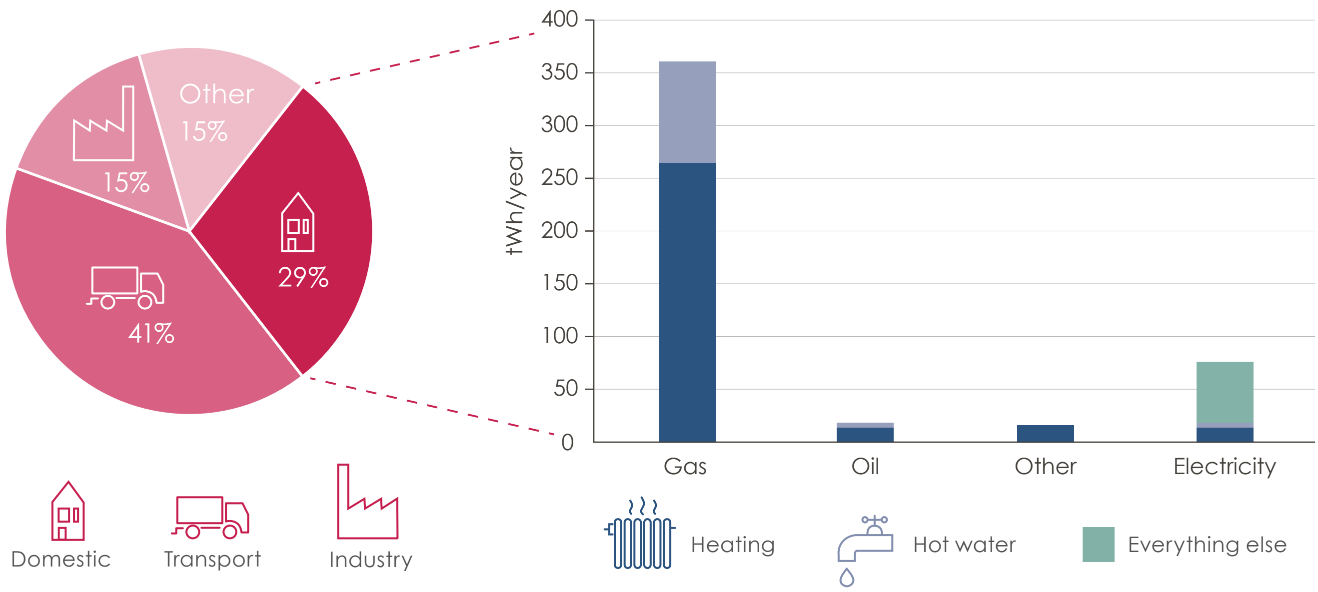


Figure 3.6 - UK sector consumption and domestic energy use breakdown (2018)[3.3].

3.2 Effect of different levels of retrofit

What can be done?

In determining the potential 'best practice' result for a retrofit (i.e. how far could we go with a property), age is not necessarily the main driving factor. LETI's analysis suggests that two principal factors largely govern the building's final heating demand. They are the building's form factor and whether there are any constraints on retrofit activity.

Form factor

The form factor is a ratio of the building's external heat loss area to its internal usable floor area. The less efficient the building's shape, the higher the form factor, and the more energy required for heating. Form factors will range from around 4 for detached single storey dwellings to 1 to 1.5 for multi-storey buildings arranged as flats.

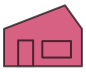
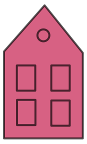
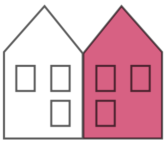
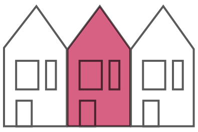
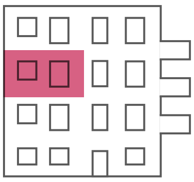
Type		Form factor	Heat demand
	Bungalow house	3.0	Most heat demand
	Detached house	2.5	
	Semi-detached (inc. end of terrace)	2.1	
	Mid-terrace house	1.7	
	End mid-floor apartment	0.8	Least heat demand

Figure 3.7 - The effect of lower (improved) form factors.

Constraints

As discussed earlier, heritage features and internal space could all limit the extent of the retrofit that can be achieved - i.e. some retrofits will be constrained. Constraints are typically: general external appearance, internal space, or access to areas/rooms. This is illustrated in Figure 3.8 and has the effect that the level of insulation improvement and perhaps improved glazing are limited when compared to an unconstrained retrofit. Furthermore, in a space-constrained retrofit, there may be limited options for additional equipment such as a MVHR, hot water tank or thermal store. External space is also required for some types of air source heat pumps.

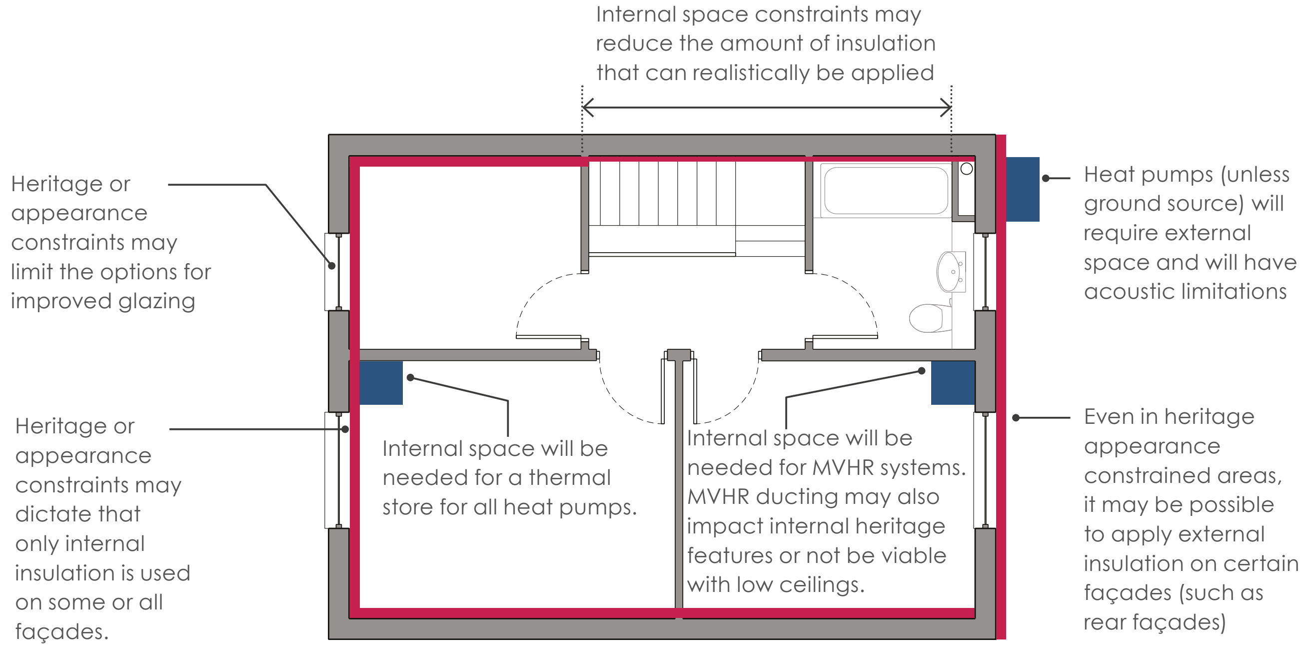


Figure 3.8 - Constraints on retrofit scope.

Modelled retrofit cases

To illustrate these principles, LETI has modelled a series of retrofit cases using the stock model:

Improved performance

Retrofit Case	Description
1. Baseline	Un-renovated, as original
2. Do minimum	Meet the Building Regulations backstop criteria for retrofit. Common retrofit measures which do not result in significant interventions into the building fabric
3. LETI best practice constrained	LETI retrofit situations where the depth of retrofit is constrained by external appearances and/or internal space
4. LETI best practice unconstrained	LETI retrofit with pragmatic and realistic element U-values and airtightness, achievable in the vast majority of unconstrained dwellings (see Annex E for an explanation of how these values have been derived)
5. LETI exemplar	The best retrofit that we could hope to achieve

Figure 3.9 - Modelled retrofit cases

SIGNPOST *Annex F - Modelling parameters*

The specific parameters associated with each retrofit case are detailed at annex F. In sum, the efficiency measures modelled are:

→ External and Internal Wall Insulation (as appropriate)
→ Improved/increased roof insulation
→ Improved/increased floor insulation
→ Improved glazing (up to triple)
→ Improved thermal performance of doors
→ Reduced permeability/Increased airtightness
→ Reduced thermal bridging
→ Improved ventilation (including Mechanical Ventilation with Heat Recovery)
→ Improved hot water tank insulation
→ Improved hot water distribution pipe insulation
→ Reduced hot water demand (lower flow fittings)

SIGNPOST *Annex K - Definitions*

It is important to note that various combinations of these measures are modelled as a coherent group of measures, rather than the sum of separately modelled measures. This means that the interaction between the measures are properly considered.

Modelled space heating demand

The results of these scenario models demonstrate that, as expected, the worst performing archetypes initially are those with poorer form factors with a spread of space heating demand between 120 and 130 kWh/m²/year. When improved to best practice the performance comes down to between 18 and 30 kWh/m²/year representing a consistent reduction of between 82 and 86% for all archetypes. Of note is that detached dwellings tend to have a lower space heating demand per m² which is due to the fact that they have the largest internal areas - not that they actually have an overall lower demand. The data also shows, perhaps surprisingly, that form factor is reasonably good for all archetypes other than bungalows and that there is a high degree of consistency in terms of the space heating demand achievable across the different wall constructions and property ages. For the LETI Unconstrained case, the improved space heating demands range between 36 and 46 kWh/m²/year representing a reduction of around 73%.

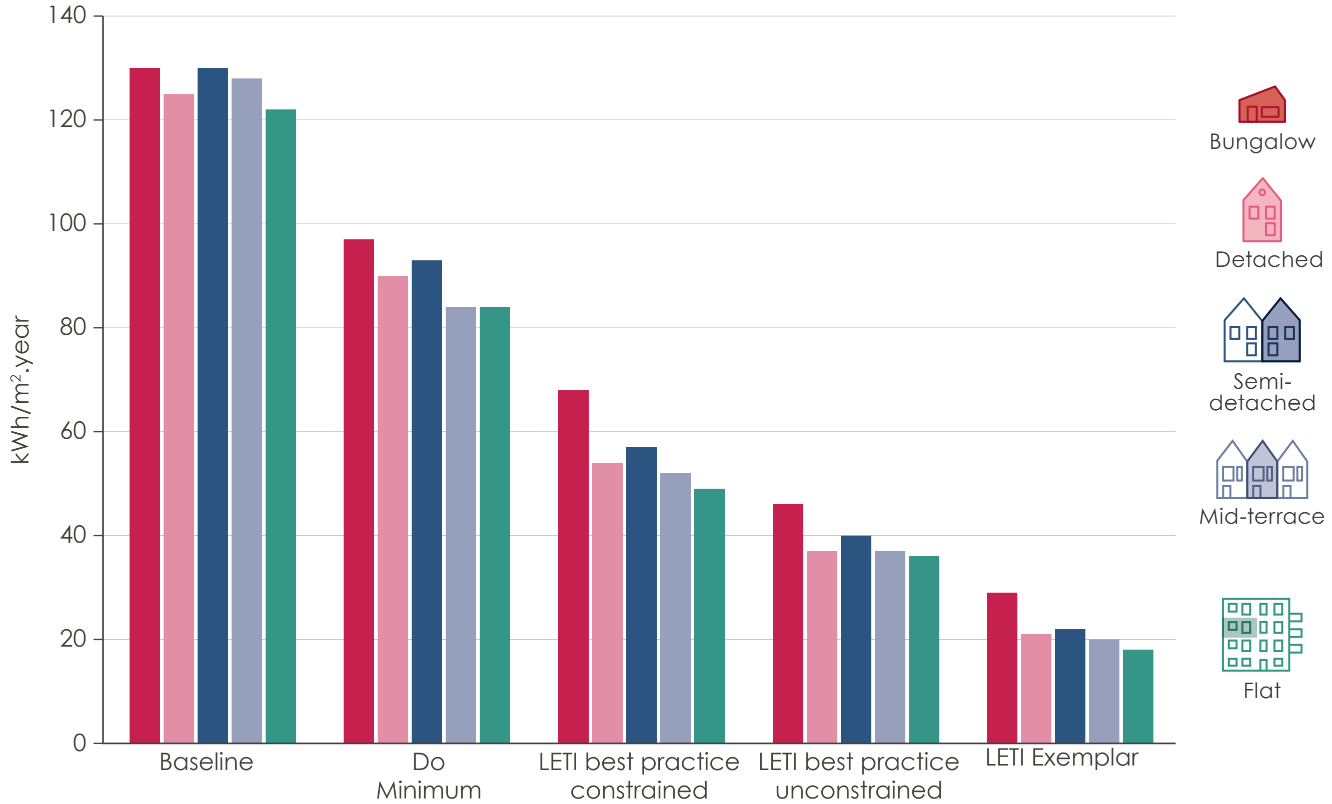


Figure 3.10 - Effect of varying retrofit scenarios on space heating demand (the energy needed to heat the space, independent of type of heat source used), by building form.

	Space heating kWh/m²/year				
	1. Baselines	**2. Do minimum**	**3. LETI best practice constrained**	**4. LETI best practice unconstrained**	**5. LETI exemplar**
Bungalow	130	97	68	46	29
Detached	125	90	54	37	21
Semi-detached	130	93	57	37	20
Mid-Terrace	128	84	52	37	20
Flat	122	84	49	36	18

Figure 3.11 - Change in space heating demand by retrofit case and by building form

Modelled hot water demand

As well as reducing space heating demand by improving the fabric, retrofit provides the opportunity to significantly reduce hot water demand. The associated parameters are shown in Annex F, but can be summarised as either reducing losses (improved insulation, shorter pipe runs, fewer dead legs, lower storage temperatures) or reducing demand (more efficient fittings and Waste Water Heat Recovery). The AECB Water Standard[3.3] provides some excellent guidance on this topic.

Hot water reductions are not subject to the same constraints as fabric improvements and are also not strongly linked to form factor. Thus, the potential reductions are far more consistent across all archetypes and scenarios, but the grouping is not as close. This is because the demand for hot water is heavily related to occupancy and the occupancy levels are more dense in the smaller archetypes, thus resulting in a higher hot water demand per m² of internal floor area. Overall, a consistent reduction of around 58% is seen from the baseline case.

SIGNPOST *Annex F - Modelling parameters*

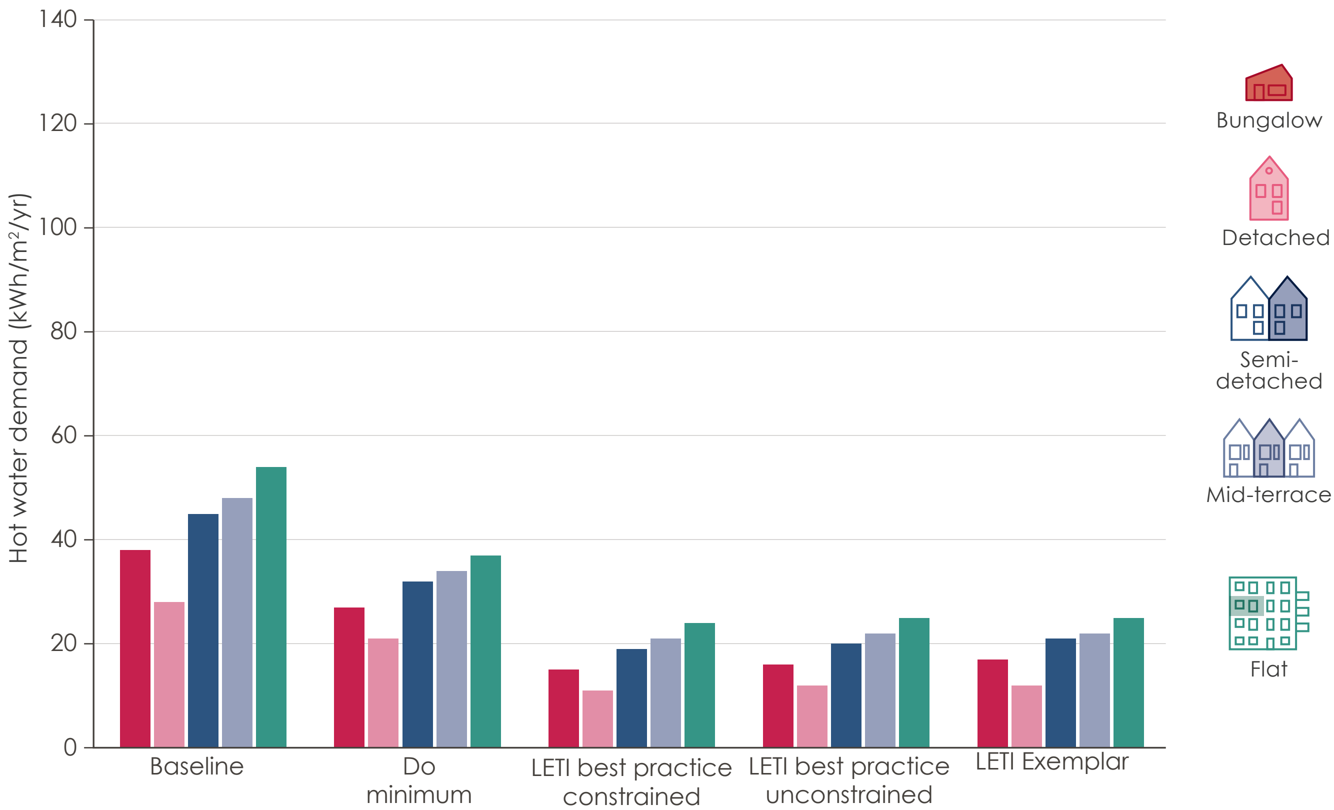


Figure 3.12 - Effect of varying retrofit scenarios on hot water demand, by building form.

SIGNPOST *Annex A - How do our homes produce carbon?*

Overall space heating and hot water reduction

This analysis demonstrates that the overall scope of what is achievable in retrofitting our existing building stock is a reduction in space heating demand (SHD) of between 37% and 85% coupled with a reduction in hot water demand of between 29% and 58%.

It should be noted that these are energy reductions not carbon reductions. Translating these results into carbon reductions will be dependent on the form of heat source used and also the carbon factors applied in the calculation. See annex A for further details.

	1. Baselines	2. Do min.	3. LETI best practice cons.	4. LETI best practice unc.	5. LETI exemplar
Average SHD reduction	0%	30%	56%	69%	83%
Average DHW reduction	0%	29%	58%	58%	58%

Figure 3.13 - Percentage reduction in space heating demand and hot water demand by retrofit case.

Energy savings by dwelling type

Applying these results across the stock model, we can map the potential for energy saving to different dwelling types - i.e. how much energy could be saved by a best practice retrofit in each case. This is shown in Figure 3.14 below. This shows that the largest opportunities for improving the energy consumption lie in post 1950 detached and semi-detached dwellings and, interestingly, insulated cavity walls as these can be further insulated to achieve higher levels of performance.

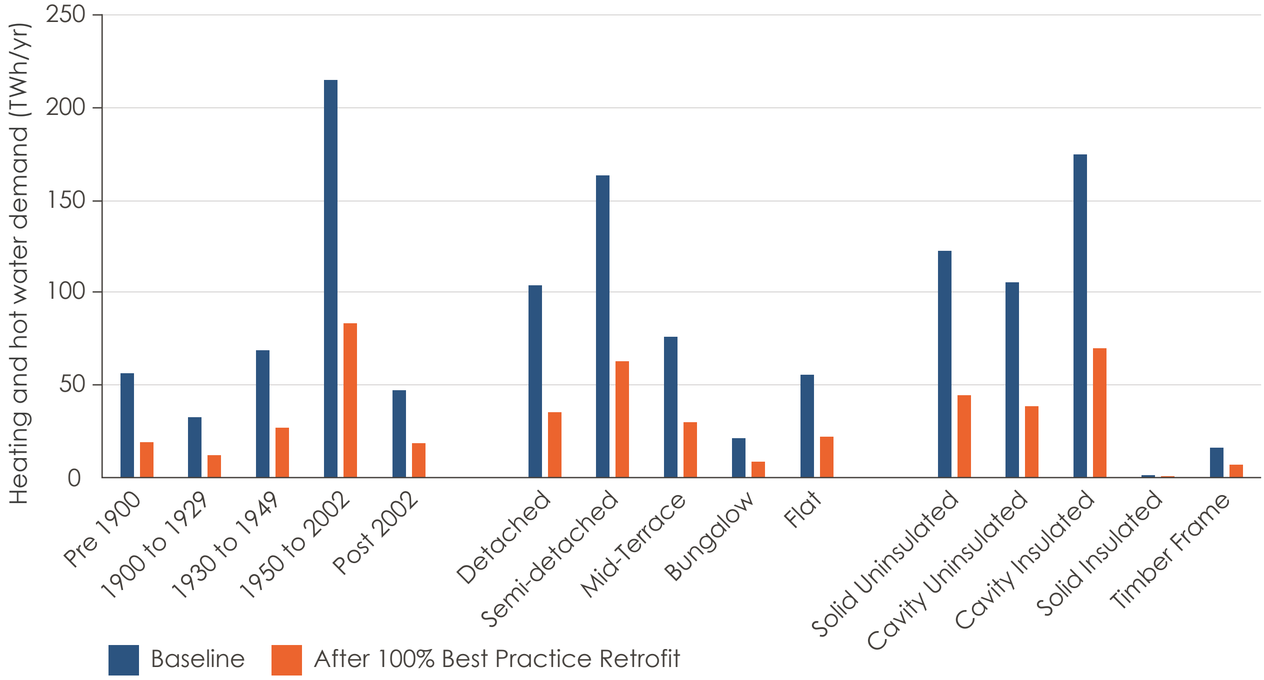


Figure 3.14 - Change in heating and hot water demand from baseline (2018) to 100% Best Practice retrofit by dwelling age, form and wall type.

Comparisons and impacts

Finally, the stock model can also be used to compare the overall average Space Heating Demand (as a proxy for fabric efficiency) and equivalent Energy Use Intensity (EUI) figures for each retrofit case as well as for a range of other new build and retrofit standards, see Figure 3.15 below. We can also look at the impact of applying an average 62%[3.4] reduction in space heating demand on the space heating demand distribution of the UK's housing stock, see Figure 3.16.

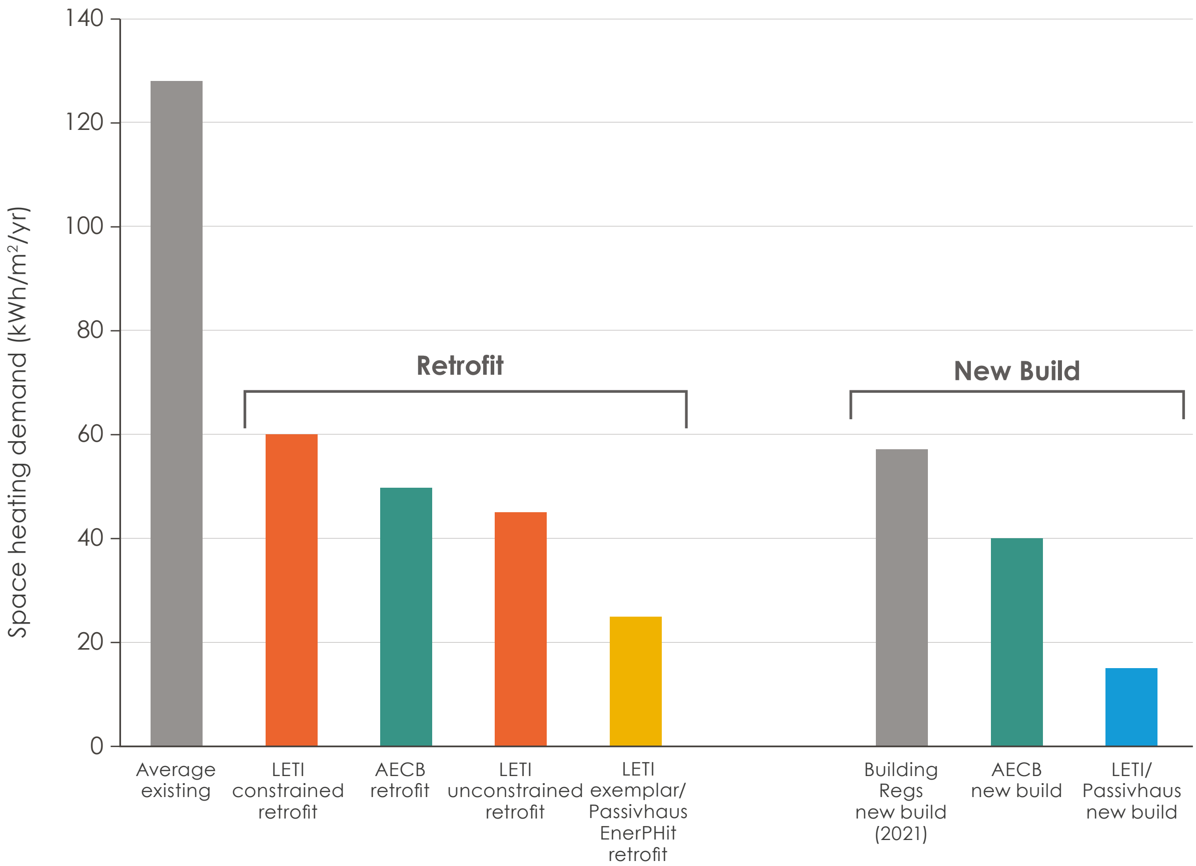
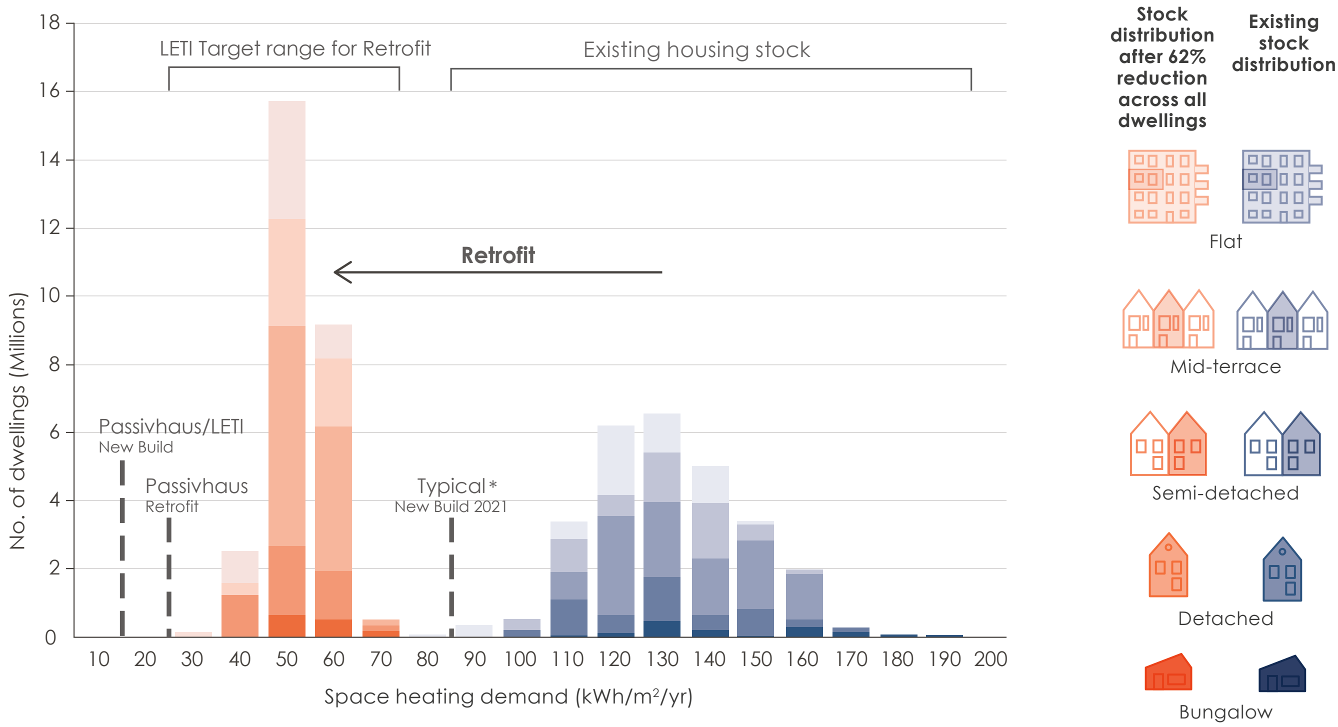


Figure 3.15 - Space heating demand comparison [3.5] (LETI retrofit cases highlighted in orange).



* Includes for an assumed performance gap

Figure 3.16 - Total number of UK dwellings broken down by their space heating demand, showing the transition required from existing levels of high demand to the LETI retrofit target range. Figure based on stock modelling carried out by LETI.

Comparisons and impacts *(cont'd)*

Notes:

→ All EUIs are modelled using heat pumps for heating and hot water, except for the Average Existing which assumes a gas boiler

→ Figures are in kWh/m²/year and include both regulated and unregulated energy consumption

The analysis shows that there is a significant opportunity to reduce heating and hot water demand. However, once these have been reduced, unregulated[3.6] energy becomes hugely significant. Whilst not necessarily an issue for retrofit (as this is not necessarily driven by the building fabric), it does highlight that this offers further opportunities for reductions.

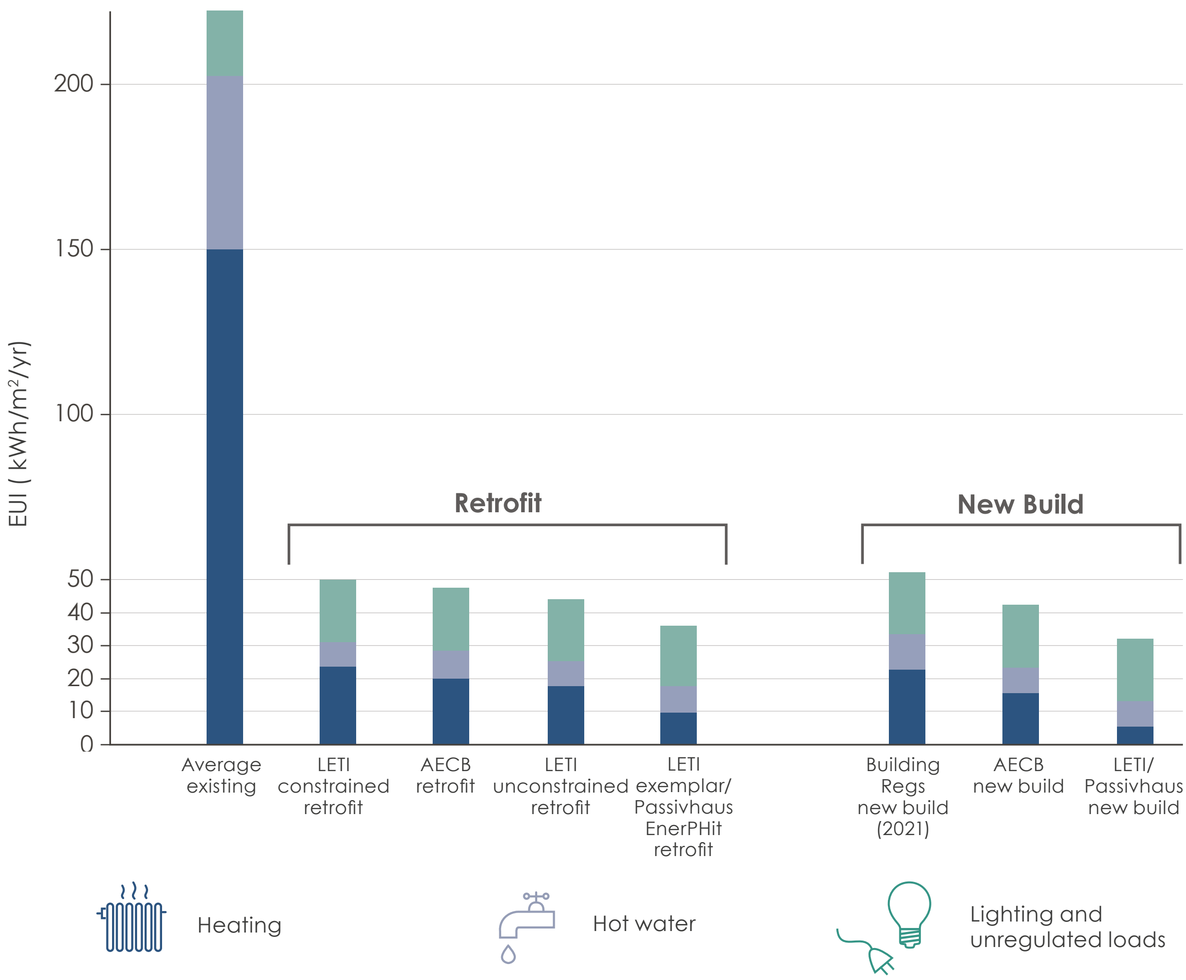


Figure 3.17 - EUI Comparison

3.3 What has the stock model told us?

The stock modelling set out above has illustrated the scope of what is possible when trying to reduce energy consumption across the UK housing stock. These results can be used to derive retrofit targets and also model the overall impact at a national scale.

Setting targets

The post retrofit space heating demand distribution shown in Fig 3.18 shows that, if every home was retrofitted to best practice standard, whilst the average home would have a space heating demand of 50 kWh/m²/year, having a target of up to 60 kWh/m²/year would encompass the vast majority of all buildings, regardless of their form, age or construction type. The LETI best practice target is set at 50 kWh/m²/year with an additional 10 kWh/m²/year for constrained homes.

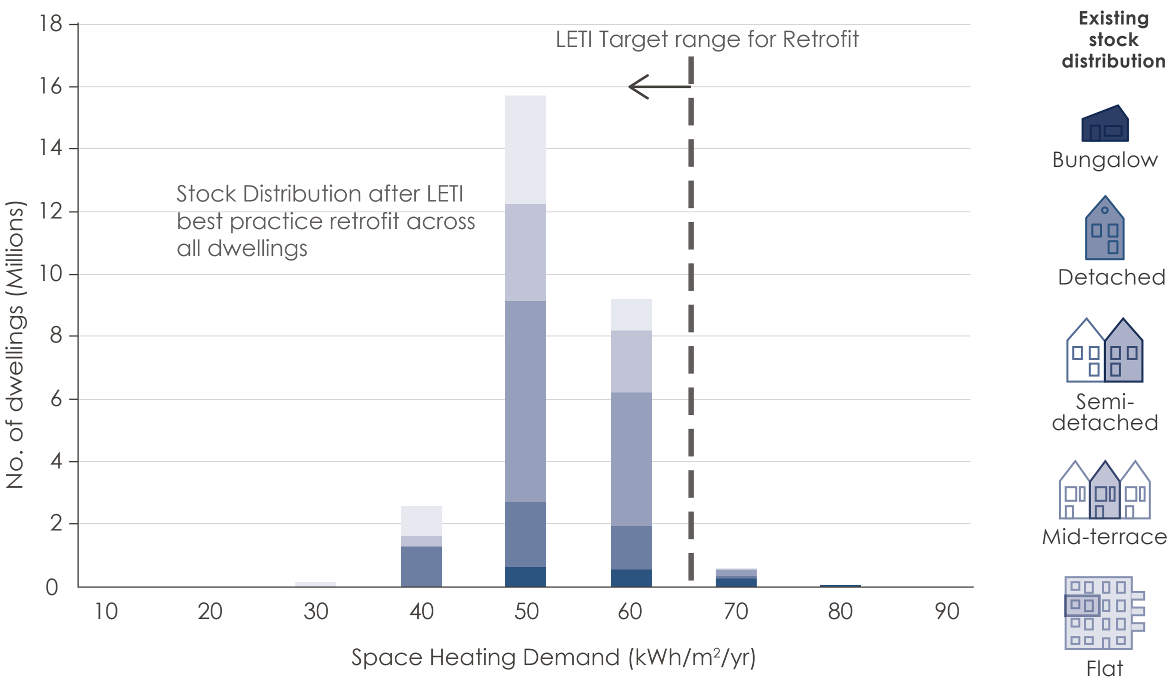


Figure 3.18 - UK Space heating demand distribution after 100% Best Practice Retrofit showing LETI's target range encompassing the vast majority of buildings.

The potential impact of retrofit at a national level

The stock model also allows us to see the overall effect on UK domestic energy consumption, and emissions, depending on the depth and reach of a national retrofit programme. To demonstrate this, three scenarios have been modelled with varying combinations of different depth of retrofits from a 2019 baseline property condition (see figure 3.19).

Each of these scenarios has then been used to illustrate the change in the overall annual energy consumption and associated annual carbon emissions reductions from the UK's domestic housing stock in 2019 to 2040 when the electricity grid carbon intensity has fallen to 41gCO_2e/kWh. For each scenario, it has been assumed that 85% of homes will have their heating and hot water provided by heat pumps or heat networks (with a similar SCOP) and the remaining 15% of homes heated by direct electricity.

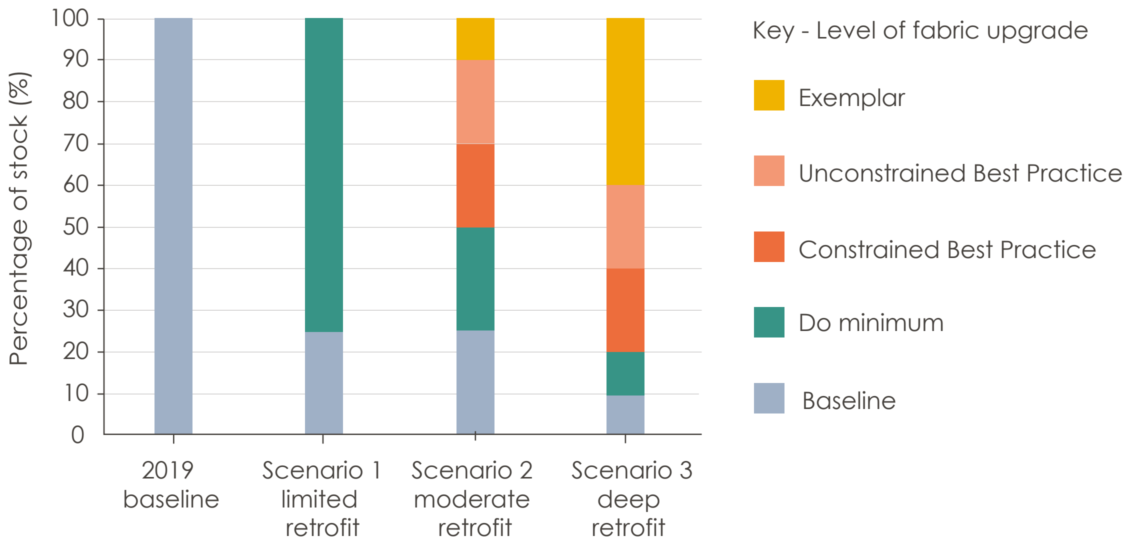


Figure 3.19 - Scenario percentage mix with varying combinations of depth of retrofit

Figure 3.20 shows that in scenario 1 replacing 85% of housing stock gas boilers with heat pumps or networks combined with a limited level of retrofit reduces the energy consumption significantly. The energy consumption more than halves and the carbon emissions drop by 91%. These results highlight the huge combined impact of moving our heating and hot water to heat pumps overlaid on grid decarbonisation. However, the scale of the impact of this transition alone masks the positive effect and necessity for a nation-wide deep retrofit programme as demonstrated by scenario 2 and 3.

As the national level of retrofit increases from scenarios 1 to 3, the energy consumption continues to drop further. The carbon emissions drop less significantly and therefore it is important to focus on the relative energy consumption to understand the full benefit of higher levels of national retrofit. Moving from a limited level of retrofit in scenario 1 to a good level of retrofit across the country in scenario 3 would reduce our demand for renewable energy by 60 tWh. Is that a lot? Well, it's the equivalent of covering around 280,000 football pitches with solar panels, or more than the entire surface area of Greater London. Furthermore, to put this into context against where we are now, in 2020 we generated just 11.3 tWh from solar energy and even our highest renewable generator, wind, produced only 54.6 tWh[3.7]. So, whilst it is theoretically possible to provide the generation capacity and associated infrastructure improvements necessary to delivery that additional 60 tWh, it is far more resource efficient, and far better for people's health, wellbeing and finances, to deliver that 60 tWh as a reduction in the heating and hot water demand of our homes through deep retrofit.

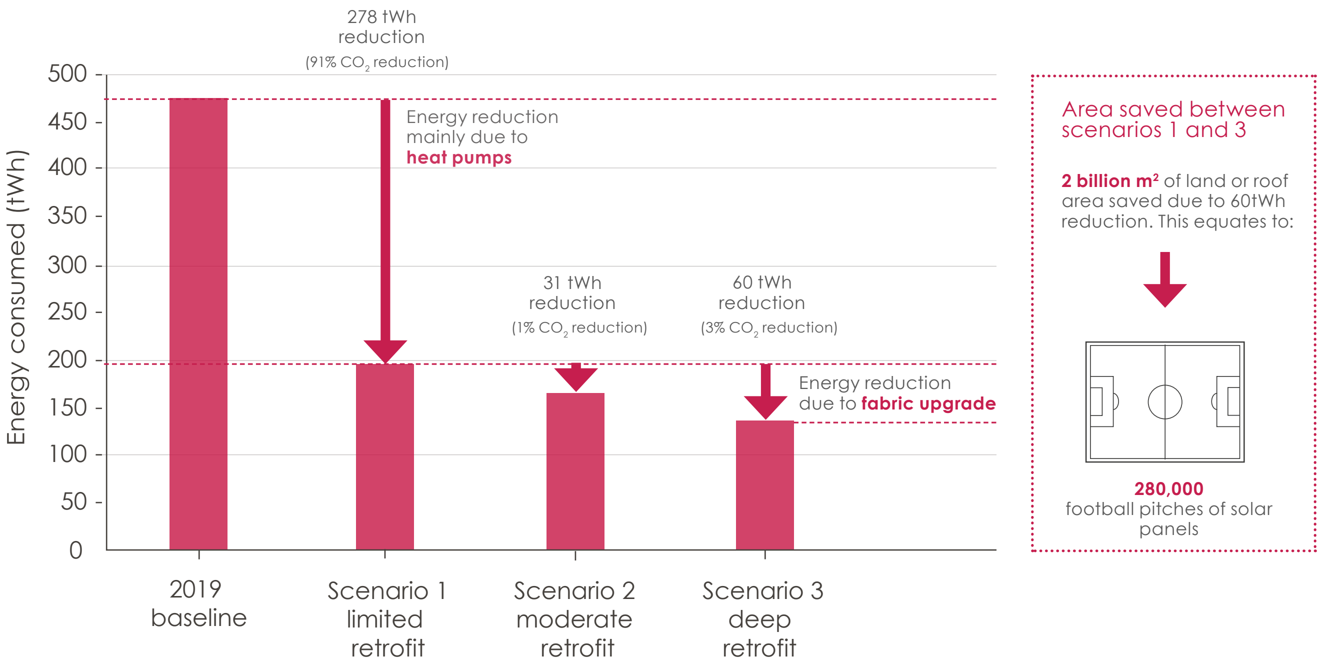


Figure 3.20 - Scenario comparison of energy consumed

3.4 References and footnotes

3.1 - The UK Passivhaus House Organisation, Research Report - Passivhaus the route to zero carbon? [Online] Available from: https://www.passivhaustrust.org.uk/guidance_detail.php?gId=40

3.2 - The Government, Energy Consumption in the UK [Online] Available from: www.gov.uk/government/statistics/energy-consumption-in-the-uk

3.3 - The Government, Energy Consumption in the UK [Online] Available from: www.gov.uk/government/statistics/energy-consumption-in-the-uk

3.4 - Assumes 50% unconstrained (69% SHD reduction) and 50% constrained (56% reduction) - see Figure 3.13

3.5 - See Definitions for a summary of the standards shown in this chart

3.6 - Unregulated energy is the energy used by appliances and any other devices in the home not related to the fixed building services that are intended to provide heating, hot water, ventilation or lighting.

3.7 - See https://cleantechnica.com/2021/01/11/solar-wind-power-growth-in-uk-from-2012-2020-charts/

4

LETI home retrofit targets

4.1 LETI home retrofit targets

The analysis in Chapter 3 has demonstrated the reductions in heating and hot water demand achievable across a range of building forms. This allows us to set out LETI best practice home retrofit targets that outlines LETI's proposed minimum targets for domestic retrofit. This chapter also sets out a higher performing LETI exemplar targets.

The suggested LETI targets for retrofit can be achieved either by the **modelling method**, or by the **constituent element method** and provides allowances for situations where external appearance or limited internal space result in a constrained retrofit.

It is recommended to use the modelling method approach which sets energy targets wherever possible, as the EUI can be easily measured post-retrofit to understand if the target is met in-use. The constituent element method approach provides fabric and system targets to give guidance where energy modelling is not viable.

4.2 Modelling method

For the modelling method, the retrofitted building should meet the best practice targets for: fossil fuels; space heating; hot water; overall Energy Use Intensity (EUI); and renewable energy as shown in Figure 4.1.

LETI recommends that predictive modelling be undertaken using the Passivhaus PHPP software to calculate these values. It is understood that in some cases this may be impractical, perhaps because of financial/time constraints or availability of modellers. If this is the case, SAP modelling can be used, however, RdSAP is not acceptable. If SAP modelling is used the building fabric U-values must not be worse than if the LETI constituent element route were taken.

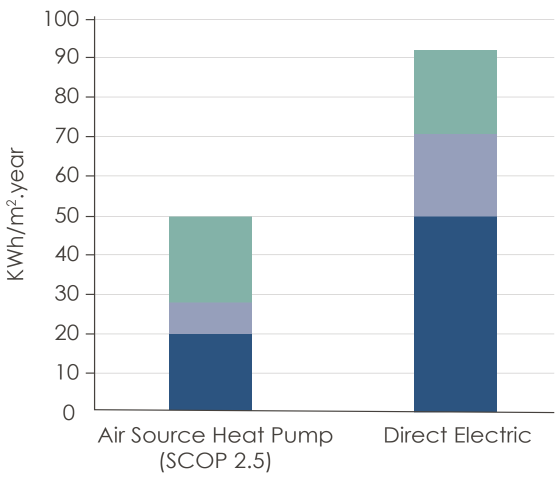
SAP does not provide a reliable calculation of unregulated energy use, therefore, PHPP or CIBSE TM54 methodology should be used for this element to calculate overall EUI.

The target EUI is based on heating and hot water being provided by a heat source with a seasonal coefficient of performance (SCOP) equivalent to a well designed ASHP system. Thus, a poorly designed heat pump, operating at higher flow temperatures, a gas boiler, or a direct electric system is unlikely to meet the target without significant compensating improvements in space heating and hot water demand. This is illustrated in Figure 4.2.

SIGNPOST *Chapter 2 - What is retrofit? - 2.5 Metrics and Energy Performance Certificates*

	LETI best practice		LETI exemplar	
Fossil fuel free	Fossil fuel free home		Fossil fuel free home	
Space heating demand	50 kWh/m²/yr	+10 kWh/m²/yr Additional allowance for constrained retrofit	25 kWh/m²/yr	
Hot water demand	20 kWh/m²/yr	+5 kWh/m²/yr Additional allowance for homes <75m²	20 kWh/m²/yr	+5 kWh/m²/yr Additional allowance for homes <75m²
Energy Use Intensity	50 kWh/m²/yr	+10 kWh/m²/yr Additional allowance for constrained retrofit	40 kWh/m²/yr	
Renewable energy	40% of roof area covered in PV panels	0% Constrained retrofits may not be able to accommodate PV. Maximise renewables where conditions are suitable to support solar generation – i.e. unshaded roofs (flat/pitched south, east, or west facing)	40% of roof area covered in PV panels	Maximise renewables where conditions are suitable to support solar generation – i.e. unshaded roofs (flat/pitched south, east, or west facing)

Figure 4.1 - LETI retrofit energy targets.
Figures given in kWh/m²/year (treated floor area or 90% of gross internal floor area)



kWh/m²/year (treated floor area or 90% of gross internal floor area)	Air Source Heat Pump (SCOP 2.5)	Direct Electric
Space Heating consumption	20	50
Hot Water consumption	8	20
Lighting and unregulated loads	22	22
Total EUI	**50**	**92**

Figure 4.2 - Graph and table showing comparison of EUI for an air source heat pump versus direct electric for the same dwelling

4.3 Constituent element method

For the constituent element method, the various components of the retrofit works should achieve the target parameters set out in Figure 4.3. This method can be used where detailed energy modelling is not possible or financially feasible on a small project. The values shown have been derived from the LETI Stock Model and equate with the overall energy targets for space heating demand, hot water and EUI set out in the modelling method.

Building element	Retrofit actions	LETI best practice			LETI exemplar
		Constrained retrofit	**Unconstrained retrofit** (Cool Temperate Climate)	**Unconstrained retrofit** (Cold Climate)	**All retrofit types**
Walls					
Cavity	External, cavity or Internal insulation[1]	0.24 W/m².K	0.18 W/m².K	0.12 W/m².K	0.15 W/m².K
Solid Uninsulated	External or Internal insulation[1]	0.32 W/m².K	0.18 W/m².K	0.12 W/m².K	0.15 W/m².K
Timber Frame	External or Internal insulation[1]	0.21 W/m².K	0.18 W/m².K	0.12 W/m².K	0.15 W/m².K
Roofs					
Cold	Insulate	0.12 W/m².K	0.12 W/m².K	0.10 W/m².K	0.12 W/m².K
Warm / Flat	Insulate	0.22 W/m².K	0.12 W/m².K	0.12 W/m².K	0.12 W/m².K
Floors					
Suspended Timber	Insulate between joists	0.20 W/m².K	0.18 W/m².K	0.12 W/m².K	0.15 W/m².K
Solid Uninsulated	Excavate and insulate below	0.80 W/m².K	0.15 W/m².K	0.10 W/m².K	0.15 W/m².K
Windows and doors					
Windows	Improve/replace	1.30 W/m².K	1.00 W/m².K	0.80 W/m².K	0.80 W/m².K
Doors	Replace	1.00 W/m².K	0.80 W/m².K	0.80 W/m².K	0.80 W/m².K
General envelope					
Thermal Bridging	Mitigate where possible	0.10 W/m.K	0.10 W/m.K	0.10 W/m.K	0.08 W/m.K
Airtightness	Draught-proofing, sealing of chimneys and vents	3.0 ach@50Pa	2.0 ach@50Pa	2.0 ach@50Pa	1.0 ach@50Pa

1 - Where internal wall insulation is used, there could be a significant risk of interstitial condensation. To minimise this risk, the post-retrofit U-value should be no better (lower) than those shown for constrained retrofits above. Furthermore, in areas where insulation can not fully cover the original wall, the approaching insulation should be tapered or reduced. See Annexes C and H for more information.

Note:

→ In determining whether to use the cool temperate climate or cold climate fabric and system targets, designers should take into account the local climate. As a rough guide, we would suggest that cold climate U-values are used in Scotland and northern areas of England.

→ Annexes C and H provide further detail on how to enact some of these actions in practice.

SIGNPOST *Annex C: Illustrative insulation strategies*

SIGNPOST *Annex D: Retrofit ventilation strategies*

SIGNPOST *Annex H: Moisture risks and how to avoid them*

		LETI best practice			LETI exemplar
Building element	**Retrofit actions**	**Constrained retrofit**	**Unconstrained retrofit** (Cool Temperate Climate)	**Unconstrained retrofit** (Cold Climate)	**All retrofit types**
Systems					
Systems and appliances	Fossil fuel free home	Fossil fuel free	Fossil fuel free	Fossil fuel free	Fossil fuel free
Ventilation Type	Install upgraded ventilation system	MVHR[2]	MVHR	MVHR	MVHR
Lighting Power	Replace lamps and fittings	50 lm/W	100 lm/W	100 lm/W	100 lm/W
Hot water					
Hot Water Tank	Increase or replace insulation	1.5 W/K	1.5 W/K	1.5 W/K	1.5 W/K
Primary Pipework	Insulate all pipework	90% of pipework insulated	90% of pipework insulated	90% of pipework insulated	90% of pipework insulated
Shower Demands	Low flow fittings	16 litres/pers.day	16 litres/pers.day	16 litres/pers.day	16 litres/pers.day
Other Demands	Low flow fittings	9 litres/pers.day	9 litres/pers.day	9 litres/pers.day	9 litres/pers.day
Renewables					
Photovoltaic Generation[3]	Rooftop installation	0 % of roof area covered in PV panels	40 % of roof area covered in PV panels[4]	40 % of roof area covered in PV panels[4]	40 % of roof area covered in PV panels[4]

2 - If not possible use demand control dMEV or demand control cMEV. Refer to Annex D.

3 - Our modelling has assumed that the vast majority of homes will be fitted with a heat pump. A heat pump will realise more hot water from a PV system than a solar thermal system, given the same amount of solar radiation (due to the effect of the heat pump's COP). Furthermore, once the hot water tank has reached its target temperature, the solar thermal panels are doing nothing. In contrast, PV can power other things and also feed back into the grid (if you do not need the power). Thus, we have focused on PV. If, however, a heat pump is not installed and roof mounted panels are considered, solar thermal is a more efficient way of generating hot water and can typically provide up to 50% of a home's hot water demand.

4 - Maximise renewables where conditions are suitable to support solar generation – i.e. unshaded roofs (flat/pitched south, east, or west facing)

Figure 4.3 - LETI retrofit fabric and systems targets

4.4 Using retrofit standards and guidance

Our analysis has demonstrated that what LETI considers to be a pragmatic, affordable and realistic level of retrofit matches closely with the AECB Retrofit standard in terms of both space heating demand and final EUI. LETI considers this to be a **best practice** retrofit. The more demanding Passivhaus EnerPhit retrofit standard achieves further reductions and is aligned with LETI's **exemplar** targets in terms of retrofit ambition.

As we are unlikely to be able to achieve a consistent level of retrofit across all our housing stock, we will need some retrofits to be in this exemplar category, both to achieve the required reduction in demand across the country, but also to drive innovation and demonstrate what can be achieved.

This document sets out guidance intended to show what a best practice retrofit looks like and how it should be undertaken. It is not a retrofit standard in itself. A key element of any construction project is robust quality assurance to ensure that the final building performs as it was designed. For this reason, LETI strongly recommends that a recognised retrofit standard and quality assurance process is used alongside the LETI guidance.

The following flowchart sets out how to decide on the appropriate retrofit target for your particular project. It should be read in conjunction with the table opposite which summarises the various retrofit standards and schemes available.

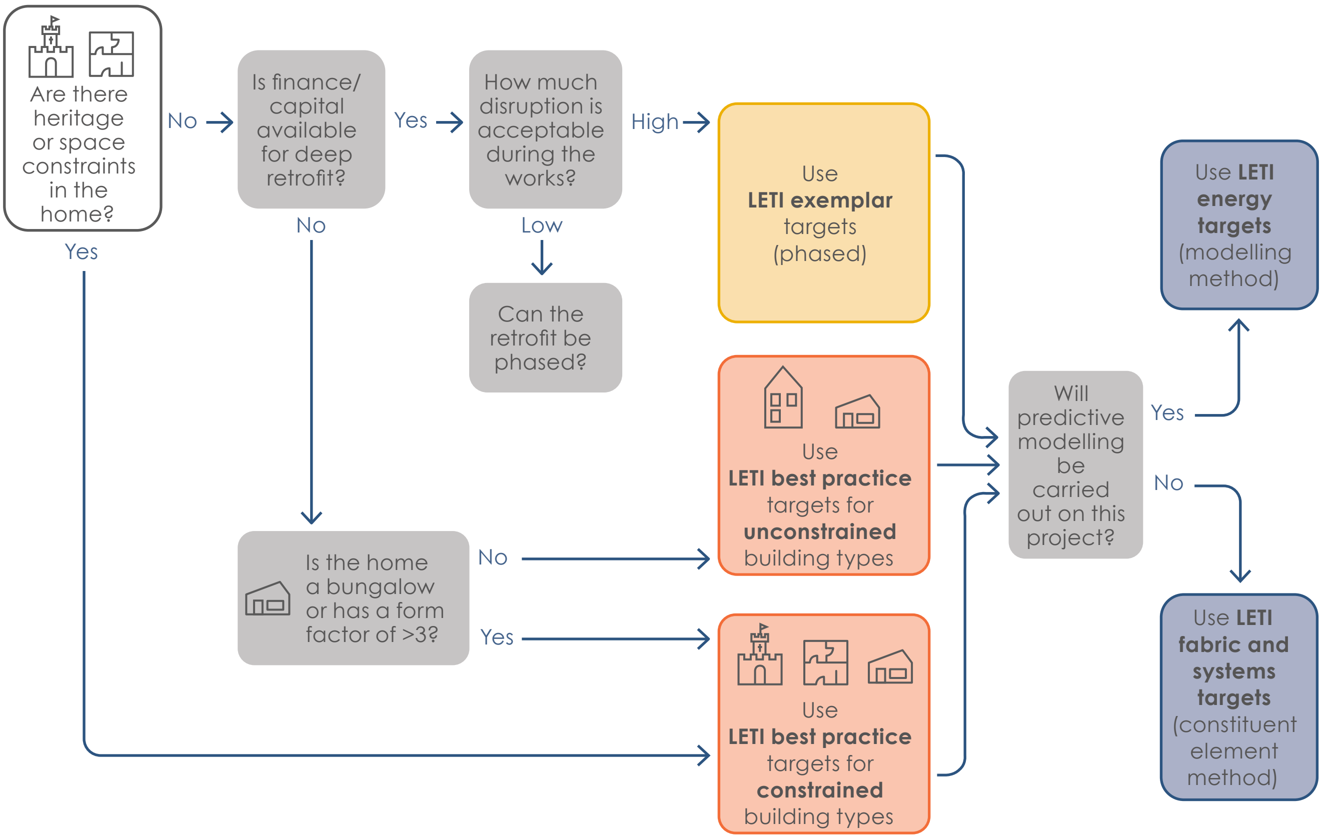


Figure 4.4 - Flowchart to assist target decision making

Name/ Reference	Description	Space Heating Demand	EUI kWh/m²/ year	Compliance method	When to use
Retrofit Guidance					
PAS 2035:2019 Department for Business, Energy & Industrial Strategy bsi.	Best Practice Guidance and a Quality Assurance process for retrofit	N/A	N/A	Employment of suitably qualified Retrofit Designer and Retrofit Coordinator to manage the Retrofit Process.	Any level of retrofit. Mandatory for government procured schemes from 2021. Should be used, at minimum, for large scale and/or high-risk retrofit where there are significant levels of intervention to the building fabric and ventilation.
LETI	LETI best practice guidance for safe and effective retrofit	50 kWh/m²/yr (up to 60 when constrained)	50 kWh/m²/yr (up to 60 when constrained)	Demonstrated either by modelling or the constituent element method. No certification or QA scheme offered.	Use the LETI flowchart in Figure 4.4 to determine when to use: LETI best practice constrained and unconstrained targets; LETI exemplar targets; and whether to use the energy targets (modelling method) or fabric and system targets (constituent element method).
	LETI exemplar guidance	25 kWh/m²/yr	40 kWh/m²/yr		
EnerPHit Certified Retrofit Passive House Institute	Independent Construction Standard for retrofit	20-25 kWh/m²/yr	EUI equivalent likely to be 35-45 kWh/m²/yr. (EnerPHit standard uses primary energy targets)	Demonstrated by PHPP modelling. Integrity of modelling and quality of construction independently verified by PH Certifier. Various routes to compliance inc. space heat demand and component approach, and a step-by-step option for both.	Exemplar levels of retrofit are being targeted, modelling in PHPP can be undertaken and quality assurance is to be achieved through an independent QA process. The range of routes to compliance make this widely applicable in the UK, this can be used to meet LETI exemplar targets and for projects following the PAS 2035 methodology.
energiesprong uk	Methodology based on fitting external panels, replacing windows/ doors, installing ventilation.	40* kWh/m²/yr	No EUI target, but scaled targets for hot water and appliance load.	Home owner or landlord enters into a contract which guarantees levels of performance specified. Thus compliance is by in-use assessment.	Good levels of retrofit are being targeted and the nature of the building itself lends itself to external cladding.
SuperHomes	Independent rating scheme for retrofit operated by the National Energy Foundation. 1-5 star performance benchmarks	5 star = 30-50* kWh/m²/yr 4 star = <50* 3 star = <60* 1-2 star = <90*	N/A	Two stage assessment process by a qualified SuperHomes assessor. 1) Design stage - 'predicted' rating based on retrofit plan and SAP calculation. 2) Evaluation stage - 'verified rating' based on 12 months performance monitoring data.	Any level of retrofit irrespective of house type and retrofit approach. Rating level is awarded based on actual measured performance meaning assessment can commence at evaluation phase. Methodology is consistent with PAS 2035 provisions.
AECB building knowledge	Independent Construction Standard for retrofit	50 kWh/m²/yr (with possible exemption up to 100)	No EUI target, but likely to be 50-70 kWh/m²/yr	AECB Retrofit standard: Published set of accompanying criteria. Modelled using PHPP and addresses other retrofit risks including moisture. Requires Retrofit or Passivhaus expert.	Good level of retrofit is being targeted, PHPP modelling can be undertaken and a recognised certification is required. The required level of quality assurance will be achieved with some additional QA processes.

Figure 4.5 - Retrofit standards and when to use them
* These figures are in GIA whereas the rest of the figures on this table are in TFA

4.5 Typical house archetype examples

So far, we have looked at the big picture to derive LETI's targets for retrofit. But what does this mean in practice? The rest of this chapter sets out a series of typical house archetypes based on average data for each building type from the stock model. We start with an existing pre-retrofit building and then show what happens when the LETI targets are applied. In some cases, we have used the 'constrained' retrofit values, whilst others show the effect of an 'unconstrained' retrofit.

In all cases, we show the pre and post-retrofit space heating demand and Energy Use Intensity as a primary measure of the impact of the retrofit. We also show the overall reduction in actual energy use for each archetype. To make the examples a bit more real, we've provided some signposts to actual case-study retrofits which are similar to the illustrative archetypes.

Retrofit improvements - the package of retrofit measures that have been undertaken to get to the post-retrofit state.

Post-retrofit energy - The total amount of energy needed over the course of a year by the building with a typical occupancy once it has been retrofitted.

Pre-retrofit energy - The total amount of energy needed over the course of a year by the building with a typical occupancy in its pre-retrofit condition.

Key

- LETI best practice unconstrained with no additional allowance
- LETI best practice constrained with additional allowance
- Additional allowance for homes under 75m^2
- LETI exemplar

Delivered - the amount of energy required by the building, this is sometimes called energy consumption, it includes the effect/efficiency of the heat source. This includes the benefit of fabric and systems. Delivered energy is independent of PV generation.

Demand

Space heating demand - the heat energy that the heat pump or boiler generates to heat the home, this figure includes systems losses. The better the building fabric the lower the space heating demand. Space heating demand is independent of the type/efficiency of heat source.

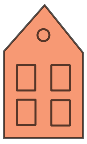
Hot water demand - the heat energy that the heat pump or boiler generates to heat domestic hot water, this figure includes systems losses. Hot water demand is independent of the type/efficiency of heat source.

Total energy demand - The space heating demand; hot water demand; and the electricity required for lights, ventilation and plug loads. Energy demand is independent of the type/ efficiency of heat source.

Energy Use Intensity (EUI) - the delivered energy (sometimes called energy consumption) per m^2 that is required by the building over the course of a year. In this document the floor area (m^2) is the 'treated floor area' unless otherwise stated. This includes regulated (heating, hot water, ventilation and lighting) and unregulated (plug loads). EUI is independent of PV generation (e.g. regardless of how much PV generation is attributed to the building the EUI is the same).

Semi-detached - LETI best practice constrained retrofit

	Targets	Achieved in example
Fossil fuel free	Fossil fuel free home	Fossil fuel free home
Space heating demand	60 (50+10) $kWh/m^2/yr$	51 $kWh/m^2/yr$
Hot water demand	20 $kWh/m^2/yr$	20 $kWh/m^2/yr$
Energy Use Intensity	60 (50+10) $kWh/m^2/yr$	60 $kWh/m^2/yr$
Renewable energy	40% of roof covered in PV	40% of rooftop covered in PV

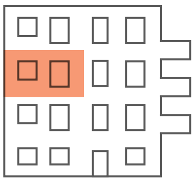


Detached - LETI best practice constrained retrofit

	Targets	Achieved in example
Fossil fuel free	Fossil fuel free home	Fossil fuel free home
Space heating demand	60 (50+10) $kWh/m^2/yr$	55 $kWh/m^2/yr$
Hot water demand	20 $kWh/m^2/yr$	14 $kWh/m^2/yr$
Energy Use Intensity	60 (50+10) $kWh/m^2/yr$	58 $kWh/m^2/yr$
Renewable energy	40% of roof covered in PV	No PV

Mid-terrace - LETI best exemplar retrofit

	Targets	Achieved in example
Fossil fuel free	Fossil fuel free home	Fossil fuel free home
Space heating demand	20 $kWh/m^2/yr$	16 $kWh/m^2/yr$
Hot water demand	20 $kWh/m^2/yr$	20 $kWh/m^2/yr$
Energy Use Intensity	40 $kWh/m^2/yr$	40 $kWh/m^2/yr$
Renewable energy	40% of roof covered in PV	40% of rooftop covered in PV

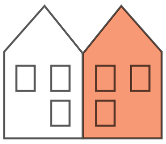


Flat - LETI best practice unconstrained retrofit

	Targets	Achieved in example
Fossil fuel free	Fossil fuel free home	Fossil fuel free home
Space heating demand	50 $kWh/m^2/yr$	26 $kWh/m^2/yr$
Hot water demand	25 (20+5) $kWh/m^2/yr$	24 $kWh/m^2/yr$
Energy Use Intensity	50 $kWh/m^2/yr$	49 $kWh/m^2/yr$
Renewable energy	40% of roof covered in PV	No PV

Figure 4.6 - Typical house archetypes from the stock model showing what could be achieved

Semi-detached example



Best practice constrained retrofit

Based on average UK building stock

Archetype data from model

Areas

Treated floor area	100 m²
Heat loss floor	48 m²
Roof	46 m²
External Walls	89 m²
Single Glazing	4 m²
Double Glazing	16 m²

Occupants

Adult Occupiers	2
Child Occupiers	1

Related case study

Zetland Road, Manchester

Deep retrofit of a semi-detached home originally constructed in 1894.

SIGNPOST *Chapter 6 - Zetland Road case study*

Energy targets

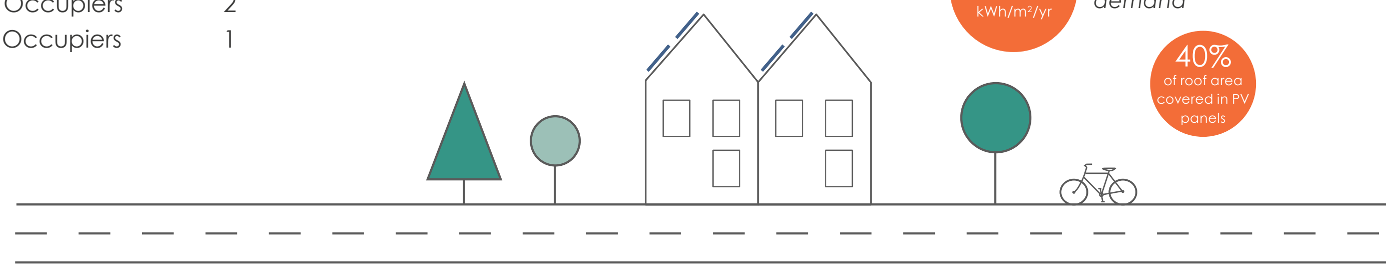
Fossil fuel free home

60 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor Area (TFA) (constrained)*

60 kWh/m²/yr — *Space heating demand (constrained)*

20 kWh/m²/yr — *Hot water demand*

40% of roof area covered in PV panels



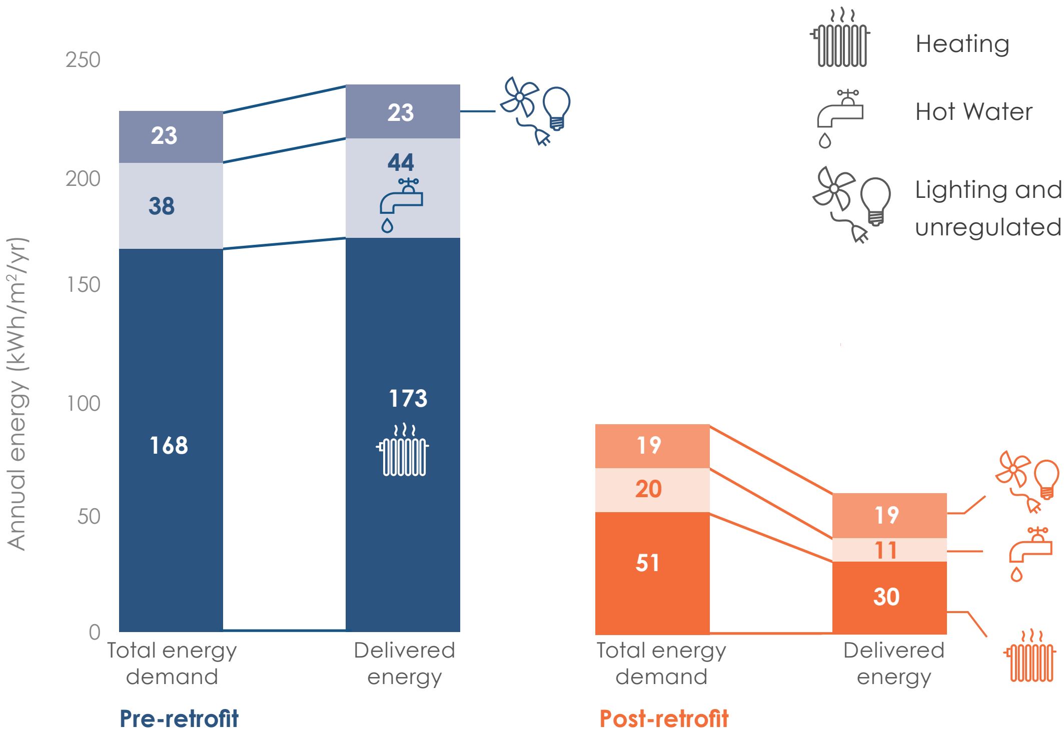
Retrofit improvements

Total energy demand the space heating demand; hot water demand; and the electricity required for lights, ventilation and plug loads.

Delivered energy refers to the energy consumed by the building for heating, hot water and electricity. It is called Energy Use Intensity when divided by the floor area of the building.

SIGNPOST

Annex A: How do our homes produce carbon?



Existing specification

Fabric		Existing
Walls	Solid uninsulated walls	1.35 W/m².K
Floors	Uninsulated suspended timber floors	1.00 W/m².K
Roof	Minimal loft insulation	1.00 W/m².K
Glazing	Single glazing	4.80 W/m².K
	Double glazing	2.00 W/m².K
Air Tightness	Leaky building	11.50 ach@50Pa
Thermal Bridging	High thermal bridging	0.20 W/m.K

Systems

Space heating
Gas

Ventilation
Natural
(with extract fans)

Hot Water

Shower Use	35.5 litres/person/day
Other Uses	15 litres/person/day
Tank Insulation	3.0 W/K
Pipe Insulation	0% *(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*

Pre-retrofit

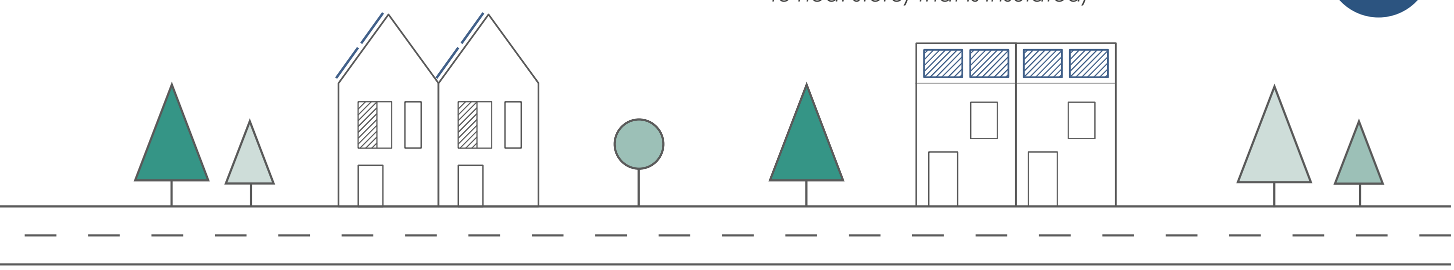
240 kWh/m²/yr — *Energy Use Intensity (EUI) over Treated Floor Area (TFA)*

(89% efficient gas boiler)

Space heating demand — **168** kWh/m²/yr

38 kWh/m²/yr — *Hot water demand*

Renewable energy — **No PV**



Final specification

Fabric		Best practice: Unconstrained	Best practice: Constrained	Exemplar
Walls	Internal wall insulation	0.18 W/m².K	<u>0.32 W/m².K</u>	0.15 W/m².K
Floors	Insulated between joists	0.18 W/m².K	<u>0.20 W/m².K</u>	0.15 W/m².K
Roof	Additional loft insulation	0.12 W/m².K	<u>0.12 W/m².K</u>	0.12 W/m².K
Glazing	Replace glazing	1.00 W/m².K	<u>1.30 W/m².K</u>	0.8 W/m².K
Air Tightness	Draught-proofing and sealing	2.00 ach@50Pa	<u>3.00 ach@50Pa</u>	1.0 ach@50Pa
Thermal Bridging	Mitigated	0.10 W/m.K	<u>0.10 W/m.K</u>	0.08 W/m.K

Underlined values have been used to achieve the post-retrofit EUI and space heating demand

Systems

Space heating
ASHP

Ventilation
MVHR

Hot water

Use of low flow fittings and improved insulation

Shower use	16 litres/person/day
Other uses	9 litres/person/day
Tank insulation	1.5 W/K
Pipe insulation	90% *(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*

Renewables

Photovoltaics
40% of rooftop fitted with PV

40% of roof area covered in PV panels

Post-retrofit

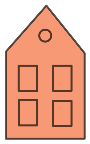
60 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor area (TFA)*

Fossil fuel free home *(0% from gas/ fossil fuel)*

51 kWh/m²/yr — *Space heating demand*

20 kWh/m²/yr — *Hot water demand*

Detached example



Best practice constrained retrofit

Based on average UK building stock

Archetype data from model

Areas

Treated floor area	172 m²
Heat loss floor	83 m²
Roof	78 m²
External Walls	162 m²
Single Glazing	12 m²
Double Glazing	25 m²

Occupants

Adult Occupiers	2
Child Occupiers	1

Related case study

The Nook, Brighton

Deep retrofit of a detached, 6 bedroom home "hard to treat" home.

SIGNPOST *Chapter 6 - The Nook case study*

Energy targets

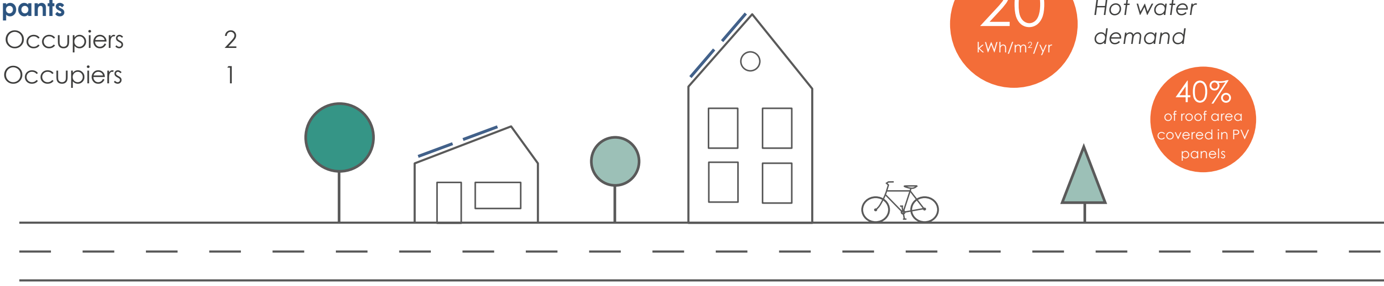
Fossil fuel free home

60 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor Area (TFA) (constrained)*

Space heating demand (constrained) — **60** kWh/m²/yr

20 kWh/m²/yr — *Hot water demand*

40% of roof area covered in PV panels



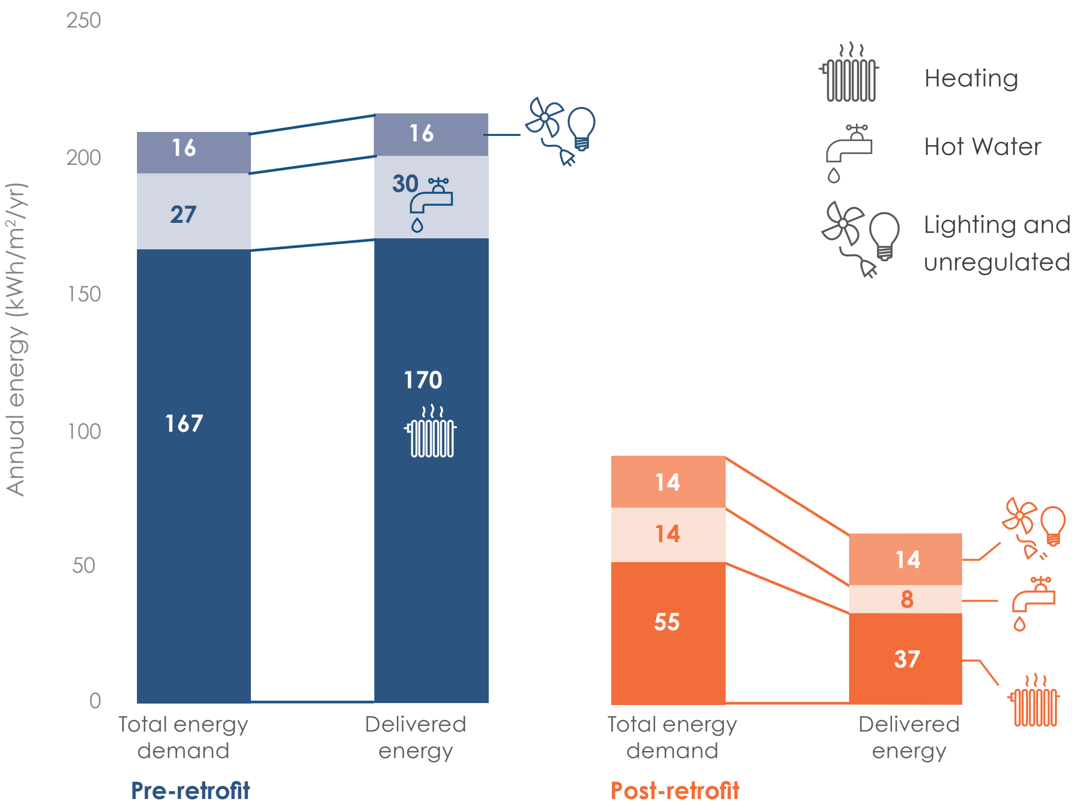
Retrofit improvements

Total energy demand the space heating demand; hot water demand; and the electricity required for lights, ventilation and plug loads.

Delivered energy refers to the energy consumed by the building for heating, hot water and electricity. It is called Energy Use Intensity when divided by the floor area of the building.

SIGNPOST

Annex A: How do our homes produce carbon?



Existing specification

Fabric

Fabric		Existing
Walls	Solid uninsulated walls	1.35 W/m².K
Floors	Uninsulated solid floors	0.80 W/m².K
Roof	Minimal loft insulation	1.00 W/m².K
Glazing	Single glazing	4.80 W/m².K
	Double glazing	2.00 W/m².K
Air Tightness	Leaky building	11.50 ach@50Pa
Thermal Bridging	High thermal bridging	0.20 W/m.K

Pre-retrofit

216 kWh/m²/yr — *Energy Use Intensity (EUI) over Treated Floor Area (TFA)*

(89% efficient gas boiler)

Space heating demand — **167** kWh/m²/yr

27 kWh/m²/yr — *Hot water demand*

Renewable energy — **No PV**

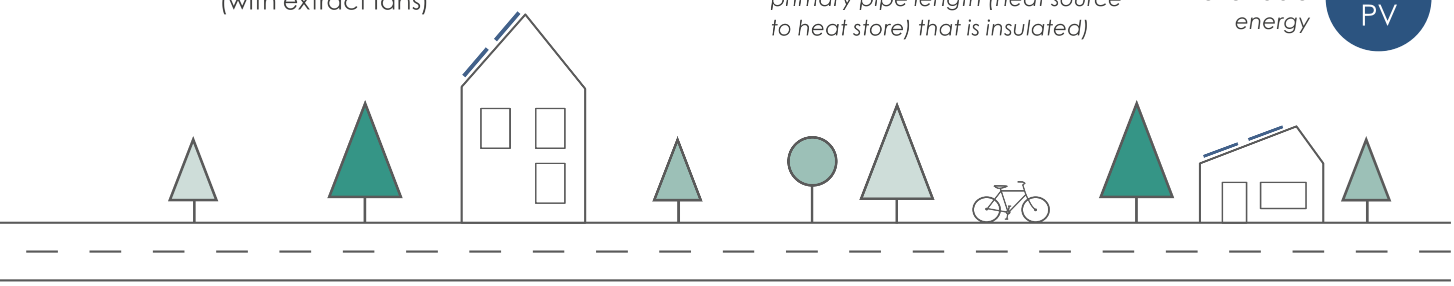
Systems

Space heating
Gas

Ventilation
Natural
(with extract fans)

Hot Water

Shower Use	35.5 litres/person/day	
Other Uses	15 litres/person/day	
Tank Insulation	3.0 W/K	
Pipe Insulation	0%	*(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*



Final specification

Fabric

Fabric		Best practice: Unconstrained	Best practice: Constrained	Exemplar
Walls	Internal wall insulation	0.18 W/m².K	<u>0.32 W/m².K</u>	0.15 W/m².K
Floors	No action	0.18 W/m².K	<u>0.80 W/m².K</u>	0.15 W/m².K
Roof	Additional loft insulation	0.12 W/m².K	<u>0.12 W/m².K</u>	0.12 W/m².K
Glazing	Replace glazing	1.00 W/m².K	<u>1.30 W/m².K</u>	0.8 W/m².K
Air Tightness	Draught-proofing and sealing	2.00 ach@50Pa	<u>3.00 ach@50Pa</u>	1.0 ach@50Pa
Thermal Bridging	Mitigated	0.10 W/m.K	<u>0.10 W/m.K</u>	0.08 W/m.K

Underlined values have been used to achieve the post-retrofit EUI and space heating demand

Systems

Space heating
ASHP

Ventilation
MVHR

Hot water

Use of low flow fittings and improved insulation

Shower use	16 litres/person/day
Other uses	9 litres/person/day
Tank insulation	1.5 W/K
Pipe insulation	90% *(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*

Renewables

Photovoltaics
None

No PV

Post-retrofit

58 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor area (TFA)*

Fossil fuel free home *(0% from gas/ fossil fuel)*

55 kWh/m²/yr — *Space heating demand*

14 kWh/m²/yr — *Hot water demand*

Mid-terrace example

Exemplar retrofit

Based on average UK building stock

Energy targets

Fossil fuel free home

40 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor Area (TFA) (exemplar)*

Space heating demand (exemplar) — **20** kWh/m²/yr

20 kWh/m²/yr — *Hot water demand*

40% of roof area covered in PV panels

Archetype data from model

Areas

Treated floor area	85 m²
Heat loss floor	41 m²
Roof	40 m²
External Walls	49 m²
Single Glazing	1 m²
Double Glazing	13 m²

Occupants

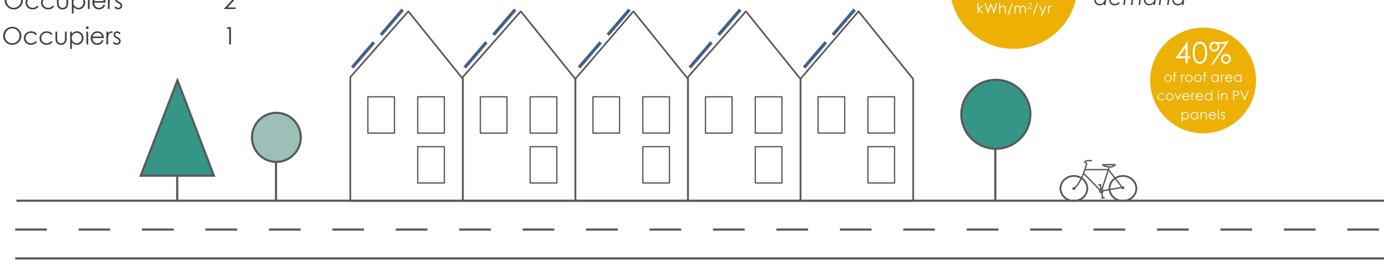
Adult Occupiers	2
Child Occupiers	1

Related case study

Haddington Way, Aylesbury

A comprehensive retrofit for a row of terraced homes.

SIGNPOST *Chapter 6 - Haddington Way case study*



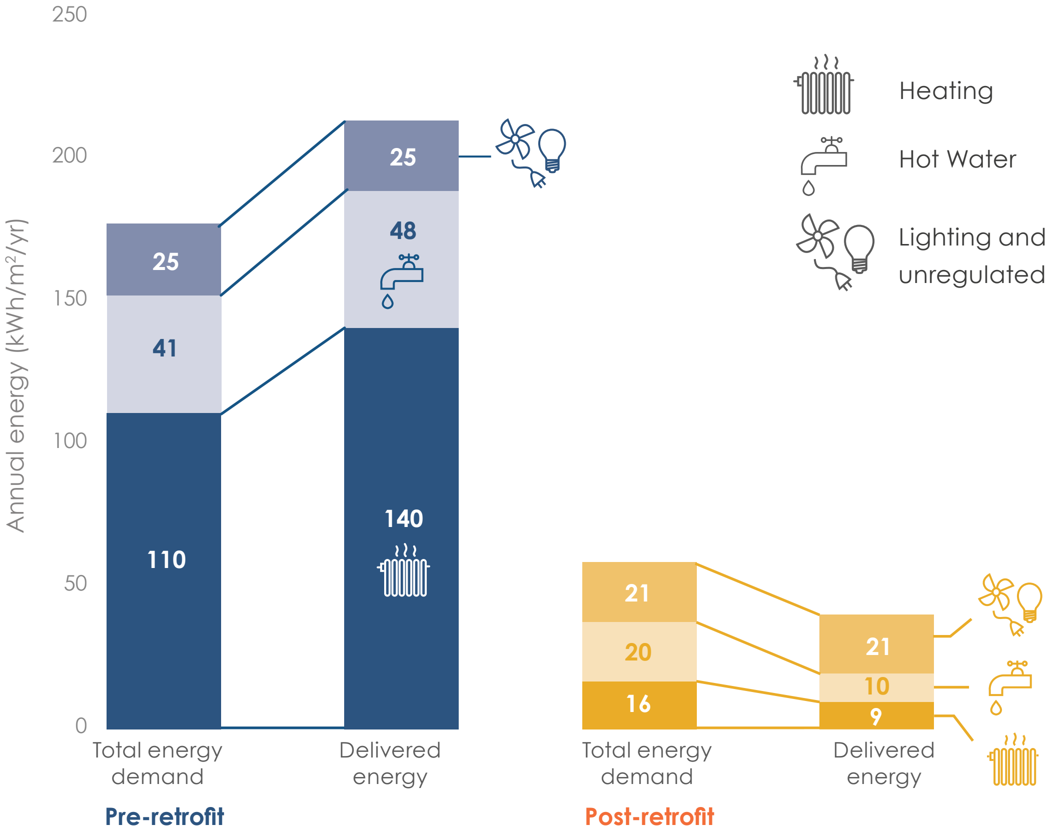
Retrofit improvements

Total energy demand the space heating demand; hot water demand; and the electricity required for lights, ventilation and plug loads.

Delivered energy refers to the energy consumed by the building for heating, hot water and electricity. It is called Energy Use Intensity when divided by the floor area of the building.

SIGNPOST

Annex A: How do our homes produce carbon?



Existing specification

Fabric		Existing
Walls	Cavity uninsulated walls	1.00 W/m².K
Floors	Uninsulated solid floors	0.35 W/m².K
Roof	Minimal loft insulation	1.00 W/m².K
Glazing	Single glazing	4.80 W/m².K
	Double glazing	2.00 W/m².K
Air Tightness	Leaky building	11.50 ach@50Pa
Thermal Bridging	High thermal bridging	0.20 W/m.K

Pre-retrofit

212 kWh/m²/yr — *Energy Use Intensity (EUI) over Treated Floor Area (TFA)*

(89% efficient gas boiler)

Space heating demand — **110** kWh/m²/yr

41 kWh/m²/yr — *Hot water demand*

Renewable energy — **No PV**

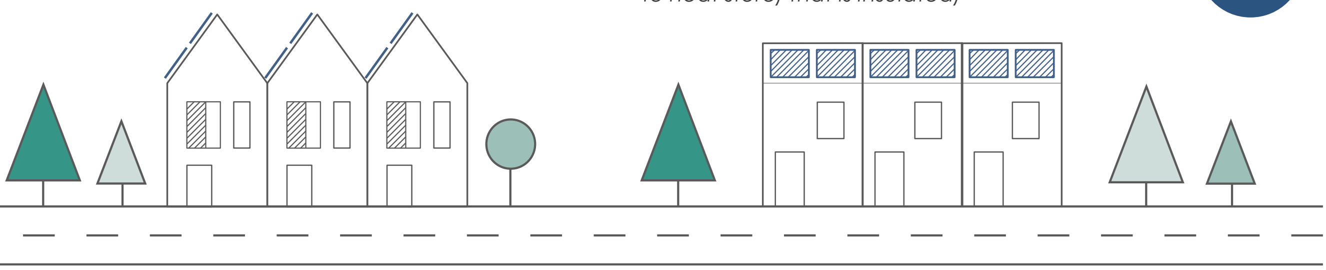
Systems

Space heating
Gas

Ventilation
Natural
(with extract fans)

Hot Water

Shower Use	35.5 litres/person/day	
Other Uses	15 litres/person/day	
Tank Insulation	3.0 W/K	
Pipe Insulation	0%	*(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*



Final specification

Fabric		Best practice Unconstrained	Best practice Constrained	Exemplar
Walls	Cavity and external insulation	0.18 W/m².K	0.32 W/m².K	<u>0.15 W/m².K</u>
Floors	Insulate below new screed	0.18 W/m².K	0.20 W/m².K	<u>0.15 W/m².K</u>
Roof	Additional loft insulation	0.12 W/m².K	0.12 W/m².K	<u>0.12 W/m².K</u>
Glazing	Replace glazing	1.00 W/m².K	1.30 W/m².K	<u>0.8 W/m².K</u>
Air Tightness	Draught-proofing and sealing	2.00 ach@50Pa	3.00 ach@50Pa	<u>1.0 ach@50Pa</u>
Thermal Bridging	Mitigated	0.10 W/m.K	0.10 W/m.K	<u>0.08 W/m.K</u>

Underlined values have been used to achieve the post-retrofit EUI and space heating demand

Systems

Space heating
ASHP

Ventilation
MVHR

Hot Water

Use of low flow fittings and improved insulation

Shower use	16 litres/person/day	
Other uses	9 litres/person/day	
Tank insulation	1.5 W/K	
Pipe insulation	90%	*(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*

Renewables

Photovoltaics
40% of rooftop fitted with PV

40% of roof area covered in PV panels

Post-retrofit

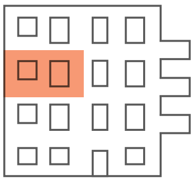
40 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor area (TFA)*

Fossil fuel free home *(0% from gas/ fossil fuel)*

20 kWh/m²/yr — *Space heating demand*

16 kWh/m²/yr — *Hot water demand*

Flat example



Best practice unconstrained retrofit

Based on average UK building stock

Archetype data from model

Areas

Treated floor area	73 m²
Heat loss floor	34 m²
Roof	18 m²
External Walls	48 m²
Single Glazing	1 m²
Double Glazing	10 m²

Occupants

Adult Occupiers	1
Child Occupiers	1

Related case study

Wilmcote House, Portsmouth

Retrofit of an existing 11 storey housing estate with residents in occupation.

SIGNPOST *Chapter 6 - Wilmcote House case study*

Energy targets

Fossil fuel free home

50 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor Area (TFA) (unconstrained)*

Space heating demand (unconstrained) — 50 kWh/m²/yr

25 kWh/m²/yr — *Hot water demand (additional allowance)*

40% of roof area covered in PV panels

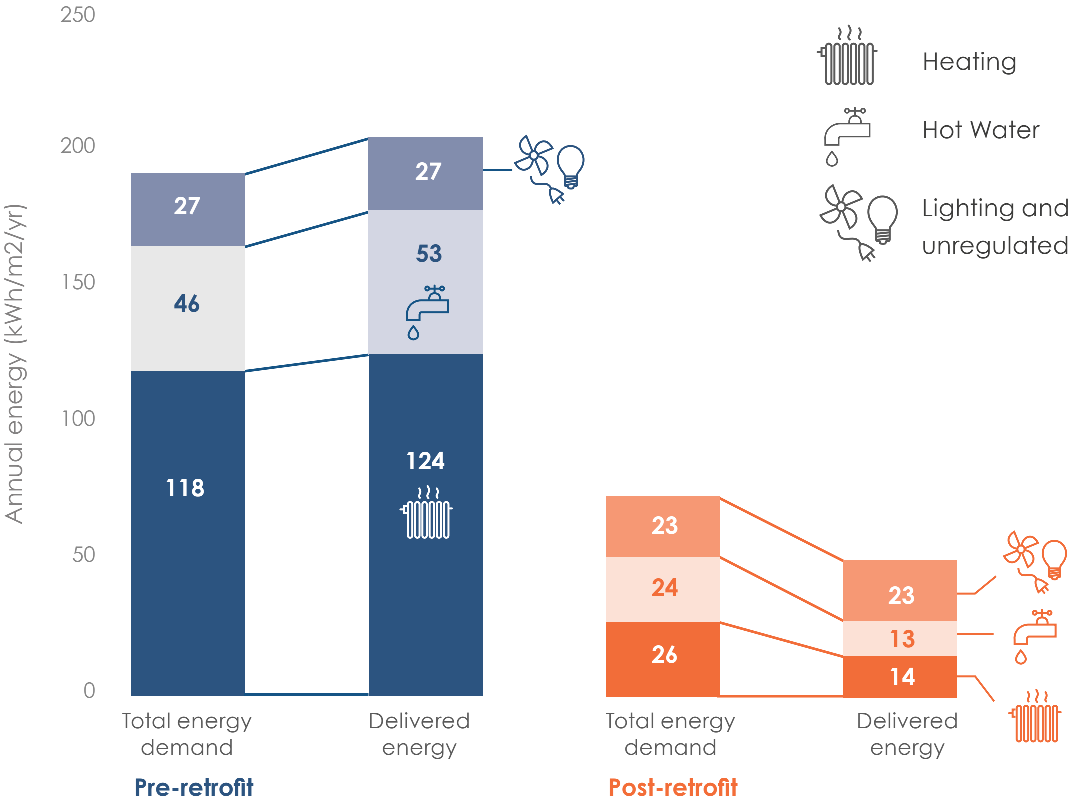
Retrofit improvements

Total energy demand the space heating demand; hot water demand; and the electricity required for lights, ventilation and plug loads.

Delivered energy refers to the energy consumed by the building for heating, hot water and electricity. It is called Energy Use Intensity when divided by the floor area of the building.

SIGNPOST

Annex A: How do our homes produce carbon?



Existing specification

Fabric

Fabric		Existing
Walls	Insulated cavity walls	0.43 W/m².K
Floors	Uninsulated solid floors	0.35 W/m².K
Roof	Minimal loft insulation	1.00 W/m².K
Glazing	Single glazing	4.80 W/m².K
	Double glazing	2.00 W/m².K
Air Tightness	Leaky building	11.50 ach@50Pa
Thermal Bridging	High thermal bridging	0.20 W/m.K

Pre-retrofit

203 kWh/m²/yr — *Energy Use Intensity (EUI) over Treated Floor Area (TFA)*

(89% efficient gas boiler)

Space heating demand — **118** kWh/m²/yr

46 kWh/m²/yr — *Hot water demand*

Renewable energy — **No PV**

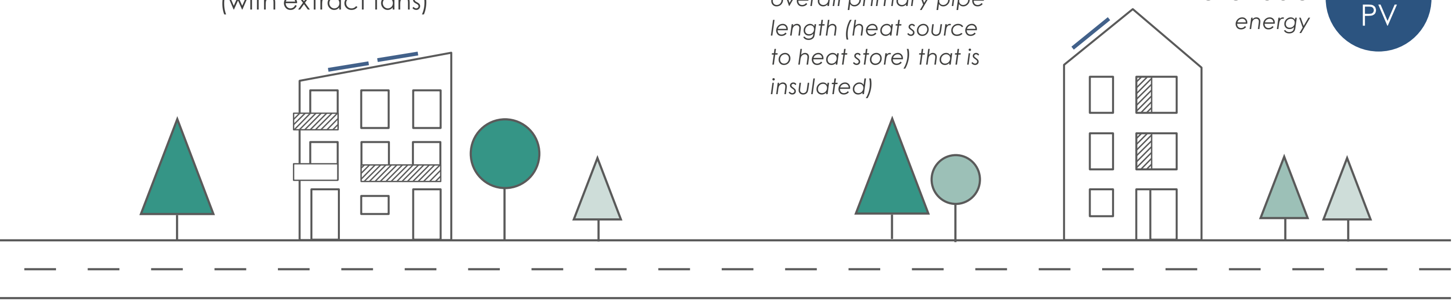
Systems

Space heating
Gas

Ventilation
Natural
(with extract fans)

Hot Water

Shower Use	35.5 litres/person/day	
Other Uses	15 litres/person/day	
Tank Insulation	3.0 W/K	
Pipe Insulation	0%	*(percentage of the overall primary pipe length (heat source to heat store) that is insulated)*



Final specification

Fabric

Fabric		Best practice: Unconstrained	Constrained	Exemplar
Walls	External wall insulation	<u>0.18 W/m².K</u>	0.32 W/m².K	0.15 W/m².K
Floors	Insulated below new screed	<u>0.18 W/m².K</u>	0.80 W/m².K	0.15 W/m².K
Roof	Additional loft insulation	<u>0.12 W/m².K</u>	0.12 W/m².K	0.12 W/m².K
Glazing	Replace glazing	<u>1.00 W/m².K</u>	1.30 W/m².K	0.8 W/m².K
Air Tightness	Draught-proofing and sealing	<u>2.00 ach@50Pa</u>	3.00 ach@50Pa	1.0 ach@50Pa
Thermal Bridging	Mitigated	<u>0.10 W/m.K</u>	0.10 W/m.K	0.08 W/m.K

Underlined values have been used to achieve the post-retrofit EUI and space heating demand

Systems

Space heating
ASHP

Ventilation
MVHR

Renewables

Photovoltaics
None

No PV

Hot Water

Use of low flow fittings and improved insulation

Shower use	16 litres/person/day
Other uses	9 litres/person/day
Tank insulation	1.5 W/K
Pipe insulation	90%

(percentage of the overall primary pipe length (heat source to heat store) that is insulated)

Post-retrofit

49 kWh/m²/yr — *Energy Use Intensity (EUI) over treated floor area (TFA)*

Fossil fuel free home *(0% from gas/ fossil fuel)*

26 kWh/m²/yr — *Space heating demand*

24 kWh/m²/yr — *Hot water demand*

5

How do we do it?

5.1 Introduction

This section provides LETI's outline process and key practical guidance for carrying out retrofit. It is intended as an overview not detailed guidance, as there are a lot of fantastic resources already available - a selection of which are provided in Annex J. This section is also intended to complement, not replace, existing guidance, retrofit tools and accreditations such as PAS2035, the STBA Retrofit Wheel, the AECB Retrofit Standard, and step by step EnerPhit (see Annex I for how the LETI Process maps onto PAS 2035).

SIGNPOST *Annex I: LETI Retrofit Process and PAS 2035*

SIGNPOST *Annex J: References and further information*

5.2 Whole building approach and Retrofit Plan

Retrofit can be complex. There are a lot of factors at play: from technical constraints, like how the existing foundations are constructed; to the number of people living in the building, how much time they spend there and their individual preferences for heating and hot water; to whether there is enough money available to do everything at once or whether it needs to be done gradually.

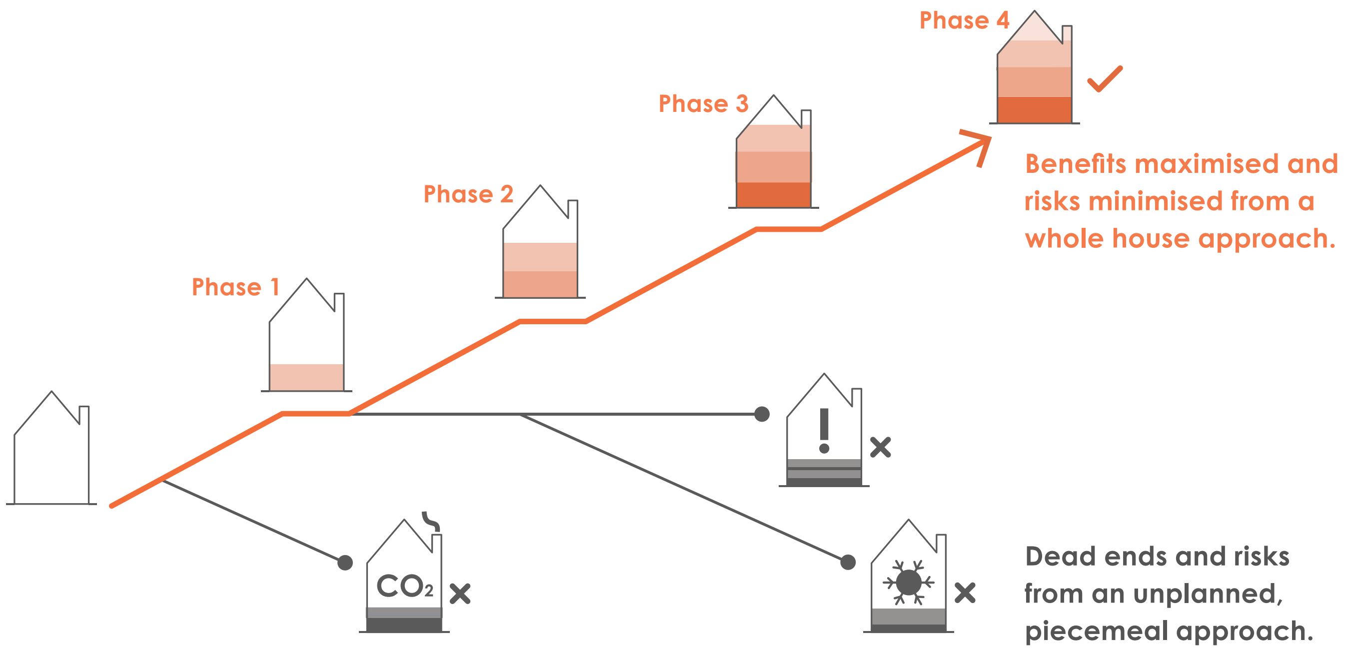
In order to successfully deliver energy savings and health and comfort improvements, a coordinated approach is needed for the whole building. The whole building might be one home, a number of connected homes in a terrace or block of flats, or have multiple uses. The work might be a whole retrofit in one go, or just one element at a time, for example replacing something that's worn out. This is called a 'whole building approach' and to do it a 'Retrofit Plan' will need to be created. (See Chapter 2 for the benefits of a whole building approach and the risks of a piecemeal approach).

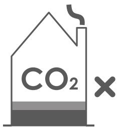
5.3 Issues with a piecemeal approach

A conventional approach to refurbishing homes is to change each element individually without considering the building as a whole. Carrying out a single piece of maintenance or improvement work as an opportunity arises is not a problem in itself, but it needs to be part of a phased and planned retrofit approach. Dealing with different parts of the building piecemeal, even if 'upgrading' the individual element, can result in negligible energy and carbon savings and potentially damage to the building.

Figure 5.1 illustrates how a whole-building approach can deliver the most benefits and avoid unintended consequences.

SIGNPOST *Chapter 2 - What is retrofit?*

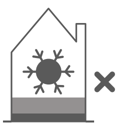




A piecemeal approach can fail to deliver the energy and carbon savings predicted.

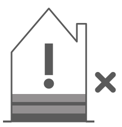
The building is a complex system and isolated interventions that may be bypassed by other bits of poor building fabric, have less impact than a considered approach to the whole building.

The occupants will also rightly take the ‘improvement in comfort’[5.1] first, meaning the retrofit has to go further to reduce overall energy use.



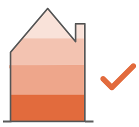
A piecemeal approach can lead to works obstructing future improvements preventing the full benefits from being realised.

A piecemeal approach can obstruct or lock in quality constraints that impede later stages of retrofit. For example installing a new fitted kitchen that prevents floor insulation and internal wall insulation from being installed to an adjacent neighbouring wall.



A piecemeal approach can cause damage to health and the building structure.

Local measures might change the internal conditions and put more stress on other parts of the home. For example replacing windows could reduce the air infiltration and so ventilation rate to the home, causing damp and poor air quality.



A whole house approach delivers the maximum benefit with the least risk.

Work is phased, meaning interventions can be designed to work together to deliver the most benefit as effectively as possible. Initial phases of work can be planned to prepare for, and not block, work in the future phases. The health of the occupants and the building can be protected throughout.

Figure 5.1 - Piecemeal versus whole house approach diagram.

5.4 A Retrofit Plan for the whole building

Before you start a retrofit it is critical to have completed a plan for the whole building, even if you are doing just a small piece of work.

A Retrofit Plan is a masterplan for all the individual pieces of work needed to improve the home, and how these interrelate. This means that when one piece of work is carried out, it can consider the impact on future phases. The Retrofit Plan might change over time, but gives a snapshot of the intention, and helps think through the consequences.

A Retrofit Plan might also be called a Whole House Plan, or be a part of a Building Renovation Passport. Building Renovation Passports are emerging in other countries and are being considered in the UK as a way of formally recording information about a building that can be shared publicly, or between owners in a digital building logbook. This would also include predicted energy performance and actual energy consumption. All these developments are an excellent step forward, however in the meantime a simple list or short document can fulfil the purpose.
The Retrofit Plan can be prepared by an architect competent in retrofit, or a specialist builder. Where required the Retrofit Plan can be prepared by someone with a Retrofit Coordinator Level 5 diploma qualification and registered with TrustMark. This could be for additional reassurance, to meet grant funding requirements, or to comply with PAS 2035. PAS 2035 is soon to be a requirement on all publicly funded retrofit projects.

SIGNPOST *Annex I: LETI Retrofit Process and PAS 2035*

This 'Retrofit Plan' should:

Set out key building information, constraints, risks, and opportunities related to the building and context (e.g. flood risk zone, local air pollution, shading and overheating risk, heritage value, client's requirements).

Set out the key works proposed along with related strategies and details. As a minimum it must cover:

→ Maintenance items that need to be resolved before making changes
→ Ventilation strategy for each phase
→ The insulation and airtightness strategy enclosing the building for walls, floors and roofs
→ The window and door upgrade strategy
→ Critical junctions between upgraded fabric elements that will need to be designed.

Set out the sequence of work. The strategy should highlight opportunities to phase the works, ensure that the design and package of measures for each part integrates with the complete retrofit, avoids obstructing future work phases, and functions in itself without causing issues with the internal conditions or structure of the home.

Be appropriate in its level of detail and intervention for the building size, context, use, owner and occupants, scope of work, and heritage value. For an owner-occupier single dwelling it might be very simple, for example a short document. For a complex historic building or a landlord-owned block containing hundreds of properties, it is likely to be a very comprehensive document.

Include a plan for monitoring and reporting energy consumption. This might include a predicted energy consumption calculation during design for comparing back to once complete, sub-metering of heating, groups of homes and electric cars, or simply an upgrade to a smart meter.

Stay with the building, recorded in a way that can be handed over to future owners. It should also be a live document, that records works that are undertaken, and may be revised with new proposed strategies and details.

Figure 5.2 - Retrofit Plan guidelines.

5.5 The LETI Retrofit Process

Overview and how the Retrofit Plan fits in

This chapter sets out the LETI 'Retrofit Process', aiming to provide a simple, widely applicable framework to help guide building owners, developers, designers, and contractors through the stages of their retrofit project.

The Retrofit Process flowchart is broken down into the following stages:

1 **Define the project and outcomes**

2 **Understand the building and risks**

3 **Plan and evaluate the improvements**

4 **Install and commission**

5 **Check outcomes**

Information produced throughout the process should be recorded in the Retrofit Plan. The stages of the Retrofit Process flowchart can be used as the structure/headings of a building's Retrofit Plan.

Note on mapping onto other tools

The Retrofit Process has been set out so that it neatly maps onto the common design approach described in the RIBA Plan of Work. It has also been designed to sit alongside and compliment PAS 2035. See Annex I for more details on mapping the LETI Retrofit Process onto PAS 2035.

SIGNPOST *Annex I: LETI Retrofit Process and PAS 2035*

Things to remember

The LETI Retrofit Process endeavours to provide a widely applicable yet flexible approach to the retrofit of existing buildings, acknowledging that:

1. Retrofitting buildings is a complex process with existing buildings being diverse in age, materials, construction, condition, location, purpose, and owner. Each retrofit project requires consideration and often individual treatment and some bespoke solutions.

2. There will be differences between some buildings and owners / occupiers. As such, some parts of the framework may be more or less relevant for certain projects (e.g. a housing association vs an owner-occupier). However, many of the core decision points are common across projects. Steps that are relevant only to certain kinds of projects are highlighted/separated in the Process.

3. A lot of decisions are interconnected. An iterative process is required, where decisions are considered in the round and initial decisions are revisited and refined as the project progresses and more information is available. The Retrofit Process is intended to be used in this iterative way.

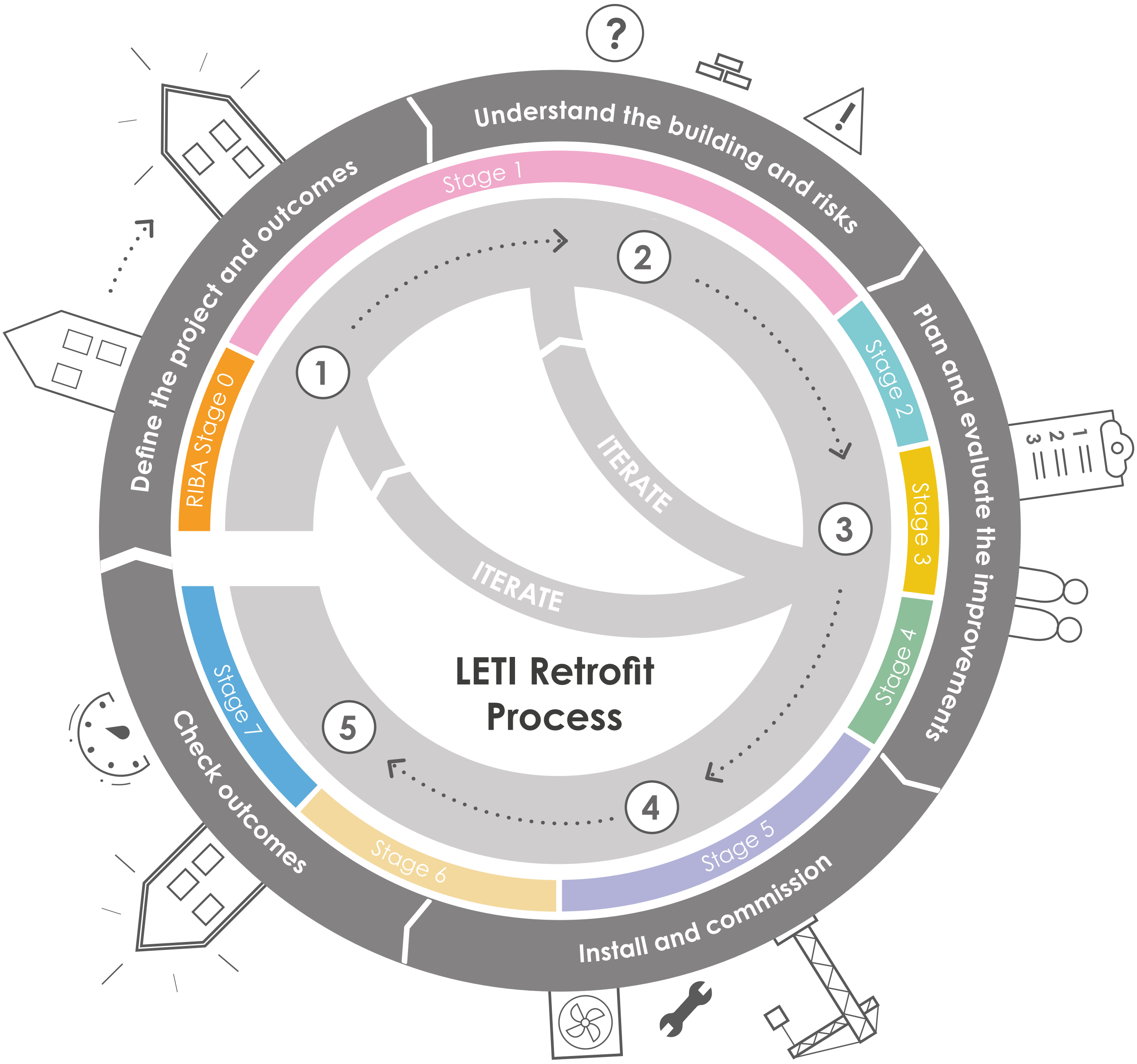


Figure 5.3 - LETI Retrofit Process summary diagram showing the key stages and how, where necessary, early design and evaluation gives a chance to revisit the project definition and building evaluation with new information.

RIBA Stages: Stages 0-1 Strategic definition, preparation and brief

LETI Retrofit Process Stages

1 Define the project and outcomes

Building(s) identified. Outcomes and evaluation strategy clearly defined and tailored to the Owner. Owner's internal processes set up to facilitate the project. Users/community initially engaged. Business case considered. 'Retrofit Plan' for whole building started recording initial information.

2 Understand the building

Project risks and constraints assessed. Building information collected and reviewed. User/Owner information collected and reviewed. 'Retrofit Plan' updated with building information. Revisit 'Define the project and outcomes' stage work if required.

Sub-Stages	Identify the building	Talk to the building users and owner	Agree outcomes	Assess constraints and risk	Collect building information
Building users + Team	**Get professional help** from an early stage	**Owner and user engagement** on project, aims challenges and insights			**Interview occupants** for insights (inc. on fire safety) If owner is an organisation: **Collect insights and constraints from owner** and FM team
General	**Identify the building** to be retrofitted in this project and **consider coordinating** with neighbours If part of a portfolio: **Identify and review portfolio** to be retrofitted **Set out retrofit roadmap** for rest of portfolio **Consider coordinating with other landlords**	If tenanted or large scale: **Define community** and carry out **initial community engagement** If owner is an organisation: **Review of owner constraints** for project (e.g. procurement reqs, existing sustainability initiatives, decision making) Establish internal **decision making processes** for project	**Agree retrofit outcomes** (energy, health, comfort targets and certifications). Set **energy targets** using the flowchart in Section 4.4 Agree non-retrofit outcomes and improvement works Agree monitoring, evaluation, and dissemination strategy Prepare a business case	Research the building and context assess constraints and risk (initial assessment, largely desktop based) Check heritage value Check flood risk Check radon gas risk	Survey the building and assess findings (inc. existing monitoring data, existing condition, existing ventilation strategy, any retrofit measures already installed) Review fire safety Review and confirm retrofit outcomes
Retrofit Plan			Start Retrofit Plan, recording building owner and outcomes information		Update Retrofit Plan with risk, constraints, and other information

Actions in grey show additional actions for certain projects. E.g. if the owner is an organisation or landlord, there is a stock portfolio to retrofit, the project is large or complex.

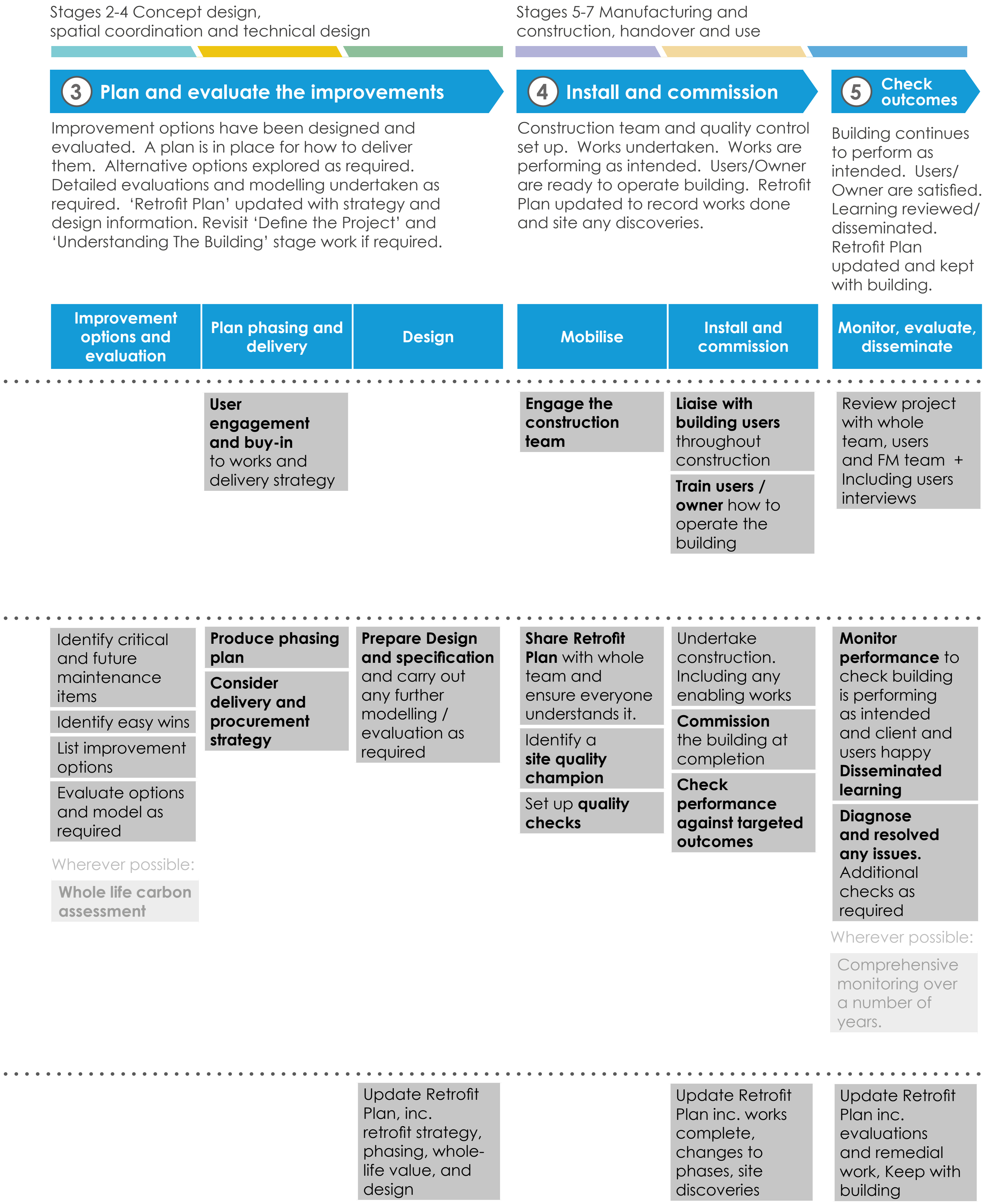


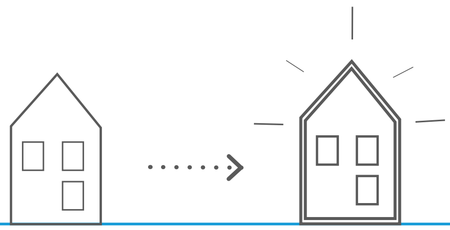
Figure 5.4 - LETI Retrofit Process flowchart mapped onto RIBA work stages

5.6 Detail on following the LETI Retrofit Process

Overview and how the whole house plan fits in

This section provides more information on some of the steps in the LETI Retrofit Process. The headings of the Process can be used to organise the Retrofit Plan document (sometimes also referred to as a 'Whole House Plan' document, 'Building Renovation Passport', or 'Building Logbook').

A lot of information is included to cover a wide range of project scales and tenure. Not all the sections will be relevant to all projects.



1 Define the project and outcomes

Identify the building(s)

For a single home this is simple, but for flats or terrace housing the Retrofit Plan may cover more than one dwelling.

Consider coordinating with neighbours or landlords to reduce the cost and have more impact. E.g. retrofitting a whole terrace rather than individual houses.

For landlords consider reviewing all of the stock and creating a retrofit strategy and roadmap for the whole portfolio. This might break the stock down into archetypes to be tackled with repeatable approaches. Consider coordinating with other landlords.

SIGNPOST *Annex B: Table of example opportunities for starting retrofit*

Talk to the building users and owner

You will need to talk to everyone using or with an interest in the building to explain the plan and aims of the project. Eventually the benefits, cost, timeline and what works are proposed may need to be communicated.

For landlords, consider whether there are existing initiatives, departments, decision makers, or procurement restrictions that need to be considered while forming the project. Consider setting up a project board to streamline decision making.

Set a baseline

Consider using available energy, water, temperature, or indoor air quality data to set a baseline case for the retrofit. Calculate current EUI from past energy bills, estimate current space heat demand. This gives something to compare the completed work against. For long term projects you could install monitoring equipment to gather data on your baseline.

Agree outcomes

Set the retrofit outcomes. Set a target, LETI best practice unconstrained, constrained or LETI exemplar) and which route will be taken (the modelling method which has energy targets or the constituent element method that sets fabric and system targets) using the flowchart in section 4.4. In addition set targets on health and comfort improvements. Be aspirational, even if there is limited funding available to start with, the Retrofit Plan should aim for the maximum benefit.

SIGNPOST *Chapter 4 - LETI home retrofit targets*

This guide starts with the goal of reducing energy demand and carbon emissions, but others might have different motivations that can be integrated with the plan. Refer to Section 2.2 'Benefits of retrofit' section to justify why. Outcomes should be clear, measurable, meaningful targets against the baseline established.

SIGNPOST *Chapter 1 - Why retrofit?*

SIGNPOST *Chapter 2 - What is retrofit?*

Consider any other maintenance or improvement works that could happen at the same time. For example an extension to give more space, or improving fire safety.

Form a high-level plan for how the outcomes will be measured and learning shared. It's easy for this to be forgotten if left until the end. Consider using a certification or a building energy standard such as the AECB Retrofit Standard or EnerPhit.

Get professional help

Setting the right outcomes is important for a successful retrofit. Consider getting professional help at an early stage and making a plan for the full team that you'll need later. You may also be required to have a Retrofit Coordinator if you are seeking grant funding or required to follow PAS 2035.

Prepare a business case

This can help communicate the benefits formally. The business case should aim to cover the whole life cost (including energy and maintenance savings, increased asset value, etc.), the cost of alternatives, and the value in non-financial benefits. For small projects, a simple budget and a description of the benefits may be enough; for larger projects a 30-40 year cash flow and net present value (NPV) calculation may be useful.

Itemise the cost of any non-retrofit works separately. E.g. Amenity improvements, replacing kitchen/bathrooms, fire safety improvements.

② Understand the building

Research the building context	Use mapping and image data to get some initial information about the building. Research planning history. Consider the constraints on retrofit (space, external appearance, conservation, context). Where is the access to the building? Are there external walls onto a street or public highway? Are there external walls onto a neighbouring property? Is the roof line affected by neighbouring properties? Use the PAS2035 risk assessment process to categorise the building and proposed work as appropriate
Check heritage value	Find out if the property or neighbours are listed or in a conservation area. Resources: Listed buildings in England: https://historicengland.org.uk/listing/the-list/ Your local authority will have a map showing conservation areas on their website. Works to listed buildings should be planned by a professional and will need planning permission. External works visible from the front of the property in a conservation area are likely to need planning permission. Even if a building is not listed or in a conservation area, there may be other external factors that will influence the retrofit design. The homeowner or neighbours may value the appearance of the building or group of buildings and the historical context should be considered. If the project is following PAS 2035, a conservation 'significance assessment' will be needed, following BS 7913:2013 (Guide to the Conservation of Historic Buildings). Based on the heritage value review targets set in stage 1 if required.
Check flood risk	Buildings with a high risk of flooding should take steps to mitigate flood damage as part of the retrofit. Check flood risk at https://flood-warning-information.service.gov.uk/long-term-flood-risk
Check radon gas risk	Buildings in an area with a high risk of Radon can use the retrofit to check infiltration into the building and reduce the chance of build up. Check whether the building is in a radon risk zone https://www.ukradon.org/information/ukmaps
Review fire safety	Existing buildings may not meet fire safety standards. Making alterations to existing buildings may affect their fire safety. Ensure retrofit works do not degrade fire safety. Consider measures to improve fire safety as part of the planned works. Single homes must be checked against the building regulations approved document Part B, which may provide enough information. But for more than one home or larger projects a specialist should be employed to survey and review fire safety as part of the works. Speak to building users for insights on current fire safety.

Survey the building

Visit the property to carry out a survey for retrofit. Inspect surfaces for damage and identify key barriers for improvements (such as space constraints preventing the addition of insulation). List the main constructions for walls, roofs and floors. Identify whether the construction is vapour open and relies on moisture escaping internally. Some invasive surveys will be required. Look in sockets, look in the loft at the tops of walls, look under the carpet. In areas where the details of the existing building fabric or construction can not easily be ascertained, note what further surveys or investigation during the start of works are needed. Alter the Retrofit Plan.

List the types of window and doors, material, glazing type, approximate age. Identify areas where the window position could limit the insulation depth, for example on a flanking wall. Look out for any windows close to a wall return that could limit the insulation depth.

Based on what has been found out, review and confirm targets set in stage 1. For example one of the walls may have space constraints thus the constrained U-value for this element may now be targeted).

Identify the current ventilation strategy for each room or area. Identify the current heating system type(s), fuel, and all heat source and hot water tank locations. Identify main service incoming locations and likely pipe runs.

Record all areas of internal and external damp and moisture and weathering. Identify external cracks, external damage or other possible structural issues. Note external ground levels in relation to internal floor levels. Note drain locations.

Consider and catalogue materials that can be reused or recycled. For further guidance see https://www.leti.london/ecp

Resources: If you are not confident inspecting the building consider a RICS building condition survey. https://www.ribuild.eu/know-your-building

Identify other surveys that may be required.

Interview the residents

Talk to the residents to understand issues with their home such as leaks, damp patches, hot or cold areas. Occupants will have knowledge about damp, draughts, uncomfortable areas of the home that may not be visible. Ask for existing building information such as previous drawings, surveys, home reports, warranties and guarantees. Ask for energy bills.

Find out what repair, improvement or extension works are planned. Retrofit improvements can be more economic, attractive and less disruptive if carried out alongside other planned improvements.

3 Plan and evaluate the improvements

Identify maintenance items

Consider urgent maintenance and replacement work (e.g. windows that need to be replaced this year). Consider future maintenance and replacements that will be required (e.g. will the existing roof need replacing in 3 years). For the business plan, these are costs that will be incurred whether the building is retrofitted or not.

Some maintenance items will impact the work that can be completed and may need to be rectified in advance. Leaking gutters, blocked drains or air bricks should be sorted early to allow the building to dry as much as possible.

Identify easy wins

Identify any easy temporary wins that could reduce energy in the short term: simple draught proofing around door and window frames, pipework, chimneys and fireplaces, and where cables enter and leave the building; insulation to primary pipework; high power light fittings; coal or oil heating when an alternative is available.

List improvement options

List all the measures that will form the retrofit improvement at its full extent. Insulation to walls, roof and floors. Ensure insulation is moisture open where existing walls depend on vapour open construction. Ventilation strategy (see Annex D). Window replacements or secondary glazing. Heating system replacement. Identify space for a hot water tank (or compact heat storage) and external heat pump. Different interventions could be as an options appraisal, or as a single recommended package of measures.

List accompanying works that will complement the energy efficiency improvements: reducing external levels, extensions or remodelling, redecoration.

SIGNPOST *Chapter 4 - LETI home retrofit targets*

SIGNPOST *Annex B: Table of example opportunities for starting retrofit*

SIGNPOST *Annex C: Illustrative insulation strategies*

SIGNPOST *Annex D: Retrofit ventilation strategies*

SIGNPOST *Annex G: U-value sweet spots*

Evaluation options

Evaluate and compare the options. Carry out computer modelling such as energy, heat transfer, and moisture risk as required to understand and check what is possible. Use modelling to understand the fabric and system upgrades needed to meet the targets set, or follow the constituent element guidelines. The unconstrained fabric and system targets should be used wherever possible based on individual elements, for example the front wall might be constrained, but the rest of the property can use the unconstrained values.

Consider undertaking a whole life carbon assessment. Consider materials that may be reused.

Produce phasing plan

Coordinate with maintenance and improvement plans and the opportunities arising from this work. Consider funding availability. It may be necessary to hold off carrying out work so that the first 'safe' phase can be afforded in its entirety. Larger packages are likely to be more cost effective and easier to manage quality, but have higher capital cost. Save plenty of contingency funds, retrofit tends to uncover further work that may increase the cost of the phase.

Package the work into one or more phases. Each phase must work on its own. Consider disruption to residents and neighbours, will the residents need to move out? Can critical disruptive work be concentrated in one phase?

SIGNPOST *Annex I: LETI Retrofit Process and PAS 2035*

Prioritise the ventilation strategy. Prioritise high heat loss areas to improve comfort, typically windows and exposed floors. The ventilation strategy must be designed for each stage of the work and it can make sense to install this in the first phase. Good ventilation reduces risks associated with all the other improvement measures.

SIGNPOST *Annex H: Moisture issues and how to avoid them*

Consider coordinating works with neighbours or other buildings in the local area to reduce cost.

Delivery and procurement strategy

Consider how the phases of work best be procured and delivered. How will the procurement deliver construction quality, what checks or oversight will be in place? Will building users need to be decanted for some or all of the phases? Consider building contracts including performance/value linked incentives based on monitoring.

Design

For each phase a detailed design should be drawn up. This must consider future phases and prepare the building. For example, if the roof is being repaired the eaves could be extended to accept external wall insulation in the future.

The design should be appropriate to the scale of the retrofit. Drawn information and a written specification are needed as a minimum. Ensure statutory requirements such as planning, Building Control, CDM are met whilst the design and retrofit strategy should be coordinated with all team members.

SIGNPOST *Chapter 4 - LETI home retrofit targets*

SIGNPOST *Annex C: Illustrative insulation strategies*

SIGNPOST *Annex D: Retrofit ventilation strategies*

Aim to keep systems, services and controls as simple as possible. For tenanted buildings aim to keep a familiar type of heating control.

Resources: https://retrofit.support/ is a publicly available library of construction details for existing buildings.

(4) Install and commission

Engage a builder or contractor

Find a contractor or builder who is familiar with your building type and construction, shows interest in what you are trying to do, and wants to understand how to improve energy efficiency. Encourage local trades and expertise, much of retrofit is just ‘good building’. Be wary of claims of lots of experience unless there is a clear project track record and separate recommendation, very little of this type of work has been carried out in the UK. Some projects will require certain qualifications from a builder or contractor.

SIGNPOST *Annex I: LETI Retrofit Process and PAS 2035*

Share the Retrofit Plan

Make sure the whole team - contractor, client and designers - are aware of the Retrofit Plan, how the phase under construction fits in with the plan, and buy into delivering the outcomes.

Highlight any known areas that require further investigation.

Identify a site quality champion

This could be a retrofit coordinator, clerk of works, architect, designer or even the homeowner. They should have a regular site presence, know the Retrofit Plan and be able to provide impartial feedback to the contractor.

Set up quality checks

Plan how the work will be reviewed and the key quality check points for the first phase. Ensure the site quality champion attends site at an appropriate frequency for the project. Focus on the installation of insulation, require sign off before it is covered. Plan any interim air leak tests.

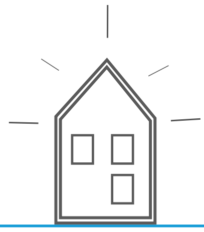
Construction

Carry out the current planned phase of works. Ensure enabling works to reduce the risk of retrofit are carried out first. Removing asbestos, repairing key maintenance items and making sure any construction that will be covered is dry and in good condition. Retrofit typically involves undoing some previous short term fixes before starting the new works.

There will be unexpected things that arise as the existing building is uncovered and may mean more work. Leave slack in the programme. Be ready for changes and put a process in place for reviewing and amending the design to account for changes.

Carry out quality checks through the construction. Check the thickness and conductivity of insulation materials, check there are no air gaps between or behind batts or boards. Discuss issues on site and solve problems with the installers. Carry out interim air tests to find and repair air leaks while the air barrier vapour control layer is accessible.

Liaise with building users throughout construction	Communicate progress and changes to the residents. Provide opportunities for residents to understand the works happening (e.g. tours and updates). Especially important where residents are staying in-situ / not decanted.
Commissioning	Commission ventilation, heating and other systems as appropriate. The ventilation system must be commissioned by an independent engineer including measuring supply and extract flow rates through room terminals, and balancing the air flow through each MVHR. More complex systems, particularly communal heat pump systems, should be commissioned again after the first winter. Demonstrate function of metering and monitoring equipment.
Check performance against outcomes at practical completion	Test project against any energy targets (SHD, HWD and EUI) that have been set. Carry out a final or end of stage air test for the building. Make sure certification submissions have been carried out.
Resident engagement and handover	Keep engagement simple and to what is necessary. Try not to overwhelm residents on the operation of their home, they should be able to live in their home as they please, even if it uses a little more energy. Provide some simple resources such as one page how-to guides in logical locations, such as near the equipment.
Record works in the Retrofit Plan	Update the Retrofit Plan to record the changes that have been made. Add any further information that is available from invasive survey. Include information on what the next phase should be and any key considerations for integrating it with the work that has been completed. Include or update a maintenance plan to include the new finishes and systems.



5 Check outcomes

Review and monitor

Post occupancy evaluation to verify the building is performing for a minimum of 1 year (including one full heating season) as intended and client and users are happy.

Compare the actual, monitored performance with the LETI energy targets (SHD, HWD and EUI) and/or Fabric and system targets agreed on for the project. On a small project this might be meter readings, a review meeting with the team, and short user interviews. Wherever possible, ideally install monitoring devices to gain additional insights (e.g. energy sub meters, CO_2 or humidity sensors). Sub-metering the main heat source (e.g. heat pump) is especially useful to estimate space heating demand and DHW consumption

Try to include setting up monitoring equipment as part of the main contract. See RIBA Plan for Use guide and Wood knowledge Wales - Building Performance Evaluation Guide for more information.

Disseminate learning to the whole team and use it to inform any future phases of work planned.

Diagnose and resolve any issues

Monitoring data can help quickly and cost-effectively diagnose issues, especially on larger projects. Carry out additional investigations or monitoring if required to diagnose reported issues.

5.7 References and footnotes

5.1 - Taking an improvement in comfort over and above reduction in energy bills: People living in poor quality housing will tend to underheat their homes, typically due to cost issues. Once the fabric is improved, residents can afford to maintain their home at higher temperatures. Thus, the direct comparison of pre and post-retrofit energy consumption will need to account for this as the before/after energy savings may not be as great as has been modelled.

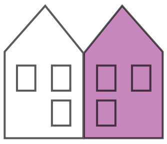
6

Case studies

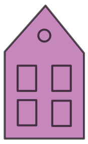
Archetype case studies

The following archetype studies focus on how properties with different form factors can be successfully retrofitted in a variety of ways. They aim to provide real life examples for the illustrative archetypes shown in Chapter 4.

SIGNPOST *Chapter 4 - LETI home retrofit targets*



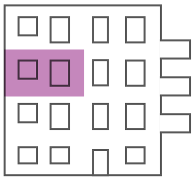
Semi-detached



Detached

Mid-terrace

End-terrace



Flat

Archetype 1, mid-terrace: Haddington Way

Location: Aylesbury

Description: Mid-terrace mid-1990 house

Completion year: 2010

Architecture: MEPK Architects

Energy and sustainability consultants: Rickaby Thompson Associates, Viridian Solar

Contractor: Willmott Dixon

Space heating post-retrofit (modelled): 41 kWh/m²/yr

Energy Use Intensity post-retrofit (modelled): 40 kWh/m²/yr

Project summary

Haddington Way, Aylesbury was comprehensively retrofitted in 2010, upgrading the thermal envelope in conjunction with a package of renewables. As part of the Technology Strategy Board Retrofit for the Future programme (TSB-31), it was monitored for 2 years after completion.

Pre-retrofit the external envelope consisted of:

→ insulated cavity walls with face brick exterior

→ suspended concrete beam and block ground floor

→ double glazed windows

→ pitched tiled roof enclosing both loft room and cold attic spaces.

Space heating was provided by a dual tariff electric storage system and hot water via a dual immersion cylinder. The property is ventilated via opening windows, with extract fans serving the kitchen and bathrooms.

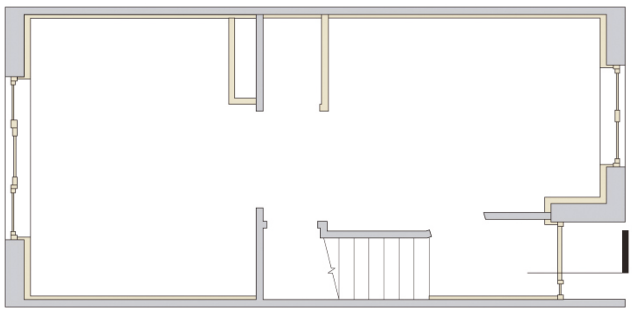


Figure 6.1 - Plan, MEPK Architects

Figure 6.2 - Front after, MEPK Architects

Figure 6.3 - Rear after, MEPK Architects

Fabric upgrade

The principle of fabric first was applied. The external walls were lined internally with Spacetherm PP, a laminated panel composed of 40mm thick aerogel insulation, 6mm plywood and 9.5 mm plasterboard interior facing. Aerogel is a very high performing insulation type, allowing a good level of improvement to be obtained whilst keeping loss of internal floor area to a minimum. Post retrofit wall U-value 0.23 W/m^2.K.

The beam and block ground floor was overlaid with 75mm Kingspan Kooltherm K3, a rigid phenolic foam insulation board under 18mm tongue and grove chipboard flooring. As this raised the floor level, the internal doors needed to be cut short and re-hung. Post retrofit floor U-value 0.17 W/m^2.K.

Existing double-glazed windows, rooflights, and external doors were replaced with new, argon filled, ultra-low-e double glazed window units (U-value 1.10 – 1.24 W/m^2.K) and insulated doors (U-value 1.6 W/m^2.K).

Roof insulation was added at rafter level in the sloping soffit ceilings; 150mm Celotex (rigid PIR insulation board) fitted between the rafters and soffits renewed with insulated plasterboard, to mitigate thermal bridging across the rafters.

Above the roof insulation, a vapour permeable breather membrane was installed with a minimum 25mm ventilation gap maintained between the insulation and the underside of the roof tiles to protect the timber roof structure from potential degradation due to condensation.

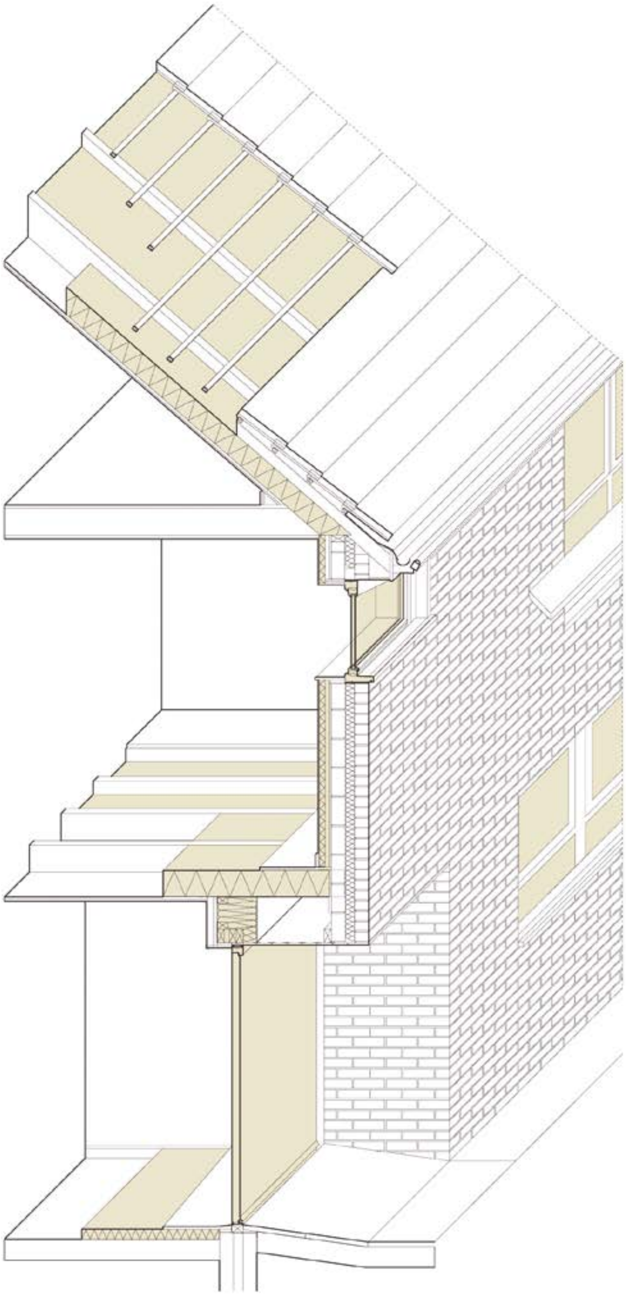


Figure 6.4 - Detailed section post retrofit, from: Baeli, M., 2013, Residential Retrofit: Twenty Case Studies. RIBA Publishing, London[6.1]

Significant measures were undertaken to eliminate unwanted air permeability and maintain a continuous air tightness layer, including: wrapping of joist ends; sealing of window reveals with Pro-Clima Tescon tape; and use of grommets where pipe penetrated air barrier layers. The measured air tightness of the house was reduced from 13 to 5 $m^3/m^2/hr@50Pa$.

Two sun-pipes were fitted between the roof and the internal bathrooms to bring in natural daylight and reduce the need for artificial light during the day. The attic space is contained within the building's thermal envelope and accommodates the new building services installations.

Building services
The space heating, hot water supply and background ventilation have been met by a combination of complementary active and renewable systems. These are to limit the amount of electricity needed to meet the dwelling's needs.

An exhaust air heat pump unit (EAHP) supplies both hot water and warms incoming ventilation air. This unit contains a 180 litre hot water cylinder and fans for the fresh air intake and stale air exhaust for the kitchen and bathroom. The EAHP recovers heat from the extracted air to produce hot water. During winter, any excess heat not needed for water heating is used to warm the fresh air supply. The design team has moved away from using this type of unit on future projects since it was heavy and hard to find space to accommodate. It struggled to meet the energy demand for space heating and hot water heating. A single direct electric panel heater is installed in the hallway of the property, to provide top-up space heating. 9m^2 photovoltaic panels by Viridian Solar provide electricity to preheat hot water for the EAHP.

A solar thermal system, 4.5m^2 of flat plate solar collector panels on the roof and a 250-litre storage cylinder in the attic supplies pre-heated water to the EAHP unit. Monitoring showed between mid-spring to mid-autumn, the solar thermal panels supplied most of the hot water.

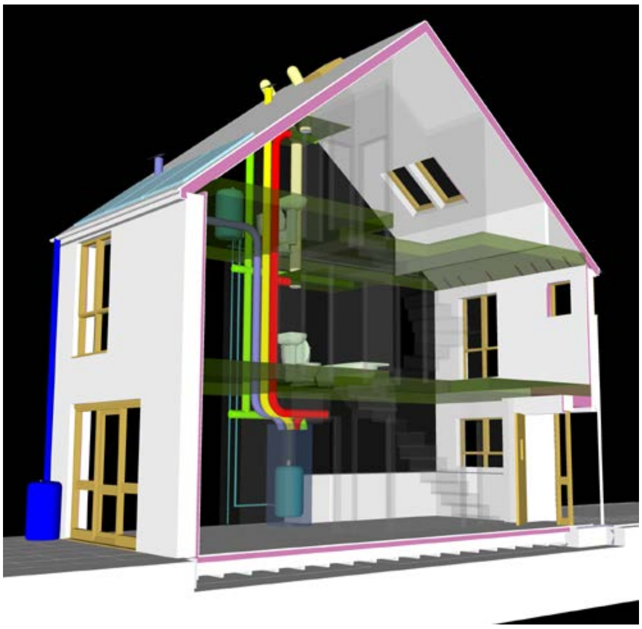
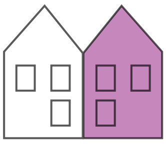


Figure 6.5 - Schematic of building services, MEPK Architects



Archetype 2, semi-detached: Zetland Road

Location: Chorlton, Manchester

Description: Pair of Victorian semi-detached - pre-1919, solid wall, uninsulated

Completion year: Autumn/winter 2018

Client, developer, project manager, building services engineer, contractor, and Passivhaus consultant: Ecospheric

Architecture: Guy Taylor Associates with Ecospheric

Structural engineer: Studio One Consulting

Electrical contractor: Environmental Building Services Ltd.

Space heating demand post-retrofit: 12.5 kWh/m^2/yr

Heat load post-retrofit: 10.4 W/m^2

Renewable energy generation post-retrofit: 41.6 kWh/m^2/yr

Heat loss form factor (PHPP): 2.20

Building type: Two Victorian semi-detached homes built in 1894, combined internal floor area of 374.3m^2 (187m^2 per house)

Budget: £887,000 (for the pair of semi-detached)

Certification or standard achieved: EnerPhit Plus certified (the two combined dwellings certified as one building, party wall not thermally insulated).

Energy Use Intensity (EUI) for the two houses

Predicted EUI (modelled): 32.4 kWh/m^2/yr

Actual EUI (measured):
Year one – 42.2 kWh/m^2/yr
Year two – 34.0 kWh/m^2/yr

Note EUI: One of the dwellings was occupied for 18 months before the other. As the original building form prevented significant party wall U-value upgrade this resulted in increased energy demand whilst the second dwelling was vacant. The results for Year 2 show the actual energy demand decreasing and it is expected to further decrease for the first whole year that both are occupied.

Electricity generated by PVs

Predicted: 53.1 kWh/m^2/yr

Measured: 48.2 kWh/m^2/yr

Note PV: The designers predicted demand and generation figures from PHPP and associated measured figures from the meters. 80% of electricity is generated when the house does not need it and is exported to the grid. There are no smart meters in either building so it has been assumed for calculation purposes that only 20% of the PV generation is consumed on site based on average usage patterns. The PV generation was lower than expected as there was a fault shortly after commissioning. Energy generation has increased since the fault resolved.

Project summary

The project included the re-conversion from flats to the two original semi-detached homes. The internal layout was reconfigured, the fabric improved thermally with new services.
The design proposed super insulating and sealing the whole envelope. In addition, the project was a test bed for technologies. Some of the project's interesting technologies are:

→ Fully breathable fabric to every external wall, floor and roof of the house
→ Electromagnetic field free electrical design and smart meter
→ Thermocline control (hot water tank that avoids de-stratification of water in tank and saves energy).

The project was uncompromising and as a technology test bed there were successes and failures with associated wastage which would result in a much more economically viable project if repeated. The technologies and specifications used are applicable to a wider class of building on future projects. The PHPP energy model, continuously updated during the project, was a useful tool and critical to the project's success. Using practically no petrochemicals, the embodied energy within building materials used in the refurb was kept to a minimum.

New external walls and roof include insulated Steico I-joists clad in Organowood. Existing brick walls at the front were modelled in WUFI where it was determined no brick creams were necessary. This was further ratified when in-situ moisture measures showed nearly all have the moisture content of a typical wall of this type. Thermalime was applied to the wood fibre boards on the side walls.

Figure 6.6 - Front after retrofit, photo by Rick McCullogh

Figure 6.7 - Rear after retrofit, photo by Rick McCullogh

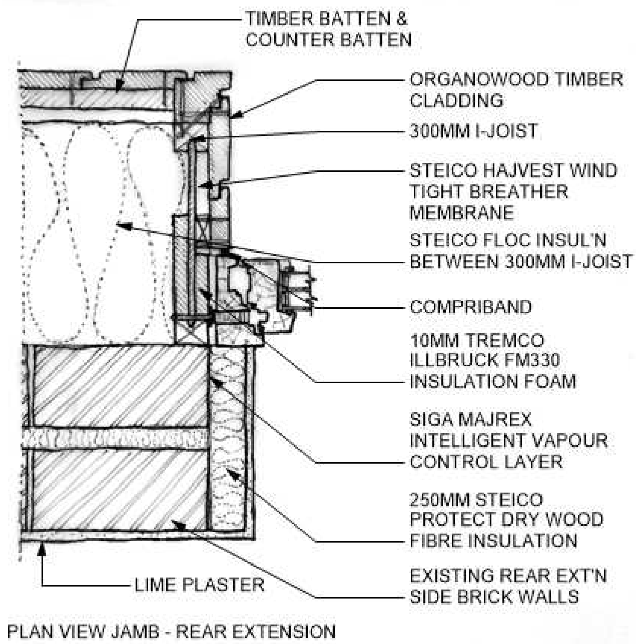
Insulation is a combination of recycled newspaper insulation blown between Steico I-joists and Steico woodfibre insulated board fixed to insulated I-joists on front, side walls and roof. The air tightness layer internally to the new I-joists, walls and roof is a Siga Majrex intelligent vapour control membrane with plasterboard on top. A parge coat of Thermalime created a consolidated level wall over which the cork lime and graphene enhanced lime paint for a fine finish capable of acting as the vapour control layer for all of the existing external brick walls. In recognition of inevitable imperfections in construction the strategy was to ensure every layer in the building fabric would be as breathable as possible to allow the fabric to dry quickly if wetted.

New windows and doors were developed with Viking. Seasonal overheating was also a concern at design stage, so to exploit the existing brick thermal mass of internal walls they were parged with cork lime plaster and painted with Graphenstone paint. In addition, a thermostatically controlled roof light with rain sensor provides effective passive cooling as part of the hybrid ventilation system. Typical U-values after completion:

→ Walls: 0.175 - 0.116 W/m^2.K
→ Floors: 0.165 W/m^2.K
→ Roof: 0.108-0.148 W/m^2.K
→ Windows: 0.68 W/m^2.K (uninstalled U-value[6.2])
→ Doors: 0.72 W/m^2.K (uninstalled U-value)
→ Roof windows: 0.81 W/m^2.K

Building services

→ Heating system: integrated 2kW electric post heater on the MVHR ventilation system, DiBT accredited Wiking log burning stove. Domestic hot water electrically heated in a Mixergy 300L tank.
→ Ventilation: Paul Novus 300 (PHI certified) heat recovery ventilation system.
→ Renewables: 30m^2 area of photovoltaic (PV) panels were added to the roof of each house to power the lighting and appliances but also heat the hot water tank.



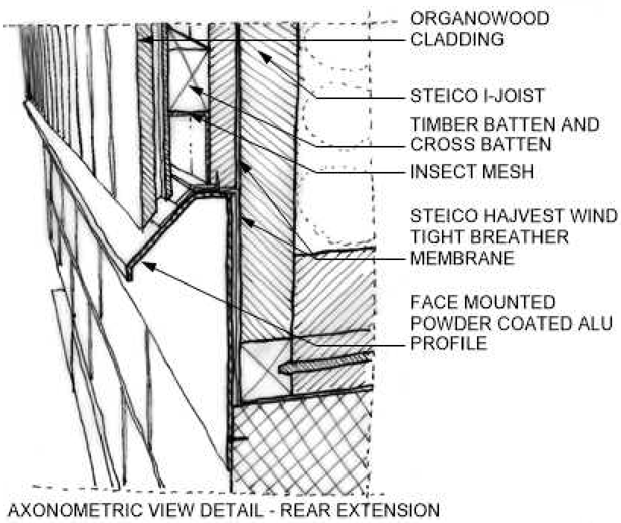
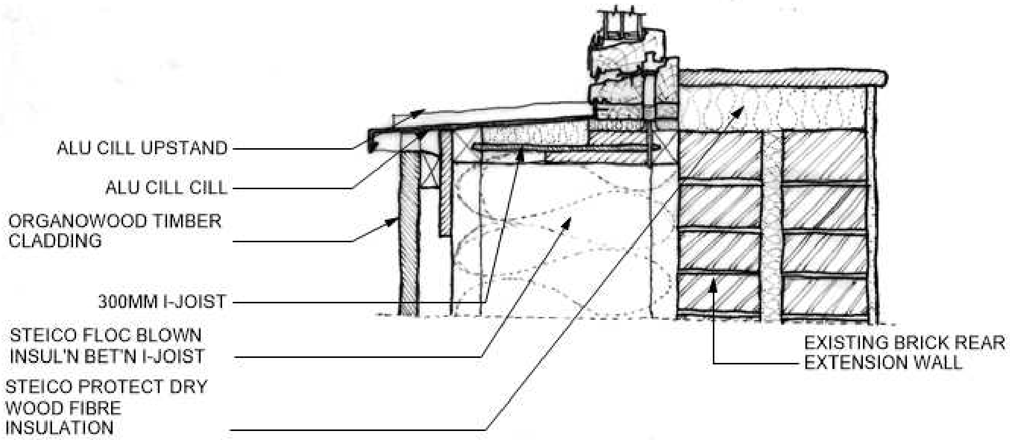
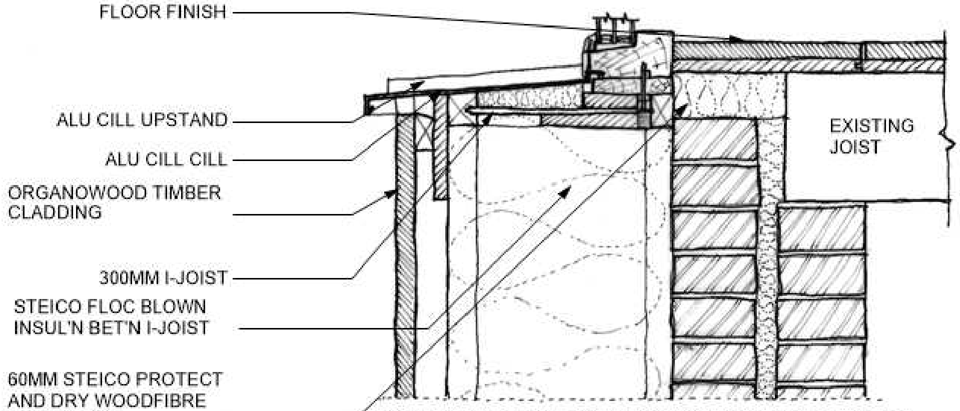


Figure 6.8 - Construction section details by Chris Rodgers, Guy Taylor Associates



SECTION CILL DETAIL REAR ELEVATION



SECTION CILL DETAIL TO FRENCH DOORS REAR ELEVATION

Archetype 3, detached: The Nook

Location: Preston Village, Brighton

Description: Detached villa - pre-1919, solid wall, uninsulated

Completion year: 2010

Client: Two Piers Housing Co-operative

Architecture: BakerBrown Studio Ltd

Consultants: Green Building Store

Contractor: Earthwise Construction

Budget: 'all-in' £166,500, and out-turn of £172,000

Certification or standard achieved: EPC B

Energy Use Intensity post-retrofit (measured): 73 kWh/m²/yr

Project summary

The Nook is a two story, detached Victorian villa' in multiple occupation (HMO), housing six adults. It has been chosen as a typical example of housing stock in Brighton and along the south coast. Prior to the retrofit it was largely uninsulated with single-glazed windows. The project aimed for a realistic, replicable and robust 'whole house' solution to retrofitting solid wall Victorian housing, demonstrating deep cuts in CO_2 emissions, and moving the property from "hard to treat" EPC F rating to EPC B by dramatically reducing space and water heating demand, and electrical consumption. The building is not listed but sits within a conservation area under an Article 4 Direction, meaning change to the appearance of the façade was restricted and the team had to deal with a number of technical, procedural and programme challenges for the retrofit.

Figure 6.9 - Front after retrofit

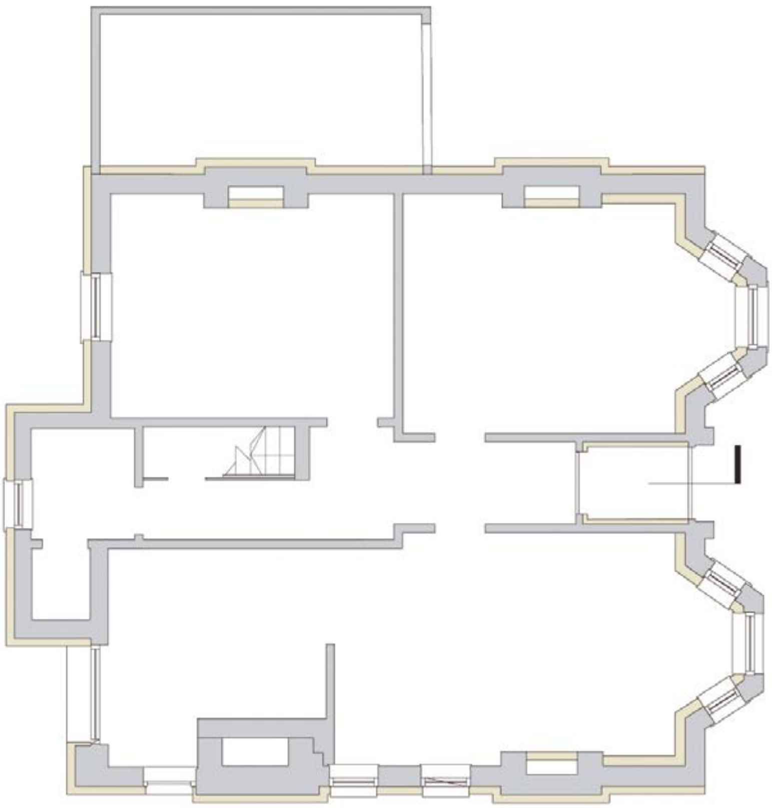


Figure 6.10 - Ground floor plan - Marion Baeli and Paul Davis + Partners[6.3]

Fabric
The retrofit introduced a 120mm internal insulation to the front façade, 120mm (2x60mm Kingspan Kooltherm) external solid wall insulation to the sides and rear, 120mm PUR ground floor insulation, and a mix of 188mm cold roof insulation, with an additional 50mm warm roof insulation, triple glazed windows to side and rear elevations and double-glazed sashes to the front. The project also employed an air tightness layer around the whole house, a Paul Novus [F] 200 DC MVHR, a condensing gas boiler, a 450L twin-coil highly-insulated hot water tank, and two Thermomax DF 100 roof-mounted evacuated tube solar thermal arrays. The heating system provides domestic hot water and top-up space heating, re-using the existing radiator circuits. Additional features included energy efficient appliances and lighting with compact fluorescents.

Planning and heritage
Resolving the planning and heritage concerns was a key challenge in the project. The internal insulation and choice of windows to the front was developed to respond to the constraints of the Article 4 Direction without undue cost. Replicating the historic features of the façade in over-cladding was cost-prohibitive. During feasibility, triple glazing had been proposed all round but was not acceptable to the Conservation Officer. After two planning applications and considerable work by the architect in collating and presenting convincing energy data on the options and in-depth work on the details, the windows were finally granted approval. The discussions with planning and the Conservation Officer delayed the start on site by over four months with significant ‘knock-on’ impacts.

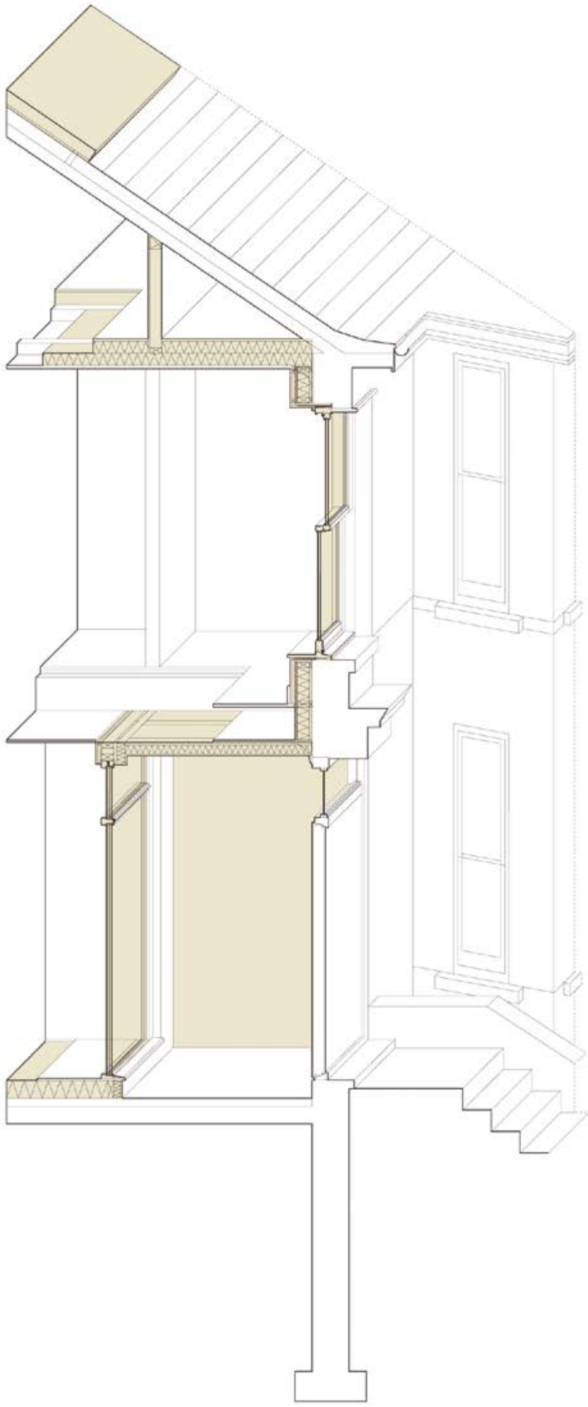


Figure 6.11 - Detailed section - Marion Baeli and Paul Davis + Partners[6.3]

The insulation strategy, including EWI to sides and rear, internal insulation to front and internal flanking returns, and a thick layer of PUR overlaying the solid floor to avoid the need to break up the ground floor slab, introduced technical challenges to avoid thermal bridging at interfaces but the resultant U-values achieved come close to Passivhaus standards. Ensuring continuity of the insulation and airtightness layer, and insulation of the internal projection of the entrance lobby into the building, required careful detailing and site workmanship, as is typical in retrofit.

Whilst the work to the building was extensive, it had to allow the occupants to remain living in the accommodation for as long as possible during the build. They remained for all but three weeks of the period during which the most invasive works were undertaken.

Budget including design fees, prelims and VAT was £166,500 and the project achieved an all-in out-turn cost of £172,000 allowing for asbestos being discovered and removed and the loss of the Low Carbon Buildings grant for solar thermal.

Key watch points were:

→ Ensure enough time in the project for negotiation with approving bodies and manage expectations.
→ Material availability: 120mm Kooltherm was subject to minimum order, making two layers of 60mm necessary and resulting in increased labour, cost and duration of installation.
→ Complexity of detailing to ensure continuity of air-tightness layer and insulation, and elimination of thermal bridges – the project team were keen to understand long-term how effective the installation has been.

Figure 6.12 - Installation of external wall insulation - BBM Sustainable Design

The completed project achieved its aims as a viable, efficient retrofit which significantly improved the energy performance of the property and could readily stand as a model for future work.

Archetype 4, flats: Wilmcote House

Location: Somerstown, Portsmouth

Description: 1960s flats (prefabricated LPS construction). 107 existing flats + 4 new ground floor flats added during the retrofit.

Completion year: staggered completion of blocks during 2017-2018

Client: Portsmouth City Council

Architecture: ECD Architects

Structural engineer: Wilde Carter Clack

Quantity surveyor and project management: Keegans

Building services: NLG

Contractor: Engie

Contractor's design team: GSA Architects; Design Buro; Curtins Engineers

Certification or standard achieved: Step-by-step EnerPHit

Space heating demand pre-retrofit (modelled): 188 kWh/m²/yr

Space heating demand post-retrofit (modelled): 23 kWh/m²/yr

Project summary

Wilmcote House is a housing estate located in Portsmouth, consisting of three 11-storey interlinked towers, with a combined treated floor area (TFA) of 10,233 m². The blocks were originally constructed as a concrete prefabricated structure in 1968, using a large panel 'Bison REEMA' variant system. With no place to relocate the residents within the existing 107 flats and maisonettes, Portsmouth City Council commissioned ECD Architects[6.4] for the building's regeneration to be achieved with the residents in occupation. The project aimed to achieve over 80% reduction in space heating demand and was designed to the EnerPHit standard; it was, at the time of completion, the largest residential EnerPHit delivered with residents in occupation in the world.

Figure 6.13 - Courtyard side completed. ECD Architects.

The existing concrete wall panels included a very small amount of insulation, but this was ineffective, and alongside inefficient double-glazed windows and old electric storage heaters, the flats experienced high levels of heat loss. Many of the residents could be classified as experiencing fuel poverty, as shown in residents' feedback carried out before the works. Studies by Teli et al.[6.5] at the University of Southampton showed economic constraints factored into many residents underheating their homes below WHO recommendations also exacerbating damp risk and mould growth.

The architect's thermal and airtightness strategy involved the simplification of the thermal envelope, with a new load-bearing steel frame erected on the garden-side elevation. This allowed the external corridors to be enclosed and allowed the living rooms to be extended to meet the new simplified external envelope. The existing stair cores were left uninsulated and outside the thermal envelope, which improved the building's form factor significantly. The 3 blocks were externally insulated with 300mm non-combustible mineral wool insulation, which wrapped the entirety of walls and roofs. The retrofit included the installation of triple-glazed windows and high-efficiency individual MVHR units in each flat.

The client partnered with the London School of Economics (LSE) in a research project which interviewed residents before, during and after the works. University of Southampton continued to monitor internal temperatures to determine the impact of the works on winter fuel poverty and summer overheating risk.

Figure 6.14 - Courtyard side during construction, showing new EWI and triple-glazed windows being fitted. ECD Architects.

The thermal performance of the building fabric was radically improved, with the estimated space heating demand reduced from 188 kWh/m^2/yr to approximately 23 kWh/m^2/yr. Initial post-occupancy evaluation conducted by University of Southampton suggests that performance is in line with predictions. Results for the 2018-19 heating seasons suggest that the building can provide WHO temperature standards in order to maintain health with little to no active heating[6.6].

Thermal comfort surveys conducted during the first round of monitoring after the insulation works were completed (2017-18) suggested a low heating usage amongst tenants, with 60% of participants utilising their heating less than once per week. Whilst 36% had not used their heating at all over the winter period.

The fabric first approach significantly improved thermal comfort conditions for residents that did not engage

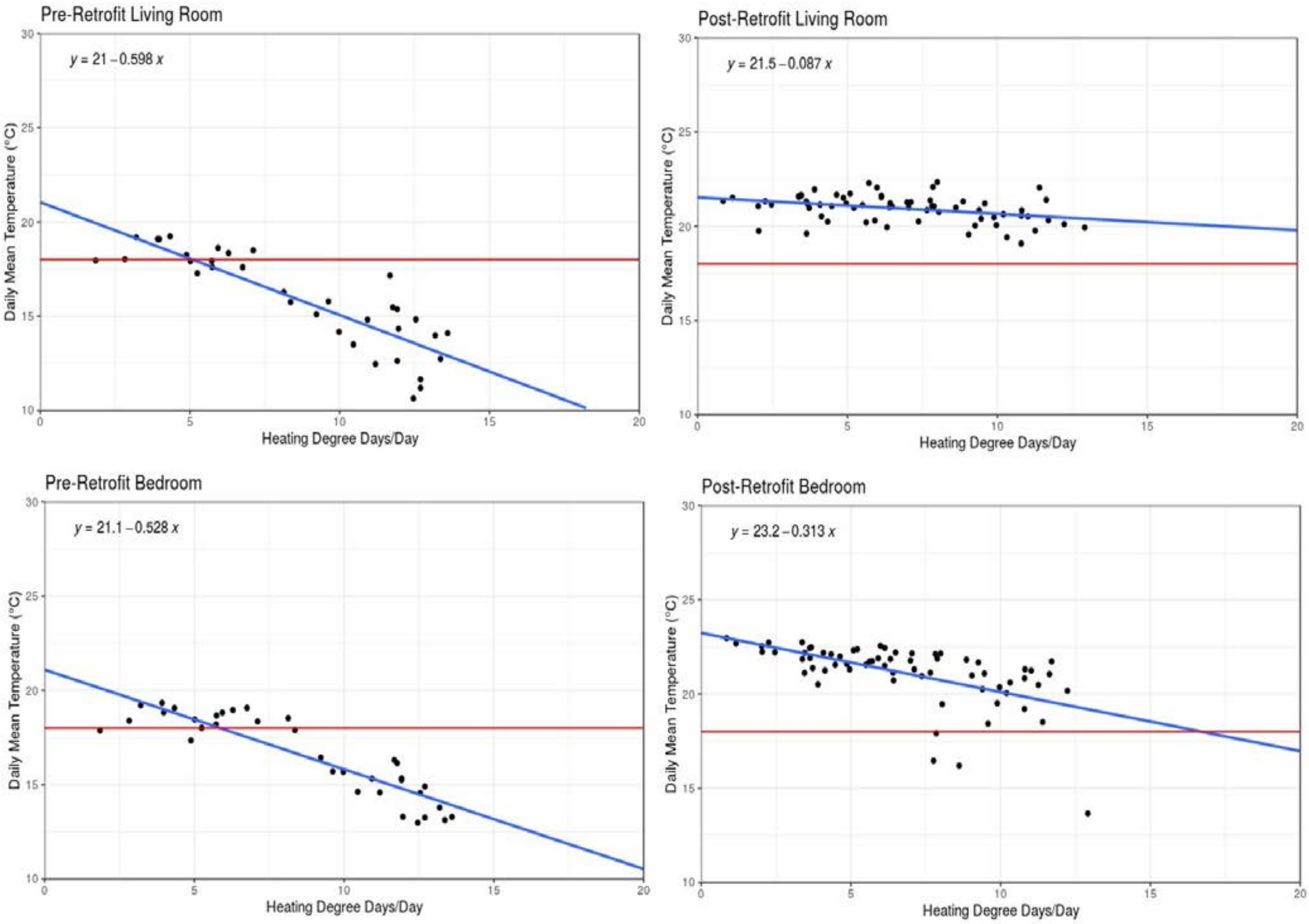


Figure 6.15 - Scatter plots show a single dwelling (living room and bedroom) that are under-heated prior to the retrofit, and currently maintains significantly better internal temperatures utilising the same heating practice post retrofit[6.6].

in a 'typical' heating strategy. In order to maintain "safe and well-balanced indoor temperatures to protect the health of general populations during cold seasons" (WHO), a minimum 18°C is utilised as the target benchmark in their study.

Figure 6.15 shows a pre- and post-retrofit comparison of a dwelling (living room and bedroom before and after the retrofit) where the resident did not use the heating in their home, possibly due to economic constraints. The point of intersection of the blue and red lines estimates a threshold for which some form of heating may be required in order to maintain a daily average of 18°C. The shift of point of intersection between pre- and post-retrofit indicates the Heating Degree Days threshold change. Prior to the retrofit, this dwelling would experience approximately 160 days annually that would require heating (in varying magnitudes) in order to maintain 18°C. Post retrofit, this dwelling in particular is able to maintain 18°C without the requirement for active heating. This study exemplifies the tangible benefits in quality of life for residents who are experiencing fuel-poverty and can transition from living in cold, draughty, mouldy flats, to living in warm, comfortable and healthy homes.

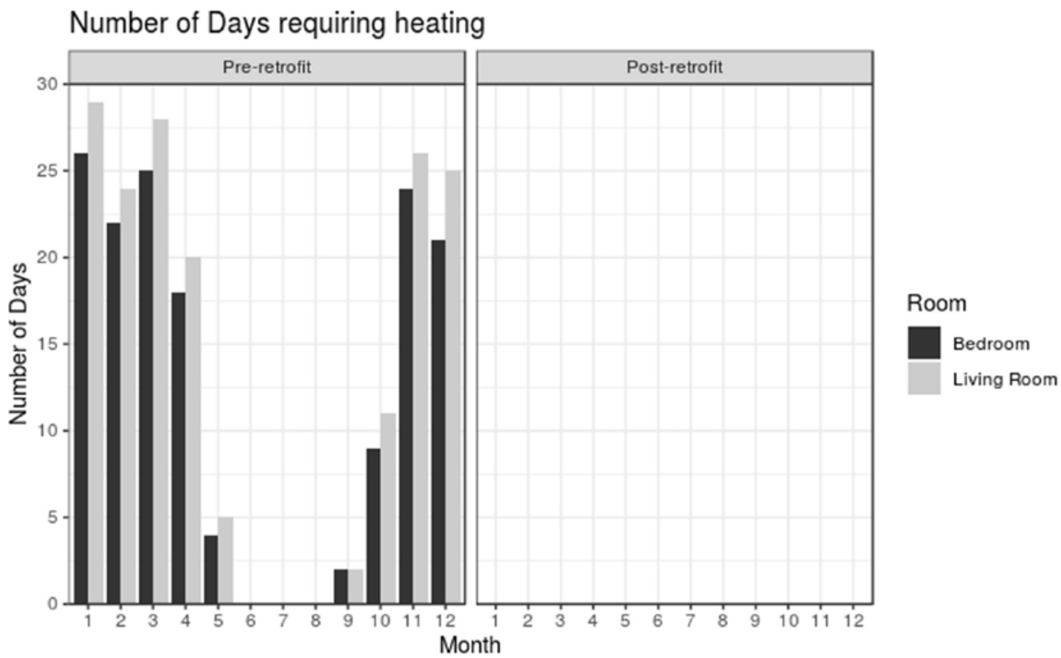


Figure 6.16 - Bar graph showing hypothetical performance under a TMY (Typical Meteorological Year). Showing the number of days that would typically require some form of heating in order to maintain 18°C[6.6]. This graph shows that no active space heating is required post-retrofit to maintain 18°C.

Archetype 5, end-terrace: Gloucester Place Mews

Location: Marylebone, London

Description: Grade II listed 'end of terrace' Mews House, pre-1919

Completion year: 2018

Client: The Portman Estate

Architecture: Feilden + Mawson LLP

Building services: Leonard Engineering Design Associates

Energy consultant: Sturgis Carbon Profiling

Structural engineer: Furness Partnership

Quantity surveyor: STACE

Contractor: Richardsons of Nyewood

Budget: £700,000, including full interior refurbishment

Certification or standard achieved:
EPC B, BREEAM Excellent, certified Passivhaus (EnerPHit) standard using the elemental method

Space heating demand post-retrofit (modelled):
37 kWh/m^2/yr

Project summary

Gloucester Place Mews is in a conservation area, which made the planners resistant to any external alterations to the house. Therefore, the project included a complete reconfiguration of the internal layout. The client has a large property portfolio of rental properties. The brief was for a high quality retrofit for rental accommodation. The client wanted to test a fabric-first approach whilst monitoring costs along with their supplier's readiness and skills. The improvements would benefit tenants with improved internal comfort levels, lower energy costs and improve air quality. It was the first listed building in the UK to be certified to EnerPHit standard.

Figure 6.17 - Open plan kitchen/dining post retrofit, Feilden + Mawson LLP

Figure 6.18 - Passivhaus certified rooflight, Feilden + Mawson LLP

Figure 6.19 - View along mews to front elevation, , Feilden + Mawson LLP

The new internal layout retained the garage at ground level, which led to a larger than average form factor; the heat loss area is 396m^2 and TFA (treated floor area) is 121m^2. The fabric upgrade was robust; the internal walls were insulated with 40mm Aerogel to avoid a reduction in internal floor area, an airtightness membrane with 30mm service void and magnesium oxide board finished with lime plaster and breathable paint. The airtight layer in the build-up of the building envelope had to be carefully detailed around the interfaces between new and existing elements. This included connections between existing external walls and new structure. Likewise the insulation was carefully detailed to eliminate thermal bridges, in particular, around the internal garage volume. Existing windows were refurbished and new triple-glazed secondary glazing fitted along with Passivhaus certified front door and rooflights.

The only element of the existing interior retained was the stairs, which itself presented challenges in achieving adequate insulation and airtightness against the external wall behind the stringer, affecting the detailing of the window when reinstalled against the front wall. Given the small and relatively complex form, the completed airtightness result of 0.7 was well within the EnerPHit threshold. A new heating and hot water system was installed along with an MVHR (mechanical ventilation and heat recovery) as well as the provision of monitoring equipment to give the client feedback to inform future projects.

The fabric first approach centred around specification, procurement/availability and quality control. Some materials were somewhat specialist and subject to long lead times. Site detailing of complex junctions and interfaces with historic fabric and detailing require very close attention. An adequately detailed survey prior to and during design would have eliminated some of the issues experienced on site.

The energy, water and indoor environment of the resultant property were monitored during 2018/2019, although the property was not fully inhabited – only one of three double bedrooms were occupied – data analysis offers some useful conclusions.

Figure 6.20 - Installation of internal wall insulation (40mm Aerogel applied to the internal walls to minimise loss of space), Feilden + Mawson LLP

Key issues identified in the occupancy study were:

→ Reliability of monitoring – meters showed some data loss, possibly due to loss of internet connectivity.

→ Habitation affects quality of data and further monitoring of different tenancies would help build better understanding of performance issues.

→ Occupant understanding of building operation is key to energy efficiency.

→ Monitoring had not been installed in downstairs bedrooms, so no data exists for those portions of the accommodation. No conclusions could be drawn for these rooms in terms of thermal comfort, particularly in a summer heatwave.

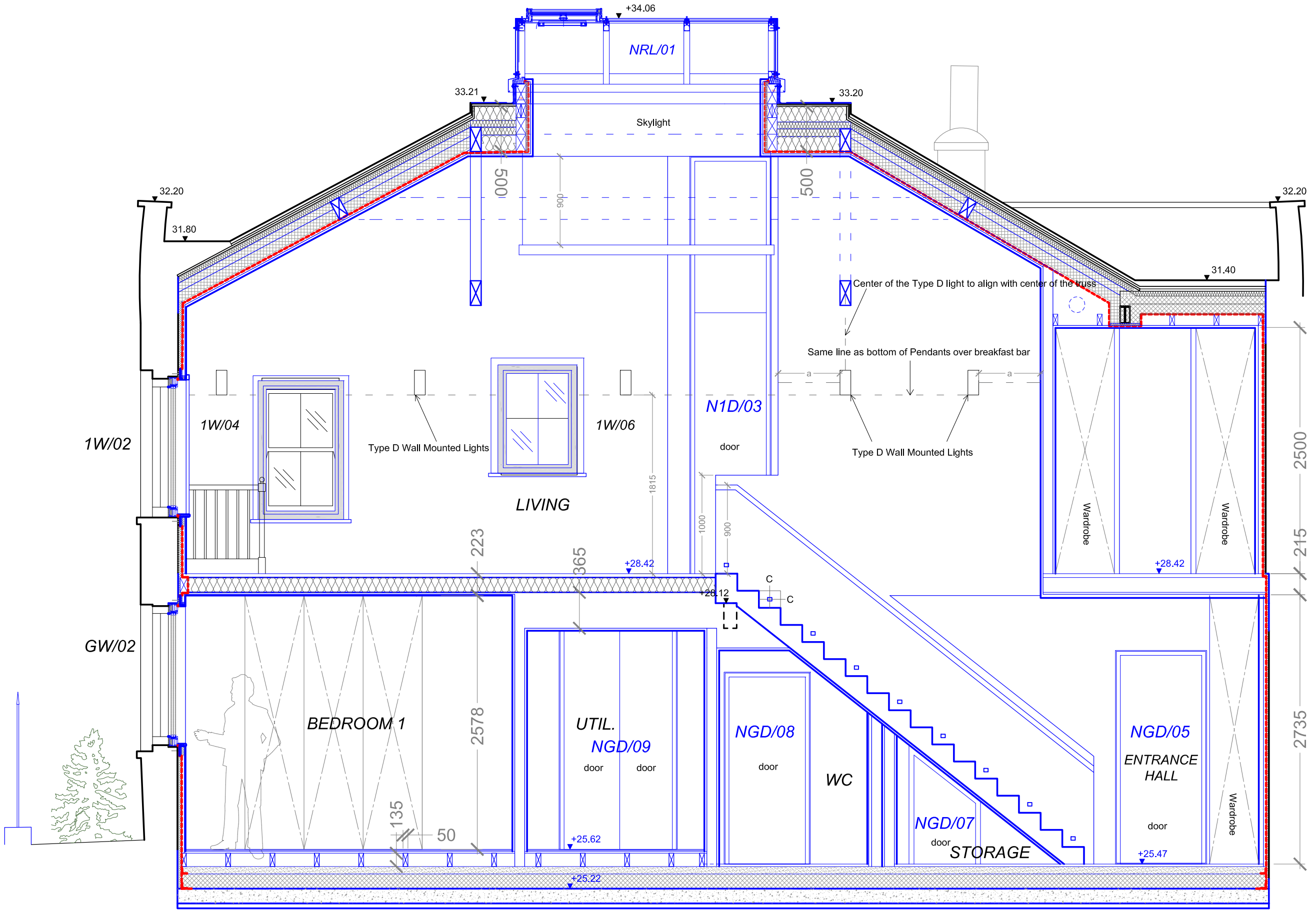


Figure 6.21 - Section, Feilden + Mawson LLP[6.7]

Thematic case studies

The case studies provide real-world examples of retrofits that align with the general themes that we have set out in the archetype pages. They may not conform fully with the archetypes, but demonstrate what can be achieved, as well as the techniques used and challenges that need to be overcome.

Deep and step-by-step retrofit

Stakeholder engagement

Windows

Insulation

Thermal bridging

Airtightness

Moisture

Case study 1: Sterndale Road

Location: Notting Hill, London

Description: Victorian mid-terrace house

Topic: Stakeholder engagement and communication

Client: Notting Hill Housing with United House Developments Limited

Architecture: Baily Garner

Contractor: United House

Budget: £108,987.00

Certification or standard achieved: EPC B

Project summary

This property in Sterndale Road[6.8] aimed to inform eco-refurb specifications for Notting Hill's Property Services and Development Department. Intended to form the basis of future mass refurbishment of Victorian, Edwardian and Georgian properties. It sought to identify technologies and products that would perform best environmentally whilst also being commercially viable.

Pre-work thermographic surveys and air pressure testing showed poor results: air leakage of 17.5 $m^3/m^2/h$ @50Pa, excessive draughts around windows and doors, numerous thermal bridges, cold spots and a minor insulation defect in the recently refurbished roof.

65mm of insulation backed plasterboard was fitted to walls to achieve 0.32 $W/m^2.K$. The flat roof, renewed and upgraded prior to the project with 240mm wood-fibre insulation, was designed to achieve 0.15 $W/m^2.K$. Existing windows were replaced with double-glazed, low-E glass to achieve 1.2 $W/m^2.K$. The lower ground floor was remediated with 220mm lightweight expanded clay aggregate, under limecrete solid floor with 55mm screed. A new A-rated gas boiler, radiators with thermostatic radiator valves, and underfloor heating in the lower-ground floor were fitted, plus a twin-coil thermal store (to accept solar hot water feed). Solar Thermal panels give half of the annual hot water demand. A 0.875 kWp photovoltaic array was installed. Lighting was upgraded to low-energy fittings throughout.

Figure 6.22 - Front post retrofit

Improvements included acoustic privacy, rainwater harvesting to toilets, water saving sanitary appliances, recycling facilities and innovative technologies (such as a smart voltage management system). The internal layout largely was unchanged but a new habitable space in the lower-ground floor created a new bedroom, home workspace and living room with access to the garden. Post-works air tightness tests showed 5.9m³/h.m²@50Pa, and the Energy Performance Certificate (EPC) moved from band G to band B.

Stakeholder involvement was critical. A notable element of the project was the measuring, monitoring and engagement strategy, which included gathering feedback from contractors on buildability and the value of different improvement measures. The Notting Hill's Residents Repairs Working Party (RRWP) was involved in the project throughout, including setting project aspirations, attending contractor interviews, and engagement in the workshops held to assess suitability of the many options of materials and technology considered for inclusion in the building. Green features specified were strongly influenced by feedback from RRWP. Operational costs were important to residents and an open day was held part-way through, which visitors were encouraged to comment and ask questions.

	Pre-refurbishment	Post-refurbishment
SAP	13	90
EPC	Band G	Band B
Annual running costs	£2020	£220
Annual CO_2 emissions	12.3 tonnes	1.95 tonnes
EcoHomes XB	7	91

Figure 6.23 - SAP rating post retrofit

Case study 2: Pavillion Road

Location: Hans Town Conservation Area, Chelsea, London

Description: Mid-terrace, mews house

Topic: Windows

Client: Cadogan Estate

Architecture: Latitude Architects

Structural engineer: ConisbeeMEP

Building services: HITEK

Project manager and cost consultant: The Trevor Patrick Partnership

Passivhaus Designer and BREEAM assessor: Sturgis Carbon Profiling

Passivhaus Certifier: CoCreate

Historic buildings consultant: Donald Insall Associates

Planning advisers: Gerald Eve

Contractor: Richardson's (Nyewood) Ltd.

Budget: The client reported a 6% increase above business as usual

Certification or standard achieved: BREEAM UK Domestic Refurbishment 2014 "Outstanding" and PassivHaus EnerPhit certification using the elemental method

Space heating demand post-retrofit (modelled): 32 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 96 kWh/m^2/yr

TFA (treated floor area): 128m^2

Project summary

This two-storey Hans Town Conservation Area, solid-wall, mews house was fully demolished internally, with façades retained and reconstructed anew as a three-storey, two-bedroom modern dwelling, to high thermal performance and quality of interior fit-out. This pilot project is part of Cadogan's sustainability strategy, reducing environmental impacts across the Estate.

The project targeted a high BREEAM rating and Passivhaus EnerPhit certification. Pre- and post-completion monitoring was extensive, including energy at meter/sub-meter level, thermal comfort, indoor air quality (IAQ), moisture/damp levels, and occupant feedback.

Retention of the historic façades introduced some issues with detailing and spatial planning, which were resolved in the finished project by internal insulation, replica triple-glazed windows, replacing doors in the same style, as well as repairing and repointing the original brickwork. The most significant challenge appears to have been obtaining Conservation Area consent for the changes to the external appearance and specifically the windows, together with some complex detailing of the insulation interface between the retained rear façades and the new mansard roof construction, impacting on the configuration of the internal space.

A 'fabric first' approach was taken:

→ A glass mineral wool insulation system was applied to the internal face of front and rear façades, rigid PIR insulation was used in the new warm-roof mansard and to the new ground floor slab, and aerogel was used to ensure appropriate visual detailing of the dormer windows to suit the aesthetics of the Conservation Area.

→ Timber sash triple-glazed windows met the conservation requirements.
→ An airtight membrane was introduced, and the contractor's workforce was specially trained in the correct use of the special sealing and bonding tapes prior to work on site. Airtightness responsibility was assigned to a designated member of site staff to help ensure every area was properly sealed prior to being covered up by subsequent construction.

Heating and ventilation was achieved using a gas boiler and a Renovent Excellent-400 (Plus) MVHR. Smart meters were installed so occupants can see usage directly.

The project is considered by Cadogan to have been very successful and achieved BREEAM 'Outstanding' as well as PassivHaus EnerPhit certification. After living in the property for over a year, the occupiers report noticeably good indoor air quality, greatly reduced noise and significantly lower energy bills than in their previous residences – with a gas bill of only £200/year for all heating, hot water and cooking. Cadogan is taking lessons from this project into future developments, increasing building efficiency on their journey towards net zero.

Figure 6.24 - Front post retrofit.

Case study 3: Shaftesbury Park Terrace

Location: Shaftesbury Park Estate Conservation Area, Wandsworth, London

Description: Pre-war (1870s) mid-terrace house

Topic: Insulation

Client: Peabody Estate

Architecture: Feilden Clegg Bradley Studios with Bill Gething

Consultants: Max Fordham, Rickaby Thompson Associates

Contractor: Wates

Budget: £80,791 of which energy saving measures and collateral costs were £78,876

Energy Use Intensity pre-retrofit (modelled): 341 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 87 kWh/m^2/yr

Project summary

This two-bedroom house is located in a conservation area. Peabody's aim for the project was to find solutions that could be applied to their 21,500 other homes in London. The occupants were to remain in situ during the majority of the works.

Pre-retrofit, the house was largely uninsulated, with solid brick walls, single-glazed sash windows, and suspended timber ground floors. Employing the principle of 'fabric first':

→ Windows were replaced with double-glazed sashes to the front and triple-glazed casements to the rear with trickle vents in line with the strategy of providing natural ventilation.

→ Internal Aerogel insulation was introduced to front and rear walls, and returned along both party walls.

→ 80mm external PUR insulation was added to the rear kitchen extension and over-clad with timber rainscreen board.

→ Insulation was provided on the ceiling line within a cold roof void.

Figure 6.25 - Front elevation. Feilden Clegg Bradley Studios

→ The suspended ground-floor timber joists originally were supported on timber wall plates bedded in the brick wall. The joist ends were cut back and new joist ends spliced on, re-supported on foam glass. The void under the joists was filled with blown polystyrene bead cavity wall insulation after re-routing services to ensure cabling did not overheat and gas pipes were not run through unventilated voids. The need to re-route services incurred additional costs for the project.

The team decided MVHR would have taken up too much space, being problematic to install through the existing structure, also its benefits would likely have been limited due to the practicality of achieving the necessary high levels of airtightness. The strategy was efficient boiler installation, heat pump recovering heat from an integrated Passive Stack Ventilation system. The ventilation strategy consisted of trickle vents on windows and a fan-assisted passive stack ventilation from the kitchen and bathroom. The passive stack vent used an experimental heat pump recovering heat from the exhaust air and an exhaust air heat pump (EAHP). The heat is fed back into the domestic hot water thermal store. Solar thermal panels pre-heat hot water for the existing retained condensing boiler, connected to radiators.

Originally, Passivhaus certified triple-glazed casements were proposed; however, these were not acceptable to the planners, due to their visual appearance impacting on the heritage value of the conservation area. Double-glazed casements were considered an acceptable balance.

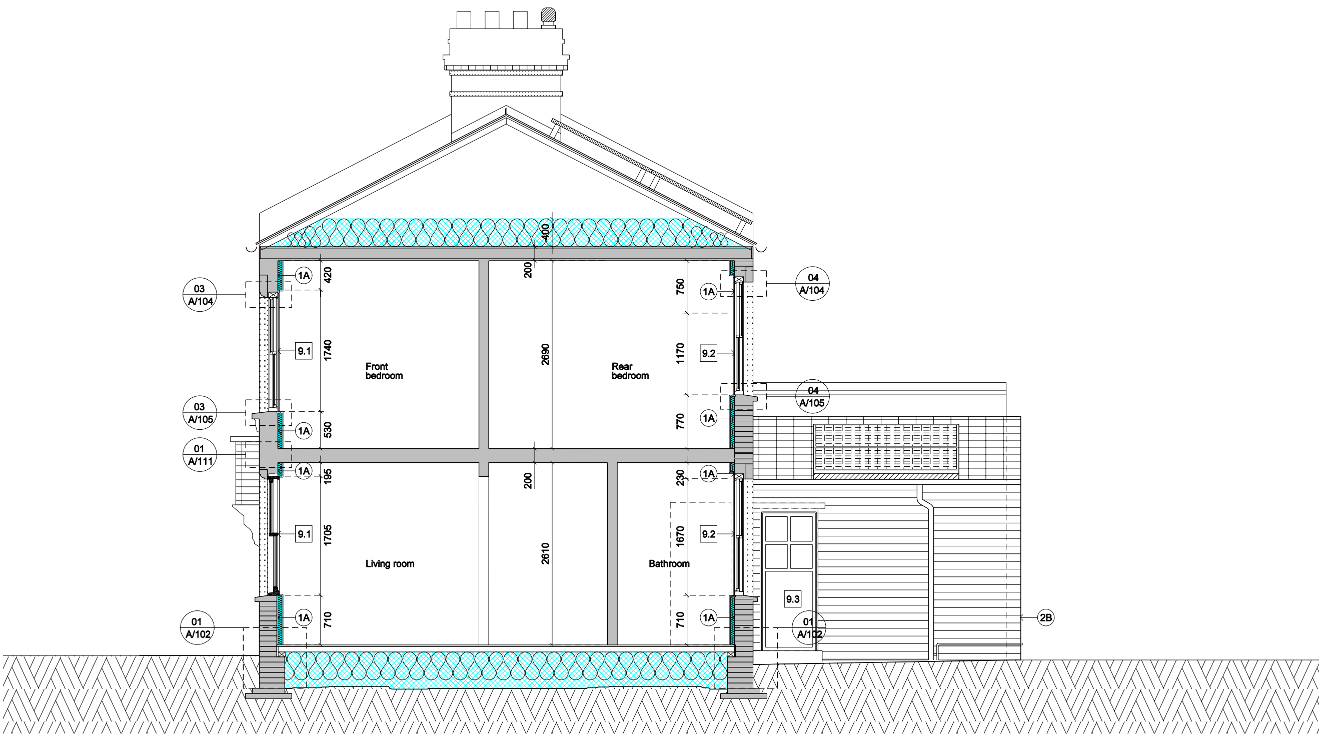


Figure 6.26 - Section - Feilden Clegg Bradley Studios

Case study 4: Passfield Drive

Location: Tower Hamlets, London

Description: Post-war (1960's) mid-terrace

Topic: Deep retrofit with residents in-situ

Client: Southern Housing Group

Architecture: bere:architects

Building services: Alan Clarke

Structural engineer: Galbraith Hunt Pennington

Contractor: AD Enviro

Budget: Design stage £89,618, Out-turn construction £115,957 (£14,943 of which was client enhancements)

Certification or standard achieved: 'Quality-Approved Energy Retrofit with Passive House Components' as set out in the certification criteria by the Passive House Institute (PHI)

Space heating demand pre-retrofit (measured): 315 kWh/m²/yr

Space heating demand post-retrofit (measured): 31 kWh/m²/yr

Energy Use Intensity pre-retrofit: 385 kWh/m²/yr

Energy Use Intensity post-retrofit: 54 kWh/m²/yr

Floor area: 96m²

Project summary

The three-storey mid-terrace house was occupied by three generations of a single family. The project, completed in 2011, aimed to establish principles of carrying out works with the occupants remaining in occupation.

Pre-retrofit, the property was under-heated, suffered damp and condensation problems. Windows were single-glazed with metal frames. Walls were solid brick (rendered externally), and the roof had minimum insulation. The ground floor was a solid concrete slab. Clear communication managed expectations from the outset, the occupants were keenly engaged in the process, and in the post-completion monitoring. Site-work took approximately 8 months from start on site to full completion.

200mm of insulation was added to the loft space prior to the start of the retrofit works. Subsequent retrofit works comprise:

→ 200mm and 250mm EPS external insulated render system to front and rear walls.

Figure 6.27 - Front post retrofit, bere:architects

- The external insulation was extended one metre below ground to foundation level, to limit the heat losses through the ground slab.
- A further 200mm mineral wool insulation was provided to the attic to give 490mm total thickness.
- High performance vacuum insulation and protective boarding to floor slab beneath finishes. Internal wood fibre insulation to flank walls and details to eliminate cold bridges from neighbouring façades and party walls.
- Continuous airtightness membrane was installed in the attic, sealed to cementitious parge coat to walls. Continuous airtight seal from parge coat to airtightness membranes in extension. Windows sealed to a parge coat with continuous tapes. Airtightness grommets fitted to all new and existing service penetrations.
- Passivhaus certified triple-glazed windows and doors with U-value of 0.8 W/m^2.K.
- New timber-framed rear extension with 375mm wood fibre insulation to walls and 225mm mineral wool and 150mm wood fibre insulation to roof.
- 92% efficient mechanical ventilation with heat recovery (MVHR) installed. Roof-mounted solar thermal array with solar cylinder and a re-configured conventional gas boiler.
- High performance insulation (0.038 W/m.K at 40°C) to hot water pipes.

Site work took longer than planned due to a number of issues: the need to work around the occupants; delays in materials procurement; and long lead-ins for specialist materials. There were significant problems with quality of workmanship and a significant amount of remedial work had to be undertaken to achieve the required airtightness. Final measured airtightness was, however, improved from 5.6ach@50Pa to 1.9ach@50Pa. Post-project reviews identified that efficiencies could be gained by undertaking the work on a larger scale, enabling training and skills for all trades.

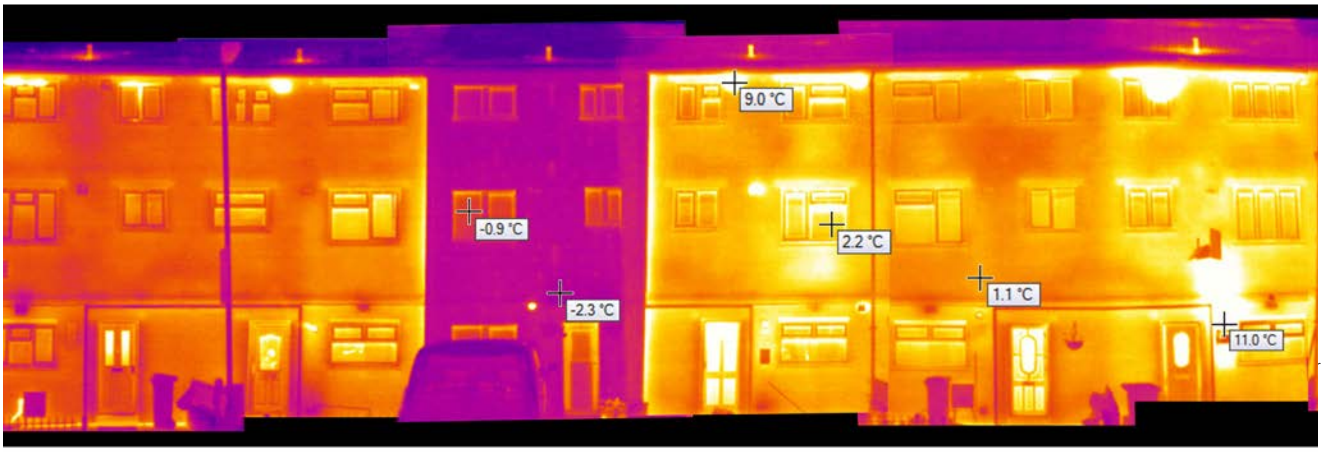


Figure 6.28 - Thermal imaging winter 2012 post retrofit, bere:architects

Case study 5: Bloomsbury House

Location: Bloomsbury, London

Description: Mid-terrace, Georgian conservation property

Topic: Windows in a listed property

Architecture: Prewett Bizley Architects

Structural engineer: Jonathan Parks

Contractor: Bow Tie Construction

Budget: Energy saving works £200k (380m^2)

Certification or standard achieved: Near miss EnerPHit

Space heating demand post-retrofit (modelled): 25 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 45 kWh/m^2/yr

Project summary

The 'Bloomsbury House' is a historic listed Georgian townhouse in Bloomsbury, London. It had been used as an office for some decades but was converted back to a single-family dwelling as part of this project. It has come close to meeting the EnerPHit standard even with the limitations of working with an existing grade II listed building. Given the listed status, great care needed to be taken with the historic fabric of the building. Original features were kept in-situ and fabric efficiency measures as well as new services were very carefully planned.

Generally, the twentieth century additions at the rear of the house were the easiest to work with and it was possible to use modern triple-glazing and modern insulations. Service runs were carefully routed through these parts and within the deep floor structure of the main house.

For the main house the internal insulation strategy includes five types of moisture open insulation (cellulose, woodfibre, glass wool, aerogel and open-cell sprayed insulation). These layers generally replaced plasterwork that had been altered or damaged in the latter part of the twentieth century. The brickwork on the outside was also carefully repaired to enhance the drying potential of the fabric.

Perhaps the greatest challenge was how to tackle the very large multi-pane sash windows. While most of these were not original (in fact they were mostly

Figure 6.29 - High performance secondary glazing post retrofit. Prewett Bizley Architects

later Victorian replacements) the conservation officer would not accept replacement sashes with insulating glass.

Therefore, the architect approached a secondary glazing supplier to see what might be possible. Together they married an existing slender frame system (normally used to carry single-glazing) with evacuated insulation glass. The result was an especially high-performance type of secondary glazing that had very little impact on the appearance of the windows when viewed from either inside or outside. As well as achieving an estimated U-value of around 1.0 $W/m^2.K$. This solution proved to be very airtight and helped with the final air test result of 1.4ach@50Pa. The secondary glazing also almost eliminated the street noise from the interiors which creates a very serene and peaceful atmosphere.

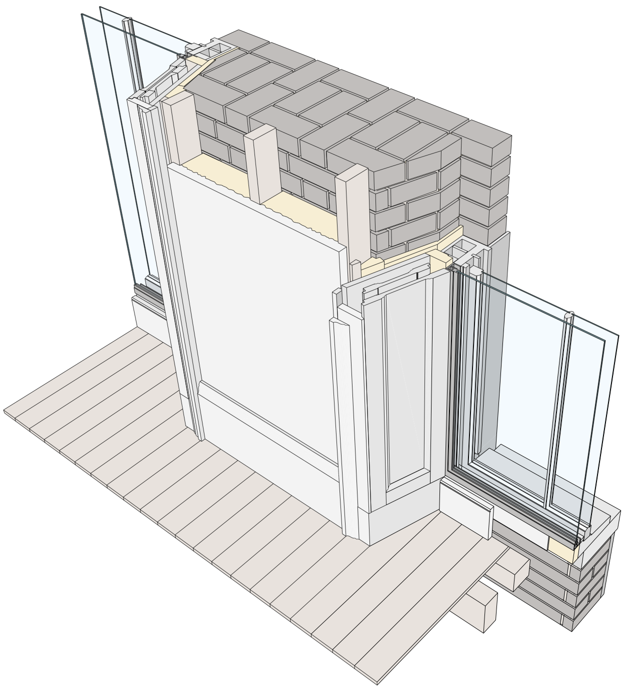


Figure 6.30 - Axonometric showing insulation to walls, shutter box and secondary glazing to existing windows, Prewett Bizley Architects

In order to minimise duct runs, two MVHR systems were fitted. The duct routes were carefully planned to have no impact on the interiors. One serves the upper part of the house and the other the lower two floors. The air quality has been measured and is especially good with CO_2 counts never exceeding 1000ppm.

The very low space heat demand enabled the radiator system to be removed altogether and the house is heated with underfloor heating. Heating and hot water are provided by an air source heat pump mounted within the 'M' of the mansard roof. Internal temperatures are impressively consistent even during very cold weather.

The project is testament that it does not need to be an either-or choice between improving energy performance or conservation. It is possible to conserve the planet and our historic buildings.

Case study 6: Erneley Close

Location: Manchester

Description: 32 walk-up flats in two separate maisonette blocks and six cottage style bungalows.

Topic: Thermal bridging

Architecture: Edelmann and Ebling

Developer: R-Gen Developments

Passivhaus consultant: Eric Parks

Building services: Alan Clarke

Structural engineer: Marston and Grundy

Contractor: The Casey Group

Budget: £3.1M

Certification or standard achieved: Passivhaus EnerPHit certification in 2015

Space heating demand post-retrofit (modelled): 23 kWh/m^2/yr (both blocks)

Energy Use Intensity post-retrofit:
Smaller block - 73.5 kWh/m^2/yr
Larger block - 76.8 kWh/m^2/yr

Space heating demand (measured): 21 kWh/m^2/yr (based on analysis interpolated from data collected January - April 2015)

Air pressure results:
Smaller block - 1.0@50pa over total floor area of 740m^2
Larger block - 1.0@50pa over total floor area of 1228.3m^2

U-values:
Roof 0.08 W/m^{2}K
Timber Frame Infill Walls: 0.097 W/m^{2}K
Gable End Walls: 0.12 W/m^{2}K
Ground Floor: 0.21 W/m^{2}K
Doors and Windows: 0.9 W/m^{2}K

Note: the EUI is higher than the LETI targets due to the heating and hot water system being a communal gas boiler system.

Project summary

In May 2015, Eastlands Housing (now One Manchester) completed work on its retrofit to EnerPHit standard of 32 social housing flats in two blocks in Erneley Close, in Gorton, Manchester. It was intended that the development would reduce energy bills, create new community greenspace and make the area a destination of choice.

The scheme not only looked to adopt the EnerPHit standard across the site, but equally created a connection of place making between the buildings. The building works included vast improvements in the fabric U-values, airtightness and in particular, addressing thermal bridging.

Figure 6.31 - Close up after retrofit

Typical of 60s maisonette blocks, these had a number of architectural features, external horizontal walkways, balconies and vertical piers. The construction used cast through concrete, where the concrete continues from internal areas to external areas which created significant thermal bridges in the structure. The Passivhaus consultant estimated the thermal bridges contributed to around a third of the total heat loss.

The solution adopted was to wrap the balconies and features with insulation and use insulated skirting where cold spots were found. Several different variations were implemented as the building works progressed and a great deal of thermal analysis was undertaken to support the best solution.

Originally, the plan was to keep the residents in situ, with the strategy for the wall performance being to retain the inner leaf blockwork walls, applying a parge coat and then adding insulation externally. However, once major works began, the blockwork walls were found to be structurally deficient and with the decanting of the residents, the decision was taken to remove the walls entirely. In place, an insulated timber frame was installed, allowing for the use of a timber framed backing wall and easier sealing of the perimeter.

This project highlighted the importance of intrusive surveys needed from the outset of the design phase to facilitate design with the necessary level of information and enable adapting the program and procurement to suit findings.

Figure 6.32- Elevation prior to retrofit

Figure 6.33 - Elevation post retrofit

Case study 7: Hensford Gardens

Location: Sydenham

Description: Mid-terrace 1960's

Topic: Step by step retrofit

Client: Marion Baeli and Robert Prewett

Architecture: Prewett Bizley Architects

Building services: Borisa Ristic; Green Building Store (MVHR)

Structural engineer: Rodrigues Associates

Contractor: Borisa Ristic

Budget: £150,000 total budget for the build. Energy efficiency measures were about £55,000

Certification or standard achieved: Step by Step EnerPhit (not registered)

Space heating demand pre-retrofit (modelled):
150 kWh/m^2/yr

Space heating demand post-retrofit (modelled):
Step 1: 40kWh/m^2/yr
Step 2: 23kWh/m^2/yr

Energy Use Intensity post-retrofit:
65 kWh/m^2/yr

Project summary

As a step by step retrofit, this project may be helpful for other home owners who do not have the capital to carry out a whole house retrofit at once. The project also involved the replanning of the house alongside the retrofit works. To start with, the owners/ architects carried out an overview of the project potential and decided that EnerPHit would be possible but that capital restrictions would mean it would have to be done in stages.

First step:
The first stage was to carry out the most disruptive works. It consisted of removing many of the internal partitions on ground floor to form a more open plan space and to add a new loft addition that would create a fourth bedroom. This reorganisation work provided the opportunity to re-roof the whole house with a thick layer of insulation and to add floor insulation over the slab on ground. The party walls which were of cavity brickwork were insulated with blown mineral wool and also insulated internally where they form external walls. The front walls and windows were left untouched save for air tightness measures in readiness for step 2. During the reorganisation of the floors, ducting for a future heat recovery ventilation system was fitted.

Figure 6.34- Front after retrofit, Marion Baeli and Robert Prewett

Second step:
Step 2 took place over 2 weeks, 3 years after the original works. It involved the complete renewal of the front and rear façades which were infill construction between the party walls. The cavity wall infill was removed and replaced with super insulated timber framing. New triple glazed windows were fitted with attention paid to avoiding the cold bridges particularly with the party wall brickwork. A precast concrete beam at first floor which was part of the original construction, required careful insulation with thin vacuum insulation panels. Following the installation of the new windows the envelope was tested for air tightness, achieving a 0.7 ach @ 50 Pa result. It is hoped that the final compliance test will remain below 1.0 in order to achieve EnerPHit.

Third step:
The MEP strategy included replacing the 15 year old gas boiler and installing a whole house ventilation system in the new roof extension. This arrangement will stay in place for a few more years, until a fourth step can be implemented which will include the replacement of the boiler with a thermal store and external air source heat pump. The enclosure of the boiler cupboard has been designed to accommodate the dimensions of a thermal store and positioned within proximity of the future air source heat pump location.

Extra consideration:
The second step aimed to recycle materials as much as possible. For this, the majority of the bricks and blocks removed were crushed and re-used to form the base of a new terrace and landscaping. The existing 5m long oak facade cladding panels from the 1960's were re-planed; repainted and re-installed in place. Even the window panes of the original pvc glazing were re-used to form allotment glass houses.

Figure 6.35 - Internal wall insulation to original external building envelope which was mostly cavity but solid in isolated location, Marion Baeli and Robert Prewett

Case study 8: Princedale Road

Location: Holland Park

Description: Mid-terrace Victorian house

Topic: Airtightness

Client: Octavia

Architecture: PDP London

Building services: Ryder Strategy ; Green Tomato (now Enhabit)

Passivhaus consultant: Green Tomato (now Enhabit)

Sustainability consultant: Eight Associates

Contractor: Ryder Strategy

Budget: £180,683 total budget for the build. Energy efficiency measures were about £59,870

Certification or standard achieved: PassivHaus certification

Space heating demand post-retrofit (modelled): 10 kWh/m²/yr

Energy Use Intensity post-retrofit (measured): 31 kWh/m²/yr

Energy bills (actual): £1,000 (annual post retrofit, electricity only)

U-values:
Front elevation: 0.15 W/m²K
Rear elevation: 0.15 W/m²K
Party walls: 0.25 W/m²K
Windows: 0.8 W/m²K
Door: 1.2 W/m²K
Floor: 0.15 W/m²K
Roof: 0.17 W/m²K
Airtightness: 0.34 m³/ m².h@50Pa

Project summary

This project was, for social housing provider Octavia, part of the 'Retrofit for the Future' Government programme aiming to reduce carbon emissions from existing dwellings by 80%.

The house is a typical mid-19th century London terraced house located in a conservation area. The project features an internal insulation strategy, a unit combining MVHR, an exhaust air source heat pump and hot water storage, solar thermal panels, triple glazed sash look-alike windows. Like all the 100 houses of the Retrofit for the Future Programme, this house has been monitored for over 2 years and delivered outstanding energy and comfort results and achieved 80% carbon reductions.

Due to its location in a conservation area, external wall insulation was not feasible. The team therefore followed the principles of PassivHaus 'fabric-first' approach with an internal wall insulation strategy as

Figure 6.36 - Front post retrofit, Paul Davis + Partners

part of the complete upgrade of the external building fabric as the house was in a very poor condition.

It was essential that the continuity of internal insulation and airtightness layers throughout the building envelope was maintained, coupled with the installation of a robust ventilation system (build tight, ventilate right). This is to avoid any water vapour condensing within the building fabric, which can cause long-term damage to buildings and must be avoided.

In this house, the approach was to keep the strategy as simple as possible with the minimum variety of materials, combined with robust detailing. The house has been retrofitted with a thick insulated and airtight layer inset within an existing Victorian building envelope. It is a rare example of a continuous strategy where the same thickness and insulation material has been installed on all floors, walls and ceilings and where the airtightness layer is made of a single material type with taped and jointed OSB timber boards. These were also strategically positioned between two layers of insulation to ensure its protection from potential penetrations (nails) and also to enable the location of sockets and switches back boxes within the top insulation layer without compromising the integrity of the airtightness line.

The airtightness test was carried out with a small fan and was done in two steps. The first was carried out at the stage when the airtightness and windows were installed but not the finishes. This enabled the team to remediate minor leaks while they were still accessible. Another test was carried out on completion to ensure that no trade intervention affected the performance of the airtight layer as a last chance to remedy any issues. This stepped approach is really important to avoid any potential difficult remedial works which might involve abortive works and impact on cost and programme of a project.

The strategy was bold but was justifiable in a house which was in a very poor state of repair. Ten years on, there are no signs of moisture anywhere in the house's fabric and the internal conditions have been comfortable and entirely draft-free giving the house a very long lease of life.

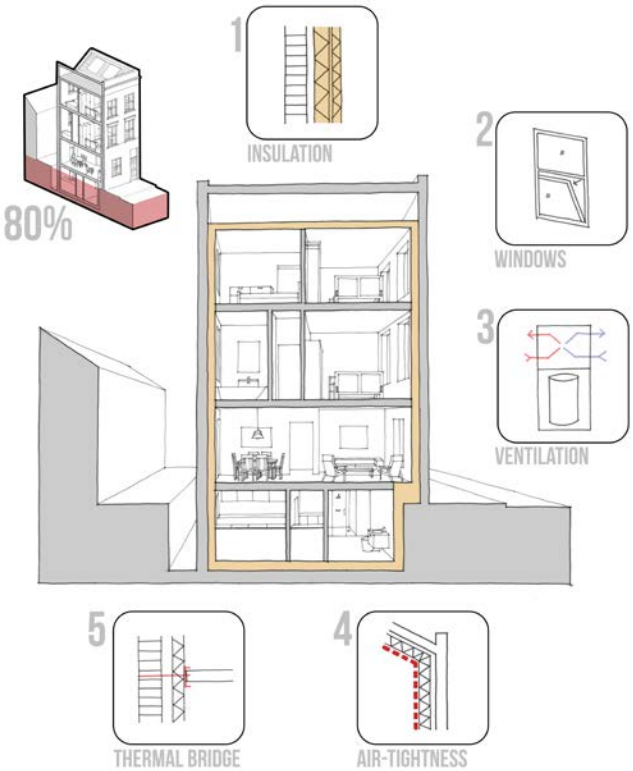


Figure 6.37 - Schematic of retrofit works, Paul Davis + Partners

Case study 9: Rectory Grove

Location: Clapham, London

Description: Semi-detached Early Victorian house Grade II listed

Topic: Internal insulation moisture content monitoring

Architecture: Harry Paticas - Arboreal Architecture

Building services: Alan Clarke

Building performance pre-design investigations: Archimetrics

Structural engineer: The Morton Partnership

Certification or standard achieved: AECB Silver

Space heating demand pre-retrofit: 180 kWh/m^2/yr

Space heating demand post-retrofit: 40 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 79 kWh/m^2/yr

Walls: 9 types of insulation used including Woodfibre, Aerogel, IQ Therm (between joists)

U-value range: 0.15 - 0.58 W/m^{2}K

Airtightness: All walls plastered with lime plaster as air tightness layer 1.8ach post-retrofit (9.6ach pre-retrofit).

Ventilation: continuous mechanical extract (MEV) from kitchen and wet rooms

Project summary

This project is an example of monitoring the hygrothermal performance (moisture content between existing masonry walls and new insulation) after a thermal upgrade along with repairs and fabric improvements of a Grade II Victorian house in a conservation area.

Pre-design investigations were carried out at the outset, an assessment was carried out of the existing building, including airtightness test, thermographic survey of fabric and a survey revealing actual U values of existing walls.

Figure 6.38 - Front elevation, Arboreal Architecture

Post construction monitoring of relative humidity and wood mositure equivalent was carried out using 19 wireless moisture sensors installed during the building construction. Some within the cold loft space and 15 mounted on Douglas fir wood blocks installed in the masonry behind the lime plaster and new insulation. The sensors aimed to obtain data to assess the risks on the moisture and temperature within the insulated walls and hence appraise the risks to buried existing timbers. All timbers built into the walls (including joist ends, lintels and wall plates) were treated with boron wood preservative paste.

Results showed the higher the thermal resistance of the insulation (i.e. better), the lower the temperature of the brickwork, which resulted in higher RH (relative humidity). There was also a correlation between the orientation of the wall (i.e. direction of prevailing wind and rain) and RH values. The data showed that the wet winter months were the worst, with the peak moisture content in February, then drying out occurred over the summer months aided by the vapour permeable materials (masonry, lime plaster, insulation and paint etc.). The walls continued to dry out slowly for a period of approximately 6 years after construction and have now equilibrated.

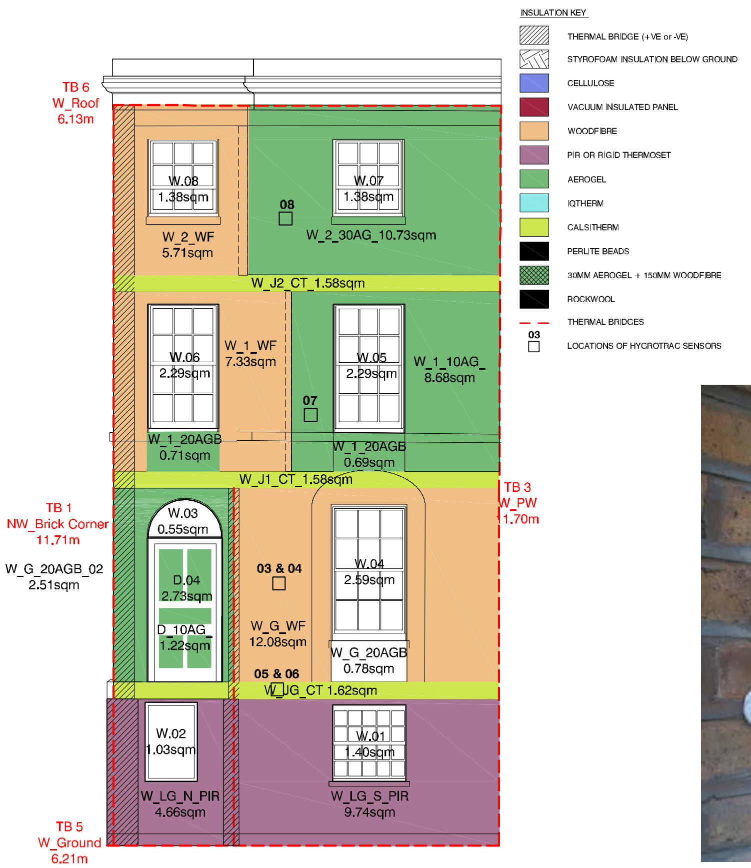


Figure 6.39 - Schematic of types of insulation to rear elevation, Arboreal Architecture

Figure 6.40 - Hygrothermal monitors between existing masonry walls and new internal insulation, Arboreal Architecture

References and footnotes

Archetype 1 - Haddington Way

6.1 - Baeli, M. (2013) Residential Retrofit: 20 case studies. RIBA Publishing. http://mepk.co.uk/project/haddington-way/

Archetype 2 - Zetland Road

6.2 - The uninstalled U-value refers to the U-value of the window or door before it is installed. This U-value includes the pane and frame, but excludes the heat loss from thermal bridging around the window/door where it meets the wall. Poor installation can reduce a window/door's U-value, as heat is lost through the frame at points where either the installation doesn't meet it, or there are thermal bridges or cold air gaps. Poor window installation can also cause condensation along window frames.

https://passivehouseplus.ie/magazine/upgrade/the-deepest-greenest-retrofit-ever

https://www.ecospheric.co.uk/zetland

https://www.passivhaustrust.org.uk/projects/detail/?cId=91

Archetype 3 - The Nook

6.3 - Baeli, M. (2013) Residential Retrofit: 20 case studies. RIBA Publishing. http://mepk.co.uk/project/haddington-way/

Archetype 4 - Wilmcote House

6.4 - ECD Architects: https://ecda.co.uk/projects/wilmcote-house-2/

6.5 - Teli et al (2015) Fuel poverty-induced 'prebound effect' in achieving the anticipated carbon savings from social housing retrofit

6.6 - Stephen, J. (2020) Southampton University monitoring data and analysis (PhD work)

Traynor, J. (2019) EnerPHit: A Step by Step Guide to Low Energy Retrofit. RIBA Publishing.

Archetype 5 - Gloucester Place Mews

6.7 - http://www.feildenandmawson.com/projects_2_gloucester_place_mews.html

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Case study 1 - Sterndale Road

6.8 - "Sterndale Road - A Refurbishment Case Study: achieving an 84% carbon saving" report by the Energy Saving Trust, 2011.

Case study 5 - Bloomsbury House

https://www.architectsjournal.co.uk/buildings/how-prewett-bizley-architects-balanced-heritage-and-building-performance

Case study 6 - Ernely Close

https://www.passivhaustrust.org.uk/UserFiles/File/UK%20PH%20Awards/2015/2015%20posters/ERNELEY%20CLOSE_Poster%20web(1).pdf

https://ukphc.org.uk/ukphc14-presentations

https://usir.salford.ac.uk/id/eprint/46328/

Case study 7 - Hensford Gardens

A

Annex

Annex A:
How do our homes produce carbon?

This annex is reproduced courtesy of the Good Homes Alliance and is taken from their Building Standards Comparison, October 2020.

In reading this document, it is useful to have a common model to explain how dwellings use energy and also take into account the impact of different types of heating technology and changing carbon factors. If we start with the dwelling itself, energy use can be broken down into 4 distinct areas:

1. Space heating
2. Hot water
3. Lighting, pumps and fans (usually associated with the heating and hot water systems)
4. Appliances (also known as plug loads or Unregulated energy)

All this energy is the actual amount of energy used by the occupants in the home and is called final demand. For example, this might include 1kWh of heat energy emitted by a radiator.

The type of energy used in items 3 and 4 will always be electrical (excluding gas hobs), whereas items 1 and 2 will vary from dwelling to dwelling – but is most often natural gas in the UK.

Once delivered to a home, electrical energy used directly is 100% efficient – e.g. 1 kW of electrical power delivered to an electric panel heater will emit 1 kW of heat. However, the heating mechanism for other fuels is not 100% efficient and so there will be losses, meaning that additional energy needs to be delivered to the home to provide the same amount of final output. This is known as the delivered energy.

For example, if a home needs 10 kW of heating and hot water on a winter's day and uses a gas boiler which is 90% efficient, then 11.1 kW of gas will need to be delivered to the property. It may also need, for example, 5kW for lighting, appliances and pumps etc.

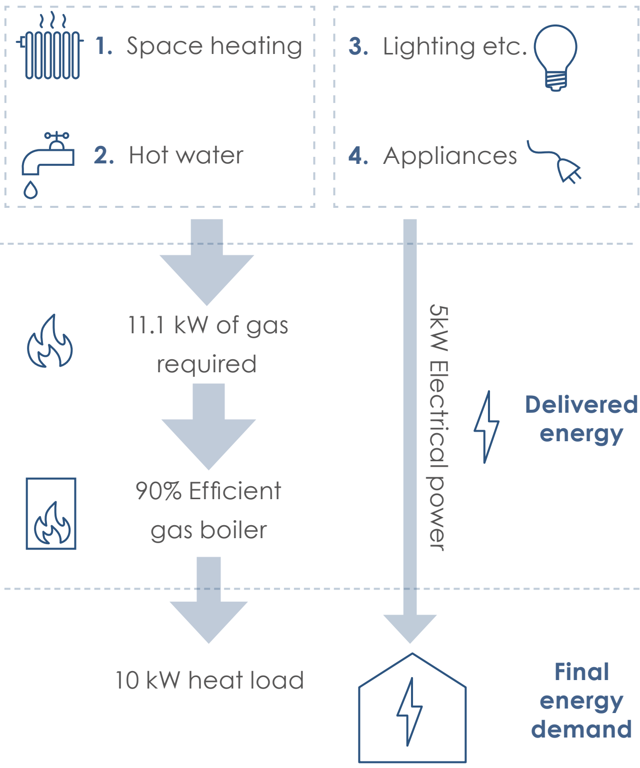


Figure A.1 - Delivered and final energy for 90% efficient gas boiler

If we were to use a heat pump instead of a gas boiler, then this is the same principle, but the heat pump uses electrical energy not gas. However, it also extracts energy from the air or ground and so is able to provide more heat energy than the electrical energy it consumes. In effect, a heat pump is more than 100% efficient. A heat pump's level of efficiency is known as its Coefficient of Performance or COP. For example, a heat pump with a COP of 2 will produce 2kW of heat for every 1kW of electrical power.

Thus, our model now becomes:

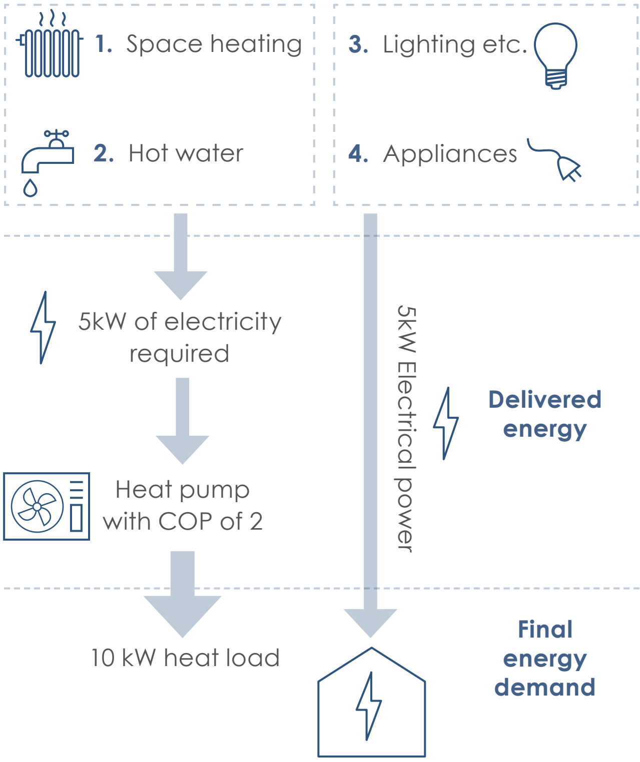


Figure A.2 - Delivered and final energy for heat pump with COP of 2

Each of these different forms of energy has different carbon factors – i.e. the amount of CO_2 emissions that result from each unit of energy consumed. For a gas boiler this will be fairly consistent over time as you are simply burning a fossil fuel. For electrical energy this changes constantly as more or less renewable energy is introduced to our national electricity grid – solar and wind energy is not that predictable. We can estimate the average carbon factor for electricity for the next few years, but in the long term, it is difficult to predict exactly what will happen. In 2020 the annual average carbon factor for electricity is around 140g of CO_2 per kWh and for gas, it is 210g[A.1]. Currently, the carbon factor in use within SAP[A.2] is 519g of CO_2 per kWh which means that SAP will significantly overestimate the carbon emissions from electricity.

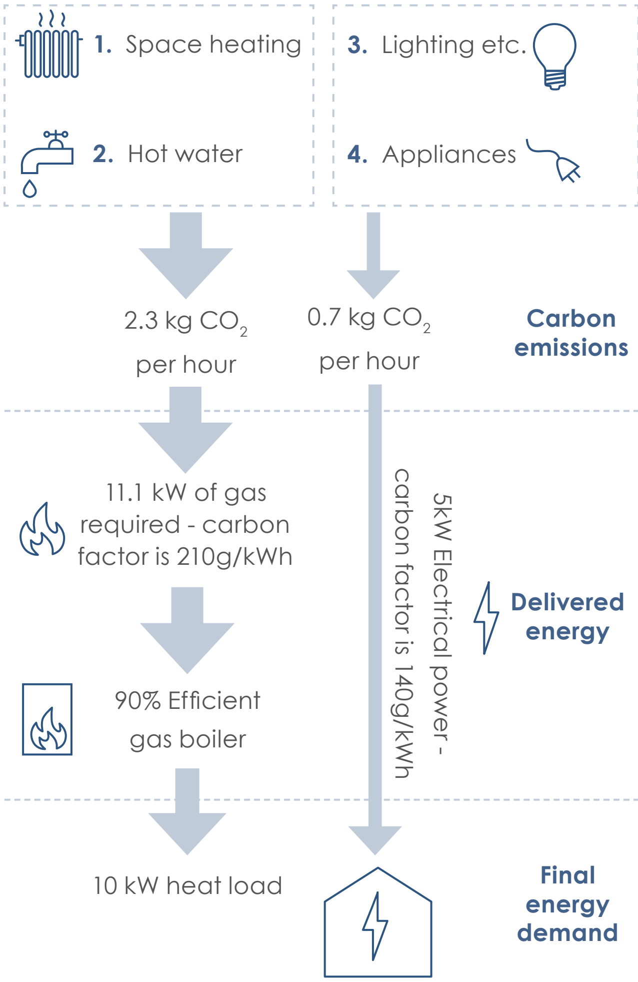


Figure A.3 - Average carbon Emissions associated with energy use

In looking at the long-term efficiency of buildings, it is important to consider how the various components of our model might change. As we have already seen, the carbon factor for electricity in particular will vary both in the short and long term. Over the next 30 years the carbon intensity of our national grid will depend on a range of factors, technologies and government policies – so is impossible to predict with absolute accuracy. Our heat generation technologies will also change. The typical lifetime of a gas boiler or heat pump is around 20 years [A.3]. At that point it will need to be replaced with perhaps a more efficient device, or something completely different. This new device will probably have a different efficiency and thus change the amount of delivered energy required.

However, the final energy required is likely to remain more consistent over the lifetime of the building. For heating, the final energy required is related in most part to the fabric performance of the building – the insulation in its walls, floors and roofs, its window performance, ventilation system and airtightness. All these are set at the point of construction and will perform consistently throughout the building's life. The demand for hot water is related in most part to the number of occupants and their living habits and so is not affected by the technology. Finally, appliance load is again related to occupancy habits, but it is also likely that future appliances will be more efficient, thus reducing the demand.

Thus, to get a true picture of the actual energy efficiency of buildings, as well as their impact on climate change over time, we must look at all aspects of the chain of delivery of energy to the building.

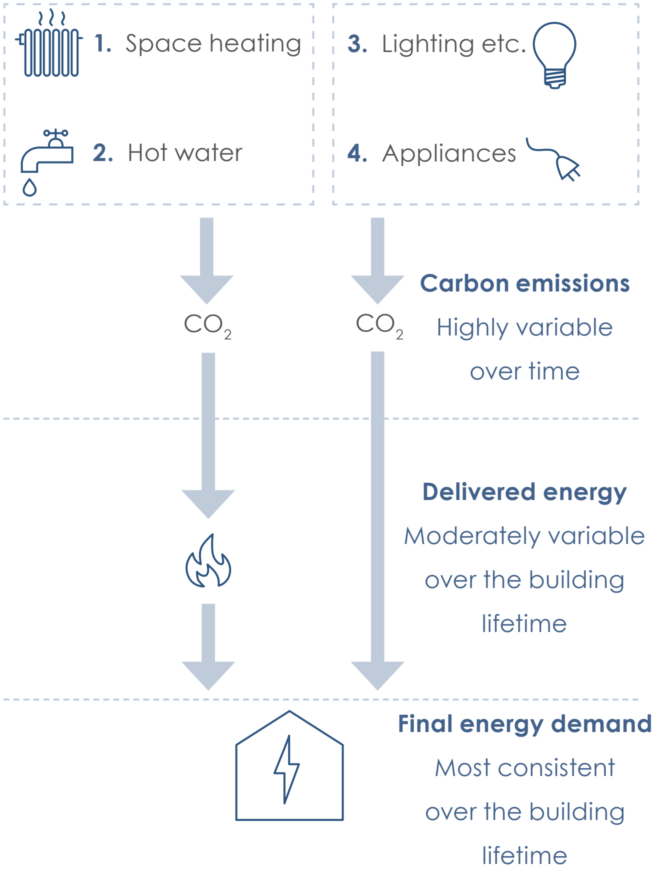


Figure A.4 - How variable is the chain of delivery of energy to the building

The Performance Gap

Whilst energy models are useful to predict energy demand, we must also consider the evidence from monitoring of actual buildings in use. This data indicates that a typical building regulations standard home will require, on average, at least 60% more energy for heating than is predicted [A.4]. Whilst the causes of this performance gap are beyond the scope of this paper, it is important that it is included in our considerations as otherwise we will make inaccurate comparisons and draw incorrect conclusions. The performance gap typically has the most impact on the space heating demand of a building as it primarily relates to the fabric performance of the building [A.5].

Thus, our model becomes:

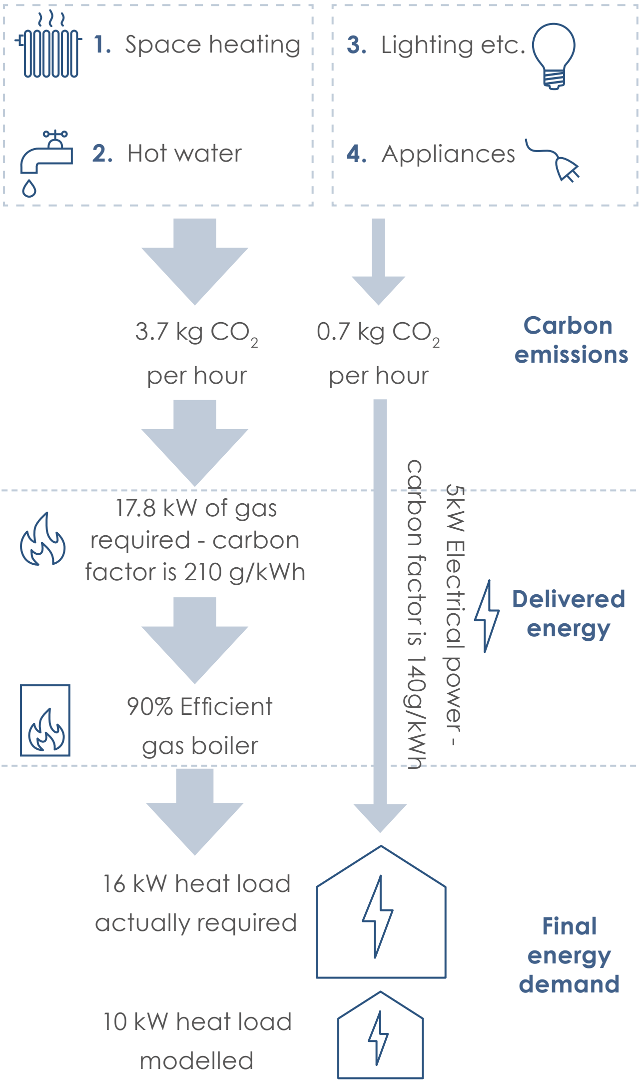


Figure A.5 - The performance gap

A.1 References and footnotes

A.1 - Proposed SAP 10.1 carbon factors – see https://www.bregroup.com/wp-content/uploads/2019/10/SAP-10.1-01-10-2019.pdf table 12d

A. 2 - The Standard Assessment Procedure (SAP) is the methodology used by the government to calculate building energy and carbon use. The current edition is 2012, version 9.92.

A. 3 - CIBSE Guide M, Appendix 12.A1: Indicative economic life expectancy

A. 4 - Passivhaus: The Route to Zero Carbon? Passivhaus Trust, March 2019, Appendix 2

A. 5 - See, for example, http://www.zerocarbonhub.org/current-projects/performance-gap

Annex B - Table of example opportunities for starting retrofit

Even when making ad-hoc or individual changes to improve, extend, or maintain a home, you should be thinking about and working towards a Retrofit Plan. Not doing so will often lock in future high carbon emissions. Don't miss an opportunity!

Here are some example changes to homes and associated thermal improvement that could be made:

Major changes	Design lifetime	Retrofit measures to **action** or consider
Extension	Building life	→ **Extension built to new build insulation and airtightness standards** → **Triple glazed new windows** → **Ventilation to extension,** duct runs and space for MVHR → **Space for heat pump and hot water tank** → External wall insulation to surrounding walls → Reduce thermal bridges to connection with existing fabric → Ground floor insulation → Consider upgrading other windows near extension works.
Loft conversion	Building life	→ **Roof insulation and airtightness** → **Triple glazed new windows** → Ventilation duct runs to the rooms below to support MVHR → Window replacement to other floors whilst there is access.
Floor repair or subsidence	Building life	→ **Floor insulation** → Reduce thermal bridges to connection with existing building.

Major changes	Design lifetime	Retrofit measures to **action** or consider
Basement dig	Building life	→ **Basement built to new-build insulation and airtightness standards** → **Ventilation to basement, duct runs and space for MVHR.** → **Space for heat pump and hot water tank** → Reduce thermal bridges to connection with existing building → Ground floor insulation to other areas.
Landscaping around building	~10-30 years+	→ **Perimeter insulation at ground to wall junction** → **Perimeter drainage** → External wall insulation.

Repair and replacement	Design lifetime	Retrofit measures to **action** or consider
Roof repair (tiles, flat roof)	~30 years	→ **Roof insulation and airtightness** → **Airtightness connections to surrounding elements.**
External render or paint	<10 years (cement) 25 years (BBA certified)	→ **External wall insulation** → Replace windows whilst there is access

Repair and replacement	Design lifetime	Retrofit measures to **action** or consider
Windows and door replacement	10 years guaranteed, although design life is typically 20-30 years for new windows	→ **Replacement triple glazed windows or best available for appearance constraint** → **Ventilation approach.** Recommend new windows don't have trickle vents, move to MVHR. Required for mechanical extract → **Airtightness connection to wall and floor** → Insulation to window reveals and connection with (future) wall insulation. → Window may need to be moved in the future.
Re-plastering wall or ceiling	~20 years	→ **Internal wall insulation** (if appearance constrained) → **Roof and wall airtightness.**
Kitchen replacement	~5-10 years	→ **Ventilation strategy.** Replace cooker hood with recirculation type if strategy is for MVHR, or continuous extract as part of MEV system → **Insulation to kitchen floor** → **Internal wall insulation behind units.**
Boiler	10-15 years	→ **Replace with heat pump system** → Building fabric improvements are required to reduce heat load so the heat pump can meet demand and operate efficiently with low running costs.
Extract fan / Cooker hood	~5-10 years	→ **Ventilation strategy.** Replace cooker hood with recirculation type if strategy is for MVHR, or continuous extract as part of MEV system → Induction hob and all electric cooking.

Repair and replacement	Design lifetime	Retrofit measures to **action** or consider
Electrical wiring	Tested every 10 years (homeowner) or 5 years (landlord)	→ **Spare capacity for installing heat pump in the future** → Metering including sub-meter for electric vehicle charging and heating → Spare capacity for electric car charging.

Maintenance	Design lifetime	Retrofit measures to **action** or consider
External paint	10 years	→ **External wall insulation.**
Internal decoration	~2-5 years	→ Internal wall insulation.

Figure B.1 - Table of example opportunities for starting retrofit

If you can't afford to upgrade to what is needed as part of the Retrofit Plan, it might be better not to do the work at all at this time, and instead save until you can do what is needed for each phase. Installing a lower specification now 'locks in' poor emissions for the future. On the other hand not doing retrofit at all might mean it never happens, and leaves the potential for future regrets. Don't decorate before you insulate.

Annex C - Illustrative insulation strategies

This annex provides some illustrative strategies for adding insulation to buildings. It provides suggestions based on the basic construction type and also whether the retrofit is likely to be constrained by heritage or conservation features. The strategies proposed here can be used to achieve the target U-values set out in this guide.

Key

1. External wall insulation
2. Option for internal or external insulation
3. Internal insulation
4. External rear wall insulation in some cases
5. New insulated roof or loft insulation
6. Loft insulation
7. External roof insulation
8. Ceiling insulation

C.1 High level insulation strategies in a conservation area

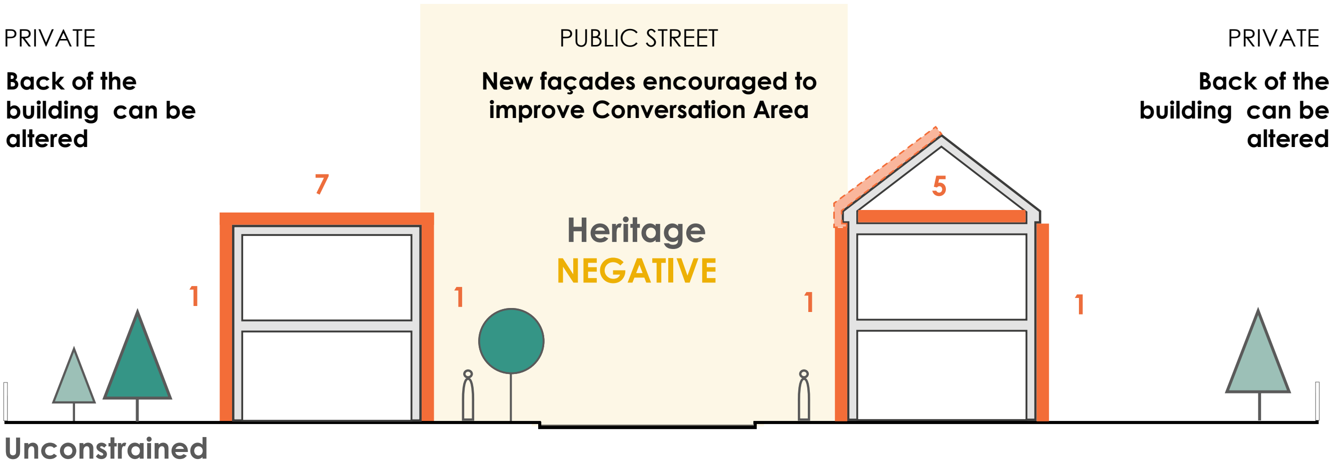


Figure C.1 - High level insulation strategy for heritage negative buildings

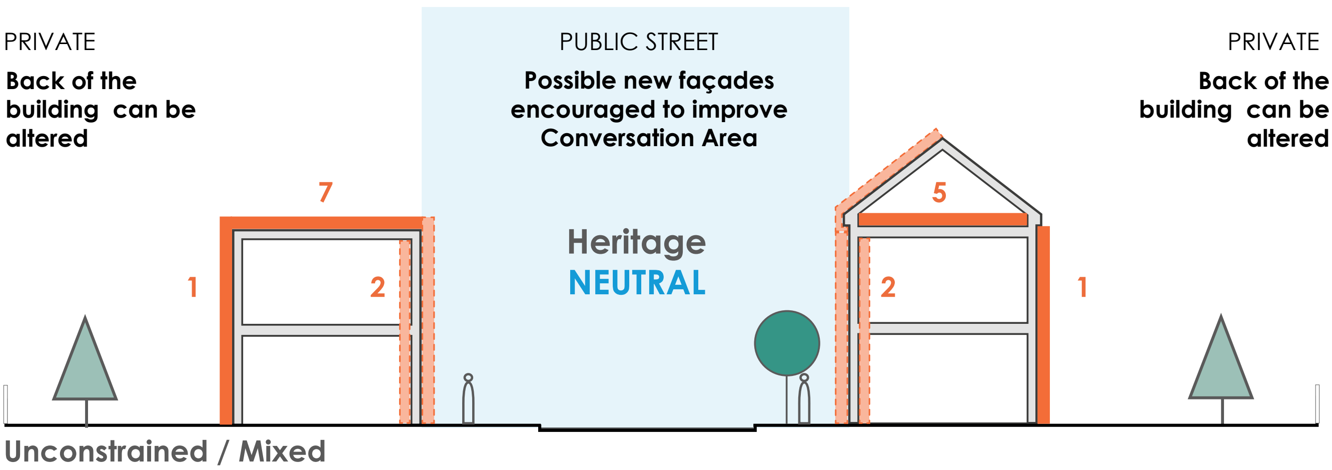


Figure C.2 - High level insulation strategy for heritage neutral buildings

Heritage Negative
Buildings in a Conservation Area with a potential for detrimental effect on building features.

Heritage Positive
Buildings in a Conservation area which have significant external heritage features which will preclude any significant change in appearance to front façades.

Heritage Neutral
Buildings in a Conservation Area with limited or no notable heritage features.

Listed Buildings
Buildings where both internal and external heritage features are likely to constrain retrofit actions.

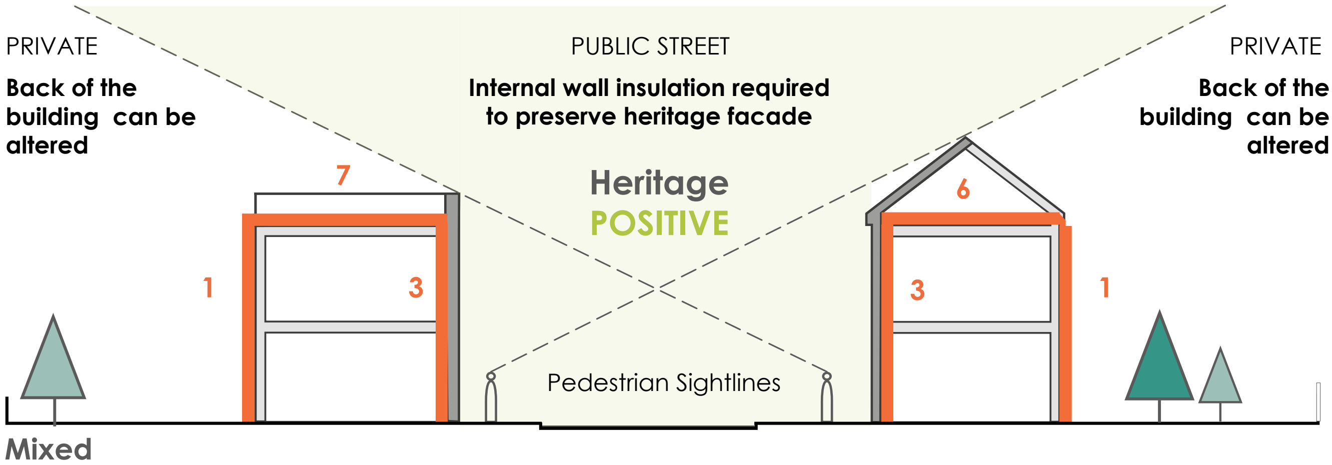


Figure C.3 - High level insulation strategy for heritage positive buildings

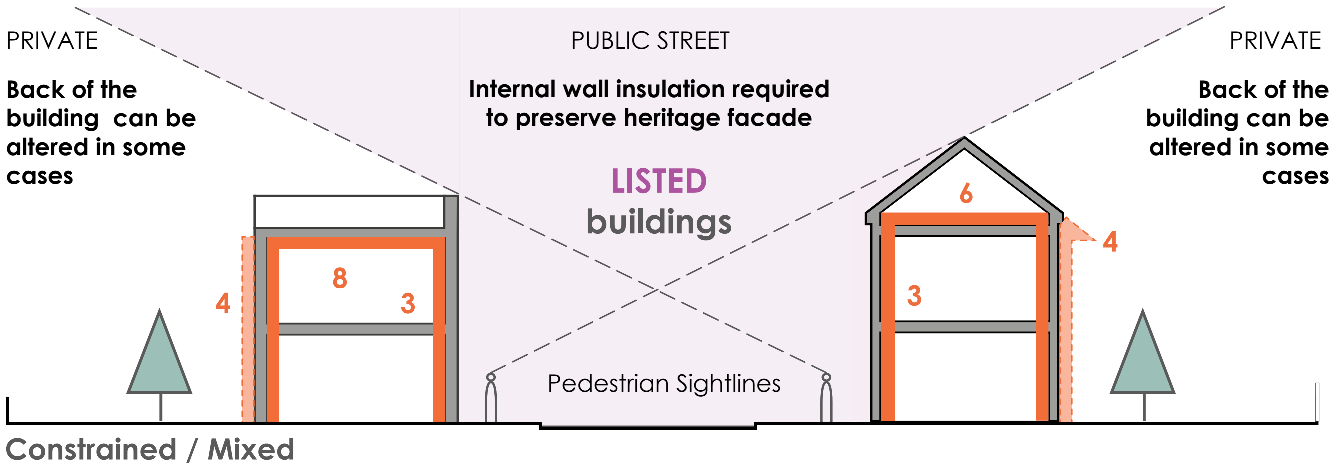


Figure C.4 - High level insulation strategy for listed buildings

C.2 Insulation strategies for floors

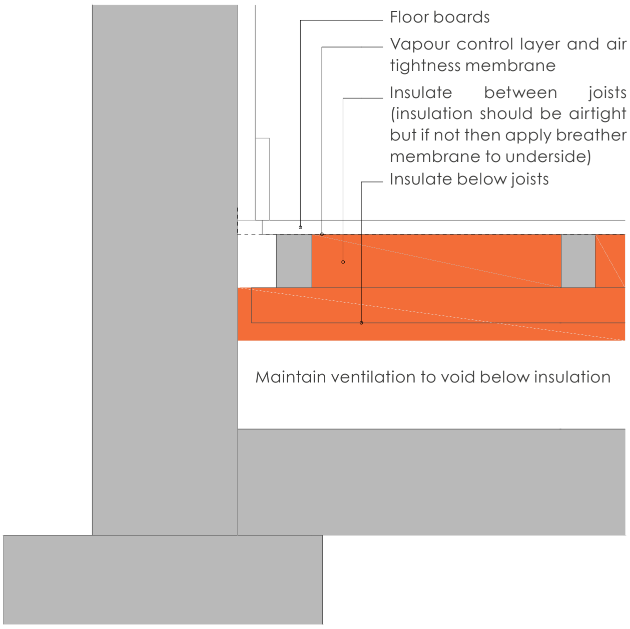


Figure C.5 - Insulation strategy for retained suspended timber floor

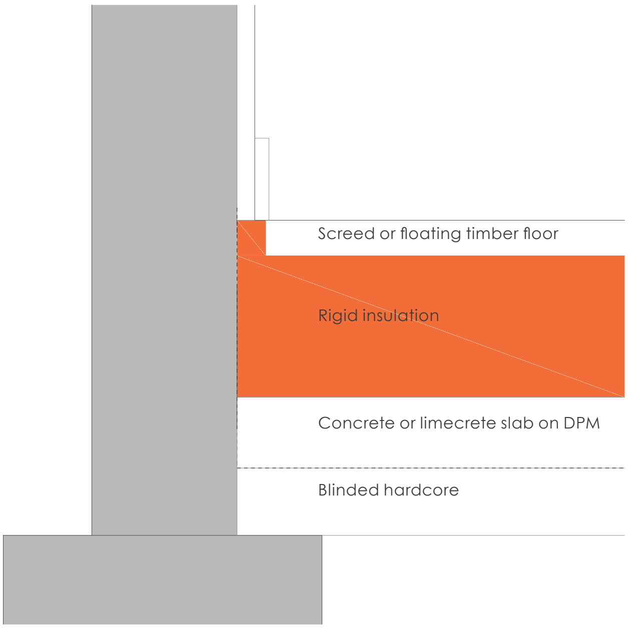


Figure C.7 - Insulation strategy for removed suspended timber floor

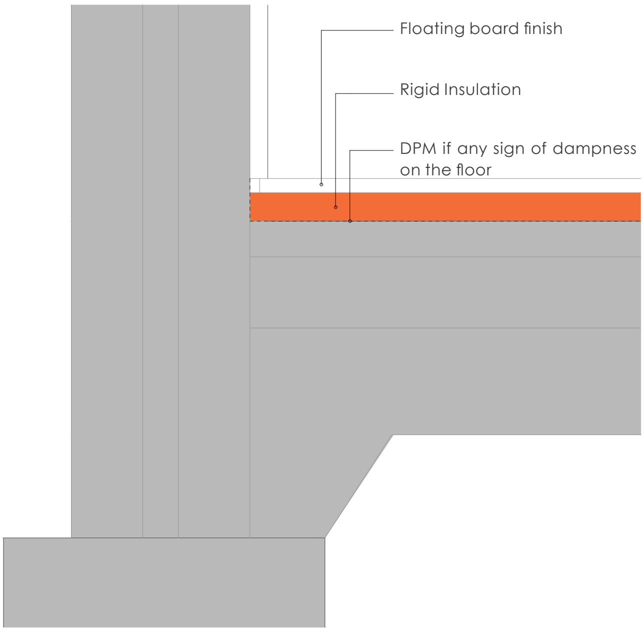


Figure C.6 - Insulation strategy for retained solid floor

C.3 Insulation strategies for walls

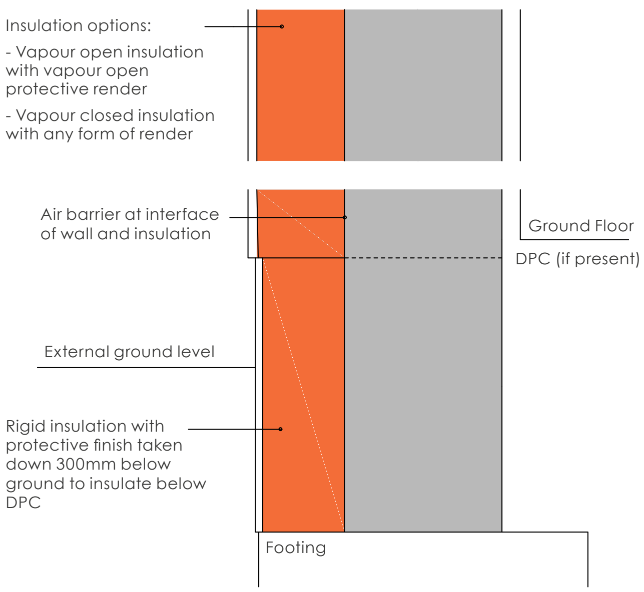


Figure C.8 - Insulation strategy for solid wall - external wall insulation (EWI)

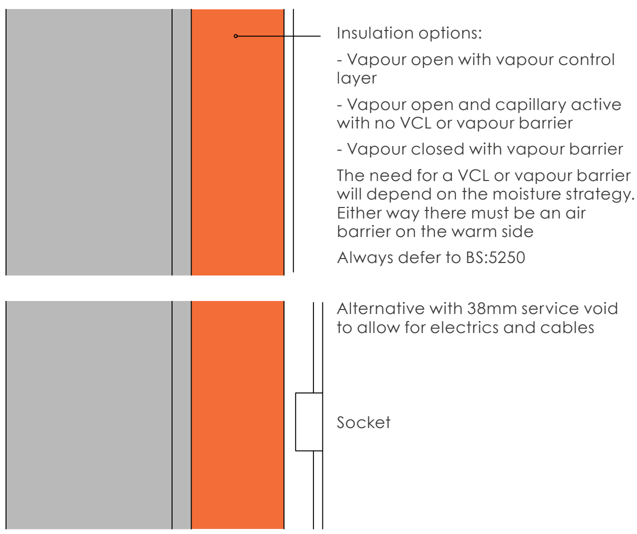


Figure C.10- Insulation strategy for solid wall - internal wall insulation (IWI)

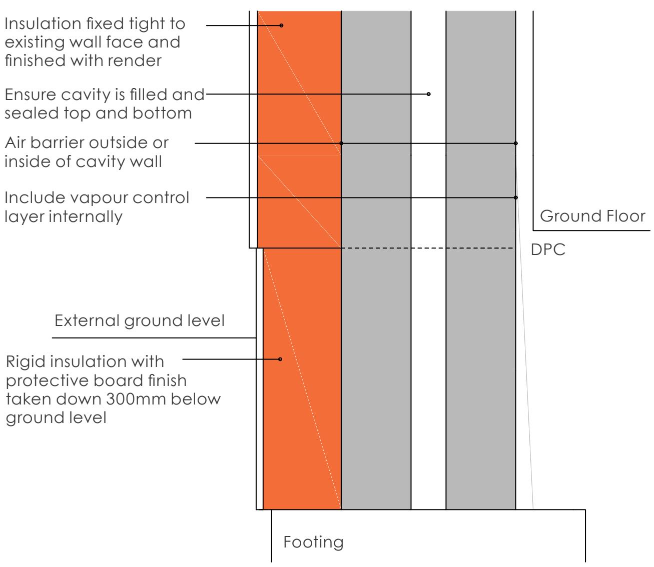


Figure C.9 - Insulation strategy for cavity wall - external wall insulation (EWI)

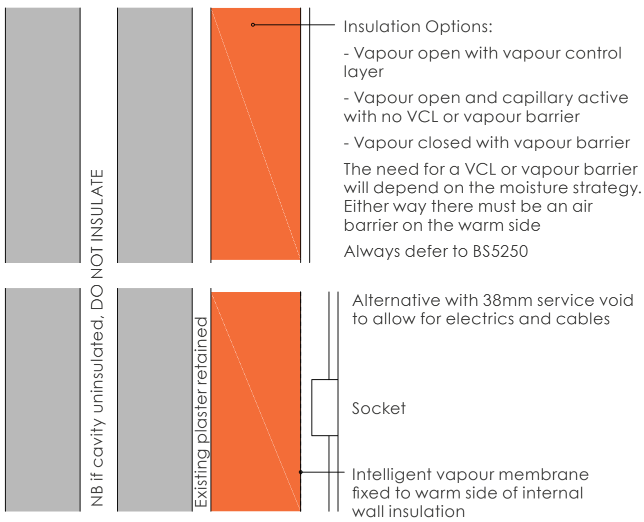


Figure C.11 - Insulation strategy for cavity wall - internal wall insulation (IWI)

C.4 Insulation strategies for roofs

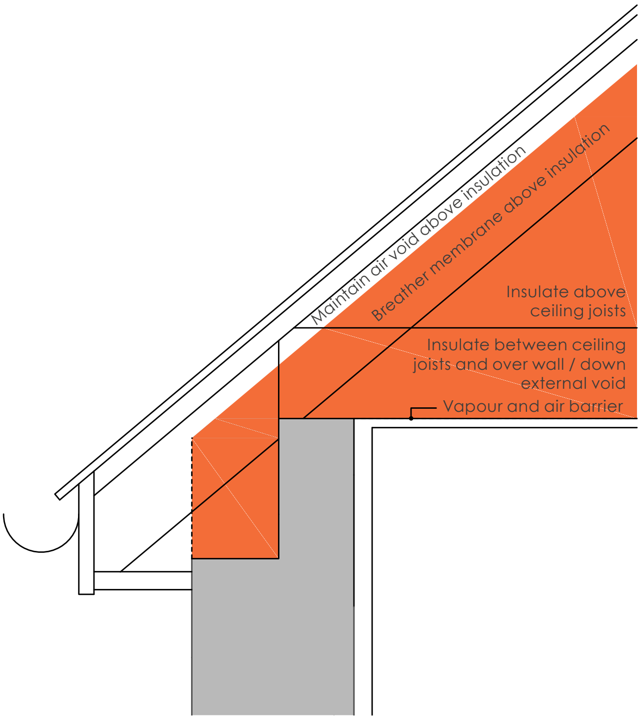


Figure C.12 - Insulation strategy for cold roof insulated between and above ceiling joists

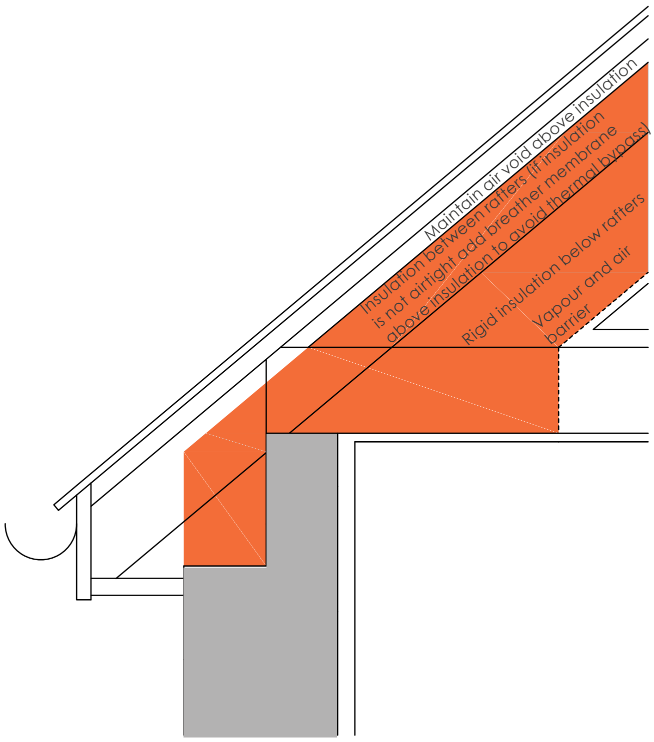


Figure C.13 - Insulation strategy for cathedral roof insulated between and below rafters

Note: a cathedral roof is a scenario where you are removing the outer roof finish (e.g. tiles) and therefore have the opportunity to add insulation above the rafters - thereby preserving more internal space.

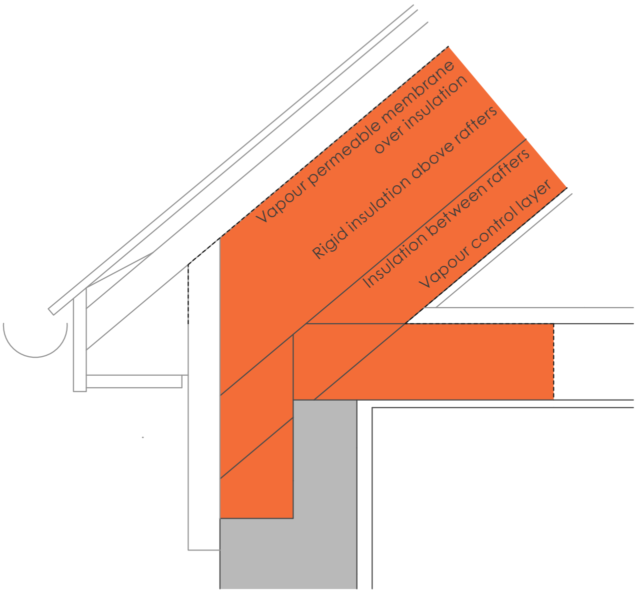


Figure C.14 - Insulation strategy for cathedral roof with removed roof finishes, insulated between and below rafters, refinish roof ensuring ventilation above insulation

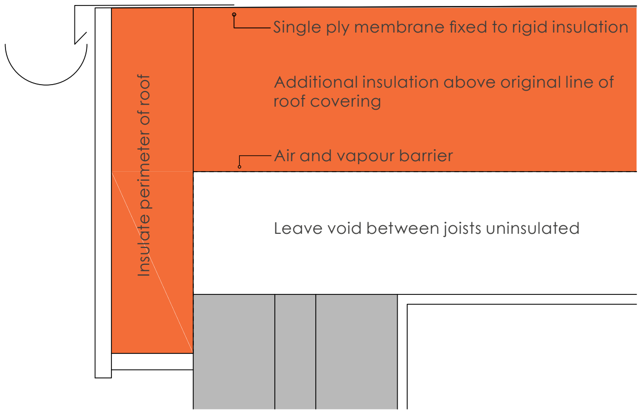


Figure C.15- Flat (warm) roof with additional insulation above roof line

Annex D - Retrofit ventilation strategies

Ventilation is a critical part of retrofit. Done properly it improves air quality and reduces condensation and moisture risk. The ventilation system is often the first thing that is carried out, to enable other works. There are two main strategies that you could use in existing buildings: central whole building ventilation with heat recovery, and a decentralised continuous extract system.

LETI recommends avoiding intermittent extract fans and wholly 'natural' ventilation for building retrofits. This typically results in very un-natural ventilation dead spots that have poor air quality and in many cases result in mould and almost continuous condensation during winter. The retrofit will change the internal environment, neglecting to update the ventilation at the same time can damage the building.

Improving ventilation can change the characteristics of the home by reducing the humidity of the air. This is mostly a (very) good thing, but in some cases it might be too dry and cause discomfort or drying out of materials and cracking. This can be guarded against by turning the fan down slightly, or by introducing more moisture sources such as house plants.

Pros and cons of retrofit ventilation strategies

	Pros	Cons
Mechanical ventilation with heat recovery (MVHR)	→ Heat is recovered from the outgoing air, therefore it is energy efficient and no cold draughts as supply air is warm. → Supply air is filtered – eliminating particulates such as soot and pollen. → Runs constantly, so deals with all indoor pollutants – e.g. humidity, VOCs, CO_2 and odours. → Savings made on space heating usually offset the running costs of the ventilation. → Centralised fan unit and good design results in a system which is effectively silent. → No external air vents in habitable rooms, so ingress of external noise is minimised.	→ MVHRs don't typically include demand control – so run constantly (albeit very efficiently). → High capital costs. → Invasive to retrofit – ducts required to every room. → MVHRs are complex systems and require expert design and commissioning to ensure correct operation. → Filters need to be changed every 6 months. → Requires a good level of airtightness to ensure most air is exchanged via the central unit.

	Pros	Cons
Centralised continuous demand-controlled extract	→ Demand control reduces running time of ventilation system making it energy efficient as it minimises heat losses from cold air entering the building. → Moderate capital costs, depending on extent of ductwork required. → Centralised fan unit and good design results in a system which is effectively silent. → Commissioning is quick and straightforward. → Demand control typically linked to humidity – so will maintain optimum humidity levels. → No maintenance required.	→ No heat recovery, cold air is introduced to ventilate the home. Potential for cold draughts. → Running costs are not offset by any savings in space heating. → Specialist design and commissioning required. → Incoming air vents will need to be fitted in certain rooms to ensure good ventilation distribution. → Requires a reasonable level of airtightness to ensure air is drawn in via the air vents as intended. → Incoming air is not filtered. → Air vents may contribute to external noise transmission into habitable rooms. → Demand control typically linked to humidity – so may not deal with other pollutants such as VOCs, CO_2 or odours (unless there are additional detectors to control the system).
Decentralised continuous demand-controlled extract	→ Demand control reduces running time of ventilation system making it energy efficient as it minimises heat losses from cold air entering the building → Low capital costs. → Can replace intermittent extract fans with continuous fans. → Simple design and easy commissioning. → Demand control typically linked to humidity – so will maintain optimum humidity levels. → No maintenance required.	→ No heat recovery, cold air is introduced to ventilate the home. Potential for cold draughts. → Running costs are not offset by any savings in space heating. → Continuous fans in every wet room may contribute to noise in homes. → Incoming air vents will need to be fitted in certain rooms to ensure good ventilation distribution → Requires a reasonable level of airtightness to ensure air is drawn in via the air vents as intended → Incoming air is not filtered → Air vents may contribute to external noise transmission into habitable rooms → Demand control typically linked to humidity – so may not deal with other pollutants such as VOCs, CO_2 or odours (unless there are additional detectors to control the system)

	Pros	Cons
Centralised continuous extract from wet rooms and kitchen (no demand control)	→ Moderate capital costs, depending on extent of ductwork required. → Centralised fan unit and good design results in a system which is effectively silent. → No maintenance required. → Will operate continually, so likely to deal with humidity and other pollutants, maintaining good levels of internal air quality. → Commissioning is quick and straightforward. → Not dependent on high levels of airtightness.	→ No heat recovery, cold air is introduced to ventilate the home. Potential for cold draughts. → Running costs are not offset by any savings in space heating. → Runs constantly, so heat losses (and therefore associated energy costs) are likely to be significant. → Incoming air/trickle vents may need to be fitted in certain rooms to ensure good ventilation distribution. → Specialist design and commissioning required. → Incoming air is not filtered.
Decentralised intermittent extract from wet rooms and kitchen (Building Regulations default)	→ Very low capital costs. → No maintenance required. → Not dependent on high levels of airtightness. → Minimal commissioning.	→ No heat recovery, cold air is introduced to ventilate the home. Potential for cold draughts. → Running costs are not offset by any savings in space heating. → Incoming air/trickle vents may need to be fitted in certain rooms to ensure good ventilation distribution. → Fans in every wet room may contribute to noise in homes. → Incoming air is not filtered. → Trickle/Air vents may contribute to external noise transmission into habitable rooms. → Needs to be augmented by window opening to achieve sufficient levels of ventilation to maintain good indoor air quality.

D.1 Central supply and extract ventilation with heat recovery (MVHR)

This is by far the preferred option and should be used wherever possible. Well designed MVHR brings fresh air into each room and extracts from each wet room with a central fan. It guarantees fresh air throughout the house, recovers more than 80% of the heat from the exhaust air, and massively reduces the risk of moisture issues in other parts of the home. MVHR is also the only domestic ventilation system which filters all incoming air and so is particularly beneficial for situations where there is external pollution. Installing MVHR and having good indoor air quality removes many of the risks of retrofit, particularly in traditional and solid wall properties.

One myth about MVHR is that you need to have a certain level of airtightness before it is worth it. This is not true (see 'The case for MVHR', Passivhaus Trust, April 2020. Link: https://www.passivhaustrust.org.uk/guidance_detail.php?gId=46). It is true that the energy savings from the MVHR are proportional to how airtight the home is, however all the other benefits of good ventilation can still be felt. MVHR also allows you to safely block up most old internal air vents to your home and fully draft proof windows and doors, which quickly improves comfort.

MVHR requires very little maintenance, a filter change once every 6 months, which can be carried out by the residents in most instances. There are two fans which use a small amount of electricity, it typically costs £30-£50/year to run an MVHR for a typical home. At the same time you are saving about 15 times as much heat energy, so even for cheap heating fuel it is normally cheaper to run the fan in winter than not.

The design of the ventilation system is critical, in particular ensuring that the unit and ducts are designed to minimise noise. The ventilation system should be inaudible. It is normally possible to integrate MVHR to an existing home, but you might need to be creative!

D.1 Central supply and extract ventilation with heat recovery (MVHR)

Supply room terminal in living and all bedrooms
Incoming air is warm and almost at room temperature.

Key requirements:
→ Air directed into the room along ceiling to avoid cold drafts.

Good locations could be:
→ On the wall above the door
→ In the ceiling.

Controls and instructions
→ Automatic controls, or simple manual controls in an easily accessible location
→ Instructions explaining operation and maintenance posted somewhere prominent.

Ventilation unit (MVHR) location.
Key requirements:
→ Adjacent to an outside wall or roof
→ Accessible for maintenance
→ Not in a bedroom or quiet area, they make some noise like a fridge.

Good locations could be:
→ Above the hot water tank
→ At the end of a row of kitchen cupboards
→ At the back of a store cupboard
→ In a porch or lean-to against the building but ideally this should be a heated space
→ In a heated loft space (cold lofts need careful design).

Ducts to outside
Key requirements:
→ As short as possible
→ Insulated 20-50mm thick with vapour proof insulation
→ Rigid ducting only.

Guidance:
→ Use pre-insulated rigid foam ducts for easiest install.

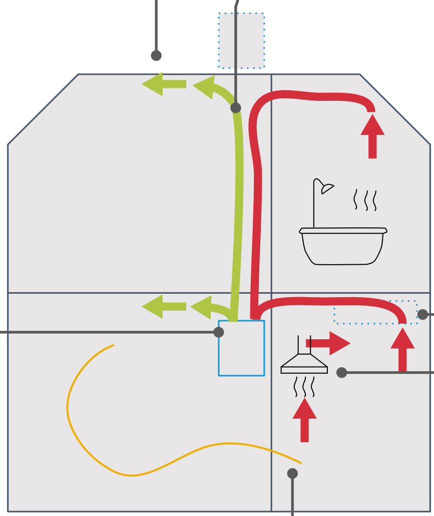
Air terminals outside
Key requirements:
→ Two grills/louvres spaced apart by at least 600mm, or specialist combined grill
→ Weather proof with drainage
→ Away from sources of pollution such as main road, bin stores, compost, smoking areas etc.

Guidance:
→ Terminal is typically 1.5 times the size of duct
→ Roof tile terminals are available
→ Existing properties could use cast iron air bricks.

Duct distribution
This is the biggest challenge for retrofitting MVHR, but it is nearly always possible.

Key requirements:
→ Enough room for ducts to pass freely
→ Enough room for acoustic attenuation where needed
→ Route to rise between floors
→ Route to each room for supply and extract.

Good routes could be:
→ Dropped ceiling in corridors
→ Boxed in to a corner of bathrooms, or either side of a chimney breast
→ In cupboards and built in shelving
→ Beneath the insulation (warm side) in a loft (care must be taken in making sure they are airtight).



Extract room terminals
Away from door to bring air into room

Kitchen extract terminal
Away from the hob.
Include a filter on the extract grill

Recirculating cooker hood
Suitable for all but those with very heavy use of fryers or very large households.
Catches the worst of the grease.
Background ventilation is from the MVHR.

Transfer through other rooms
Rooms that are between supply and extract areas may not need their own room terminal.

For example:
→ Corridors
→ Open plan living areas.

Door undercuts
Air needs to get between rooms. The simplest way is to have a small door undercut, or acoustic or fire damped grills are possible

Key requirements:
→ 10mm clear above the floor finish for doors.

Figure D.1 - Central supply and extract ventilation with heat recovery (MVHR)

D.2 Centralised constant extract ventilation with demand control

Where MVHR cannot be fitted (for instance where space for a heat exchanger or the attendant ductwork is not possible) continuous extract ventilation may provide a next best solution. Centralised systems use a single fan and ductwork to the wet rooms only. The fan box is typically approx. 600 mm square by 200 mm deep which is much more compact than with MVHR as no heat exchanger is included and the system is not insulated (as the air streams are all warm).

By extracting from wet (kitchens, bathrooms, utility, WC's) spaces, the house interior is put into modest negative pressure. Inlets (either as window or through the wall vents) allow fresh supply air into the habitable rooms. These vents can be managed by the user but should always allow some air through.

By having continuous extract, better air quality can provide than with intermittent fans and for retrofits aiming for better than $5m^3/m^2hr$ continuous extract is recommended to maintain air quality. The primary disadvantage of this type of system is that it is constantly drawing cold external air into the dwelling, whether it is needed or not, which will need to be warmed by the heating system.

Demand control

To counter the inefficiency of a constant extract system many of the MEV systems available now allow for demand control so that air quality and energy efficiency can both be optimised.

Some systems can auto regulate the supply inlets by having humidity sensitive devices that open or close the aperture. Alternatively, users can adjust the trickle vents manually. The central MEV fan control will monitor pressure and, when there is a drop – i.e. a supply inlet has opened, it will increase flow rate to re-pressurise and thus increase air flow through the room where the supply valve was opened.

The extract flow rates from each wet space can also respond to use, normally by using sensors to detect either presence (in a WC), or humidity (in a shower or kitchen area). The sensor can command the associated extract terminal to open its aperture and/or increase the fan speed, thereby increasing flow rate.

Constraints and considerations

The ductwork runs are normally moderate and the fan box is relatively small meaning that its is possible in most situation to accommodate.

Care does need to be taken to design the duct runs a carefully and to consider any necessary builder's work. In projects where existing windows may be staying in-situ it is also important to ensure that the trickle vent solution for supply is appropriately matched with the system. Special care may be needed to avoid compromising fire separation between spaces such as habitable rooms and escape routes.

For houses where the wet room are especially spread out the duct runs may become problematic. It may make sense to fit two systems in such homes.

As long as the duct runs are kept reasonably short, the noise levels associated with these systems are normally very low. As each wet space has a single duct, then cross talk is also not a problem.

D.2 Centralised constant extract ventilation with demand control

Supply vents
All rooms without extract fans need a supply air path. Incoming supply air is cold. Some systems use trickle vents which respond to humidity in order to control air flow.

Key requirements:
→ Vents at high level to avoid low cold drafts
→ Can be shut off for comfort, but should not be possible to block completely.

Good locations could be:
→ Trickle vents integrated with windows
→ Dedicated air brick with internal damper.

Ventilation unit (MEV) location
Key requirements:
→ Near to an outside wall or roof
→ Accessible for maintenance
→ Not in a bedroom or quiet area, they make some noise like a fridge.

Good locations could be:
→ Above the hot water tank
→ At the end of a row of kitchen cupboards
→ At the back of a store cupboard
→ In a porch or lean-to against the building but ideally this should be a heated space
→ In a heated loft space (cold lofts need careful design).
→ Above a washing machine.

Ducts to outside
Key requirements:
→ Short-moderate length of duct to outside.
→ Rigid ducting only.
→ Vertical ducts through roofs should include a drain and outlet to prevent condensate flowing back into machine.

Air terminals outside
Key requirements:
→ One grill/louvre of sufficient size to avoid back pressure/noise.
→ Weather proof with drainage.

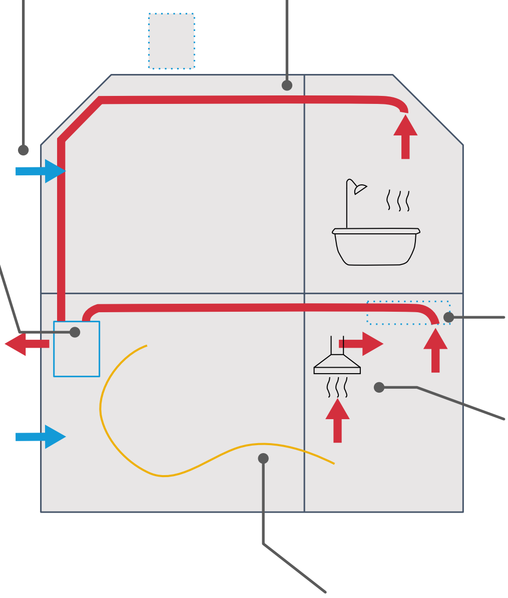
Guidance:
→ Terminal is typically 1.5 times the size of duct
→ Roof tile terminals are available
→ Existing properties could use cast iron air bricks.

Controls and instructions
→ Typically fully automatic. Sensors (presence detector or humidistat normally, also sometimes CO_2 levels). When sensor is triggered the extract terminal dilates to allow greater airflow.
→ Generally no user interaction if maintenance kept up.

Duct distribution
Compared to MVHR,challenge is much reduced for MEV as number of ducts is at least half.

Key requirements:
→ Enough room for ducts to pass freely
→ Enough room for acoustic attenuation where needed
→ Route to rise between floors
→ Route to each wet space for extract.

Good routes could be:
→ Dropped ceiling in corridors
→ Boxed in to a corner of bathrooms, or either side of a chimney breast
→ In cupboards and built in shelving
→ Beneath the insulation (warm side) in a loft (care must be taken in making sure they are airtight).



Extract room terminals
Away from door to bring air into room

Kitchen extract terminal
Away from the hob.
Include a filter on the extract grill

Recirculating cooker hood
Suitable for all but those with very heavy use of fryers or very large households.
Catches the worst of the grease.
Background ventilation is from the MVHR.

Transfer through other rooms
Rooms that are between supply and extract areas are ventilated by transfer air.

Door undercuts
Air needs to get between rooms. The simplest way is to have a small door undercut, or acoustic or fire damped grills are possible

Key requirements:
→ 10mm clear above the floor finish for doors.

Figure D.2 - Centralised constant extract ventilation with demand control (dcMEV)

D.3 Decentralised constant extract ventilation

For very space constrained properties it is possible to use a decentralised system with extract only. The disadvantages of this are that you can not guarantee where the supply air is coming from, so some rooms may be very under ventilated. Providing air inlets/ trickle vents to try and address this may be difficult in some rooms and particularly if there are heritage constraints. There is also no heat recovery, so all the ventilation air is lost heat, although it can be reduced using demand control, this can be as much as 25-50% of the energy needed by the home. However decentralised ventilation does provide good constant ventilation and is a useful and necessary strategy in many locations.

Homes where decentralised ventilation might be necessary:

→ Existing flats with very low ceilings and small rooms, where boxing in and duct distribution would be obstructive.

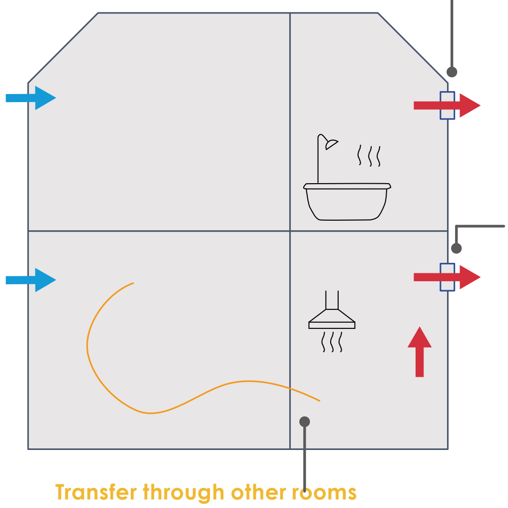
→ Listed buildings with internal heritage features that would be damaged by an installation (although balanced supply and extract ventilation is still possible in some cases)

Decentralised fans with heat recovery are available and could be considered in some cases. They would be an improvement over extract only, but they typically do not achieve the same air quality as a central system. Similarly decentralised ventilation with very sophisticated demand control (based on humidity) can also offer benefits by reducing the actual ventilation rate.

Supply vents
All rooms without extract fans need a supply air path. Incoming supply air is cold and there is no control which vent the majority of air is coming from.

Key requirements:
→ Vents at high level to avoid low cold drafts
→ Can be shut off for comfort, but should not be possible to block completely

Good locations could be:
→ Trickle vents integrated with windows
→ Dedicated air brick with internal damper



Door undercuts
Air needs to get between rooms. The simplest way is to have a small door undercut, or acoustic or fire damped grills are possible.

Key requirements:
→ 10mm clear above the floor finish for doors.

Transfer through other rooms
Rooms that are between supply and extract areas are ventilated by transfer air.

Bathroom fans
Key requirements:
→ Constant trickle ventilation
→ Boost function with humidity sensor or manual timed switch.

Guidance:
→ Avoid fans directly boosted from light switch (due to noise)
→ Ensure there is constant ventilation even when boost mode is off.

Kitchen extract fan
Can be integrated with kitchen cooker hood, or a separate fan with a recirculating cooker hood.

Key requirements:
→ Constant trickle ventilation with user controlled boost setting
→ Direct connection to outside.

Air terminals outside
Key requirements:
→ Weather proof with drainage
→ Typically more external terminals than MVHR.

Guidance:
→ Terminal as close to fan as possible (or integrated)
→ External dampers should not impede air flow.

Figure D.3 - Decentralised constant extract ventilation

Annex E: Stock modelling method and assumptions

The conclusions drawn in chapter 3 are based on a Great Britain (GB)[E.1] stock model which predicts the energy consumption of all the UK's domestic dwellings. This annex sets out how this modelling has been undertaken and the associated assumptions.

Step 1 - Creating a Stock Model

There is no detailed single source of housing data for the GB as a whole. The most accurate dataset in the public domain is the 2011 English Housing Survey (EHS) data which is included in the Cambridge Housing Model[E.2]. Subsequent iterations of the English Housing Survey are published by BEIS in summary form only[E.3]. A summary of housing data for Scotland and Wales is provided within BRE's The Housing Stock of The United Kingdom report published in February 2020[E.4]. The baseline 2011 stock model has therefore been extrapolated to 2018 and to include Wales and Scotland by applying the following method and assumptions:

→ Summary data from the 2018/19 EHS was used to determine the number of cavity wall insulations, solid wall insulations and double glazing installations between 2011 and 2018.

→ These measures were assumed to have occurred proportionally across all the stock that was eligible for those upgrades

→ The distribution of dwelling types in Wales and Scotland was assumed to be the same as for England

This process resulted in an updated stock mode of 28.2M dwellings which correlates with actual data for 2018.

Step 2 - Standardising and reducing the data

The EHS model has over 14,000 different archetypes. Modelling all these archetypes is very time consuming and does not necessarily lead to more accurate results as some of the parameters that vary between archetypes would not affect the energy demand significantly. LETI therefore reduced the key parameters down to five, and within those five, reduced the possible variations to a minimum. These parameters are summarised in Figure E.1. The total number of possible combinations of the parameters is 1,125. However, some of the combinations result in archetypes which don't actually exist in the EHS and thus, the final number of archetypes was 486.

For each archetype, a set of modelling data was then extracted. Some of this data came directly, or was derived, from the stock model and other data was inferred using the baseline modelling parameters shown in Annex F. For example, where the EHS data indicates an uninsulated cavity wall, a U-value of 1.00 W/m^{2}K is applied. A summary of the full dataset for each archetype is shown in Figure E.4.

Step 3 - Creating an energy model

A modified PHPP model was then created to analyse each archetype. The PHPP was adapted using data tables to insert the data for each archetype in turn into the model and then generate the associated results. The model was set up to run for one of the five retrofit cases each time - i.e. Baseline, Do Minimum, LETI Constrained, LETI Unconstrained and Best Practice. The illustrative output from a single archetype is shown in Figure E.2.

Dwelling age		Dwelling form		Wall construction		Windows		Loft insulation
Pre - 1900		Detached		Solid Uninsulated		Single		Minimal
1900 - 1929		Semi - detached		Cavity Uninsulated		Double		Moderate
1930-1949	X	Mid - terrace	X	Cavity Insulated	X	Mixed	X	Good
1950 - 2002		Bungalow		Solid Insulated				
Post 2002		Flat		Timber Frame				

Figure E.1 - Key parameters used to define LETI archetypes

Illustrative Archetype Results		
Space Heating Demand	101	kWh/m²/year
Adjusted Space Heating Demand	96	kWh/m²/year
Hot Water Demand	63	kWh/m²/year
Peak Load (Heating)	51	W/m²
Heating and Hot Water Demand	159	kWh/m²/year
Space Heating Delivered (Gas)	113	kWh/m²/year
Heating and Hot Water Delivered (Gas)	187	kWh/m²/year
Lighting and Unregulated Demand	39	kWh/m²/year
Overall Demand	197	kWh/m²/year
Overall Delivered Energy (Gas)	225	kWh/m²/year
Overheating Percentage	2.22	%

Figure E.2 - Illustrative output from a single archetype for the scenario where heating and hot water is generated with a gas boiler

Baseline Case (GB)		
Gas Peak Load	152	GW
Total Heating Demand	267	TWh / year
Total Hot Water Demand	97	TWh / year
Total Gas Demand for Heating	266	TWh / year
Total Gas Demand for Hot Water	96	TWh / year
Total Gas Demand	362	TWh / year
Total Oil Demand for Heating	14	TWh / year
Total Oil Demand for Hot Water	5	TWh / year
Total Oil Demand	19	TWh / year
Total Electricity Demand for Heating	14	TWh / year
Total Electricity Demand for Hot Water	5	TWh / year
Total Other Demand for Heating	16	TWh / year
Total Electricity Demand Lighting and Unregulated	58	TWh / year
Total Electricity Demand	77	TWh / year
Total Thermal Energy Demand	415	TWh / year
Total Energy Delivered (All Types)	474	TWh / year

Figure E.3 - Nationwide energy data for GB based on the modelled baseline case

The total outputs for each case were then summed to give total GB data. The GB data for the baseline case is shown in Figure E.3 (above). In deriving these outputs, the following assumptions were made:

→ 84.5% of GB dwellings have a gas boiler [E.5]

→ The average gas boiler efficiency is 85%

→ The average Seasonal COP (SCOP) for an Air Source Heat Pump is 2.5[E.6]

Step 4 - Validating and adjusting the model

The initial modelling results showed an overall space heating demand far higher than BEIS consumption figures suggested. This was considered to be for three reasons:

1. Not all dwellings are occupied all the time. An empty homes reduction of 5% was therefore applied to the model.

2. The default PHPP model assumes a constant internal temperature of 20°C throughout the heating season. For a Passivhaus dwelling this is a correct assumption. However, for a more typical dwelling, and especially for a dwelling with a poor fabric, this is not a valid assumption. A typical dwelling will use periodic heating (i.e. heating will be on for periods when the dwelling is occupied and off overnight) and will cool down below the target temperature outside of those periods. The worse the building fabric, the more rapidly it will cool and thus the lower the average temperature. The PHPP model was therefore modified to include the same methodology that is used in SAP. The heat loss parameter of the dwelling is calculated and then used to determine an average monthly internal temperature based on a standard heating pattern. This adjusted temperature is then used for the dwelling's heat loss calculations.

Parameter	Unit	Source
No. of dwellings represented	No.	EHS Direct
External Wall Type	N/A	EHS Direct
Floor type	N/A	EHS Direct
Form	N/A	EHS Derived
Internal Floor Area	m^2	EHS Direct
Loft Insulation	Type	EHS Derived
External Wall Area	m^2	EHS Direct
Heat Loss Floor Area	m^2	EHS Direct
Roof Area	m^2	EHS Direct
Single Glazing Area	m^2	EHS Direct
Double Glazing Area	m^2	EHS Direct
Door Area	m^2	EHS Direct
Property Age	Range	EHS Derived
Original Heating Source	Type	EHS Direct
Original Hot Water Source	Type	EHS Direct
Adult Occupancy	No.	EHS Direct
Child Occupancy	No.	EHS Direct
External Wall U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Roof U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Floor U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Single Glazing U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Double Glazing U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Door U-value	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Thermal Bridging Allowance	W/m^2K	Modelling parameters (Figures F.1 and F.2)
Airtightness	ACH@50Pa	Modelling parameters (Figures F.1 and F.2)
Ventilation Type	Type	Modelling parameters (Figures F.1 and F.2)
Lighting Power	lm/watt	Modelling parameters (Figures F.1 and F.2)
HW Tank Insulation	mm	Modelling parameters (Figures F.1 and F.2)
WWHR Efficiency	%	Modelling parameters (Figures F.1 and F.2)
Primary Pipework Insulation	%	Modelling parameters (Figures F.1 and F.2)
DHW Demand Showering	litres / person . day	Modelling parameters (Figures F.1 and F.2)
DHW Demand Other	litres / person . day	Modelling parameters (Figures F.1 and F.2)
Heating Source	Type	Modelling parameters (Figures F.1 and F.2)
Hot Water Source	Type	Modelling parameters (Figures F.1 and F.2)
Overhang Shading	Y/N	Modelling parameters (Figures F.1 and F.2)
PV	% of roof	Modelling parameters (Figures F.1 and F.2)
Solar Thermal	m^2/person	Modelling parameters (Figures F.1 and F.2)

Figure E.4 - Summary of the dataset for each archetype

SIGNPOST *Annex F - Modelling parameters*

3. For dwellings which have a particularly poor fabric, anecdotal evidence suggests that the set-point temperature may not be met during the heating periods and that some areas/rooms may not be heated at all due to fuel cost issues. A correction factor was therefore applied to the space heating demand whereby a tapered reduction of up to 30% was applied to dwellings which had a heat loss parameter (HLP) of more than 3. The parameters and response characteristics of this adjustment are in Figure E.5 and E.6.

The calibrated model was compared against the actual consumption data (for gas and electricity) from 2018[E.7] to demonstrate that the model was producing accurate results. This is illustrated below and shows a total consumption of 484 TWh versus a modelled total of 474 TWh (Figure E.7).

E.1 References and footnotes

E.1 - Great Britain (GB) in this context refers to mainland UK - i.e. England, Scotland and Wales. This is because the source data available for measured energy consumption is based on this geographical area and thus allowed calibration/validation of the modelling.

E.2 - https://www.gov.uk/government/publications/cambridge-housing-model-and-user-guide

E.3 - https://www.gov.uk/government/collections/english-housing-survey

E.4 - https://files.bregroup.com/bretrust/The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf

E.5 - Source: https://files.bregroup.com/bretrust/The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf

E.6 - Derived from Heat Pump Retrofit in London, Carbon Trust, August 2020, Page 149 - Field Trial Data.

E.7 - Reported consumption taken from www.gov.uk/government/statistics/energy-consumption-in-the-uk

Cold Homes Adjustment		
Heat loss parameter above which homes are adjusted	3	W/m²K
Maximum reduction	30	%
Maximum HLP in total population	5.7	W/m²K

Figure E.5 - Heat Loss Parameter adjustment for cold dwellings

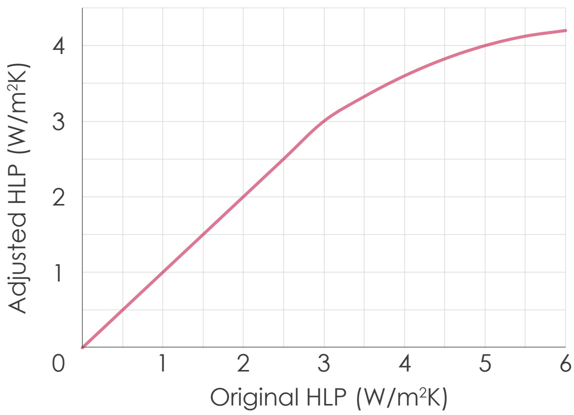


Figure E.6 - Heat Loss Parameter adjustment curve

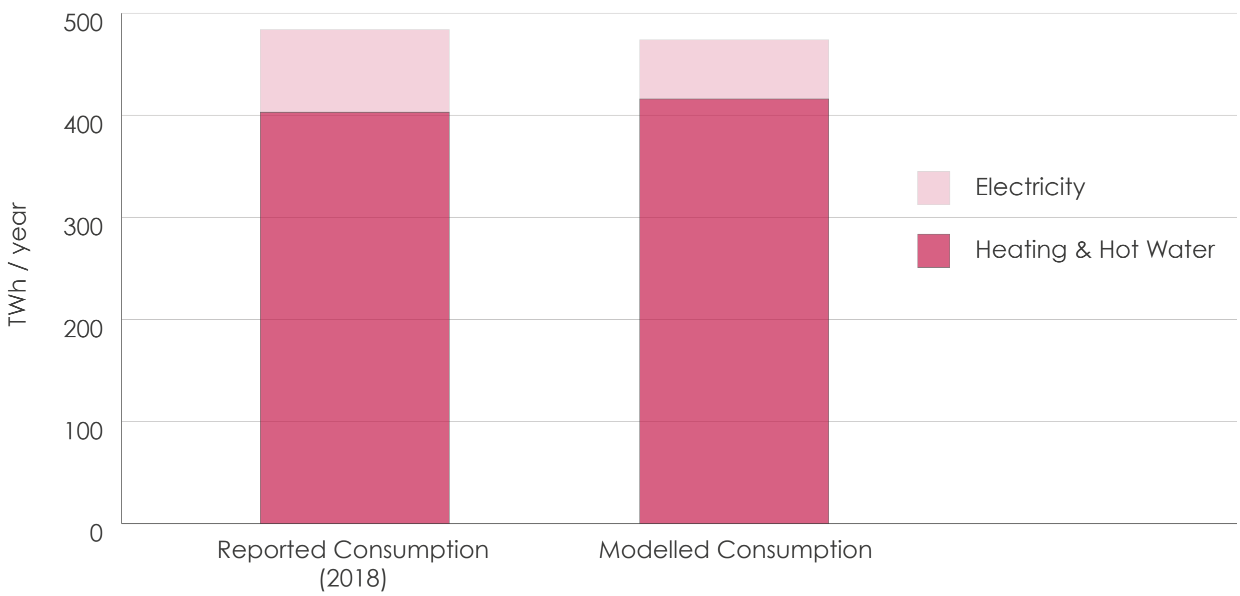


Figure E.7 - Actual national consumption data for 2018 compared to modelled demand

Annex F: Modelling parameters

The following parameters were used for modelling each retrofit case:

Wall Types	Unit	Baseline	Do Minimum	LETI best practice constrained	LETI best practice unconstr.	LETI exemplar
Cavity Uninsulated	W/m²K	1	0.7	0.24	0.18	0.15
Cavity Insulated	W/m²K	0.43	0.55	0.24	0.18	0.15
Solid Uninsulated	W/m²K	1.35	0.7	0.32	0.18	0.15
Solid Insulated	W/m²K	0.37	0.3	0.32	0.18	0.15
Timber Frame	W/m²K	0.5	0.3	0.21	0.18	0.15

Roof Types*	Unit	Baseline	Do Minimum	LETI best practice constrained	LETI best practice unconstr.	LETI exemplar
Good (Insulated at ceiling)	W/m²K	0.17	0.16	0.12	0.12	0.12
Moderate	W/m²K	0.25	0.16	0.22	0.12	0.12
Minimal	W/m²K	1	0.16	0.31	0.12	0.12

Floor Type	Unit	Baseline	Do Minimum	LETI best practice constrained	LETI best practice unconstr.	LETI exemplar
Suspended Timber	W/m²K	1.04	0.25	0.2	0.18	0.15
Solid Uninsulated	W/m²K	0.80	0.25	0.8	0.15	0.15

* As defined by the baseline English Housing Survey

Figure F.1 - Modelling parameters (walls, roofs and floors)

Windows and doors	Unit	Baseline	Do Minimum	LETI best practice constrained	LETI best practice unconstr.	LETI exemplar
Glazing Type 1 (single in Baseline)	W/m²K	4.8	1.6	1.3	1	0.8
Glazing Type 2 (double in Baseline)	W/m²K	2	1.6	1.3	1	0.8
Doors	W/m²K	3	1.8	1	0.8	0.8

Other	Unit	Baseline	Do Minimum	LETI best practice constrained	LETI best practice unconstr.	LETI exemplar
Thermal Bridging (y-value)	W/m²K	0.2	0.15	0.1	0.1	0.08
Airtightness	ACH	11.5	10	3	2	1.0
Ventilation Type	Type	Natural ventilation with extract fans	Natural ventilation with extract fans	MVHR	MVHR	MVHR
Lighting Power	lm/watt	12	45	50	100	100
HW Tank Insulation	W/K	3	1.5	1.5	1.5	1.5
WWHR	-	None	None	None	None	None
Primary Pipework insulation	%	0	0	90	90	90
DHW Demand Showering	Litres/ pers.day	35.5	25	16	16	16
DHW Demand Other	Litres/ pers.day	15	15	9	9	9

Figure F.2 - Modelling parameters (windows and doors, other)

Annex G:
U-value sweet spots

Key factors in determining how much insulation is appropriate

In deciding what level of insulation is sufficient for retrofit of existing buildings, there are several factors which may be taken into consideration to arrive at an approximate optimal value:

→ **Minimum comfort limit.** Achieving an internal surface temperature of greater than 17°C when outside temperatures are at a minimum will ensure radiant comfort for the occupants.

→ **Achieving significant reductions in heat loss.** As there is an inverse relationship between insulation thickness and heat loss, the amount of heat loss reduction that is achieved decreases proportionally as the insulation thickness increases - i.e. there are diminishing returns for the amount of insulation being applied. This means that chasing the last 20% of heat loss reductions will require significantly thicker insulation. This is illustrated in Figure G.1 which shows that, in the example of a 100m^2 solid wall with external temperatures at 0°C, the first 150mm of insulation saves 1600W (80%) whereas the second 150mm only saves 220W (11%). This will be similar for most cases and LETI is therefore suggesting that an 80% reduction in heat loss from the baseline construction would be an optimal point. This rule of thumb will be appropriate for a starting point where the construction is poorly insulated. Where there is already a good level of insulation then 80% further reduction may not be economically viable.

→ **Best value.** In contrast to heat loss savings, the cost of applying an increasing thickness of insulation is more linear. In addition, the costs will include what is usually a significant element of fixed costs which are independent of the amount of insulation applied. By merging these two functions, we can generate a cost per watt saved index. This will be particular to the construction type being considered and also the proportion of fixed costs. However, in general these indices appear to have the shape shown in Figure G.2. This suggests that there is an optimal cost point, where the cost per watt saved is at its minimum and therefore best value is being achieved. This may not necessarily equate with best practice levels of insulation.

→ **Minimises carbon.** Ensuring that we use the optimum amount of insulation from an operational energy perspective often means that we keep the associated embodied carbon to a minimum

→ **Low levels of heat loss.** The actual amount of heat loss through the element will be a key factor in determining the overall level of performance of the building. LETI is suggesting that a heat loss of 3.5 W/m2 in the coldest outdoor conditions for the building's location is a good and achievable level which will deliver comfortable low energy buildings.

→ **Practicality.** Large thicknesses of insulation become impractical to apply as there are limitations on supporting materials such as fixings and wall ties. Furthermore, for homes adjacent to pavements, there is a limit on the amount of insulation overhang which would be considered acceptable. There is therefore a degree of informed judgement as to what is practical.

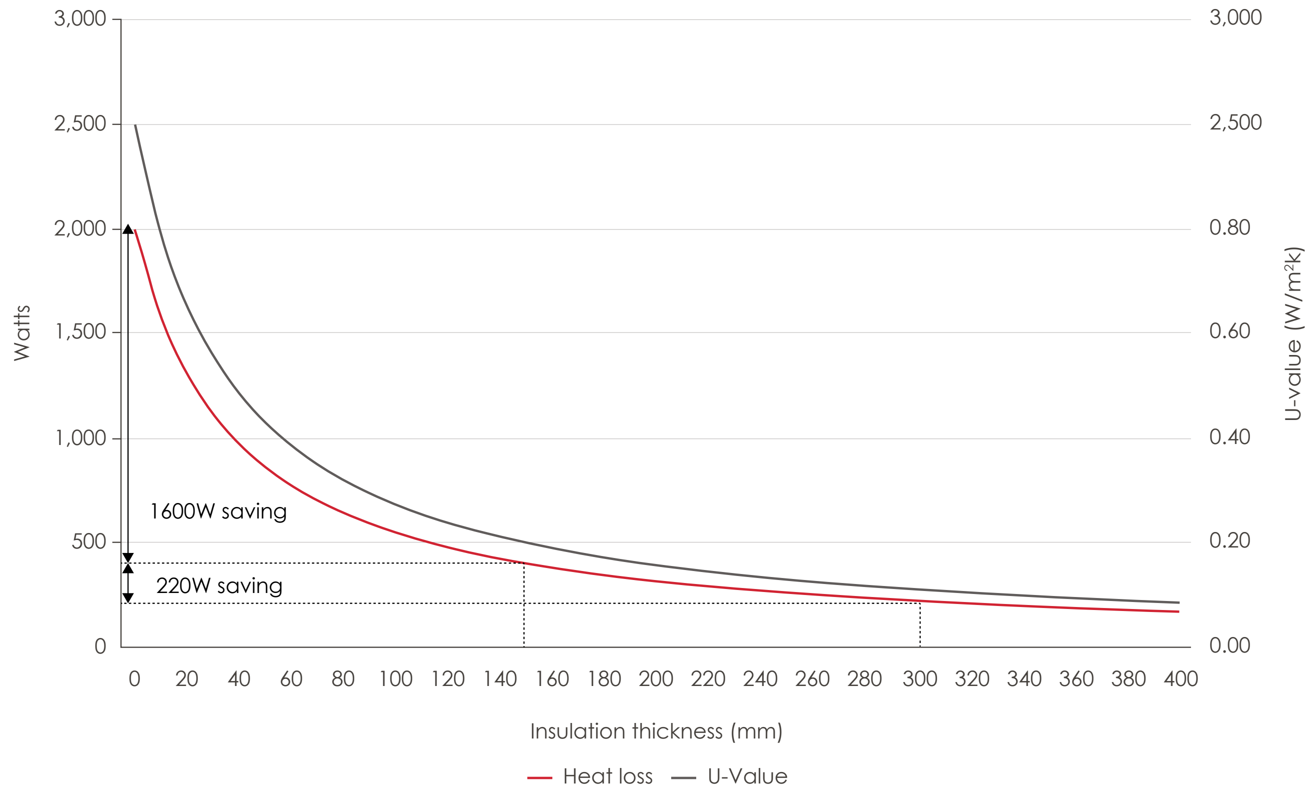


Figure G.1 - Diminishing returns for the amount of insulation being applied to a 100m² solid wall with external temperatures at 0°C

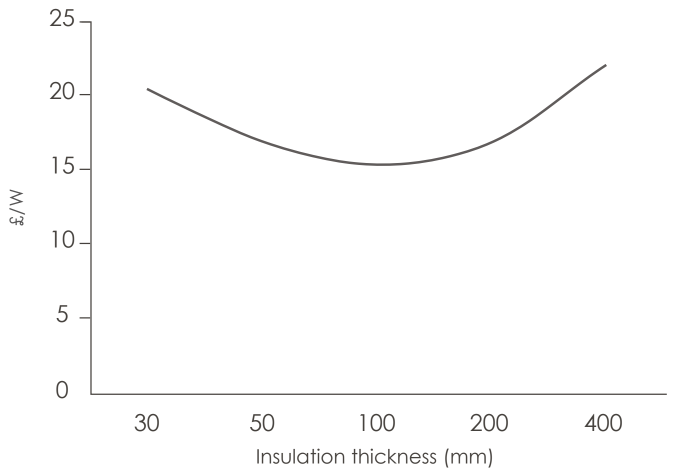


Figure G.2 - Cost per watt index

→ **Minimum external temperatures.** The minimum external temperatures likely to be experienced within a region will drive the level of insulation that is required. LETI have therefore provided indicative insulation thickness and U-values for three different climate conditions:
  - → **Mild - minimum external temperature 0°C**
  - → **Moderate - minimal external temperature -5°C**
  - → **Cold - minimal external temperature -10°C**

To illustrate what LETI believe to be an appropriate range of pragmatic target insulation thicknesses and U-values, we have calculated the required additional thickness of insulation and associated U-value for these baseline construction types from each of the factors set out above - i.e. surface temperatures, heat loss reduction, best value, low heat loss level and external temperatures.

For these illustrative calculations, we have used an insulation with a thermal conductivity of 0.038W/m.K. Whilst higher performance insulation can be used, this figure represents a reasonable level of insulation performance which is achievable using natural and vapour open materials i.e. these levels of performance should be achievable in any construction type.

If a higher performing but vapour closed insulation is used, then careful attention must be paid to moisture risk. See Annex H for more details.

SIGNPOST *Annex H: Moisture risks and how to avoid them*

Note that these illustrations are only applicable to existing buildings and are based on the cost of insulation to the existing fabric only. Therefore where work is already happening in this area (for new construction) the additional cost of more insulation may be lower. The costs are correct relative to one another, however actual market cost of installation may rise and fall, having an impact on the result.

On the following graphs, the suggested range of insulation thickness (for this type of insulation) and associated U-values are denoted by the shaded grey bars.

Baseline construction types

LETI have considered these factors for the following baseline construction types:

No.	Description	Starting U-value (W/m²K)
1	Cavity Uninsulated Wall	1.00
2	Cavity Insulated Wall	0.43
3	Solid Uninsulated Wall	1.35
4	Cold Roof Uninsulated	1.00
5	Suspended Timber Floor	1.04
6	Solid Uninsulated Floor	2.00

Figure G.3 - Baseline construction types

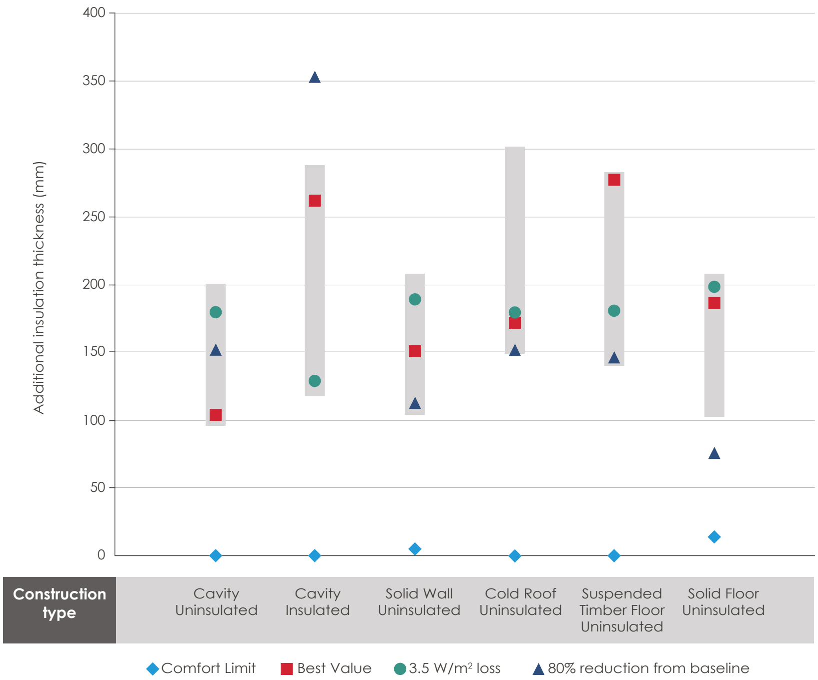


Figure G.4 - Thickness of additional insulation by baseline construction (ext temp 0 Degrees Celsius)

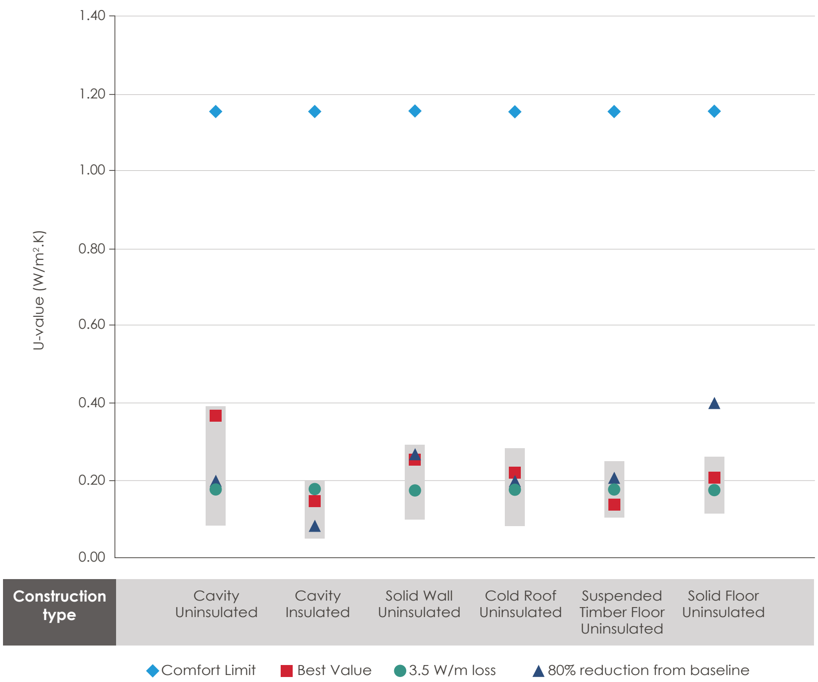


Figure G.5 - Final U-values by baseline construction (ext temp 0 Degrees Celsius)

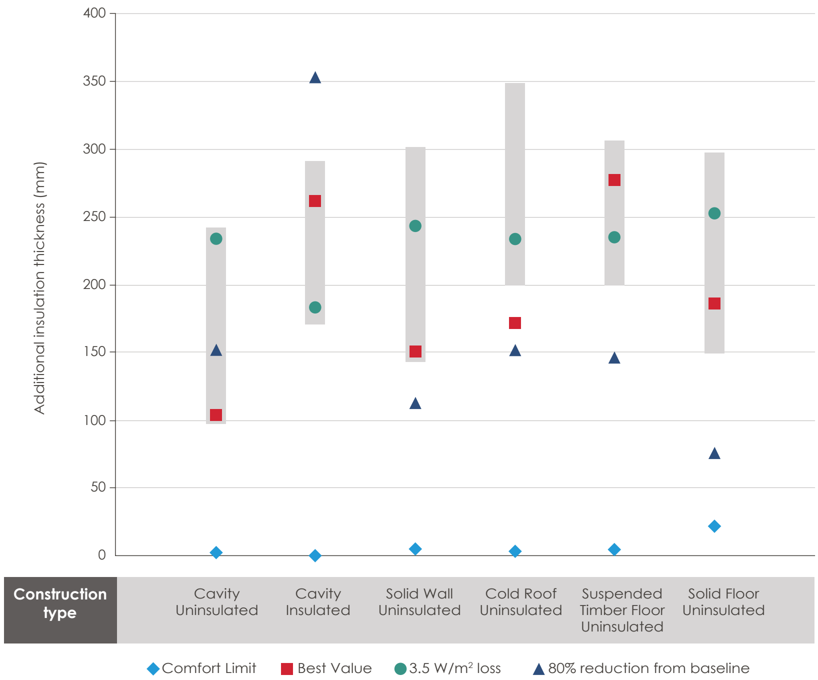


Figure G.6 - Thickness of additional insulation by baseline construction (ext temp -5 Degrees Celsius)

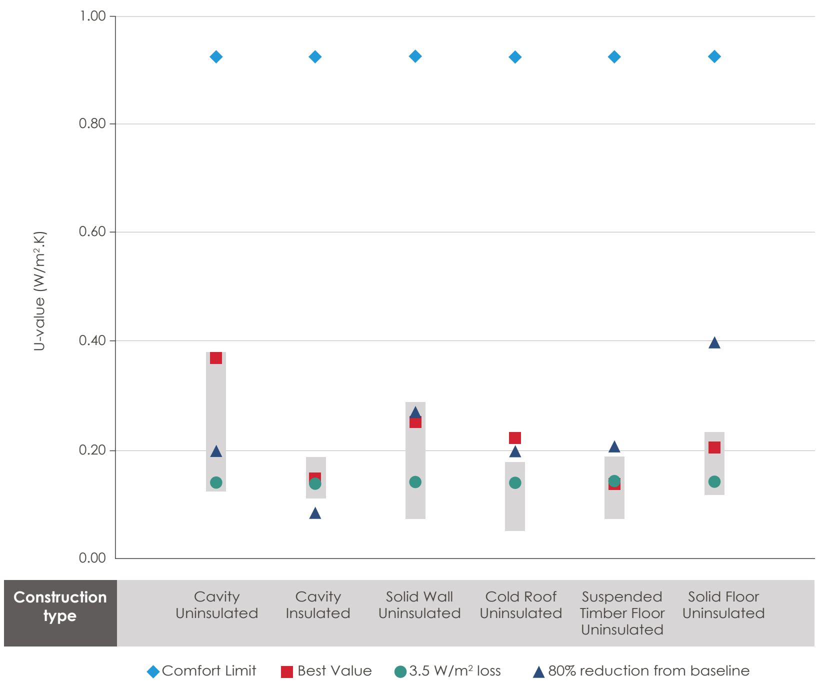


Figure G.7 - Final U-values by baseline construction (ext temp -5 Degrees Celsius)

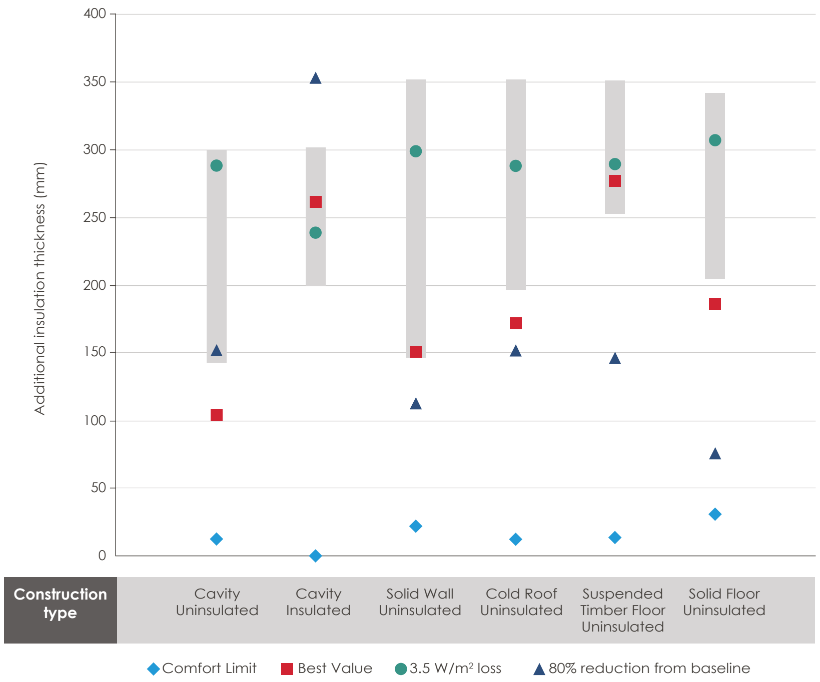


Figure G.8 - Thickness of additional insulation by baseline construction (ext temp -10 Degrees Celsius)

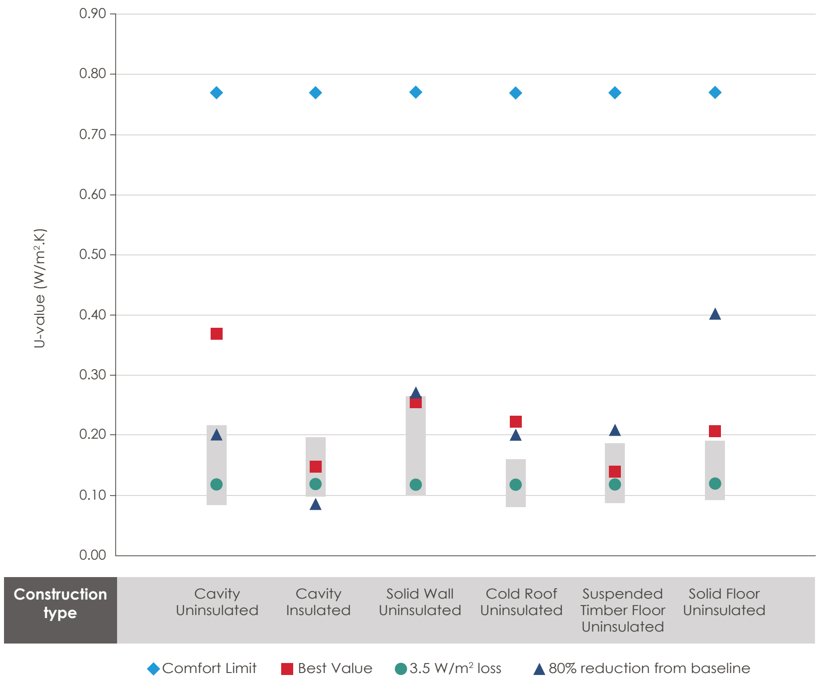


Figure G.9 - Final U-values by baseline construction (ext temp -10 Degrees Celsius)

Annex H: Moisture risks and how to avoid them

When retrofitting existing buildings, a few key principles must be followed to avoid exacerbating or introducing moisture problems such as excessive indoor humidity, surface condensation and mould, trapped moisture within the building fabric and rot/decay/spalling.

1. Repair and weatherproof well - to prevent (excessive) rainwater ingress.
2. Ensure the building is dry before retrofitting.
3. Ventilate well - to maintain healthy indoor humidity levels and reduce dampness.
4. If the existing construction is vapour balanced (or vapour open), keep it vapour balanced - to avoid moisture becoming trapped within the building fabric.
5. If the existing construction is vapour closed, keep it vapour closed - to minimise moisture entering the building fabric where it will become trapped.
6. Improve airtightness - to minimise water vapour entering the building fabric through air leakage.
7. Ventilate cold roofs/floors - to evacuate humid air and reduce risk of interstitial condensation.
8. Minimise thermal bridges - to prevent internal surface condensation and mould.

These principles as well as the concepts of 'vapour balanced' and 'vapour closed' are illustrated in Figures H.1 and H.2.

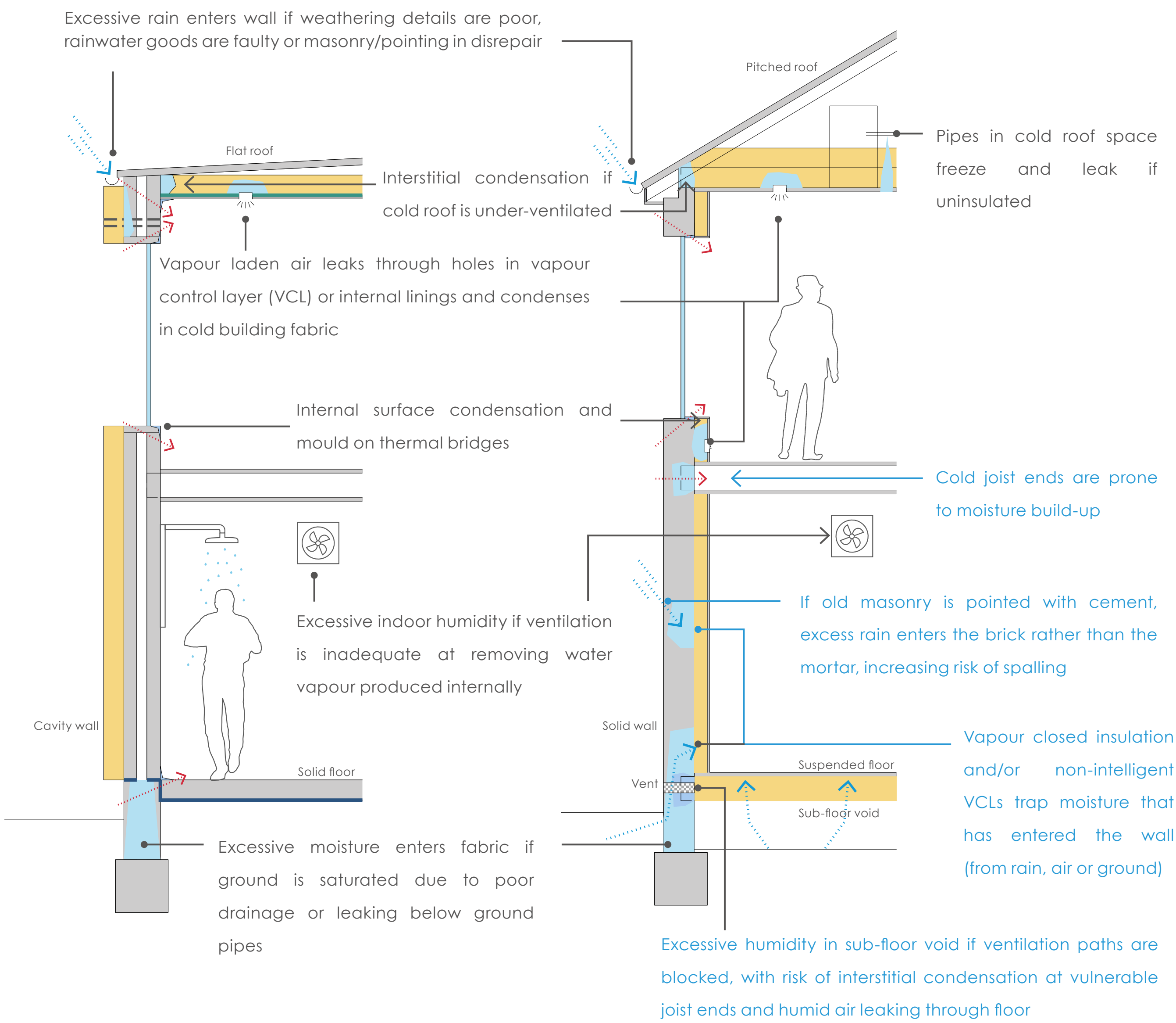
Notes:
Note 1: Insulation cannot be very thick - otherwise it overly impedes drying out, even if vapour open. Insulations which are also capillary active and/or hygroscopic will further aid drying out to the inside and are advisable in exposed walls.

Note 2: Where EWI is installed on cavity walls, it is advisable to fill the cavity to avoid thermal bypass within the cavity undermining the performance of the EWI. Extended DPC to ensure ground moisture does not rise up insulation.

Note 3: Whilst not shown in the diagram, vapour closed walls can be insulated internally and vapour balanced walls can be insulated externally. In both cases - the vapour open/balanced nature of the wall should be maintained.

Note 4: Floors can be insulated above or below the floor - below being preferable, if feasible

H.1 Bad retrofit increases moisture risks



Key

- Moisture
- Thermal bridge
- Damp Proof Course (DPC) / Damp Proof Membrane (DPM)
- Vapour closed airtightness line
- Vapour open airtightness line

Vapour Balanced Walls

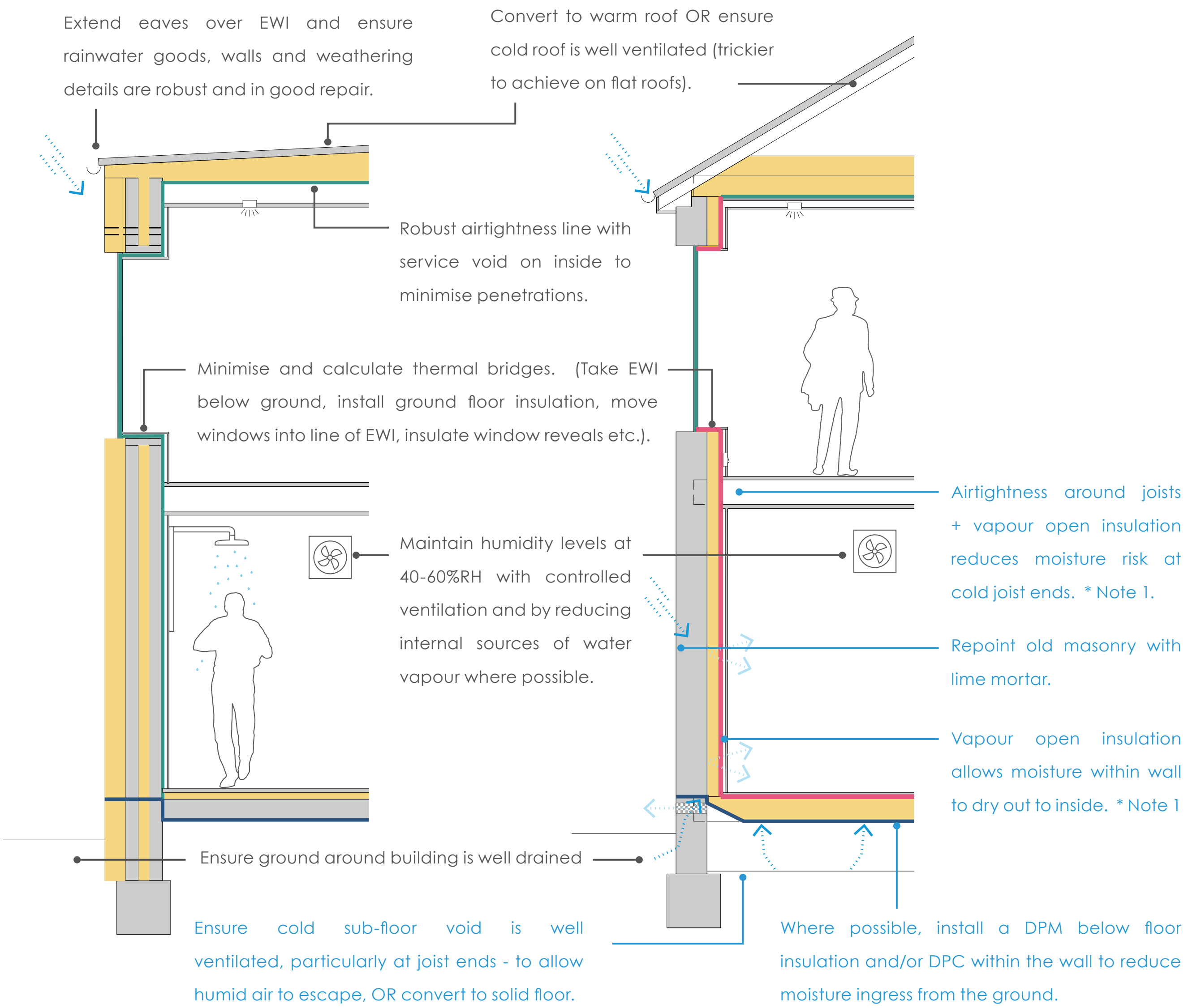
Moisture can enter the wall structure as a liquid or vapour, but the walls can dry out to both the inside and outside when conditions change.

Vapour Closed Walls

Moisture is kept out of the wall structure through DPMs, DPCs, cavities and VCLs

Figure H.1 - Bad retrofit measures increase moisture risk

H.2 Best practice retrofit reduces moisture risks



Key

- Moisture
- Thermal bridge
- Damp Proof Course (DPC) / Damp Proof Membrane (DPM)
- Vapour closed airtightness line
- Vapour open airtightness line

Vapour Closed Walls

If the existing walls are vapour closed, keep them vapour closed. Don't let moisture in.

Vapour Balanced Walls

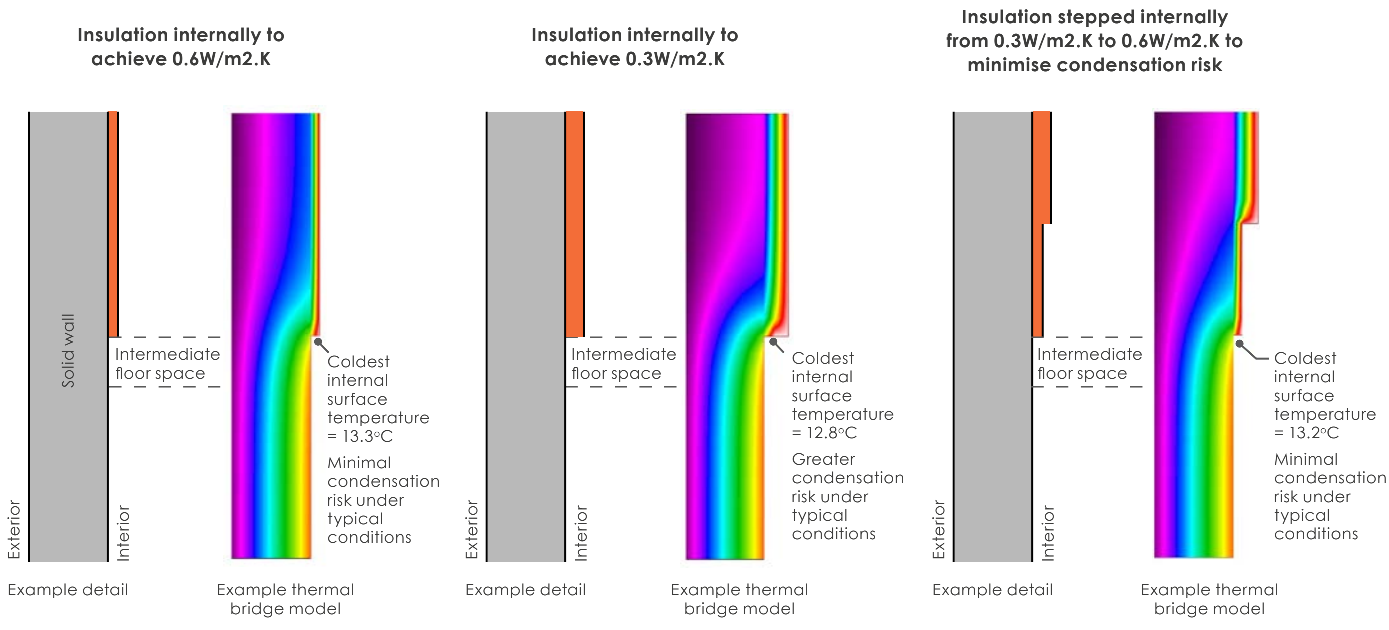
If the existing walls are vapour balanced, keep them vapour balanced. Moisture will get in - ensure it can get back out again.

Figure H.2 - Best practice retrofit measures reduce moisture risk

H.3 Internal wall insulation moisture risk

Internal wall insulation presents a risk of interstitial condensation – i.e. condensation when warm, humid internal air meets a sufficiently cold surface within the wall build-up. This risk can be minimised by using vapour open insulation materials which are adhered directly to the original wall – thus, there is no exposed surface for condensation to form, and any moisture that does form, can escape through the insulation layer.

However, in many retrofit situations, it is impossible to fully cover the original walls with insulation (e.g. in intermediate floor spaces), so there is a boundary where the original wall becomes exposed to the internal warm air. In these areas, the temperature of the external wall may be low enough to result in condensation. Thus, approaching these areas, it would be prudent to increase the U-value of the insulated wall from 0.3 W/m^2.K to around 0.6 W/m^2.K to reduce this risk. In these situations LETI suggest that detailed condensation risk and hygrothermal modelling is undertaken to confirm construction details and levels of insulation.



Modelling parameters: 0°C externally, 20°C internally. Brick conductivity 0.77W/m.K; insulation conductivity, 0.04W/m.K

Figure H.3- Example solid wall internal wall insulation details to reduce interstitial condensation

Annex I:
LETI Retrofit Process and PAS 2035

'PAS 2035 Retrofitting Dwellings for Improved Energy Efficiency–Specification and Guidance' is a framework and guidance document for delivering retrofit projects, published by the British Standards Institute (BSI). It promotes a fabric-first, whole house approach with particular concern for ventilation. It focuses on proper retrofit planning and quality assurance and requires the appointment of accredited professionals - including a Retrofit Coordinator - to oversee the retrofit project. PAS 2035 does not set energy efficiency targets or define how 'deep' one should go. Its aim is to avoid the unintended consequences, defects and performance gap of poor retrofit.

All retrofit projects receiving central government funding will be required to be PAS 2035 compliant from June 2021.

PAS 2035 uses a risk classification system to identify the potential riskiness of the retrofit project. The risk grade (grade A = low risk, grade B = medium risk, grade C = high risk) depends on the scale of the project, the number and types of measures being introduced and the construction and built form of the building. Carry out risk assessment to determine 'risk grade' (grade A, B, or C), then following the corresponding path through the PAS 2035 process (path A, B, or C). If grade A criteria cannot be met on a project, then the project is grade B, if grade B criteria cannot be met, then the project is grade C. See Figure I.1.

Once the grade is known the corresponding path and implications on requirements for responsible retrofit is chosen. High rise buildings, listed buildings, and homes

Risk grade	No. of dwellings to be improved	No. of measures per dwelling	Technical risk of highest risk measure	Highest risk combination of measures	Construction and built form
A (low risk)	1-10	1-2	1	Green	Conventional, (not high rise or protected)
B (medium risk)	11-30	3-5	2/3	Orange/ yellow	Traditional or system built (not high rise or protected)
C (high risk)	>30	>5			High rise or protected building of any construction

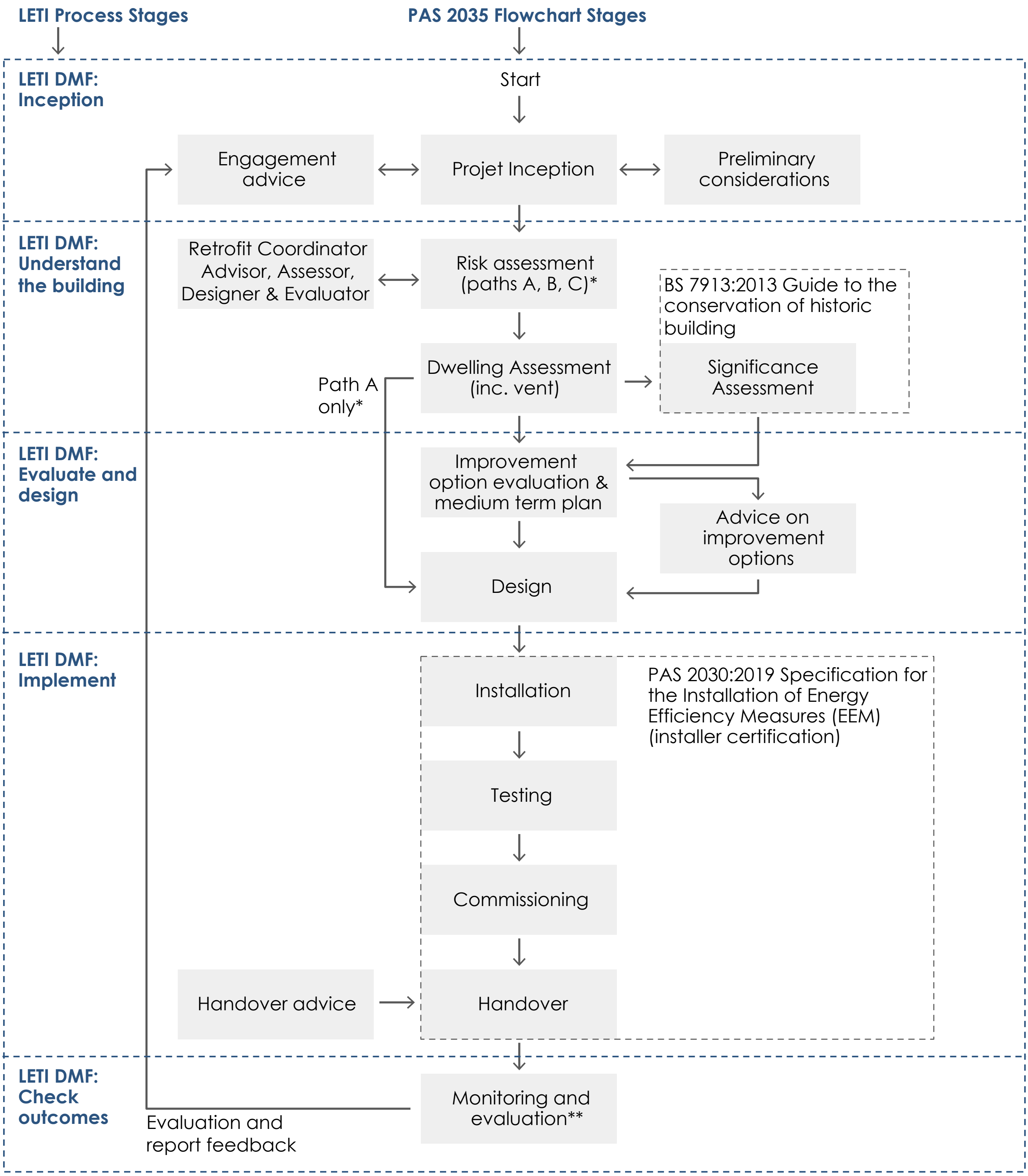
Technical risk = graded risks between 1 and 3. E.g. riskier measures such as internal solid wall insulation, flat roof insulation, floor insulation are grade 3. See PAS 2035 for details.
High rise >= 12m or >4 storeys above ground
Protected = listed, conservation area, world heritage site
Conventional = masonry cavity wall with/without render/cladding
Traditional = solid brick/stone walls or timber framed walls with infill
System built = timber/steel/concrete frame and pre-fab panel or timber frame walls and brick/stone cladding

Figure I.1 - PAS 2035 Risk Classification of Building Retrofit in conservation areas will always be considered risk grade C. The riskier the project, the more onerous the design, implementation and monitoring requirements. For example: on path C projects, an airtightness test will be required. Also, Retrofit Designers working on heritage buildings must have a heritage qualification.

PAS 2035 requires some post occupancy evaluation but this is primarily to identify problems rather than evaluate building performance. An occupant survey 3 months post retrofit is required, but no ongoing monitoring, unless serious problems have been identified that need further assessment to be resolved.

PAS 2035 works in tandem with 'PAS 2030 Specification' for the installation of energy efficiency measures in existing dwellings and insulation in residential park homes. Crudely speaking, PAS 2035 addresses the overall retrofit design and PAS 2030 deals with the installation. Also, in 2020, the BSI published their draft PAS 2038 Retrofitting non-domestic buildings for improved energy efficiency – Specification.

The LETI Retrofit Process is designed to map onto and complement PAS 2035 - broadly mirroring the PAS 2035 process/flow through inception, risk assessment and inspection, design, implementation, monitoring and evaluation. It does not make reference to path A as this is essentially only for single-measure works, which will not achieve the depth of retrofit promoted by LETI.



* LETI does not support Risk Path A, which is for single measure works and therefore does not meet LETI's definition of retrofit.
** PAS 2035 refers to this stage as 'monitoring and evaluation' however LETI does not consider PAS 2035's very light touch minimum requirements at this stage to be thorough/robust enough.

Figure I.2 - LETI Retrofit Process mapped onto the PAS 2035 process. The diagram above overlays the stages of the LETI Retrofit Process over the PAS 2035 flowchart process from PAS 2035:2019, page V: 'Figure 0.1 – A diagrammatic overview of the domestic Retrofit Process required by PAS 2035 and PAS 2030' and 'Figure 0.1 illustrates the broad overall process that users of PAS 2035 are expected to follow in order to comply with its requirements.'

Annex J: References and further information

Unfortunately, there is a huge retrofit knowledge gap between best-practice and the understanding of many in the construction industry, particularly with regard to traditional buildings. This is exacerbated by poor or inaccurate guidance - in particular insulation manufacturers' guidance that fails to address moisture properly.

Trusted sources for good information about retrofit are:

→ AECB - Association for Environment Conscious Building
→ STBA - Sustainable Traditional Buildings Alliance (Guidance Wheel illustrating the interaction of retrofit measures)
→ EH - English Heritage
→ HES - Historic Environment Scotland
→ Passivhaus EnerPhit
→ The Green Register (Trains and educates construction professionals across the UK)
→ The Retrofit Academy (Trains Retrofit Coordinators)
→ Retrofit.Support website
→ UKCMB - the UK Centre for Moisture in Buildings

The reference sources for the Benefits of retrofit infographic in Chapter 1 are as follows:

Water

→ Existing Water Usage https://waterwise.org.uk/wp-content/uploads/2019/10/WWT-Report-.pdf
→ RIBA target - RIBA Climate Challenge https://www.architecture.com/-/media/files/Climate-action/RIBA-2030-Climate-Challenge.pdf?la=en
→ AECB Water Standard (https://www.aecb.net/aecbwater-standard/)

Energy Bills

The statistic on fuel poverty is an amalgamation of individual stats for the home nations (note that definition of fuel poverty is different for England than for Wales, Scotland and N.Ireland)

→ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/882404/annual-fuel-poverty-statistics-report-2020-2018-data.pdf
→ https://www.gov.scot/publications/scottish-house-condition-survey-2018-key-findings/pages/6/
→ https://gov.wales/fuel-poverty-estimates-wales-2018
→ https://www.nihe.gov.uk/Documents/Research/HCS-2016-Main-Reports/HCS-2016-Infographic-Summary.aspx

Energy Demand Control

→ LETI Climate Emergency Design Guide

Air Quality

→ Air pollution deaths - https://www.gov.uk/government/news/public-health-england-publishes-air-pollution-evidence-review
→ NOX emissions - https://eciu.net/news-and-events/press-releases/2020/analysis-gas-boilers-and-nox-the-hidden-emitter
→ Children with Asthma - POSTNote 366, 2020, Houses of Parliament
→ https://www.parliament.uk/globalassets/documents/post/postpn366_indoor_air_quality.pdf
→ 1million homes with damp - Housing with Damp Problems, 2020, MHCLG
→ https://www.ethnicity-facts-figures.service.gov.uk/housing/housing-conditions/housing-with-damp-problems/latest

Heritage

→ https://historicengland.org.uk/content/docs/research/valuing-carbon-pre-1919-residential-buildings/

Acoustics

→ https://www.euro.who.int/en/health-topics/environment-and-health/noise/data-and-statistics

Thermal Comfort

→ https://www.ukgbc.org/wp-content/uploads/2017/12/Healthy-Homes-Full-Report.pdf

Climate Resilience

→ Heat Related Deaths - https://www.theccc.org.uk/wp-content/uploads/2016/07/CCRA-Ch5-People-and-the-built-environment-fact-sheet.pdf

→ 20% of homes at risk of overheating - https://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingInHomes-TheBigPicture-01.1.pdf

UK Average Home Energy Consumption

→ Calculated for a $60m^2$ home

→ Uses LETI Stock Model data average for UK homes energy use

→ Calculated using PHPP Modelling software

UK Average Home Emissions

→ Uses annual energy consumption figure calculated from LETI Stock Model

→ Uses cumulative grid and gas carbon factors from 2021 to 2050 taken from the Treasury Green Book

UK Average Energy Bills

→ Taken from UK Power average gas and electricity bills 2020

Peak Demand

→ UK Grid Peak Capacity for 2030 and 2050 taken from National Grid Future Energy Scenarios 2020

→ UK peak heat demand taken from: https://www.sciencedirect.com/science/article/pii/S0301421518307249

Comfort Section

Excess winter deaths over 28,000, source:

→ https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/esswintermortalityinenglandandwales/2019to2020provisionaland2018to2019final

Proportion due to cold homes up to 10,000, source:

→ https://www.nea.org.uk/articles/what-is-fuel-poverty/?parent=about-us

Annual cost to NHS of excess cold is £0.85 Bn, source:

→ https://www.bre.co.uk/filelibrary/pdf/87741-Cost-of-Poor-Housing-Briefing-Paper-v3.pdf Table 2

Excess Summer deaths source:

→ MHCLG, Research into overheating in new homes Phase 1 report, Sep 2019

Annex K: Definitions

AECB New Build: The AECB standard for new-build dwellings. See https://aecb.net/aecb-building-certification/

AECB Retrofit: The Retrofit standard proposed by the AECB. See https://aecb.net/aecb-retrofit-standard/

Air source heat pump: An energy efficient heating or cooling system that transfers heat to or from the air, typically to generate hot water and space heating or cooling.

Airtightness: A measure of the permeability of a building - i.e. how much external air enters or leaves the building in an uncontrolled fashion. Also called infiltration. This is measured either in $m^3/m^2.h$ - i.e. what volume of air escapes per hour for every m^2 of the external envelope, or in Air Changes per Hour (ACH) i.e. what proportion of the volume of air in the building escapes every hour.

Archetype: In the context of this document, one of four building typologies used as a means of modelling certain design criteria and targets to determine specific recommendations.

Biomass boiler: A form of direct combustion, heating and/or electricity derived from biomass (agricultural, forest, urban or industrial residues as opposed to fossil fuel).

Building Regulations new build 2021: In the context of this document, it refers to Approved Document Part L. Following a two-stage consultation on the Future Home Standard and Future Building Standard. The government has committed to an interim uplift to Part L of Building Regulations. Details will be published in Dec 2021 and the new standard will come into force in June 2022.

Carbon factor: The factor that is applied to electricity that is consumed by buildings, to understand that carbon emissions associated with the electricity use. The carbon factor of the UK grid changes throughout the day and the seasons depending on how much renewable energy is being generated.

Coefficient of Performance: As for Seasonal Coefficient of Performance, but relating to a particular instant or condition, rather than over the course of a year. For example, a heat pump could be rated as delivering a COP of 3.5 when the external temperature is 20°C. However, over the course of a year, the SCOP will be less.

Cold roof: A pitched roof construction where the insulation layer is at joist level above the ceiling of the top floor . Thus, the roof space itself is not heated.

Deep retrofit: A retrofit which has included work to the vast majority of the building fabric as well as changes to the building's heat source and ventilation systems. This type of retrofit would typically occur at the same time as major renovations or extension and could be expected to realise around a 70% reduction in energy demand.

Demand response: 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, electricity grid availability). Refer to the LETI Climate Emergency Design Guide, Chapter 4.

Embodied carbon emissions: The carbon emissions of an asset are the total GHG emissions and removals associated with materials and construction processes throughout the whole life cycle of an asset (Modules A1-A5, B1-B5, C1-C4). This includes emissions associated with the extraction and processing of materials and the energy and water consumption used by the factory in producing products and constructing the building. It also includes the 'in-use' stage (maintenance, replacement, and emissions associated with refrigerant leakage) and ‘end of life’ stage (demolition, disassembly, and disposal of any parts of product or building) and any transportation relating to the above.

Energy Performance Certificate: A certificate (now provided online) produced for new-build and existing dwellings which provides an A-G rating indicating the relative energy cost for that home

EnerPHit: The Passivhaus retrofit standard. See https://passipedia.org/certification/enerphit

EUI: Energy Use Intensity - the amount of energy (in kWh/m^2/year) that needs to be delivered to a building to provide for all its requirements - both regulated and unregulated energy. The EUI is not the sum of space heating and hot water demand. The actual energy used by the building for these purposes will be reduced by the coefficient of performance of the heat pump (consumption).

Fabric first: The concept of focussing on the building fabric before trying to reduce emissions using more efficient heat sources, or using renewable energy systems. The building fabric includes walls, floors, roofs, windows, doors and the ventilation system.

Fossil fuel: A natural fuel such as petroleum, coal or gas, formed in the geological past from the remains of living organisms. The burning of fossil fuels by humans is the largest source of emissions of carbon dioxide, which is one of the greenhouse gases that allows radiative forcing and contributes to global warming.

Fossil fuel free home: A home that does not use fossil fuels on site e.g. for heating, hot water or cooking.

Fuel poverty: Households who need to spend more than 10% of their income on heating their home (note: exact definitions vary across the UK nations).

Gross Internal Area: The internal area of a dwelling taken from the internal surface of the walls that define the boundary to outside and ignoring all internal arrangements. Measured on all habitable floors.

Ground source heat pump: An energy efficient heating or cooling system that transfers heat to or from the ground, typically to generate hot water and space heating or cooling.

Heat pump: Heat pumps transfer heat from a lower temperature source to one of a higher temperature. This is the opposite of the natural flow of heat. Heat pumps can be used to provide space heating, cooling and hot water. A refrigerant fluid is run through the lower temperature source (ambient air, ground, water, etc.). The fluid ‘absorbs’ heat and boils, even at temperatures below 0°C (although the coefficient of performance (COP) decreases with lower temperature). The resulting gas is then compressed, which further increases its temperature. The gas is passed into heat exchanger coils, where it condenses, releasing its latent heat. The process then repeats. (Adapted from https://www.designingbuildings.co.uk/wiki/Heat_pump).

Indoor air quality: The quality of air inside a home. This could be affected by: CO2 levels, Volatile Organic Compounds (VOCs), particulates, odour, humidity, combustion products/fumes.

LETI Best practice constrained retrofit: Best practice level of safe retrofit which can be applied to a building which may have external appearance and/or internal space constraints.

LETI Best practice unconstrained retrofit: Best practice level of safe retrofit which can be applied to a building without any significant appearance or internal space constraints.

Annex K: Definitions

LETI exemplar retrofit: Aligned with EnerPhit retrofit standard, and achieves further reductions in terms of retrofit ambition. As we are unlikely to be able to achieve a consistent level of retrofit across all our housing stock, we will need some retrofits to be in this exemplar category, both to achieve the required reduction in demand across the country, but also to drive innovation and demonstrate what can be achieved.

Low and zero carbon technologies: Technologies which provide heat energy whilst producing no or little carbon emissions.

Mechanical ventilation with heat recovery (MVHR): MVHR, heat recovery ventilation (HRV) or ventilation heat recovery (VHR) uses a heat exchanger to recover heat from extract air that would otherwise be rejected to the outside and uses this heat to pre-heat the 'fresh' supply air. (https://www.designingbuildings.co.uk/wiki/Thermal_bridging_in_buildings) As a result, MVHR is more energy efficient than natural ventilation, whilst also providing air quality and acoustics benefits.

Operational emissions: The carbon dioxide and equivalent global warming potential (GWP) of other gases associated with the in-use operation of the building. This usually includes carbon emissions associated with heating, hot water, cooling, ventilation, and lighting systems, as well as those associated with cooking, equipment, and lifts (i.e. both regulated and unregulated energy uses).

Overheating: The condition where the internal temperature of a dwelling, typically in summer, spends a certain amount of time above what is considered comfortable. Exact limits vary depending on the standard, but typically anything above 25°C could be considered overheating.

Part F: The Building Regulations Approved Document for England which sets out the regulations for ventilation in new and existing dwellings.

Part L: The Building Regulations Approved Document for England which sets out the regulations for conservation of fuel and power in new and existing dwellings.

Passivhaus new build: The Passivhaus standard for new-build dwellings. See https://passipedia.org/basics.

Peak demand: Refers to the times of day when our electricity consumption is at its highest which, in the UK, occurs between 5-30pm to 6pm each weekday evening.

Performance gap: This term refers to the discrepancy between energy predictions at design stage, compared to in-use energy consumption of buildings.

Permeability: See airtightness

Primary energy: Primary energy is energy that has not undergone any conversion or transformation. As a common example, each kWh of grid electricity used in a UK building requires 1.5 kWh of primary energy; this accounts for the energy required for power generation (including fuel extraction and transport to thermal or nuclear power stations), transmission and distribution.

Primary pipework: The pipework between the hot water source (e.g. heat pump) and the hot water tank. This pipework will tend to be of a large diameter and will be used whenever the tank needs to be brought back up to temperature.

Regulated energy: Energy used by the fixed building services to provide heating, hot water, ventilation and lighting.

Retrofit: The retrospective upgrading of a building to enable it to respond to the imperative of climate change.

Seasonal Coefficient of Performance (SCOP): The ratio of input to output energy that a heat pump is able to deliver, on average, across the course of a year. For example, a SCOP of 2 means that, on average, a heat pump will deliver 2kWh of heat energy for every 1kWh of electrical energy it draws from the grid.

Shallow retrofit: A retrofit involving several, relatively minor interventions (e.g. loft insulation, cavity wall insulation) which may also include a change to the heat source and ventilations systems. This type of retrofit could be expected to realise no more than a 30% reduction in energy demand.

Space heating demand (SHD): The amount of energy per m^2, over the course of an average year, which is needed to maintain a comfortable internal temperature. This is directly related to the thermal performance of the building and is therefore a good proxy for fabric efficiency.

Standard Assessment Procedure (SAP): A government-approved methodology for calculating regulated energy demand (heating, hot water, lighting) in homes.

Step-by-step: The concept of planning a retrofit in a series of stages – perhaps over several years. This approach goes alongside the whole house approach to ensure that the final result is a dwelling which has been retrofitted to its full potential without adverse impact on the building fabric or the internal living environment.

Thermal bridge: A discontinuity in the insulation layer which results in additional heat loss. If the bridge is particularly bad, then condensation could occur internally.

Thermal comfort: The maintenance of a dwelling's internal environment to ensure an appropriate range of internal temperatures throughout the year. This is typically between 20 and 25°C.

Treated Floor Area (TFA): The internal area of a dwelling less the footprint of internal walls and other uninhabitable spaces. Measured on all habitable floors. Typically this is around 90% of the Gross Internal Area.

U-value: The rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The units of measurement are W/m².K. A lower U-value indicates a structure which conducts less heat.

Unregulated energy: Energy consumed by a building that is outside of the scope of Building Regulations, e.g. energy associated with equipment such as fridges, washing machines, TVs, computers, lifts, and cooking.

Warm roof: A pitched roof construction where the insulation layer is in line with the roof rafters, just below the outer layer of tiles/slates. Thus the roof space is heated and can be occupied.

Whole house approach: The concept of treating the whole house as a system when planning a retrofit and thus ensuring that any action taken does not preclude another action at a later date. It also means that actions which may affect other aspects of the dwelling's performance are properly considered to ensure that they do not result in any unintended consequences.

Whole house Retrofit Plan: A coherent plan which sets out the proposed retrofit measures for a particular house. In creating the plan, the effect and interaction of the measures will have been considered to ensure that there is no adverse effect on the building fabric or the internal living environment. The plan could be staged over several years (see also whole house approach and Step-by-step).

Annex L: Abbreviations

A/C	Air Conditioning
ACH	Air changes per hour
AHU	Air Handling Unit
ASHP	Air-source Heat Pump
BSI	British Standards Institute
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power unit (usually gas-fired)
CIBSE	Chartered Institution of Building Services Engineers
CLT	Cross Laminated Timber
CO_2	Carbon Dioxide
COP	Coefficient of Performance
DHW	Domestic Hot Water
DiBt	Deutsche Insitiut fur Bautechnik
DNO	Distribution Network Operator
EAHP	Exhaust air source heat pump
EC	Embodied Carbon
EHA	English Housing Survey
EHS	English Housing Survey
EPC	Energy performance Certificate
EUI	Energy Use Intensity
EWI	External Wall insulation
GB	Great Britain
GHG	Greenhouse Gases
GIA	Gross Internal Area
GWP	Global Warming Potential
HACT	Housing Associations' Charitable Trust
HHSRS	Housing Health and Safety Rating System
HLP	Heat Loss Parameter
HVAC	Heating Ventilation and Air Conditioning
IEA	International energy Agency
IWI	Internal Wall insulation
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelised Cost of Energy
LETI	London Energy Transformation Initiative
MEV	Mechanical Extract Ventilation
MVHR	Mechanical Ventilation with Heat Recovery
NLA	Net Lettable Area
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PH	Passivhaus
PHPP	Passivhaus Planning Package
PIR	polyisocyanurate insulation
POE	Post Occupancy Evaluation
ppm	Parts per million
PUR	polyurethane insulation
PV	Photovoltaic panels
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
RRWP	The Notting Hill's Residents Repairs Working Party
SCOP	Seasonal Coefficient of Performance
SHD	Space heating demand
SFP	Specific Fan Power
SHQS	Scottish Housing Quality Standard
TFA	Treated Floor Area
UK	United Kingdom
VCL	Vapor Control Layer
WHO	World Health Organisation
WLC	Whole Life Carbon
WSHP	Water Source Heat Pump
WWHR	Waste water heat recovery
ZC	Zero Carbon

Annex M: Acknowledgements

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This is a climate emergency

We urgently need to retrofit our existing buildings to reduce energy consumption and carbon emissions. All too often, poor retrofits can result in damage to the building fabric and a worsening of the living environment, with perhaps even damp and mould.

But with deep retrofitting of the building fabric and the inclusion of a heat pump the average energy demand of a home can be reduced by up to 75%.

LETI have developed this Climate Emergency Retrofit Guide to provide practical solutions for the built environment - setting out best practice and exemplar targets for retrofit, which we believe are achievable in the vast majority of UK dwellings.

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