Retrofitting Surrey’s housing stock to reach net zero: lessons from the Passivhaus approach

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Housing | Energy | Development | Sustainability

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Executive Summary

Various methods of creating low-carbon, energy efficient homes have been developed in recent years. The Passivhaus standard is one of the most well-regarded solutions, with a growing portfolio of successful projects. It is often cited that to develop low-carbon homes the priority should be on the Passivhaus standard approach of 'fabric-first', focusing on saving energy, before generating 'clean' energy. This approach can also be applied when retrofitting properties, with other approaches being whole-house or technology led. This project explores the details and specifications on how best to approach retrofitting to maximise the potential benefits.

Heating is the largest use of domestic energy[1], therefore measures to reduce space heating demand will have a large impact on energy use within the home. Achieving the Passivhaus-approved EnerPHit standards for Surrey's existing housing stock would require large-scale, intrusive, deep retrofits. Specialist consultants 'QODA consulting', conducted building energy modelling of three different Surrey archetypical homes, with the aim of understanding how these real homes could achieve EnerPHit standards.

The modelling showed that reductions in carbon emissions for space heating could be reduced by up to 89 – 94%. In the properties modelled, this represented maximum savings of between 2920 and 7765 $kgCO2/m^2$ depending on the property type. The space heating demands were modelled to reach as low as 91, 72 and 45 $kWh/m^2/yr$. These figures indicate that EnerPHit may not be achievable because the standard requires space heating demands to reduce to 20 $kWh/m^2.yr$. The modelling did not include solid floor insulation as a retrofit measure, due to the intrusiveness of installation, but it is worth noting that even if floor insulation had been included, the lowest space heating requirement would work out at 36 $kWh/m^2/yr$ - still failing to meet the EnerPHit requirement.

This work highlighted the importance of insulating walls, which often yields the biggest drop in heating demand, followed by replacing or upgrading windows with better performing options, either new double or triple glazing. Roof insulation can also be another easy win, whereas floor insulation requires much more intrusive works to improve this key component of the building envelope. The reports emphasised the necessity of improving both airtightness and a high-quality ventilation strategy to further benefit from reduced heating demand and increased level of comfort.

Another significant point raised throughout the modelling reports was the importance of good communication with building control if carrying out these retrofits. When renovating existing dwellings, there are energy efficiency standards that should be met under the Building Regulations Part L1B – different thermal elements (walls, floors, etc) must achieve a certain U-value[2] of performance. In many cases, applying retrofit measures that achieved the Building Regulation U-values caused other negative impacts, such as an increased condensation risk. As a result, upgrades of a lower standard were recommended to mitigate this risk, and so close cooperation with Building Control is necessary to ensure all parties support the design.

The stipulation in the regulations that renovations must comply *'…in so far as that is technically, functionally and economically feasible'* provides the flexibility required to work with building control to reach the most suitable solution. Even where upgrades may not meet the Building Control energy performance requirement, involved discussion ensures that measures installed will still not only improve the energy performance and reduce heating demand but also ensure the home remains a healthy and comfortable place to live.

[1] Help and advice for heating your home - Energy Saving Trust

[2] U-values measure the thermal resistance of a building element in W/m^2K (watts per meter square kelvin). The lower the U-value, the less energy is required to maintain comfortable conditions inside a building.

Background

All Local Authorities in Surrey have targets for reaching net-zero in the near future, following a ‘climate emergency’ declaration. As a county this is reflected in the goals of the climate change strategy to reach net-zero by 2050.

Since households are responsible for around 40% of UK greenhouse gas emissions[3] and 80% of the housing stock that will exist in 2050 has already been built today, effective retrofit is critical to meeting carbon neutrality goals. Specifically, emissions related to domestic heating will need to be reduced by 95% to reach the 2050 net zero goal[4]. Achieving this level of ambition will need to take the form of large-scale projects, adopting a ‘fabric-first’ approach to drastically reduce the quantity of energy used to heat these homes.

Various methods of creating low-carbon, energy efficient homes have been developed in recent years. The Passivhaus standard is one of the most well-regarded solutions, with a growing portfolio of successful projects. Following the Passivhaus standard produces dwellings with high levels of occupant comfort that use very little energy for heating and cooling.

The standard and costs are relatively straightforward for new-build properties, but applying the standard to retrofit becomes more complex. It is also more difficult to achieve the performance standard since there is little to no control over very influential factors such as the building orientation, structure and glazing.

EnerPHit is a retrofit certification that follows Passivhaus principles. The EnerPHit standard relaxes some of the Passivhaus criteria, recognising the limitations associated with applying the standards of Passivhaus to retrofit properties. These limitations include building orientation, form factor (external surface area to volume ratio) and glazing. However, EnerPHit still requires very demanding criteria and will typically result in a building out-performing a new-build property in both energy use and comfort.

[3] Emissions (data.gov.uk)
[4] Help and advice for heating your home - Energy Saving Trust

Project Overview

Bringing the housing stock close to net zero ready is a complex task. With many different paths to decarbonising homes available, it is useful to understand the feasibility, impact and implications of applying one path/method to different types of housing. As a well-established and proven path, Passivhaus and EnerPHit standards could hold a huge potential for achieving a net-zero ready housing stock. This project will explore this with the following goals:

1. To assess three different typical Surrey housing archetypes using information gathered by a Chartered Surveyor and a Passivhaus design consultant to analyse the potential energy performance of a property if measures are applied.
2. To identify the physical constraints and considerations for households looking to install the measures required to meet Passivhaus/EnerPHit standards.
3. To use the findings to inform the practical considerations of upgrading the Surrey housing stock to Passivhaus/ultra-low carbon standards.

Approach

Action Surrey (Surrey's energy efficiency partnership operated by ThamesWey), in collaboration with partner Surrey Local Authorities, commissioned design engineering consultants 'QODA Consulting' to complete a fabric options assessment on three different properties that represent typical housing archetypes found in Surrey.

The 'baseline' annual heat load for each property was modelled using the Passivhaus Planning Package (PHPP). The heat losses were then modelled for three levels of proposed improvements, with basic, easily achievable improvements in Option 1, up to more extensive measures in Option 3. The details for each Option for the three properties modelled can be found in Appendix 1. The detail of these reports is explored here with regards to the heat demand, physical constraints and considerations for households looking to install the measures required to meet Passivhaus/EnerPHit standards.

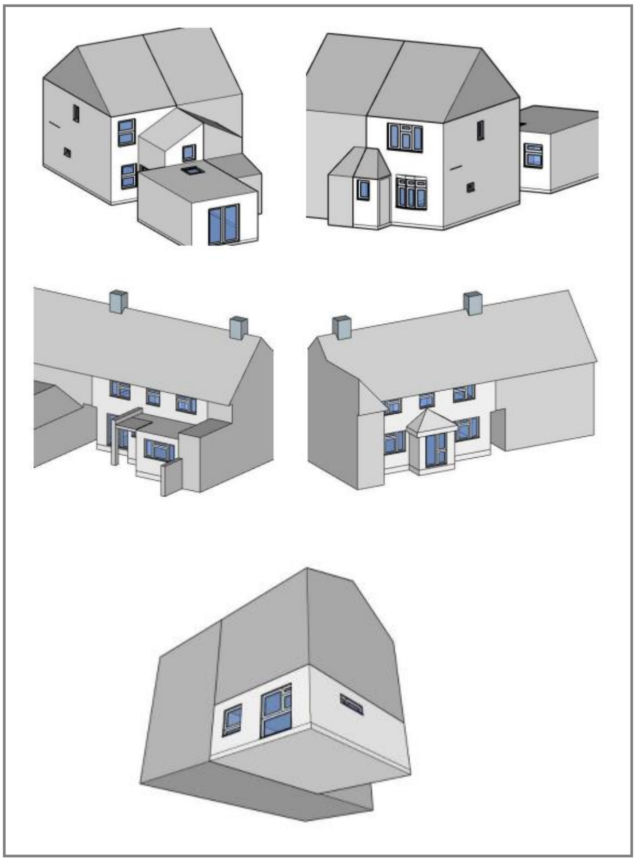

Figure 1: The properties modelled for this project (top to bottom):
- *1930's Semi-detached house*
- *1970's Mid-terrace*
- *1970's ground floor flat*

Summary of Findings

The Passivhaus standard covers five key design principles; insulation, high performance triple glazed windows, Mechanical Ventilation with Heat Recovery (MVHR), airtightness and a thermal bridge free design.

The first of these steps to take is to optimise the efficiency of the thermal envelope to minimise heat losses – also known as 'fabric first'. The remaining energy demand is then met through incorporating energy efficient systems and potentially renewables.

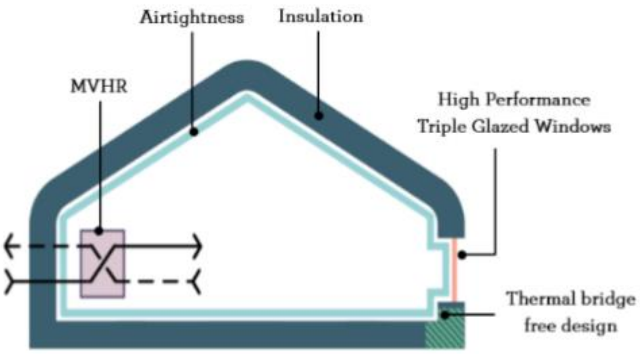

Figure 2: Passivhaus principles illustrated. Image courtesy of QODA Consulting.

Insulation

A well-insulated building envelope keeps warmth in during the cold months and excess heat out during the summer months. There are several elements of insulation; wall, roof and floor, each is discussed separately below.

Wall insulation

In all three of the surveyed properties the walls represented the highest area heat losses, therefore measures to reduce these losses would have the most significant impact on the energy demand of the property.

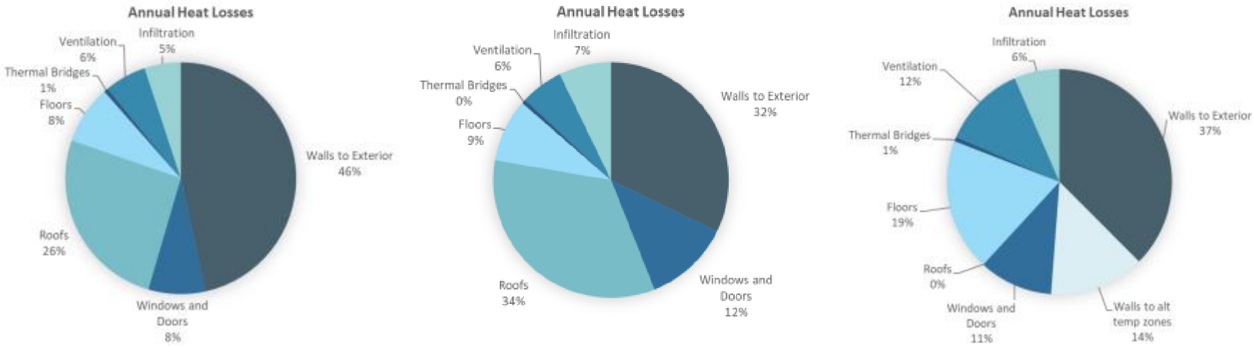

Figure 3: Baseline annual heat losses from each property. From left to right: Semi-detached, Mid-terrace, Ground floor flat.

There are property characteristics that must be considered for before installing wall insulation:

Wall type

The most common wall types are either cavity or solid. Cavity walls are insulated primarily by filling the cavity with insultation such as blown mineral wool or polyurethane foam. Certain criteria will need to be met to ensure cavity wall insulation won't lead to internal damp. If the property has solid walls, either internal or external insulation can be used.

Property layout

In regards to external insulation, the thickness of the insulation may be restricted by the shape of the property and the distance to other properties, especially concerning boundary encroachment. Internally, space can also be an issue, where thicker insulation begins to take up too much floorspace.

Internal versus External

To push the wall insulation measures to their limits, combining several types of insulation and using thicker internal and external insulation could achieve impressive levels of reduction in heat demand. There are pros and cons to both internal and external insulation, with the main points listed in the table below.

Internal Wall Insulation Advantages	External Wall Insulation Advantages
No change to external appearance of property	Lower risk of interstitial condensation than internal insulation
Planning permission not required	Better airtightness performance
No need for scaffolding (and associated costs)	Avoids thermal bridges reducing surface condensation and mould growth risk
	Less risk of timber joists rotting, kept warmer
	Installation less disruptive if occupants living in property
	No loss of floor area
	Lower risk of summer overheating due to preservation of existing thermal mass

Overall, there are more risks associated with internal insulation, so external insulation should be considered first where feasible. Internal insulation is more liable to condensation, primarily due to increased chances of creating thermal bridges and moisture accumulation. This can lead to fabric damage, mould growth and can decrease the fabric's thermal performance. There are options available to minimise this risk:

- Breathability. Using breathable, 'vapour-open' materials for internal insulation to avoid moisture accumulation. This can include materials such as wood fibre or hemp. However, these materials are less insulating than more typical products such as Celotex or insulated plasterboard.
- Good ventilation strategy. More details can be found in a later section.
- Appropriate insulation design. Careful consideration when designing the insulation strategy for the whole property can minimise thermal bridging.

- Applying a ‘masonry protection cream’. This is applicable to cavity wall or cavity wall with internal wall insulation. The external brick leaf is protected from water ingress from wind-driven rain, by providing an invisible, water repellent layer to protect the insulation layer within the cavity. Prior to application, the external walls should be free from defects, damage and inadequate pointing.

Easy wins

The findings of the surveys show that installing even just one layer of wall insulation can make the biggest difference of all available measures. In the semi-detached property, adding 90mm of external wall insulation cut the heating demand by 44%.

Essentially the larger the external surface area, the more gains can be made from insulating that area. In a detached or semi-detached property, the walls are likely to have the highest externally facing surface area and so prioritising wall insulation will provide the biggest reduction in heat loss. In terraced properties or bungalows, the roof may make up a higher proportion of the external surface area and should therefore be higher on the priority list. This is illustrated in the modelling for the terrace property which showed that applying the simplest Option 1 measures gave a 20% reduction from the baseline for wall insulation, compared to a 27% reduction for roof insulation.

Using a variety of wall insulation methods

Using a combination of different insulation types can yield more efficiency gains. Terraces, maisonettes and flats will likely require more than one type of wall insulation regardless, due to different wall types such as shared walls and potential limits on external measures. This is demonstrated in the modelling of the terrace property where adding cavity wall insulation to the cavity walls and internal insulation on the solid walls reduced the heating demand by 26%, compared to cavity wall insulation alone, which would reduce heat demand by 20%. The internal insulation for the solid wall would require discussions with Building Control. This is because a thinner or breathable material layer of insulation would be the preference to minimise the risk of condensation in the property, but this is then unlikely to meet building regulation U-values. It is worth having this dialogue because even a thin layer of internal insulation can produce a further 6% reduction in overall heating demand compared to just using cavity wall insulation.

Doubling up on wall insulation can decrease heat losses further but may be limited by planning or heritage restrictions. Doubling up using external wall insulation may reduce heating demand further than doubling up using internal wall insulation. In the terrace property adding external insulation on top of the single layer of cavity and internal insulation could provide an additional 6% reduction compared to the additional 5% if internal insulation were used on all the walls, along with cavity insulation on the cavity walls.

Flats and apartments

Flats are unlikely to be able to install external or cavity insulation, unless an agreement is reached for the entire block to receive the insulation. If this can be done it is highly recommended; cavity wall insulation combined with even a thin layer of internal insulation on communal walls can offer savings around the 40% mark. The internal insulation only needs to be relatively thin - 40mm to make a difference, but this would not meet the required U-value for building regulations. A thicker layer (over 80mm) would be needed to achieve the required U-value, however this would significantly reduce the floor area of the relevant rooms. It is recommended to discuss this dilemma with building control, as they may accept a thinner layer of internal insulation on an internal wall because it will typically have much lower levels of heat loss than external walls. Adding internal insulation to all walls of the property, in combination with external or cavity wall insulation could reduce the heating demand by a further 5%.

In flats and apartments, external insulation is likely to produce more savings than internal, especially as the internal insulation should be a breathable material as mentioned above. If there are restrictions on external or cavity wall insulation, there is a limited amount that can be achieved using internal insulation alone, due to space requirements limiting the thickness of the insulation.

Detached and semi-detached

In a detached or semi-detached house external insulation may be enough on its own to produce significant reductions in heat demand, at around 40% from the baseline. Increasing the thickness of the external insulation will enhance the savings, though past a certain point, further increases are subject to diminishing returns. For example, 90mm of external insulation can reduce the heat demand of a semi-detached property by around 44%, whilst also meeting building regulations. Increasing this thickness to 120mm provides a further 2% reduction, but could cost an estimated 20% more to install. From a lifetime perspective it is still worth considering as the savings made may eventually pay back the cost over time, but the payback period could be disproportionally longer. To illustrate, if we assume a lifespan of 40 years on insulation and 75m² floorspace heated with a gas boiler [5], the lifetime savings of reducing the heating demand by an extra 2% using 120mm thickness rather than 90mm, would be an estimated £2,211.

Roof insulation

The area with the second highest heat loss on average is the roof. In some cases, where roof space represents a larger proportion of the external surface area of a property (e.g. terraced properties, bungalows), it can be the largest source of heat losses.

The most valuable finding from the surveys is the balance of the small improvement in potential results when insulating around the joists, not just in between, with providing continuity in the thermal envelope to eliminate thermal bridging.

For insulation of pitched roofs at ceiling level, to reach Building regulation U-values, an extra layer of mineral wool insulation either above or below the joists is required in combination with insulation between the joists. This extra layer only needs to be relatively thin – 100mm, to make a difference. Using a thicker extra layer of insulation, for example 200mm instead of 100mm, does not offer a sufficient difference in the heat loss to make it worth using, with the surveys modelling just 1 or 2 extra kWh/m².yr difference.

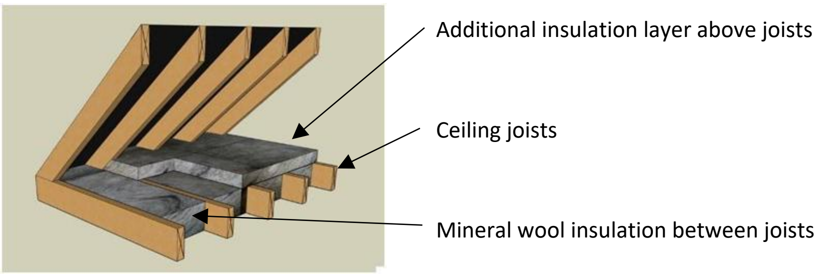

Figure 4: Ceiling level insulation for a pitched roof. Image courtesy of EnergyQuarter.com.

If the property has both pitched and flat roofs it is worth insulating both. Insulating the main pitched roof at ceiling level in between and above the joists, along with insulating between the joists of any auxiliary and flat roofs can produce heating demand reductions of between a quarter and a third from the baseline, roughly an extra 5 – 10% on top of insulating the main pitched roof alone.

When renovating flat roofs insulating between the joists is recommended. However, this alone is not enough to meet the required U-values for building regulations, an extra 100mm layer of insulation would suffice. This extra layer could be placed above or below the joists, but both need careful consideration. An extra layer above the joists in a flat roof would require re-roofing and in many cases it would only be feasible in a full house renovation was planned as it could add a considerable cost and an extra hurdle with planning applications. Adding a layer below the joists may also be impractical as it could reduce room heights to an unacceptable and/or non-compliant level. These extra steps for the additional layer of insulation to meet building regulation U-values end up only making a minor difference to the heat demand, likely just 1 kWh/m².yr, so it would be worth working with building control to find the best solution.

[5] Based on this example, 2% saving is 10 kWh/m².yr, based on 7.37p/kWh (April 2022) saves 73.7p/m².yr, £55.28/yr for 40 years

An important point highlighted in the analysis of the modelling is the impact of additional layers of roof insulation on thermal bridging. As mentioned above, increasing the thickness of above or below joist insulation does not offer much benefit in terms of reducing heat loss, but does provide an important benefit in eliminating thermal bridging.

Again, these points emphasise the importance of good communications with Building Control to find the most acceptable way forward. The requirements to meet building regulation U-values are likely to involve more intrusive and extensive works, primarily re-roofing, meaning significant extra costs and administration for comparatively little gain.

Floor insulation

As another significant source of heat loss, insulating the floor can significantly reduce the heating demand of a property. In conjunction with wall insulation, adding floor insulation could reduce heating demand by 21 kWh/m².yr. Complete floor removal and reconstruction with 150mm insulation board could reduce this by a further 39 kWh/m².yr.

However, this is a highly intrusive installation process and floor insulation is often dismissed because of this. If undertaking a total retrofit where prolonged disruption is expected, then a total floor reconstruction would be worth doing to reach the minimum energy demand for the property. Using the most extreme measures considered in the surveys could reduce the energy demand of a typical semi-detached property to as low as 36kWh/m².yr.

Whilst there are considerable gains to be made by insulating the floor, it may be easier to concentrate efforts in other areas such as the walls, to more make a significant difference with less disruption. It is worth noting that if wall and roof insulation is installed, the losses from the floor will then become proportionally larger and will likely become the biggest source of heat loss going forward. This is particularly evident in ground floor flats where there is little to no heat loss from the ‘roof’, therefore after insulating other areas, the floor could become accountable for up to half of the heat loss from the property.

If the insulation is being considered as part of a whole house renovation, the inconvenience of pulling up all the flooring may not be such a barrier. However, there are still factors that may prevent the installation with regards to building control, especially for solid floors. Floor insulation will not be possible if the addition of a layer of insulation reduces the floor-to-ceiling height beyond the building regulation minimum. Door thresholds and step heights would also be affected and introduce the need for further remedial works.

There is a more convenient option for suspended floors where the insulation is installed using a small robotic device that can travel in the crawlspace. Using this installation method only a small amount of floor needs to be lifted, just enough to lower the device under the floor level and is therefore far less intrusive.

Windows

In Passivhaus design triple glazed windows are strategically positioned to make optimum use of the sun’s energy through solar heat gains, without overheating the property. In retrofit changing the orientation of windows is incredibly difficult and therefore not a requirement for EnerPHit.

The recommendations from the surveys are that if the current windows are single glazed, these should be replaced with double glazed at a minimum. If the current windows are already double glazed but are old (10-15 years or more) or leaky these should also be replaced, even if just updated with new double glazing, as the performance of these has improved vastly over the years.

Triple glazed windows would offer further benefits, especially when installing alongside other insulating measures. Triple glazing also offers increased levels of acoustic insulation which is worth considering if the property is in a noisy area. Triple glazing can also further guarantee occupier comfort if a lot of time is spent next to windows, due to the superior airtightness they provide.

Regarding building regulation requirements, the 2021 regulations stipulate that window and door renovations should meet U-values of 1.4 W/m²K or have an Energy Rating band of B or above. The surveys showed that upgrading the existing double glazing to new, better performing double glazing would decrease the U-value from an average of 2.29 W/m²K to around 1.55 W/m²K. This achieves the old building regulation U-value (1.6 W/m²K), but just misses the updated requirement. As long as the units have an Energy Rating of B or above, these U-values would be acceptable.

Ventilation

Whilst insulation is undoubtedly the most impactful retrofit for creating more energy efficient homes, it absolutely must be done in combination with a high-quality ventilation strategy. The focus on reducing airtightness from an estimated 6 air changes per hour to 1-2 can mean ventilation has a tendency to be neglected. Without good ventilation, the highly insulated and airtight property will likely develop stale air, condensation and mould.

Trickle vents above windows and intermittent mechanical ventilation in the 'wet' areas of a home, such as bathrooms and kitchens are now commonplace but in highly insulated and airtight homes, this will not be enough to manage humidity levels to prevent damp building up and so continuous ventilation is deemed absolutely necessary.

Mechanical ventilation with heat recovery (MVHR)

Mechanical ventilation with heat recovery (MVHR) is a core part of Passivhaus design. It provides pollen and dust-free air; filtered from external particles, with maximum energy efficiency achieved through heat recovery. However, there are a number of potential obstacles that make installation challenging.

- Unit size – for medium or larger properties the MVHR unit requires space of a washing machine, with access for maintenance. Medium sized properties that require this larger specification may not have a suitable place to install the unit, especially when considering the next point.
- Unit position – the MVHR unit needs to be placed close to external walls as possible, or in a loft, ensuring it is still within the thermal envelope of the property i.e. only if there is no ceiling level insulation. If ceiling level insulation is present, it may be feasible for the unit to be in a loft if an insulated 'room' can be created around the unit.
- Intrusive installation – MVHR requires ducts to be connected from the unit to all rooms. These can be hidden in the ceiling (although this involves opening the ceiling up) by creating a suspended ceiling, or carefully configuring the ducts in a group and boxing them in. The two main layouts are a branch system or a radial system. Radial uses smaller diameter ducts, with at least one for each room, whereas branch uses larger diameter 'trunk' ducts, with smaller ducts that branch off into each room. The layout may be made even more complex because the end valves in each room should ideally face away from doorways.
- Cost – MVHR will be more expensive than the alternatives.

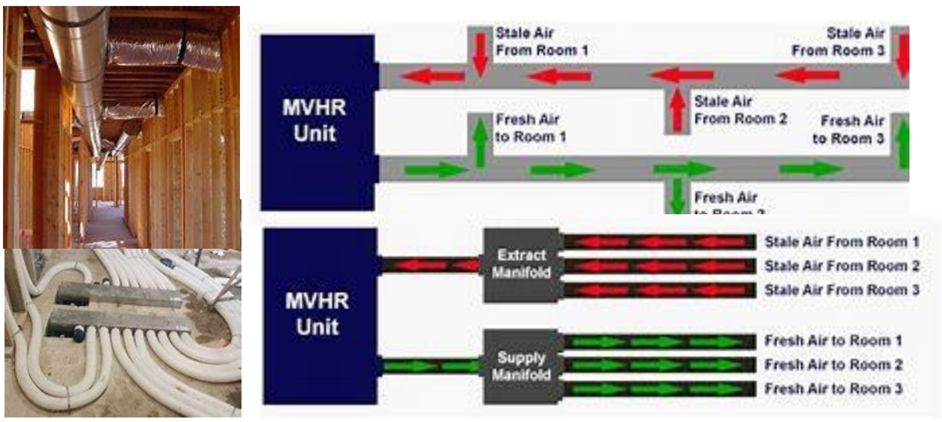

Figure 5: Examples of installed branch (top, LennoxPros.com) and radial (bottom, HeatSpaceandLight.com) MVHR systems. Diagrams further illustrate layouts, credit: ExtractorFanWorld.co.uk

Centralised Mechanical Extract Ventilation

Centralised Mechanical Extract Ventilation provides a continuous level of ventilation, rather than intermittent, extracting from wet rooms including the kitchen and bathroom. Installing a centralised MEV will achieve the level of ventilation needed for highly insulated properties and will cost 3 to 6 times less[6] than MVHR systems. However, without a 'heat recovery' feature the incoming air will be unheated and remain at outside temperature. In the climatic zones in the UK this unheated air will cool the internal temperature for most of the year, therefore these units will not deliver the same level of energy efficiency as more energy will be required to maintain a comfortable internal temperature. This compromises any reductions in space heating demand made through improving air tightness.

Airtightness

The building envelope should be as airtight as possible to avoid leakage, draughts and moisture damage. Air leakage paths occur in a variety of locations within a property, including but not limited to: gaps in suspended timber floors, leaky windows and doors, ceiling to wall joints in eaves, chimneys, loft hatches, light and electrical fittings, vents, gaps around pipes and settlement cracks in floor to wall joints. An airtightness test is recommended and can help identify problem areas.

There are specialised materials that can be used to block these pathways of air. The structure can be reinforced through re-plastering walls if needed and adding airtightness boards or membrane to ceilings. Airtight rubber seals can close gaps around service penetrations such as pipe inlets. Membrane tapes and spay-on films can be used for junctions.

Thermal Bridging

Attention should be given to 'weak' points or discontinuity in the thermal envelope, typically at joints and corners, which can create a path for heat to be transferred out of the property. Measures should be taken to ensure consistent internal temperatures, eliminate moisture damage and improve energy efficiency.

The easiest way to minimise thermal bridging is to consider the total continuity of the thermal envelope throughout the entire insulation installation. This is often achieved by overlapping insulation to minimise the risk of thermal bridging at joints. The surveys reported the following areas to focus on:

- Externally bringing the external wall insulation 300mm below the internal ground level and adding specialised insulation, such as XPS which prevents moisture absorption, below the damp proof course level if applicable.
- If a combination of internal and external wall insulation has been used, ensure they overlap by 400mm at the wall joints.
- Internally overlapping insulation around the loft perimeter to cover the wall to ceiling joint. For flat roofs, adding additional insulation at the joists and parapets, or overlapping internal and external insulation by 400mm.
- Windows should have a thin layer of insulation around the reveals or if the windows are being replaced they should be placed in line with the surrounding wall insulation to create a continuous layer.

[6] How to choose between MEV and MVHR | Aereco

- If internal wall insulation is installed, even a thin layer of floor insulation would help reduce thermal bridging.

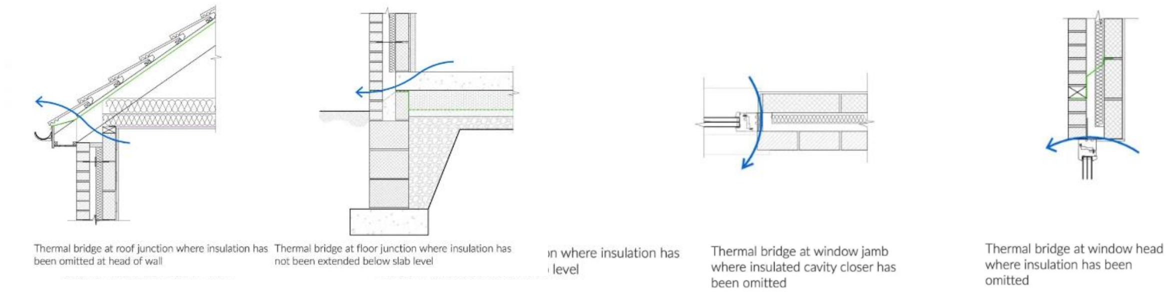

Figure 6: Common thermal bridging points. Image credit firstinarchitecture.co.uk.

A note on costs

This project has focused on the practical feasibility of retrofitting homes in Surrey to Passivhaus/EnerPHit standards. There are lots of factors to consider when undertaking building upgrades and something that this project has not covered is the costs. Cost-effectiveness is another key aspect in selecting the most suitable level of retrofit and which components to prioritise. This has been touched upon in the recommendations above, but the project has not analysed the installation cost and energy bill savings of the various measures.

Evaluation of the Passivhaus approach to carbon-zero homes in Surrey

The modelling showed that none of the three houses surveyed could reach Passivhaus or EnerPHit requirements, even under the most extensive retrofit option 3. The terraced property achieved the lowest heating demand under Option 3 – short of EnerPHit standards, but did meet 'AECB' retrofit standards, after reducing the heating demand to 45kWh/m².yr. The 'AECB' retrofit standards offer a pragmatic approach to reducing carbon in homes, whilst not as ambitious as Passivhaus and EnerPHit it still strives for low energy demand targets whilst remaining attainable. This standard is a good resource[7], especially in regards to its focus on managing retrofit risks to avoid unintended consequences.

The modelling undertaken in this project did not include floor insulation in any of the 3 levels of improvement options. This was due to the measure being deemed as too intrusive to install in large-scale retrofit projects. Even with floor insulation, it remains highly unlikely that EnerPHit standards would be achieved. The closest result modelled was the semi-detached property, using the most extreme measures used for the surveys with a significant amount of floor insulation – 150mm. This produced a space heating demand of 36 kWh/m².yr, still a way off the 20 kWh/m².yr EnerPHit requirement, but notably under the 50 kWh/m².yr requirement for the 'AECB' retrofit standard.

Whilst Passivhaus and EnerPHit may not be attainable, the approach that they embody is extremely relevant to improving the current, inefficient housing stock. The standards are a good reference point, even if it is not the intention to go for certification.

A whole house retrofit would include a substantial amount of work and may be typically beyond reach of the average household, or even large landlords and estate managers. A phased approach could be worth exploring - potentially to be integrated into existing asset management plans for the latter. The measures to prioritise, that will provide the biggest immediate difference, are insulating the areas with the largest externally facing surface area. This is most likely to be the walls or the roof, to have the largest reduction on energy demand. The most difficult measure to install retrospectively is floor insulation. Floor insulation should be considered during the new build process to prevent the need for highly intrusive retrofitting.

Ventilation cannot be overlooked and must be thought through alongside retrofitting any other measures. Ventilation is the measure that has the potential to cause the most on-going maintenance and impact on internal space due to the size of the unit and ducts layout. If MEV is chosen, the airtightness of the property is compromised but it is the less intrusive and less expensive option.

In order to achieve carbon natural homes, we will need to look beyond the Passivhaus approach. There are lessons that may be taken from the variety of retrofit methods available. Whilst this study has shown that there are huge gains to be made towards lowering the carbon footprint of the housing stock through a 'fabric-first approach', it has also shown that this alone will not achieve the net zero targets. An integrated approach, linking ideas from fabric first with technology-led solutions should be explored. The gap left after reducing energy demand to a minimum will need to be addressed through renewable technologies.

Useful links

[Passivhaus: A route to net zero retrofit]

[AECB Retrofit Standard - AECB]

[7] AECB Retrofit Standard - AECB

Appendix 1: Modelling scenarios per property

Semi-detached

	Baseline	Option 1	Option 2	Option 3
External Walls	No insulation	90mm external wall insulation	120mm external wall insulation	150mm external wall insulation
Floor	No insulation	No insulation	No insulation	No insulation
Roof - Pitched – Rafters' level	No insulation	150mm mineral wool in between the rafters	150mm mineral wool in between the rafters & 100mm mineral wool below/above the rafters	150mm mineral wool in between the rafters & 100mm mineral wool below/above the rafters
Roof - Flat	No insulation	150mm mineral wool in between the joists	150mm mineral wool in between the joists & 100mm mineral wool below/above the joists	150mm mineral wool in between the joists & 150mm mineral wool above the joists
Roof - Pitched - Ceiling level	No insulation	150mm mineral wool in between the joists & 100mm mineral wool above the joists	150mm mineral wool in between the joists & 150mm mineral wool above the joists	150mm mineral wool in between the joists & 200mm mineral wool above the joists
Windows	Existing double glazing	New double glazing	Triple glazing	Triple glazing
Airtightness	6 ach	4 ach	2 ach	1 ach
Ventilation	Natural Ventilation & Intermittent extract fans in wet rooms	Centralized Mechanical Extract Ventilation (CMEV)	Mechanical Ventilation with Heat Recovery (MVHR)	Mechanical Ventilation with Heat Recovery (MVHR)
Heating & Hot water	Gas boiler	Gas boiler	ASHP	ASHP

Mid-terrace

	Baseline	Option 1	Option 2	Option 3
External Walls	No insulation	Insulation in the cavity	Insulation in the cavity & 100mm additional external wall insulation	Insulation in the cavity & 150mm additional external wall insulation
Walls towards Undercroft	No insulation	40mm internal wall insulation	40mm internal wall insulation	80mm internal wall insulation
Floor	No insulation	No insulation	No insulation	No insulation
Floor Overhanging	No insulation	150mm mineral wool in between the joists	150mm mineral wool in between the joists	150mm mineral wool in between the joists
Roof - Flat	No insulation	150mm mineral wool in between the joists	150mm mineral wool in between the joists & 100mm mineral wool above/below the joists	150mm mineral wool in between the joists & 150mm mineral wool above the joists
Roof - Pitched - Ceiling level	No insulation	150mm mineral wool in between the joists & 100mm mineral wool above the joists	150mm mineral wool in between the joists & 150mm mineral wool above the joists	150mm mineral wool in between the joists & 200mm mineral wool above the joists
Windows	Existing double glazing	New double glazing	Triple glazing	Triple glazing
Airtightness	6 ach	4 ach	2 ach	1 ach
Ventilation	Natural Ventilation & Intermittent extract fans in wet rooms	Centralized Mechanical Extract Ventilation (CMEV)	Mechanical Ventilation with Heat Recovery (MVHR)	Mechanical Ventilation with Heat Recovery (MVHR)
Heating & Hot water	Gas boiler	Gas boiler	ASHP	ASHP

Ground floor flat

	Baseline	Option 1	Option 2	Option 3
External Walls	No insulation	Insulation in the cavity	Insulation in the cavity & 100mm additional external wall insulation	Insulation in the cavity & 150mm additional external wall insulation
Walls to Communal space	No insulation	40mm internal wall insulation	40mm internal wall insulation	80mm internal wall insulation
Floor	No insulation	No insulation	No insulation	No insulation
Roof	No insulation	No insulation	No insulation	No insulation
Windows	Existing double glazing	New double glazing	Triple glazing	Triple glazing
Airtightness	6 ach	4 ach	2 ach	1 ach
Ventilation	Natural Ventilation & Intermittent extract fans in wet rooms	Centralized Mechanical Extract Ventilation (CMEV)	Mechanical Ventilation with Heat Recovery (MVHR)	Mechanical Ventilation with Heat Recovery (MVHR)
Heating & Hot water	Gas boiler	Gas boiler	ASHP	ASHP

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