Passivhaus Trust
The UK Passive House Organisation

The right time for heat pumps

Decarbonising home heating in a staged retrofit

April 2024

I was working as a physicist. I read that the construction industry had experimented with adding insulation to new buildings and that energy consumption had failed to reduce. This offended me – it was counter to the basic laws of physics. I knew that they must be doing something wrong. So I made it my mission to find out what, and to establish what was needed to do it right.

— **Prof. Dr. Wolfgang Feist**

Acknowledgements

Author:
Alan Clarke

Contributing author:
Kate de Selincourt

Technical review:
Matt Bridgestock John Gilbert Architects
Sally Godber WARM
Nick Grant Elemental Solutions
Hannah Jones Greengauge
Gervase Mangwana Waxwing Energy
Tim Martel AECB
Kym Mead MEAD Consulting
Rachel Mitchell Greenbox Associates
Sarah Price Spruce Retrofit Consultancy
Mark Siddall LEAP
Andy Simmonds AECB
Will South Etude
Gwilym Still Max Fordham

Passivhaus Trust publications team:
Sarah Lewis Passivhaus Trust
Laura Soar Passivhaus Trust

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FOREWORD

The UK has some of the worst performing housing stock in Europe. Nearly 40% of the UK's homes were built before 1946, in comparison to 21% in Italy and 11% in Spain[1], and some data indicates that they lose heat on average nearly 3 times as fast as in some of our continental neighbours[2]. In 2024, estimates of fuel poverty in England alone range from 12.6% to 36.4% of households[3], and the situation is worse in Scotland, Wales and Northern Ireland. Too many homes suffer damp and mould, resulting in poor health outcomes and a cost to the NHS that has been estimated at more than £1 billion[4].

At the same time, we urgently need to decarbonise our energy use across every sector of the economy in the face of the climate crisis – and heating our buildings is responsible for 23% of the UK's carbon emissions[5]. There is an argument that the fastest way to reduce that percentage is to simply electrify everything, relying on the decarbonisation of the National Grid to solve the emissions challenge. Advances in heat pump technology are starting to make this a viable proposal[6]. But the question of how and when to implement the switch to avoid any risk of unintended consequences, such as an increase in running costs for householders or reduction in comfort, must be answered for it to be an acceptable solution. And as a solution, it leaves the first part of the retrofit challenge untouched – it doesn't address health, comfort or affordability.

A fabric first approach to retrofit addresses both challenges simultaneously by massively reducing energy demand and improving the condition of the building, creating a much better indoor environment.

If done well – as in a certified EnerPHit – fabric first retrofit:

- **delivers consistent comfortable indoor temperatures**
- **tackles damp and mould**
- **creates a healthy living environment**

It also:

- **reduces operational cost, even in cases where a heat pump is already cheaper than gas**
- **increases the ability to use energy when it is free or cheap (time of use tariffs)**
- **reduces required heat emitter area for a given flow temperature (lower capital cost)**
- **reduces required size of heat pump (lower capital cost)**
- **reduces the peak demand on the grid**
- **reduces the need for seasonal grid storage**

Heat demand reduction of 127 TWh is achieved in Leading the Way in 2050 through higher building standards and behavioural change

DECARBONISING THE GRID[7]

The task faced by National Grid ESO is huge. To achieve the UK's 2035 power sector decarbonisation target, the amount of electricity generation connected to GB's electricity network will need to treble. And under the Consumer Transformation and Leading the Way scenarios, a net zero grid will only be achieved with both accelerated heat pump uptake and extensive energy efficiency improvements in GB homes; the Leading the Way scenario envisages a total consumer heat demand reduction of 127 TWh in 2050. Energy efficiency is crucial for unlocking demand-side flexibility and reducing the total peak load on the grid. The residential sector can't simply rely on the grid to decarbonise: the grid is relying on us to reduce demand.

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WHAT IS ENERPHIT?

EnerPHit** is the Passivhaus retrofit standard, with more flexibility than the new build standard. It maintains Passivhaus quality assurance, but allows tailored approaches. The heating demand method relaxes new build criteria slightly. The component method sets some elemental targets. Step-by-Step EnerPHit certification enables staged retrofits. For more on EnerPHit, see **Passivhaus Retrofit in the UK (PHT, 2021) *and **How to Build a Passivhaus: Good Practice Guide*** (PHT, 2023).

But the work needed to deliver these benefits can be expensive, difficult and disruptive. One way to make it more manageable is to take a staged approach, which might take place over several years. The Step-by-Step EnerPHit standard has been designed to facilitate this approach: a **PHPP** model is used to break down the full retrofit into several distinct stages, and certification is achieved after completion of Step 1 and verification of the full plan (**ERP**). Having the full plan at the outset ensures that each step enables, rather than precludes, future improvements. For cases where informed analysis indicates that the full EnerPHit standard will remain out of reach, the AECB CarbonLite Retrofit Standard is a less demanding alternative, and it also supports a stepped approach.

So, to achieve the fastest decarbonisation, best lifetime carbon savings, and also make progress towards better buildings that are more comfortable, healthier and cheaper to run, is early installation of a heat pump in a staged retrofit plan the answer that would deliver the best of both worlds?

The aim of this paper is therefore to examine when, in the context of a staged retrofit, is the optimum time to install a heat pump. It focuses on the running cost implications of the installation of an air source heat pump at different levels of fabric performance, and at current energy prices. The modelling does not analyse the potential of alternative technologies to change the equation – for example, air-to-air or 'mini-split' heat pumps, or different emitter options such as fan convectors, which are also able to provide cooling. Maintenance costs have also not been evaluated – these will of course apply in both the gas boiler and ASHP case, but the exact comparison is dependent on external factors such as supply chain maturity and skills, so is not considered here. But the key takeaway is that there is a quantifiable level of fabric performance, however it's achieved, that makes a heat pump installation viable in running cost terms now, and it's not that high.

Enabling heat pumps and fabric to work in synergy to maximum effect is the "people first" choice - it will deliver not only CO_2 emission reductions but also running cost savings, comfort, and health. We **can** have healthy homes that cut carbon: if doctors could prescribe housing, then Passivhaus is probably what they would choose (some have even said as much)[8]. With a Step-by-Step EnerPHit that leverages the most efficient fossil-fuel-free technologies, and with the right sequencing, it is perfectly possible for retrofit both to save carbon fast and to ultimately enhance health.

– Passivhaus Trust

SUMMARY – WHEN TO INSTALL A HEAT PUMP IN A STAGED RETROFIT

This paper aims to answer the question "when should you install a heat pump in a staged retrofit?" The answer seems to be "it depends". There are those who say install heat pumps immediately as this reduces carbon emissions fastest. However, social landlords have found this approach has problems[9].

We modelled some typical retrofit scenarios, both "light" and "deep" retrofit, using the Passivhaus energy model PHPP to estimate energy demand and hence running costs.

We found that minimal or no fabric improvements are likely to lead to higher running costs than with gas, but this can be addressed with new radiators, and may be the route for historic building fabric. This works for "able to pay" homeowners who can spread energy costs and afford to run heat pumps in continuous mode.

A reasonably low cost and low disruption retrofit, for example cavity wall and loft insulation in a house with replacement double glazing, can reduce heat pump running costs to that of gas after the same retrofit. Deeper retrofit such as EnerPHit actually favours heat pumps thanks to the steady internal temperature, which suits continuous heat pump operation.

Where householders have a restricted energy budget, however, they are likely to run their heating system in an intermittent "on demand" fashion, only heating for a limited number of hours per day. This doesn't work for heat pumps, as they need long running at low flow temperature to achieve their anticipated efficiency. So for this group of people a heat pump without adequate fabric retrofit is likely (and has been seen)[10] to cause increased energy costs and reduced comfort.

So for social landlords the decision to install heat pumps needs to be considered in conjunction with fabric measures to limit heating demand to a level where tenants can operate heat pumps efficiently. There may be cases where this cannot be achieved and if this is the case, air to air heat pumps are a better approach.

A key aspect to heat pump running costs is energy tariffs, as these put electricity at roughly four times the cost of gas for a kWh unit of energy. This is a choice made in the pricing mechanism for our electricity supply and could be changed, but not by retrofit designers. There are promising developments with either time-of-day or directly metered heat pump tariffs, which offer lower running costs and tilt the balance towards decarbonisation with heat pumps.

CONTEXT – WHY "FABRIC FIRST"?

When the Passivhaus Trust was formed in 2010, the carbon intensity of electricity in the UK was 457 gCO_2/kWh. The Energy Saving Trust's 2009-2010 domestic heat pump trials[11] reported COPs ranging from 1.4 to 2.2, average 1.8 (**COP, or coefficient of performance**, is the ratio of heat output to electrical energy input). So heat from a heat pump came out at 250 gCO_2/kWh compared with 215 gCO_2/kWh from a gas condensing boiler. Decarbonisation had to be fabric first, second and third.

In 2023, however, UK electricity generation was at 145 gCO_2/kWh and recent monitoring of heat pump performance reports average COPs of 2.95, putting heat out at 49 gCO_2/kWh[12]. Simply replacing a gas boiler with such a heat pump reduces carbon emissions by 77% – previously only achievable through an EnerPHit level retrofit.

It is clear that the facts have changed and to reduce carbon emissions from heating as quickly as possible, the best time to install a heat pump is immediately. But this strategy doesn't address health, comfort or affordability. For these, you need fabric and ventilation improvements as well.

The effects of poor building fabric and ventilation on health and comfort are not addressed by installing a heat pump, so, while key to an EnerPHit retrofit, they are on a parallel track to heat pump installation and not discussed in detail here[13]. Affordability, however, is impacted when heat pumps are installed – exactly how it is impacted depends on the mix of fabric and heating system improvements accompanying the installation. We want to disentangle these to identify what measures are needed to ensure that a heat pump retrofit delivers on all possible fronts, not just decarbonisation.

Currently the electricity price per kWh is 4 times that of gas, so on the face of it a heat pump needs an average COP of 3.4 to beat an 85% efficient gas boiler on running cost. Removing the gas meter and standing charge will improve the case for a heat pump slightly (though this also assumes the switch from gas to electric for cooking, which has its own cost implications). So given the energy prices we have, how can we ensure a heat pump retrofit reduces running costs? And how could different electricity tariffs change things?

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IMPACT OF HEATING SYSTEM TEMPERATURE ON HEAT PUMP PERFORMANCE

A heat pump uses energy to raise the temperature of a refrigerant from outdoor air to that required by the heating system – and the energy required is proportional to that rise in temperature. So heating system temperature is critical. Radiator heat output is, roughly put, the radiator room temperature difference times the size of the radiator. So bigger radiators help here, but heating period can be more important. If you can heat a house to say 20°C with heating only on for a third of the time, then those same radiators can keep it at 20°C by running 24 hours a day at much lower heating system temperature, and hence lower heat pump electricity use.

You may have heard of high temperature heat pumps being the solution now. By using refrigerants better suited to heating instead of the traditional sort we can now pump heat to 70°C. But the thermodynamics doesn't change – the energy required is still proportional to rise in temperature so these heat pumps are expensive to run if they are run at their maximum temperatures.

INSULATION LEVEL AND CONTINUOUS VS INTERMITTENT HEATING

Because heat pumps are most efficient supplying heat at a low temperature the usual recommendation is to run a heat pump system continuously with controls that run the radiator temperature as low as you can get away with. This is how to run an average COP above 3. The downside of this is that heating continuously increases overall heating demand compared with intermittent heating (as shown in Figure 1), since the temperature stays high overnight and when you're out (a typical recommendation for heat pumps is to reduce by just one degree compared with occupied times). There's a trade off – run longer hours: lose more heat but generate it more efficiently.

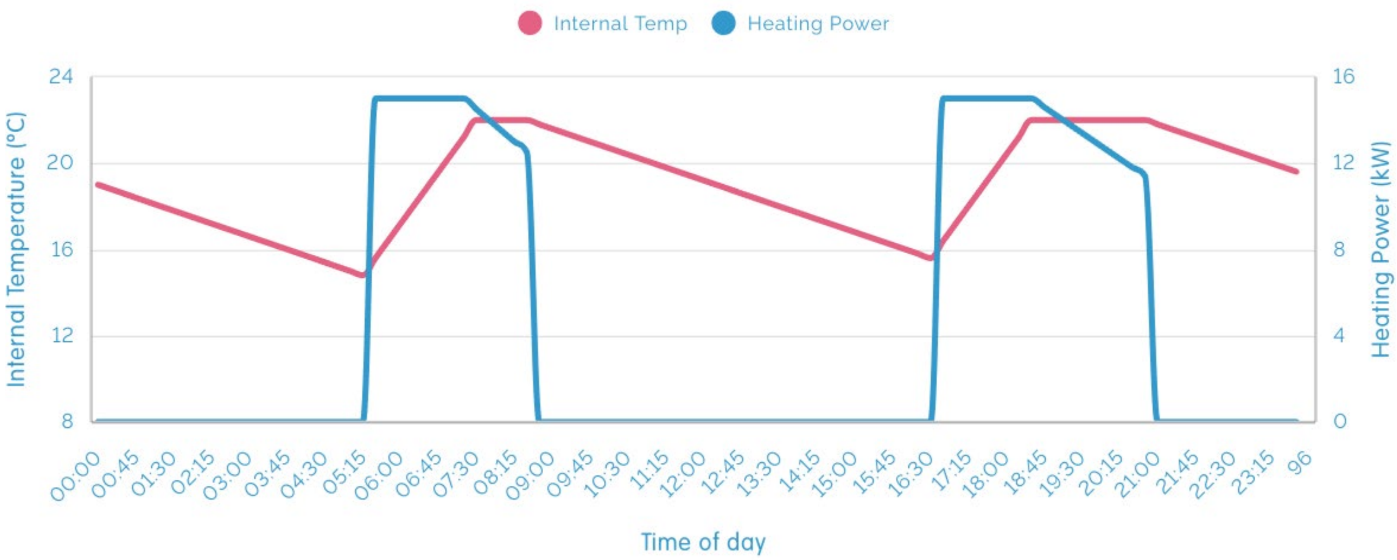

Figure 1: *A typical intermittent home heating pattern – temperatures drop overnight and during working hours, and are brought back up to a comfortable level with two bursts of heating, in the morning and evening.*

The more insulated a building is, the less difference there is in heat loss between intermittent and continuous operation, since internal temperatures drop less between heating periods. But it's not immediately obvious at which point running heating for longer than normal will reduce energy consumption and cost.

To investigate this we have looked at a range of house insulation levels and compared heat pump energy use under intermittent and continuous heating regimes. The aim is to understand what sort of insulation level is needed to reach the point where the increased heat input resulting from continuous heating is compensated for in running cost terms by the improved efficiency this offers a heat pump.

House insulation level can be characterised as a **heat loss parameter, HLP**, which is stated in terms of watts per m² of floor area per degree (Celsius) temperature difference between inside and out. A Passivhaus losing 10 W/m² with a 20 K temperature difference has an HLP of 0.5 W/m².K; an uninsulated 19th century dwelling may have an HLP as high as 5 W/m².K.

We have used PHPP to model a typical two storey semi-detached house (90m², form factor of 3, located in Manchester) over a range of fabric performance examples, with the HLP for each quantifying the overall fabric performance. There are two fabric types: solid and cavity wall, modelled as found and then with limited retrofit along the lines of the AECB CarbonLite Retrofit Standard Step 1 (see Appendix). The modelling includes cavity fill (but not insulation of solid walls), loft insulation, double glazing and basic airtightness measures, with continuous mechanical ventilation .

HOW DOES THIS FIT INTO A CERTIFIED STEP-BY-STEP PLAN?

The "light" retrofit modelled case could form all or part of Step 1 in the AECB CarbonLite Retrofit Standard staged approach. In a staged EnerPHit process, steps would need to include MVHR and triple glazing without trickle vents – which could be programmed for a future stage – to avoid locking in poor performance through lower specification upgrades. Both AECB CarbonLite Retrofit Step 1 and the first step in a Step-by-Step EnerPHit require PHPP modelling showing the further measures to be taken to achieve the full criteria. AECB CarbonLite Retrofit Standard Step 1 also stipulates that running costs do not increase, which could be achieved by upsizing the radiators – see below.

The final case is full EnerPHit with external wall insulation, so cavity and solid wall cases now have the same HLP.

To enable modelling of the heating system it is assumed that the existing heating system achieves comfort conditions (20°C in living rooms) on intermittent use. This means that daily heating demand is met by heating for 9 hours a day at a boiler temperature of 75°C. Working back to the radiator capacity needed for this led to an ASHP **design flow temperature** of 45-50°C. The PHPP model uses the design flow temperature, heat pump data, and building heat demand profile to work out an average COP for the year (previous work has found this model to be reasonably accurate – more accurate than manufacturer's quoted "seasonal COP"). These flow temperatures lead to an average COP of around 3.3 with a continuous heating regime of 20°C for occupied hours and setback to 19°C for unoccupied and overnight. (In practice for a heat pump retrofit, heat load calculations need to be carried out and compared with actual installed radiator capacity and condition in each room.)

For each case we determined the average indoor temperatures that would be achieved under intermittent and continuous heating, using the SAP algorithm and SAP assumed hours of use (though with 20°C setpoint rather than 21°C). We estimated the radiator temperature required for each mode; and then used PHPP to model the electrical energy required to run a heat pump for each option.

Finally annual heating costs are arrived at using Jan 2024 Ofgem standard tariffs, including the gas standing charge for gas heating only. The electricity standing charge is not included in heating costs as it will always be paid anyway.

The results (plotted in Figure 2 and Table 1 below) show that the intermittent heating average temperature reduces with increasing HLP. Heating cost increases generally with increasing HLP, as expected. Comparing the two heating systems there is a relatively higher heating cost for ASHP (continuous) vs gas (intermittent) at high HLP and the reverse for low HLP.

This indicates that installing a heat pump in poor fabric risks higher running costs – but with good levels of insulation a heat pump will actually be cheaper to run than a gas boiler.

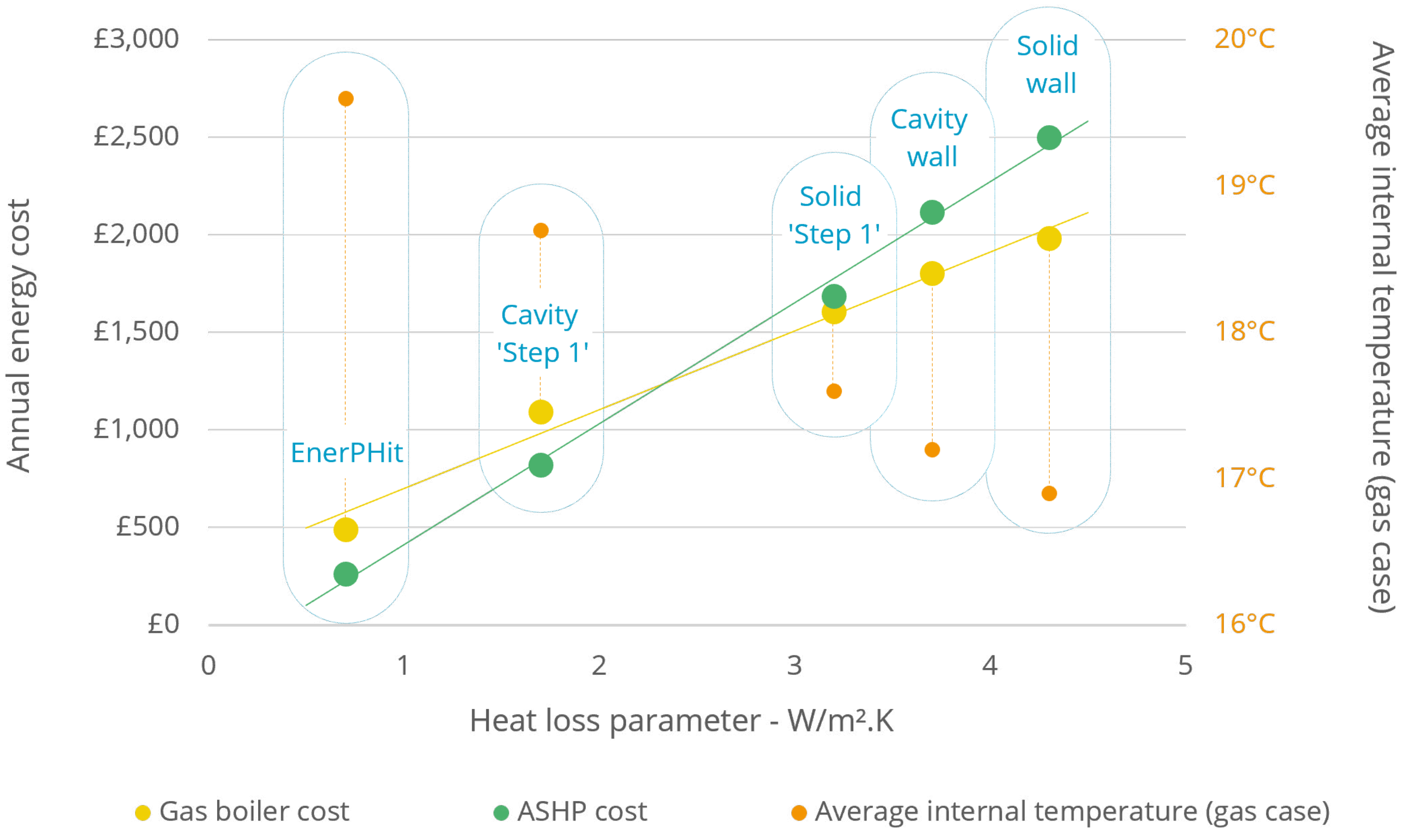

Figure 2: *Heating costs according to HLP for two stages of retrofit of solid and cavity wall houses, with gas or air source heat pump, all retaining existing radiators.*

Case	Performance			Heat demand kWh		Energy demand kWh		Annual energy cost	
	HLP W/m².K	Avg temp °C	SPF	Gas	ASHP	Gas	ASHP	Gas	ASHP
Solid wall	4.3	16.9	3.3	21707	28731	25255	8734	£1,982	£2,500
Cavity wall	3.7	17.2	3.3	19626	24715	22840	7403	£1,803	£2,119
Solid wall 'Step 1'	3.2	17.6	3.7	17414	21726	20226	5894	£1,609	£1,687
Cavity wall 'Step 1'	1.7	18.7	4.3	11424	12375	13277	2867	£1,093	£821
EnerPHit	0.7	19.6	4.3	4065	3931	5157	916	£491	£262

Table 1: *Heating demand for gas and ASHP systems and energy cost estimates for retrofit stages*

One conclusion here is that there is a break-even point where HLP is low enough for a switch from gas to ASHP (using existing radiators) not to increase energy costs, and this is around HLP 2.5 – which is met by the 'Step 1' retrofit level for a cavity wall dwelling, but not lesser levels of retrofit. Note this is totally dependent on relative gas and electricity prices – Jan 2024 Ofgem "price cap" figures are used here – so this HLP break-even point is not a fixed result at all (and also depends on heating regime, as discussed below). Furthermore, it assumes a particular level of radiator provision for the gas heating installation, but there is no guarantee this exists, especially in older systems.

Another conclusion is that at current energy prices a 'Step 1' oriented retrofit of a previously uninsulated building, which includes the switch from gas to continuous-run ASHP, would reduce running costs compared with doing nothing. It would do so comfortably in the cavity wall case, but not by much in the solid wall case – as the modelled 'Step 1' type of retrofit excludes solid wall insulation, the HLP is still quite high here after retrofit.

Since ASHP running cost clearly depends on COP and this can be improved with bigger radiators, radiator replacement was modelled for the highest 2 HLP cases over a range of radiator sizes, from unchanged to 3x output. This is shown in greater detail in Figure 3 and Table 2 below. Over this range the average COP increased from 3.3 to 4.8 and electricity costs reduced by up to 33%. So for these uninsulated cases a new radiator system of around 2x or more capacity will bring energy costs down to below that of the gas boiler (this is with continuous operation of ASHP to maximise COP). This additional measure therefore takes our modelled 'Step 1' solid wall case to the AECB CarbonLite Retrofit Standard Step 1.

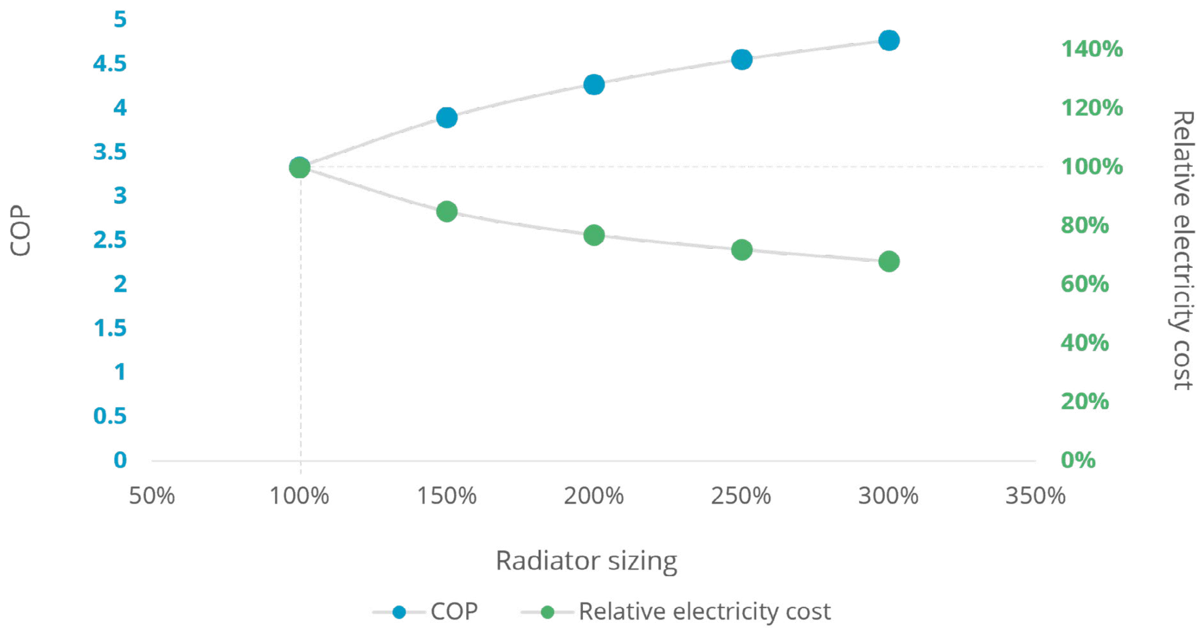

Figure 3: *Impact of radiator sizing on running cost of ASHP*

Radiator size	Design flow temp	Electricity cost	Relative elec. cost
100%	49.3°C	£2,119	100%
150%	42°C	£1,792	85%
200%	38°C	£1,623	77%
250%	35.4°C	£1,517	72%
300%	33.7°C	£1,444	60%

Table 2: *Relationship between radiator oversizing and flow temperature*

Interestingly, running cost turned out pretty much proportional to design flow temperature:

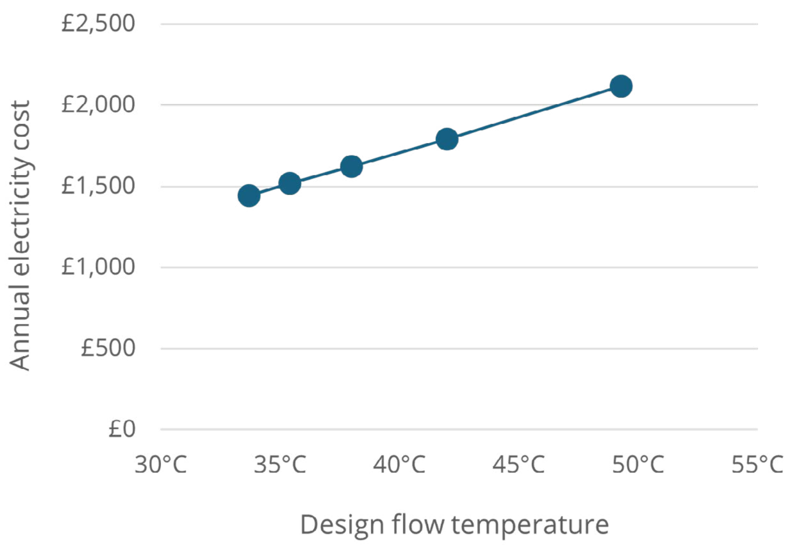

Figure 4: *Impact of radiator design flow temperature and annual heat pump electricity cost*

RADIATOR REPLACEMENT

Radiator replacement has a range of costs and complexities. With a reasonably modern heating system (say < 20 years old) it can be a case of simply swapping out slim radiators for fatter ones. Older heating systems may require more pipework modification and are more likely to need extensive work to the point where a completely new system may make most sense.

To further explore the benefits of larger radiators all the heat pump systems were remodelled in PHPP on the assumption that new radiator systems were installed at 250% of gas system design rating. The design flow temperature was around 36°C and **SPF** around 4.5. This approach has been demonstrated on a number of cases seen on the heatpumpmonitor.org website which publishes measured performance data.

Combined with continuous operation this showed reduced running costs were achieved in all cases without undertaking fabric measures (Figure 5):

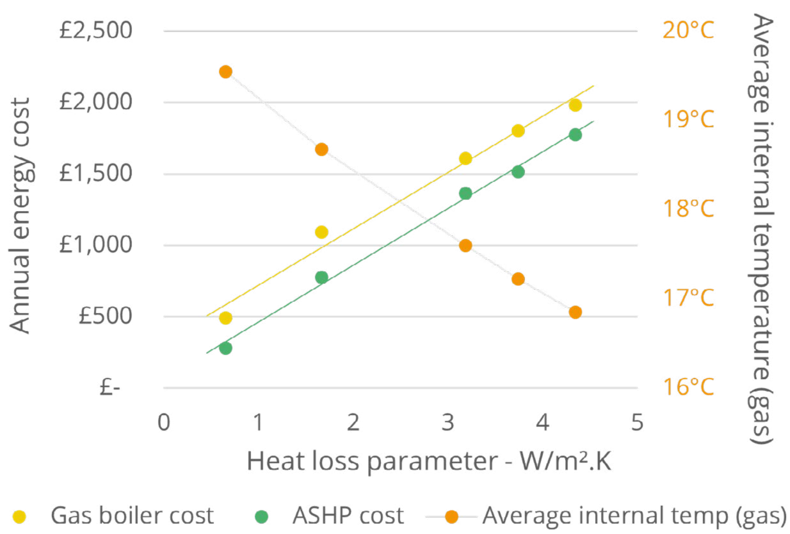

Figure 5: *Energy cost estimates for gas and ASHP systems with new "oversized" radiator systems*

So, with larger replacement radiators it is possible to decarbonise heating without making fabric improvements yet keep running costs below the previous level. But the question remains: is this how people will actually use their heating in such poorly insulated homes? What happens if occupants reduce run time to save money?

HEATING ON A BUDGET – INTERMITTENT VS CONTINUOUS OPERATION OF ASHP

To answer that question, we compared our “ideal” scenario used above of continuous heat pump use with the intermittent regime traditionally used with a gas boiler (see Figure 6 below). There will be many individual variations on this theme – the idea here is to see the general difference between the approaches, here comparing 'Step 1' equivalent fabric improvements of cavity and solid wall houses and the same “standard” heating hours from SAP as for the gas heating (heating 0700-0900 and 1600-2300, a total of 9 hours per day).

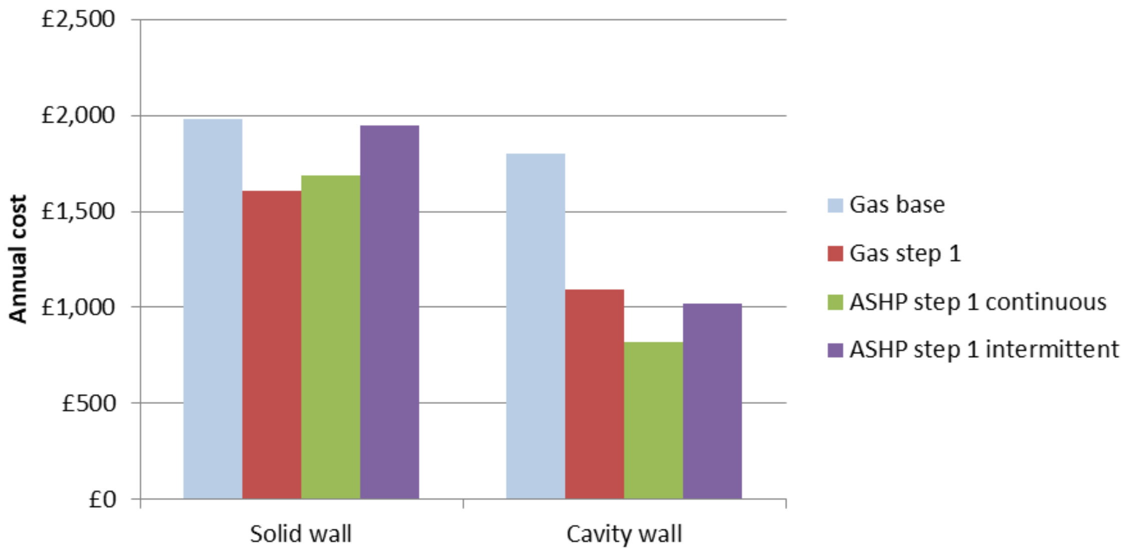

Figure 6: *Energy costs for retrofit comparing keeping gas with ASHP either run continuously or intermittently*

Here the ASHP comes out more expensive when run intermittently. This is due to the higher flow temperatures needed to heat over a shorter time, even though the 24 hr average temperature is lower, especially in the solid wall case. Note that this is still heating over traditional gas central heating hours assuming the householder isn’t afraid of the bills.

The risk here is that any attempt to reduce ASHP running costs by limiting run time – a common and effective method with conventional heating – will increase running costs if still heating to the same room temperature. So we have the solid wall 'Step 1' ASHP running cost as comfortably below the gas base case if the system is run continuously, but only barely if run intermittently. If the running cost is beyond the occupants' heating budget and they only run for limited hours, then there is a risk the ASHP will increase heating costs instead.

An important issue here is the variation of COP with external temperature. Running a gas boiler will always give you more or less the same heat output for a given cost, so it can be budgeted for. Running a heat pump in colder weather will give you significantly less heat output than in warm weather (it can be less than 50%), so a limited daily budget will give you less heat than you’d get with gas in cold weather.

With gas central heating, people on low and even middling incomes often do not heat for as much as nine hours a day, and hours of heating have been observed to fall as a direct response to energy price rises (according to data from Switchee[14]). There have been anecdotal reports of residents continuing to use a highly intermittent regime after heat pump installation, and suffering unexpectedly high energy bills as a result, while still struggling to reach the same temperatures as they would have done with a gas boiler.

HEAT PUMP TARIFFS

As we've seen, heat pumps are effective at reducing delivered energy demand and associated carbon emissions, but can risk being higher cost than gas heating. Some novel electricity tariffs are starting to address this. At the time of writing Octopus has a heat pump tariff called Cosy which has two 3 hour periods of lower rate electricity, but also has a 4-7pm peak rate at higher than normal cost. However just 6 hours of off-peak tariff is not ideal for optimum heat pump operation, and the peak rate could reduce savings as it is charged at a time of high demand. OVO has a different approach which is a roughly half price tariff for just the heat pump. This will be linked to an installer programme, and requires specific heat pumps with built in metering and internet communication. (We have not modelled the running costs using these tariffs.)

PRE-PAYMENT METERS

if someone is forced to use a pre-payment meter then they will have a limited daily energy budget and be unable to spread costs over the year as you would with a monthly direct debit. A household with a prepayment meter is very unlikely to be suitable for a heat pump in any circumstances.

CONCLUSIONS

It is clear that changing from a gas boiler to a heat pump will significantly reduce the carbon emissions for heating – but that doesn't mean there's no need to insulate a building well. In particular comfort, health and wellbeing for occupants are best addressed by a fabric first approach, and at a national level, fabric improvements will be crucial to reducing peak load and realising the grid's 2035 decarbonisation target. Fabric also impacts running costs, and here we have looked in more detail at the financial aspects for building users.

Heat pumps work in uninsulated buildings, but modelling performance over a wide range of insulation levels shows that it is harder to get a heat pump running cost to match or better that of gas heating in a poorly insulated building. On top of that, occupants of such a building are more likely to have a tightly constrained heating budget (as overall costs will be high), leading to intermittent use of heating. When this is the case, heat pumps tend to work significantly worse than when left to run continuously – leading to a combination of higher running costs and poorer internal conditions.

In terms of a staged retrofit there is a good case for holding off on heat pump installation until it can be combined with fabric improvements that give a heat loss parameter between 2 and 3 W/m².K – or about 40 to 60 W/m² peak heat load. For this level of fabric performance heating bills are more affordable and continuous operation of a heat pump is a sensible route to efficient operation. This level of fabric performance is usually achievable with low cost measures – cavity wall insulation, loft top up, in situ airtightness measures, and MEV for ventilation or a cost-effective MVHR solution[15].

Homeowners may want to install a heat pump sooner in order to minimise carbon emissions, and in this case they are advised to also replace radiators with larger ones, and be prepared to run the heat pump in a continuous heating mode. This leads to high daily electricity use in cold weather, but monthly direct debit tariffs will spread the cost throughout the year. In the context of a phased retrofit plan, radiator replacement makes less sense as later planned fabric improvements would make the larger size unnecessary.

For low income households there is clearly a risk in putting in heat pumps without sufficient insulation, and there have been cases where this has backfired. For home owners in uninsulated homes who can afford their heating, then new radiator systems can keep running costs down, though in all cases we recommend combining heat pump installation with affordable fabric improvements, along the lines of the AECB CarbonLite Retrofit Standard Step 1, which includes good ventilation.

Where heating budgets and fabric improvements are more limited, then air-to-air heat pumps ("mini-splits") may be a better alternative to the usual air-to-water system. Even though they are less efficient than air-to-water for long running periods, air-to-air systems can heat the space for short periods without losing efficiency.

Another issue not covered in detail here is the risk of oversizing a heat pump. In some cases a step 1 retrofit can cut peak heat load by 50%. Larger heat pumps cost more, and after a fabric retrofit a smaller heat pump would run more efficiently than the large one – so again, combining heat pump installation with fabric improvements is ideal.

HOW DOES THIS LOOK IN THE CONTEXT OF THE LONG TERM RETROFIT PLAN?

Firstly, if you have low cost insulation measures that can be implemented then these are a sensible first step in a full retrofit, including to EnerPHit, in part because this sometimes removes the need to upgrade radiators. With cavity wall insulation costs for a modest house around £1k, this could pay for itself in unneeded new radiators and a smaller heat pump. (In England and Wales currently heat pump subsidies are also contingent on such work being done).

We also recommend improving airtightness and ventilation at this point. The step-wise approach may be to carry out airtightness measures without significant disruption (eg floor replacement would be avoided), which puts the full EnerPHit standard out of reach at this stage but could form the first phase in a Step-by-Step EnerPHit. Accompanying improved airtightness, continuous mechanical ventilation will be needed to ensure good air quality and this should be in line with the full retrofit plan. An MEV system can be reasonably cheap (£1k) but locks in poorer performance; MVHR is likely to be £5k+, although there are innovations which can significantly reduce costs, particularly for small residential units[16], and MVHR provides the best health outcomes[17].

After or alongside these basic measures a rapid move to installing a heat pump is the quickest route to decarbonisation – this installation may include new radiators and hot water cylinder. Base costs for this are around £10k, with large variations for size of job and availability of heating engineers, but in England and Wales a £7.5k subsidy reduces the cost significantly.

Further along this process window replacement, floor replacement and additional wall insulation would complete the retrofit, but this is likely to total £40k+. So in general this approach emphasises rapid and lower cost decarbonisation that ensures running costs don't rise, with more expensive fabric upgrades scheduled into replacement and refurbishment cycles to maximise cost-effectiveness.

We have however identified high heat loss houses, typically solid walled, as posing some risks with this approach. With current standard energy tariffs and low income residents there is a case for including more expensive fabric measures such as solid wall insulation at the stage of heat pump installation, to both manage running costs and improve comfort and health.

A further direction to be explored is deployment of heat pump specific energy tariffs, i.e. lower cost electricity either varying with time of day, or ring-fenced just for powering the heat pump. If this lowers the running costs sufficiently that efficient long running heat pump operation is affordable, then this offers a route to an earlier switch from gas.

NOTES

1 *Housing Horizons: Examining UK Housing Stock in an International Context*, Home Builders Federation (October 2023)

2 According to research by tado° (2020) https://www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours

3 Suzanna Hinson and Paul Bolton, 'Fuel Poverty', House of Commons Library no. 8730 (February 2024) – the wide range reflects different definitions of fuel poverty

4 *The Sixth Carbon Budget - Buildings*, Climate Change Committee (2020).

5 *The cost of ignoring poor housing* , BRE (2023). Available online: https://bregroup.com/news/poor-housing-will-cost-over-135.5bn-over-the-next-30-years-without-urgent-action

6 Nick Eyre et al., 'Fabric First: Is it still the right approach?' *Buildings and Cities*, 4(1) (2023). Available online: https://doi.org/10.5334/bc.388

7 *Future Energy Scenarios 2023*, National Grid ESO (July 2023)

8 Karl A. Holden et al., 'The impact of poor housing and indoor air quality on respiratory health in children', *Breathe* (2023) Available online: https://doi.org/10.1183/20734735.0058-2023

9 National Energy Action, personal communication

10 *Making heat pumps work for fuel-poor households: Common challenges and top tips for overcoming them*, National Energy Action (2022). Available online: https://www.nea.org.uk/publications/making-heat-pumps-work-for-fuel-poor-households

11 *Analysis from the first phase of the Energy Saving Trust's heat pump trial: April 2009 to April 2010*, EST for DECC (2012)

12 *Interim Heat Pump Performance Data Analysis Report*, Energy Systems Catapult for DESNZ (2023) https://doc.ukdataservice.ac.uk/doc/9050/mrdoc/pdf/9050_eoh_interim_heat_pump_performance_data_analysis_report.pdf

13 For an in-depth review of the health and wellbeing impacts of building performance, see Kate de Selincourt, *Health, Wellbeing and People Performance*, PHT (2023), and for an overview, see chapters 3 and 4 of *Passivhaus Benefits*, PHT (2021). Available online: https://pht.guide/Benefits

14 Data from Switchee via personal communication. See also switchee.com

15 Low-cost home ventilation solutions that also contribute to affordable housing were highlighted in the Passive House Institute's Component Award in 2018. Two easy-to-integrate and low-cost solutions particularly suited to small residential units shared first place, and a further two centralised and decentralised facade-integrated ventilation concepts shared second place.

16 See footnote 13

17 Kate de Selincourt, *Health, Wellbeing and People Performance*, PHT (2023). Available online: https://pht.guide/HealthandWellbeing

DISCLAIMER

All results here are obtained through modelling – no actual measurements were made in the production of this report. Previous work has found monitored ASHP performance compares well with the PHPP modelling. Detailed monitoring as seen at heatpumpmonitor.org has provided insight into real life heat pump operation.

APPENDIX - MODEL PARAMETERS

AECB CarbonLite Retrofit Standard criteria with step 1 highlighted

Headline certification criteria - *updated Sept 2023*

Criteria	Carbonlite Retrofit Step-by-step	Carbonlite Retrofit	Carbonlite New Build
Delivered space heating and cooling (kWh/m2/a)	report result	≤ 50 kWh/m^2.a (≤ 100 kWh/m^2.a with certifier-approved exemption)	≤ 40 kWh/m^2.a
EITHER Primary Energy (PE, varies) **OR** Renewable (PER) (kWh/m2/anum)	report result report result	report result report result	≤ 85 kWh/m^2.a ≤ 75 kWh/m^2.a
Ensure ventilation	Continuous MEV or MVHR must be installed : follow PAS 2035 Annexe C or as required by Part F of the Building Regulations.		
Airtightness (q50)	≤5.0 m^3/m^2.h	≤2.0 m^3/m^2.h	≤ 1.5 m^3/m^2.h
Thermal Bridges	N/A. If some additional & significant fabric measures are being replaced or installed, certifiers will advise whether full Retrofit Standard requirements are applicable.	Assumed to be less than 0.01 W/mK, else accounted for in PHPP or for retrofits a default heat loss factor may be used.	Assumed to be less than 0.01 W/mK, else accounted for in PHPP
Surface Condensation (fRsi) assessed		fRsi to meet criteria in PHPP, or 0.75 (as Building Regulations/ PAS2035), or local standards - whichever is more onerous.	fRsi to meet criteria in PHPP, or 0.75 (as Building Regulations/ PAS2035), or local standards - whichever is more onerous.
Heating System	Change existing fossil fuel (or direct electric) heating system to a heat pump.	Existing heating systems may be retained, but a practical plan to allow for future low carbon heating supply must be in place.	Install a non fossil fuel system or connect to a low carbon district heating network.
Thermal Comfort	PHPP modelled overheating risk, <10% Acceptable (Guidance: <5% Good practice or <3% Best practice)		
Running cost comparison	Must be same/lower running costs than base case **	-	-
Where a heat pump is installed			
Certifiers must liaise with the building owner and the MCS heating system designer in order to ensure that:			
Maximum flow temperature for the designed and installed heating system (space heating only)	no greater than 50°C ; Best Practice - heating system is designed and installed for flow temp <45°C		
Energy Model using PHPP, showing:			
	A. Pre-retrofit Baseline *B. Step 1 achieved* *C. Retrofit scenario showing how Full Retrofit could be achieved (≤ 50 - 100 kWh/m2.a)*	*Retrofit Standard achieved (≤ 50kWh/m^2.a or ≤100 kWh/m^2.a with certifier approved exemption)*	*Building Standard achieved*

For more information about the AECB CarbonLite Standards, visit the AECB website at https://aecb.net/the-aecb-carbonlite-standards/.

U-values used in model, W/m^2.K

Case	Floor (PHPP)	Floor (SAP)	Wall	Roof	Windows
Solid base	2.27	0.78	1.77	0.54	3.02
Solid 'Step 1'	2.00	0.66	1.77	0.14	1.48
Cavity base	2.27	0.78	1.29	0.54	3.02
Cavity 'Step 1'	2.00	0.66	0.59	0.14	1.48
EnerPHit	0.17	0.12	0.16	0.11	0.78

Ventilation parameters used in model

Case	ACH (n50)	Ventilation type	MV ACH
Solid base	10	Window	n/a
Solid 'Step 1'	5	MEV	0.4
Cavity base	10	Window	n/a
Cavity 'Step 1'	5	MEV	0.4
EnerPHit	1	MVHR	0.4

GLOSSARY

COP: coefficient of performance The amount of useful heating or cooling delivered by a heat pump, divided by the amount of electrical energy used by the heat pump.

sCOP (see SPF)

SPF: Seasonal Performance Factor The COP of a heat pump will vary depending on a number of factors, including outdoor temperature. The SPF takes outdoor temperature into account and reports the average COP of a heat pump over the full heating season. It can also be called the sCOP (seasonal coefficient of performance).

Design flow temperature This is the flow temperature needed to meet the heat load on the standardised "coldest day of the year"

PHPP: The Passivhaus Planning Package PHPP is the modelling tool used in both design and certification of any Passivhaus project, whether new build or retrofit. It creates a bespoke energy balance for each project, quickly identifying what aspects are the most significant and what is important for you to work on.

EnerPHit The Passivhaus retrofit standard, with more flexibility than the new build standard. It maintains Passivhaus quality assurance, but allows tailored approaches. The heating demand method relaxes new build criteria slightly. The component method sets some elemental targets. Step-by-Step EnerPHit certification enables staged retrofits.

HLP: Heat Loss Parameter A metric that characterises the fabric performance of a building, evaluating heat loss in terms of watts per m^2 of floor area, per degree (Celsius) temperature difference between inside and out: $W/m^2.K$.

EiRP: EnerPHit-informed Retrofit Plan This plan includes an assessment of retrofit strategy and certification strategy (single phase or step-wise), surveys to gather data about the existing building, and strategies to address the specific demands of the building and site. This whole building retrofit plan includes modelling the existing building in PHPP to provide detailed calculations of the existing fabric performance of the building. Importantly, all approaches to retrofit, including EnerPHit, require some augmentation to deliver robust solutions addressing all aspects of the retrofit performance gap and unintended consequences.

ERP: EnerPHit Retrofit Plan The plan generated using PHPP that shows the details of each step in a Step-by-Step EnerPHit, and for each step, the predicted energy demand and generation, energy costs, and CO_2 emissions. This plan is required for certification, alongside completion of the first step.

The Passivhaus Trust is an independent, non-profit organisation that provides leadership in the UK for the adoption of the Passivhaus standard and methodology.

Passivhaus is the leading international low energy design standard, backed with over 30 years of building performance evidence. It is a tried & tested solution that enables a meaningful transition to net-zero now. Over 65,000 buildings have been certified to this standard worldwide. The Trust promotes Passivhaus as a robust way of providing high standards of occupant comfort and health AND slashing energy use and carbon emissions from buildings in the UK.

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