RETROFIT-AT-SCALE

how many
how deep
what cost

Upgrading our homes to meet UK climate targets

A call to action to industry and policy makers

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Preface

The current 'top-down' national net zero carbon policy advice to government sets home retrofit as a low priority. In a nutshell, it is substantially cheaper to add wind farms than to retrofit homes for delivering reduced carbon emissions. In the meantime, the vulnerability of household energy bills to shocks during an energy transition has been cruelly exposed, fuel poverty has soared, and energy retrofit funding challenges for reducing bills have increased significantly.

During preparation of the LETI Climate Emergency Retrofit Guide[1] these issues were identifed, but touched on only lightly given limited resources. Consequently, a dedicated workstream was set up to address these under the strapline of *'How many, how deep, at what cost?'*. This examined how retrofit could, and should, become a mass rollout across 28 million UK homes. This RETROFIT-AT-SCALE publication is the output of this workstream.

The context upon which current policy advice is based needs to be changed, to show there is an alternative more equitable route to net zero carbon. This needs a fundamental reassessment of how we as an industry do retrofit, including the need to significantly increasing productivity to drive down costs and scale up delivery using our limited resources. It also examines wider savings if reducing housing energy demand, such as needing less energy supply infrastructure which enables redirection of funding into retrofit. Overall, it shows that a halving of home heat demand, and energy bills, can be achieved for no increase in overall cost for our route to net zero carbon.

RETROFIT-AT-SCALE is a 'call to action' to both policymakers and industry. It seeks to demonstrate what is possible. For LETI, it is important that this is published due to its potentially significant impact. So, with limited internal capacity, the decision was taken to enable publication under a different banner.

The RETROFIT-AT-SCALE workstream consisted of some 80 contributing volunteers made up of dedicated and passionate retrofit specialists, engineers, architects, cost consultants, contractors, suppliers, housing association professionals, academics, technicians, heritage specialists, planners, facilities managers and local authorities representatives.

A huge thank you must go to all the contributors who gave their free time in the common belief this commercially non-aligned document fills a large hole in the current debate about our route to net zero carbon.

Chris Twinn

“LETI supports the publication of Retrofit-at-Scale with its introduction of a minimum 'no frills' Basic retrofit standard to help decarbonise the UK. It is important to LETI that this document be published in a timely manner, due to its significant impact potential. It is encouraging that so many volunteers from across so many disciplines are willing to contribute ideas for unlocking a national retrofit mass rollout – to whom we offer our thanks.”

Clara Bagenal George, LETI

"The UK’s homes are among the least efficient in Europe, with 19 million in dire need of upgrades. We must decarbonise the built environment and bring existing stock up to scratch.

The Retrofit-at-Scale report can play an important part. We will continue to call for action on retrofit and urge government to commit to a well-funded, long term National Retrofit Strategy.”

Muyiwa Oki, President - RIBA

"This comprehensive report brings together leading retrofit approaches and finds similarity in their levels of ambition and approach. The AECB welcomes the report's recognition of our CarbonLite Retrofit Standard as an example of a best practice solution and applauds the spirit of collaboration embraced in this work."”

Andy Simmonds, CEO - AECB

“The National Retrofit Hub supports Retrofit-at-Scale for the help it provides expanding the discussion on options to meet the challenges of scaling up retrofit for the UK. We appreciate the huge amount of work that has gone into this document. Retrofitting our housing stock is a multifaceted challenge, and this publication seeks to explore new approaches for various cross-linking blockages between process, design, products, productivity, and costs.”

Rachael Owens, Co-Director - National Retrofit Hub

”This is an important contribution to the discussion on mapping out workable strategies for upgrading the nation’s homes. It’s radical in places, and rightly so – we’re in a climate and energy bill crisis. It explores that large proportion of the stock that tend to fall between current models, instead proposing different ways of doing retrofit. It draws in local communities, national governments, and the various strands of industry, with ideas to better appeal to householders to make it work for everyone.”

Louise Hutchins, Head of Policy and Public Affairs for UK Green Building Council

“This report offers a valuable proposal for an intermediate level of retrofit that could be rolled out for a low-cost at scale. The concept includes sufficient fabric improvements to enable retention of the existing heating system, which would help reduce disruption and increase buy-in from occupants, and then shows, through a worked example, the innovations and technologies that might be needed in order to make the concept work in reality.”

Jon Bootland, Director - Sustainable Development Foundation

The following organisations contributed directly and indirectly, providing: support and enthusiasm; innovative ideas; volunteer contributors, leadership and reviewers; or advice as the project progressed. This melting pot means the views expressed may not be representative for each organisation.

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Many of the contributors were drawn from voluntary organisations including LETI, the UKGBC, ACAN, AECB and the National Retrofit Hub. Valuable review contributions were received from many external retrofit experts. Contributors retain the right to agree or disagree with aspects of this publication.

Contents

Executive summary

Halving housing heat demand while delivering zero carbon for no more cost

We are falling dramatically short of the home energy retrofits we need:

- almost 2 homes per minute from now to 2050 to be made net zero carbon ready[2]
- greater than ten-fold increase in heat pump uptake from 55,000 to 600,000 per year[3]
- means for addressing the third of UK households now being drawn into fuel poverty[4 5]
- solutions for the housing retrofit affordability crisis[6]

RETROFIT-AT-SCALE explains how we can address all these by putting in place an equitable mass retrofit rollout strategy based on a new affordable low-cost whole-house retrofit standard.

So far, the UK has failed to initiate such a retrofit strategy due to short-term policy switching[7], a disjointed construction sector without the method or means to deliver at scale into the existing housing stock, (Chapt 6.3) the complexity of tenures and housing types, a challenging starting point of the worst performing housing stock in northern Europe (Figure B.1), and a retrofit offering that does simply does not appeal to householders and owners (Annex A.1).

Figure 0.1
Even with a rapid scaling up of best practice retrofit initiatives there remains a large unfilled majority of homes without an energy retrofit. A new low-cost BASIC retrofit standard is proposed to fill this gap.

Invest in reduced energy needs, instead of just into energy supply capacity

RETROFIT-AT-SCALE addresses the four major mutually dependent component needs:

- **A well-grounded mass retrofit proposal to give the Climate Change Committee confidence to change their homes retrofit policy recommendations from a 12% efficiency target to a halving of heating demand**
- **A site level productivity step-change to reduce costs and allow a housing mass retrofit rollout without exceeding the CCC planned cost for delivering net zero carbon**
- **A whole system approach that allows resulting savings in energy supply infrastructure and other co-benefits to be redirected as investment into mass housing retrofit**
- **A national policy suite to enable support and development of the retrofit initiative, and to manage funding redirection for a mass rollout of the whole housing stock**

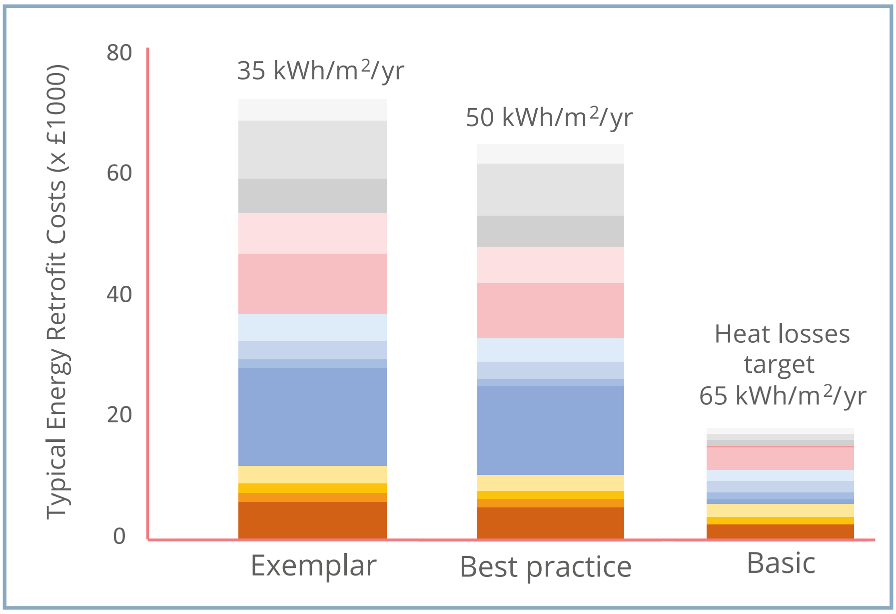
The **RETROFIT-AT-SCALE** research identified large gaps in the top-down policy framework, as well as the bottom-up home retrofit delivery.

In policy direction terms there is a vacuum largely created by the Climate Change Committee (CCC) in their 6th Carbon Budget, recommending only 12% energy improvements across the housing stock for delivery of net zero carbon (Chapt 6.1). This takes no account of the high energy costs to householders where affordability is already at crisis point, who would then disproportionately end up paying for the route to net zero carbon[8]

Meanwhile at the retrofit delivery end, there is the lack of low-cost whole-house solutions for mass rollout to the majority of homes (Figure 1.1)

To address both these, this **RETROFIT-AT-SCALE** document builds on two years of research to propose a new low-cost **BASIC** retrofit standard suitable for delivering a 50% heat demand reduction (Figure 0.1). This seeks to change the way we do retrofit, using productivity improvements as a means of reducing costs (Figure 0.2).

Figure 0.2 – The potential for a step-change in productivity and cost effectiveness arising from the BASIC approach, to enable whole-dwelling energy retrofits to be rolled out across the mass market (see Annex E)



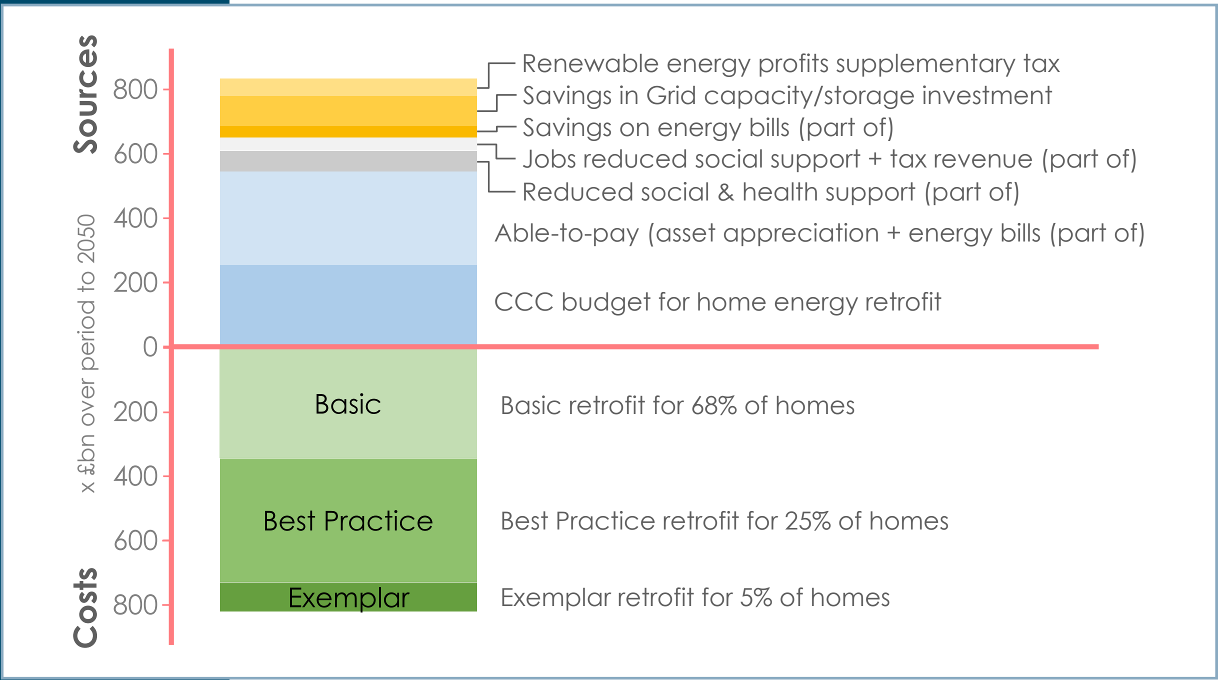


Figure 0.3 – Summary of cost for retrofit mass rollout, together with funding sources.

Ensuring the cost of getting to zero carbon is more equitably spread across society

RETROFIT-AT-SCALE explains how changes to the products used and implementation practices can push down costs. To drive these productivity improvements will need a parallel enabling policy framework, encouraging industry current practices to change (Chpt 3).

A mass retrofit rollout provides a critical mass that enables related opportunities. This includes reduced peak energy supply requirements, reduced supply system investments, and increased energy export potential. Many of these would allow redirected funds into enabling of energy demand reductions created by retrofit. Alongside a range of contributions from other co-benefits (Figure 0.3), this additionally delivers significant social benefits, without adding to the national cost of getting to net zero carbon – in other words – deep retrofit for net zero extra cost.

The aim behind this **RETROFIT-AT-SCALE** research and this **BASIC** retrofit standard is to provide a retrofit offering that delivers a more equitable route to net zero carbon, as well as appealing to householders so they can ***want*** and ***expect*** this for their homes.

FINDING YOUR WAY AROUND RETROFIT-AT-SCALE

Chapters

Annexes

Chapter

1

A new Retrofit Paradigm

Chapter key takeaways:

- *A retrofit mass rollout step-change needs a step-change from stakeholders*
- *Changes at top-down are dependent on bottom-up changes*
- *Top-down Climate Change Committee policy advice needs to change*
- *But to allow this, bottom-up industry must show it has the ideas for delivering far more efficiently*
- *A whole system approach shows how this can be paid for without increasing the UK cost of getting to net zero carbon*

Without increasing the cost impact to the UK, we can halve the UK's home heat demand and bills, while improving home living conditions for millions of households.

'how many, how deep, at what cost?'

Chapter 1: A new Retrofit Paradigm

1.1 Introduction

Our energy bills are too high, and we are not meeting our carbon targets[9]. We are falling well short on heat pump installations[10]. The proportion of society unable to pay their energy bill has rocketed[11] despite the UK's increasing carbon-free energy generation.

To put the issue of energy bills into perspective, the doubling of 2019 home energy bills, if considered through to 2050, is equivalent on its own to the cost of paying for the whole of the UK's pathway to net-zero carbon[12]. Continuing along the current path means those least able to pay in society are in effect funding the whole of the UK's switch to net-zero carbon.

Reducing energy bills by rolling out the current approaches to retrofit is also not tenable. Applying typical best practice retrofit across the housing stock would cost more than twice the cost of all sectors combined (transport, industry, energy supply and buildings) getting to net-zero carbon. Put another way, if all the net-zero carbon budget for all UK sectors combined were to be spent solely on retrofitting homes, this would equate to just £35,000 per home (see Chpt 5.1).

There must be a better way.

This **RETROFIT-AT-SCALE** research illustrates there is a better way. Without increasing the cost impact to the UK, we can halve the UK's home heat demand and bills, while improving home living conditions for millions of households.

The brief for **RETROFIT-AT-SCALE** was to address **'how many, how deep, at what cost?'** following a review of the LETI Climate Emergency Retrofit Guide (CERG)[13]. **RETROFIT-AT-SCALE** has added a top-down analysis of where we as a nation need to get to, with a reconciliation with a bottom-up deep-dive analysis of how more home retrofits can cost-effectively be delivered. This identified a major gap and a series of blockers in the market preventing mass retrofit adoption. So, while there is increasing public awareness and acceptance by householders and owners that their homes need to better contribute to our zero-carbon trajectory, the policy context and the offering from the retrofit industry does not appeal or support them in taking the needed practical action (see Annex A).

For addressing the blockers, the bottom-up research identified new ways of home retrofit delivery using improved productivity to reduce costs by two thirds, while also reducing household disruption, and delivering an average of 50% reduction in heating bills. This has been pulled together into a new **BASIC** retrofit standard, complete with illustrative examples, to form the basis of a mass rollout with a specific focus on generating more appeal for homeowners of all types.

1.2 Who leads this change

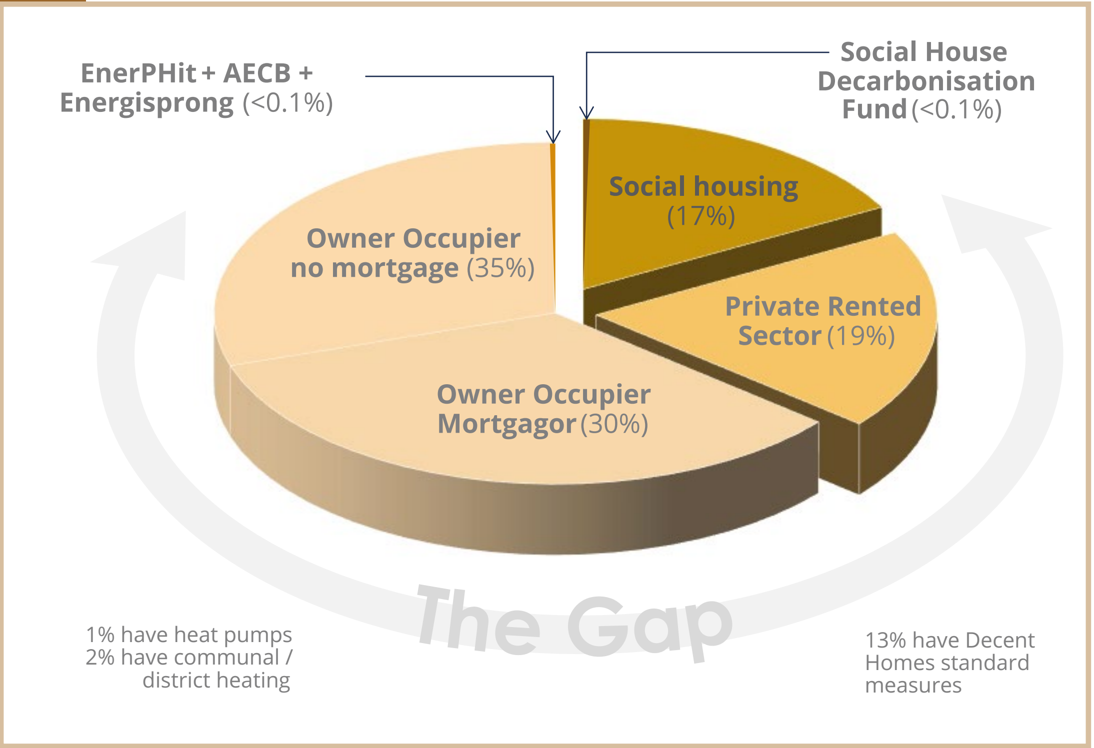
This document is addressed to a broad readership. Retrofitting our homes is a multi-facetted 'wicked' problem and will need new top-down integrated policymaking in parallel with new bottom-up improved delivery. Neither can deliver without the other. This will involve new commitments and new ways of working from all parties:

- Policymakers to reshape market priorities
- Politicians to set the unambiguous direction of travel
- Designers to offer new retrofit options
- Contractors to work in different ways
- Component suppliers to provide new products
- Energy supply chain to refocus on demand reduction
- Consultants and advisors to support a new retrofit alternative

1.3 Why do we need to change

The Climate Change Committee (CCC) current recommendation of 12% home energy demand reduction, and the Government's EPC 'C' target, both fall woefully short of what is needed if we consider who pays for our pathway to net zero carbon (Chpt 6). A more equitable way involves shifting the focus onto reducing energy demand, instead of just decarbonising the energy supply. This needs a mass rollout of cost effective energy retrofits across our 28 million homes.

Figure 1.1
Proportion of existing stock households by tenure, together with the scale of current energy retrofit initiatives.



the
BASIC
standard

The result is a simpler, quicker, less disruptive, less costly and more occupant friendly energy retrofit

For a mass rollout to be viable and practical, industry needs to deliver retrofits for less cost, and be able to guarantee it actually delivers on the energy savings. This will involve changing the way we do retrofit, including using more appropriate products, and more integrated implementation processes. The industry will need to deliver far more retrofits using less time, with the expected limited workforce availability (Annex G.2).

A mass retrofit rollout opens up further opportunities, such as freeing up the UK's burgeoning green energy supply industry to become a net-exporter into a world where demand will be high, given all countries will be seeking to decarbonise quickly, yet most have insufficient renewables generation potential of their own (Chpt 5.13).

Heating our homes is responsible for 18% of the UK's territorial greenhouse gas emissions[14] but with current policies and the general electrification of heat, our homes will need a disproportionate 45% of the future enlarged energy supply infrastructure[15]. These sorts of wider systems issues need to be included in the considerations of a retrofit scaling up. A focus on reducing energy demand not only reduces the future infrastructure costs, but also lowers consumer bills.

1.4 What do we need to deliver

The LETI Climate Emergency Retrofit Guide (CERG) identified why we need more retrofits, and the key issues involved. It introduced LETI Exemplar and LETI Best Practice retrofit levels. Following from this, **RETROFIT-AT-SCALE** research expanded the scope to include the challenges of costs and market penetration. While certain small parts of the housing sector are now reasonably well served with retrofit standards, there are major market gaps, consumer blockers, and policy blockers for the majority of the UK stock. (Figure 1.1, Chpt 2).

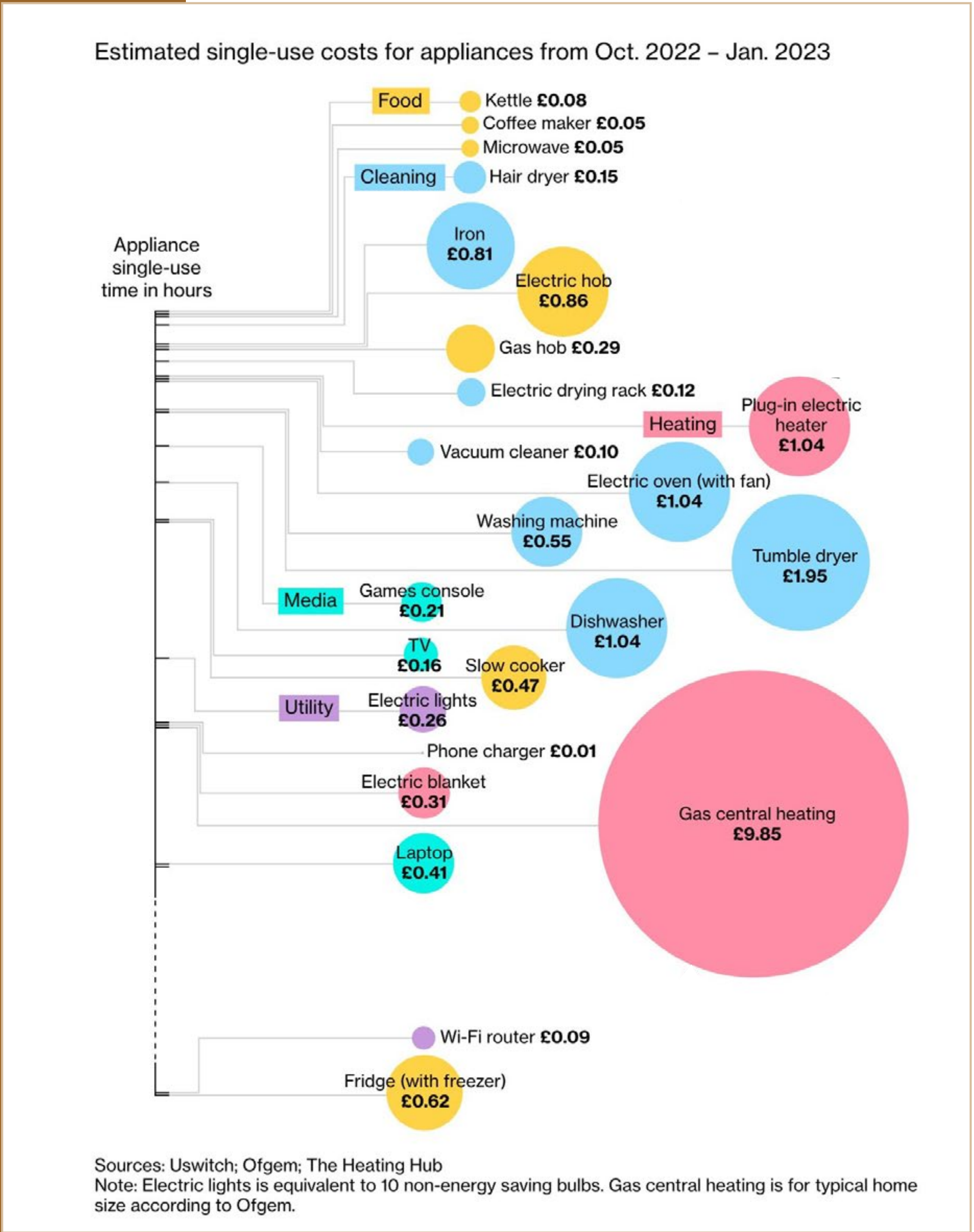
A new **BASIC** minimum retrofit standard has been developed to fill the gap left by the existing standards and deliberately tailored to address specific blockers identified for major parts of the UK's housing stock (Chpt 3). **BASIC** retrofit has been pitched at the level to be a minimum standard anyone and everyone can ask for, as well as a potential steppingstone to higher energy standards where appropriate.

In cost terms, the **RETROFIT-AT-SCALE** research identified a specific 'sweet-spot' that reduces the costs by two thirds compared with best practice 'deep retrofit' alternatives (Annex E). Identifying this involved taking apart what is normal practice and using a fine granular approach for isolating the most cost-effective measures and processes. It included identifying combinations that delivered compounded energy savings exceeding the sum of the individual measures (Chpt 4). **BASIC** also proposes changes to products, site works, and processes (Annex B, C and E). Overall, the result is a simpler, quicker, less disruptive and more occupant-friendly energy retrofit for much less cost than alternatives delivering similar standards.

The **RETROFIT-AT-SCALE** research dug deeper into the consequences of a mass rollout. The halving of UK overall home heat demand means the future National Grid capacity can be reduced by about a quarter, namely about 38 GW (Figure 5.5). There are associated reductions in future power generation and energy storage needs for coping with the UK peak demand periods, because these peaks are largely driven by home heating. The high technical

Figure 1.2
As heating is the major home energy cost, BASIC focuses on this hard-to-decarbonise issue (Graphics source: Bloomberg)

and cost risks associated with the currently assumed dependence on yet-to-be proven large scale carbon capture and energy storage are also reduced. Instead, low tech home retrofit solutions achieve the same end goal but with costs and health co-benefits for the UK's householders and local communities. The green energy generation freed up to become a valuable UK export product, due to this halving of heat demand, equates to around 47 TWh annually (Annex G.6). All this helps to ease the transition to net zero carbon for the energy supply systems, as well as for the wider society.



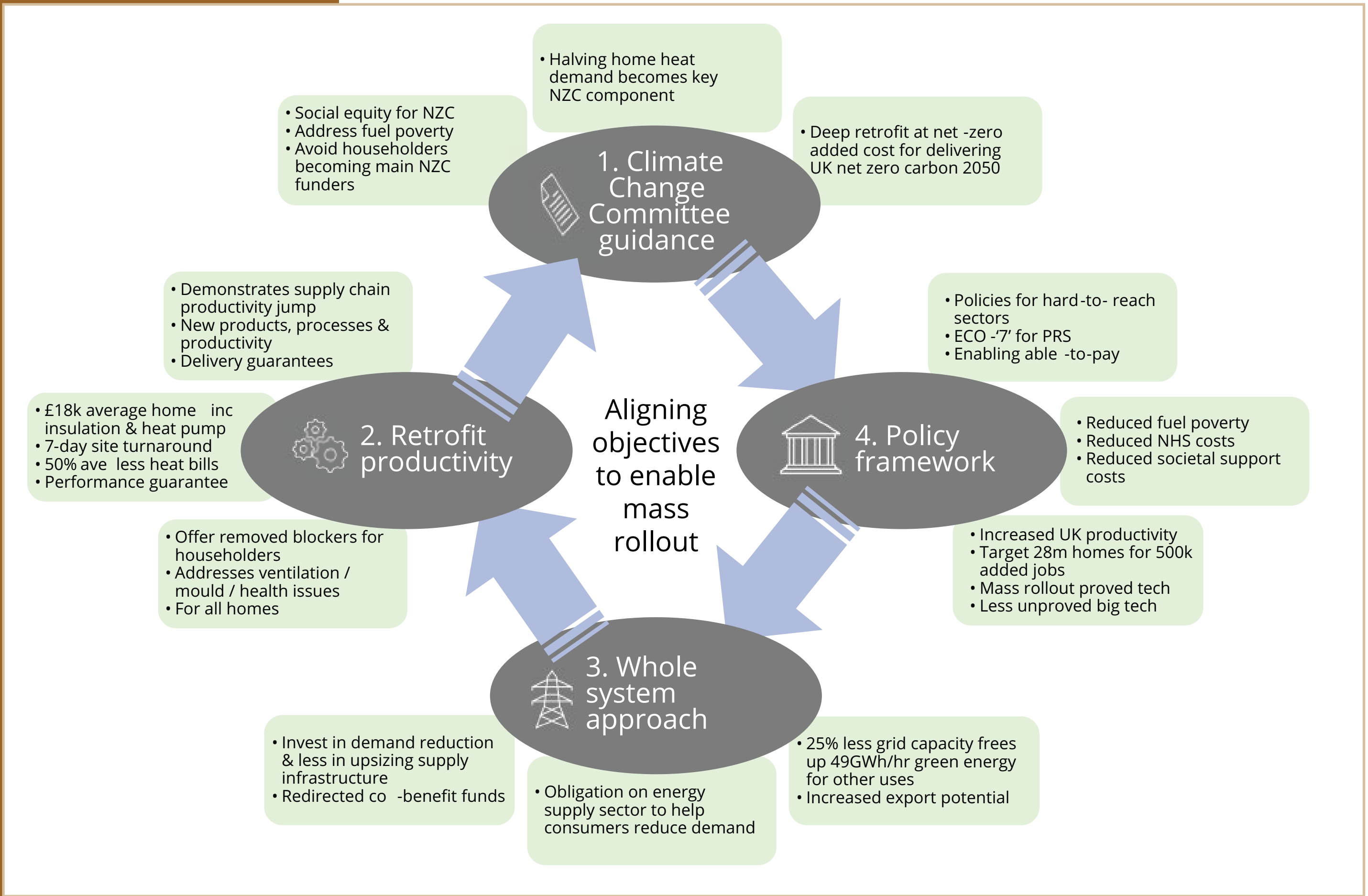


Figure 1.3
The four key inter-dependent components with their linkages

Reducing home heat demands reduces the Grid size needed, allowing redirected funds into retrofit

1.5 How do we deliver

Figure 1.3 shows the linkages between the four major mutually dependent components needed for a national retrofit programme.

A robust and long term retrofit policy framework is required. Without this, our fragmented and fledgling retrofit industry will not respond at the speed and scale needed given the discouragement fostered by previous policy false starts.

This policy framework needs to be informed by clear guidance from the Climate Change Committee (CCC) on how mass retrofit of homes is essential to be able to deliver a just and equitable route to net zero carbon. For CCC to have confidence to advocate such guidance, industry must provide well-grounded proposals on how it can deliver. This is what the **BASIC** retrofit standard aims to provide.

A mass retrofit rollout needs to be considered in whole energy supply system terms, given the disproportionate impact of changing home heat demand. Reducing the demand on the future system allows the redirection of investment funds. This becomes one of a number of important contributors to funding a mass retrofit rollout.

However, to allow this freed-up finance to be enough to deliver sufficient reductions in heat demands, the cost of deep energy retrofits needs to be reduced significantly. This is what the **BASIC** retrofit standard increased productivity aims to provide.

The **RETROFIT-AT-SCALE** new **BASIC** standard provides the key missing factor in solving the multi-facetted retrofit 'wicked' problem posed by **'how many, how deep, at what cost?'**

Chapter 2

The gap to be filled

Chapter key takeaways:

- *We are hardly scratching the surface on retrofit numbers or switching to carbon free energy sources*
- *The industry's solutions do not best suit much of our housing stock*
- *There is a fundamental lack of householder appeal*
- *Consumer protection is still in the dark ages*
- *Householders want a wider choice of price points*

Currently we are tackling less than 1% of the housing stock – we need mass scale up

Chapter 2: The gap to be filled

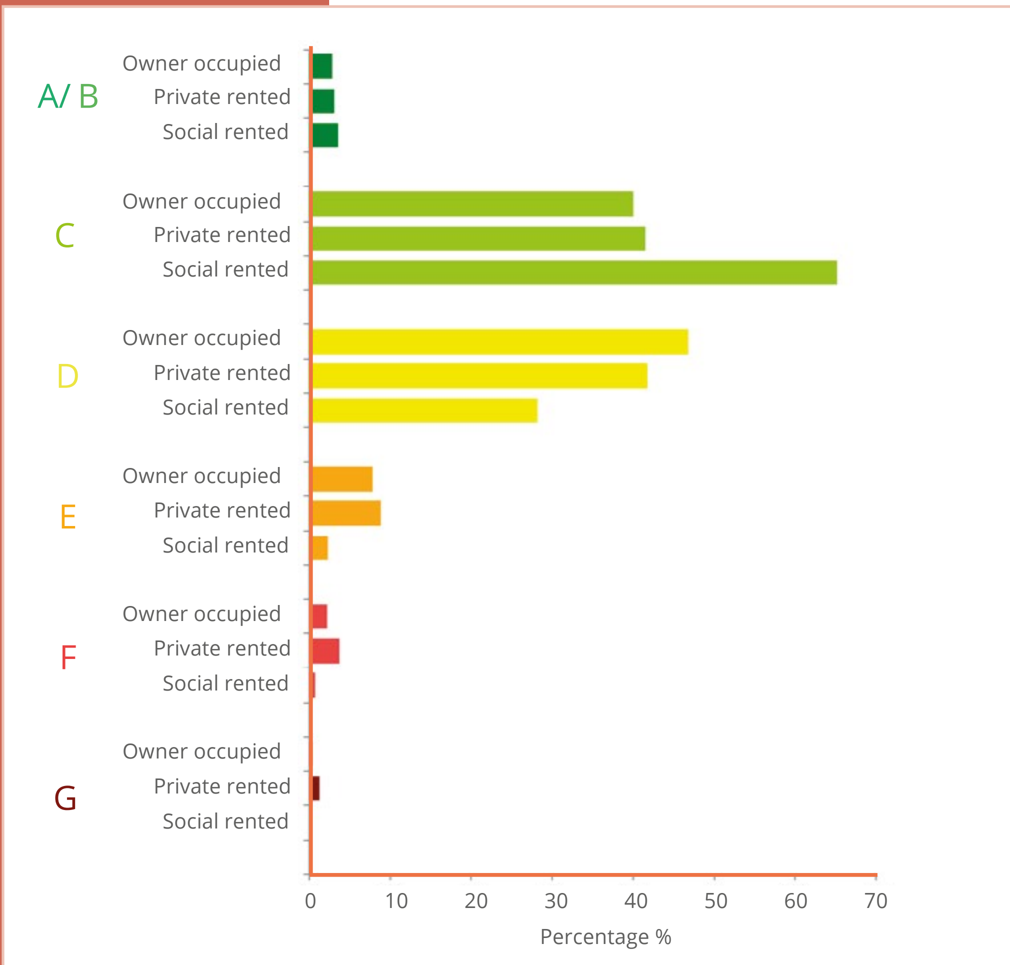
This chapter sets out the scale of the UK's home retrofit challenge, the primary blockers to mass rollout, and the issues a new BASIC retrofit standard must address.

2.1 Scale of the home retrofit challenge

Figure 1.1 provides an overview of how the UK existing housing stock is divided up. An indicator of the stock energy performance is provided by data collected from energy performance certificates (EPCs) in Figure 2.1. This shows the private rented sector (PRS) and owner occupier sector have noticeably worst performance that the social rented sector. For the latter, past policies like the Decent Homes Standard[16] have helped lift minimum energy standards to a very limited degree. However, this is just one sector and most of the stock has been left behind.

The UK Government policy aim for the social rented sector is EPC 'C', with some funding funnelled via the Social Housing Decarbonisation Fund (SHDC) for England and similar schemes under the devolved administrations. In approximate terms the EPC 'C' target equates with the CCC 12% energy efficiency target. So far, the SHDF has delivered just 10,000 home upgrades, compared with 24.9 million dwellings in England. At the current rate it would take well in excess of 1000 years to upgrade all EPC 'D' or worse homes across the UK to only this modest energy standard.

Figure 2.1
Energy efficiency rating bands for occupied dweling by tenure, 2021[20]



Deeper energy retrofits, as represented by AECB CarbonLite[17], EnerPHit[18] and Energisprong[19], are spread across social housing and owner occupier sectors. The number of these delivered retrofits is considerably less than 0.5% of the existing housing stock.

Collectively, these low rates of retrofit need to be of the order of 250 times higher and delivered each year, for the whole stock to be upgraded in preparation by 2050.

2.2 Complex-to-decarbonise homes

There are many different types of housing in the UK stock, which in itself forms a major constraint to rolling out mass retrofit. But housing archetype form is but one variant set, with tenure and occupant aspects being arguably more dominant for the wider adoption as outlined in Annex A. Two particular constraints repeatedly crop up as occupant driven major blockers, namely limited internal space, and building character preferences.

Figure 2.2
LETI Climate Emergency Retrofit Guide (CERG) includes assessment of extent of heritage and architectural constrained homes.[22]

Retrofit practitioners cite space constraints as a key reason householders of modest and average sized houses and flats are discouraged from taking forward energy retrofits. Accommodating the hot water store required by a new heat pump system is particularly problematic. Reducing the room size and having to move fitted furniture when installing internal wall insulation is also a major issue. While research for CCC identified smaller homes may have a space issue[21], practitioner feedback suggests this constraint goes far further, driven by widespread householder perceptions that their homes and their outdoor areas are normally smaller than they would like them to be (Annex A.1). Consequently, to get mass market buy-in, **BASIC** needs to be able to offer technical solutions that do not reduce a home's indoor and outdoor useable space.

Heritage and architecturally constrained homes were previously identified in the LETI Climate Emergency Retrofit Guide (Figure 2.2) as roughly 23% of the stock, namely about 7 million homes across the UK. These include formally identified heritage dwellings, but also those perceived by their householders to have character value. Such a large proportion of UK homes cannot be left without energy upgrades. Not least, a significant proportion of the fuel poor live in such homes. The aim is to ensure the **BASIC** level of retrofit could be applied to the majority of these heritage and visually constrained homes. Consequently, the **BASIC** heating target has been deliberately pitched at a level that can be achieved without requiring such measures as external wall insulation to the front façade. Likewise, the **BASIC** target can be achieved without internal wall insulation that might cover room character features. This pragmatic setting of the target brought down to about 2% the proportion of homes where heritage and architectural constraints are likely to mean **BASIC** is unsuitable (Annex F.4).

There are also regional climate differences and differing construction and building massing variants that create other complex-to-decarbonise homes. **RETROFIT-AT-SCALE** aims to illustrates an overall retrofit approach with a target heat loss, while allowing freedom to consider alternative efficiency measures combinations for delivering the **BASIC** heat loss target. Hence, while flank wall external wall insulation (EWI) is proposed, this does not preclude rear elevation EWI or the selection of alternative or additional measures where they may be better suited.

2.3 Lack of householder appeal

Today, major interventions in homes need the engagement and full support of all the occupants, as well as the householder. This is unlike the 1970's natural gas switchover which, while on a similar scale, was of a previous era with centrally imposed regional rollouts implemented by a nationalised industry without a householder say and without today's social media[23].

The lack of robust and long term political and policy direction also provides an unnerving context for householders. While there have been big political statements, there is a lack of joined up consistent narrative on how these then relate to the multiplicity of individual householder situations (Annex A).

While there has been a major sea change in general public understanding and awareness since the 2019 Climate Change Act, the majority of householders still feel unable to act. Not least, they are unsure who to trust, with mainstream media and social media contributing to a lack of clarity, much information that is conflicting, unsubstantiated anecdotes, and a general lack of in-depth practical knowledge.

Overall, there is information overload, largely driven by commercial interests offering conflicting information. We are surrounded by suppliers and 'professionals' telling householders there is only one type of kit or one level of energy efficiency measures; neither explaining the complete story, nor guiding them through the whole energy retrofit process or how to fund it. In short, the retrofit industry is not providing an appealing offer. Indeed, it is loaded against the consumer. Take for instance a heat pump installer, there is no incentive for them to offer some thermal insulation and hence a reduced heat pump size and with it guarenteed reduced running costs.

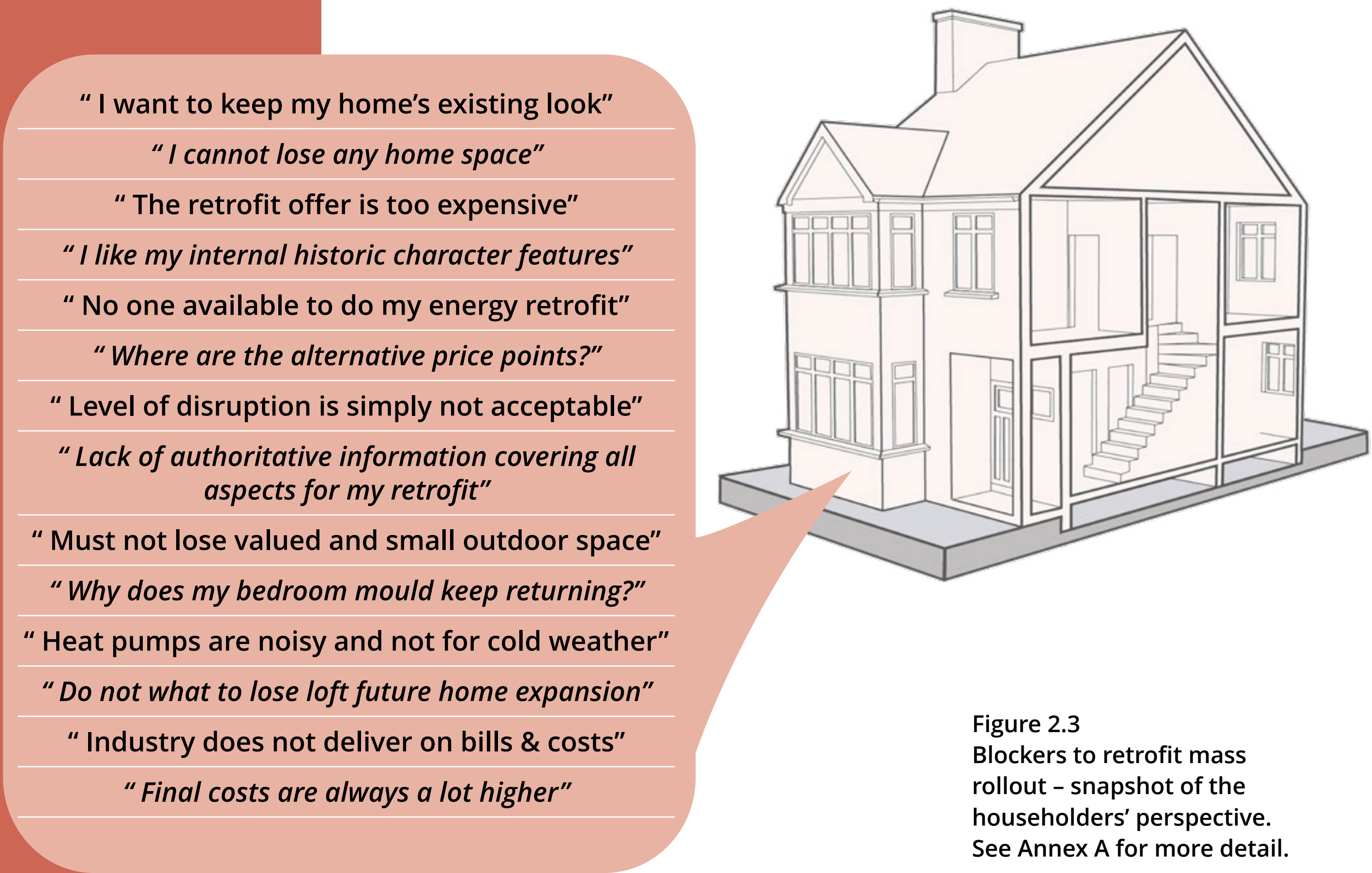


Figure 2.3
Blockers to retrofit mass rollout – snapshot of the householders' perspective. See Annex A for more detail.

Why is energy retrofit a turn-off for most householders?

To help individual householders and as a bedrock for a mass rollout, there must be local community level engagement. Householders are more likely to trust people they know and those with whom they can establish longer term relationships. This needs local leadership and local community routes for provides appropriate two-way information flows with individual householders (Chpt 3). This is the primary route for gaining positive in-person feedback of retrofits done well. Local retrofit supply chains need to become part of this community-based engagement so the all-round confidence can be built over time.

The householder (or housing owner portfolio holder) is the one who needs to be provided with the individually appropriate, comprehensive, and coordinated knowledge, sufficient for them to make sound decisions for themselves on what level of retrofit is appropriate for them. This has to be good enough for them to engage and be involved in the selection of the delivery team most appropriate for their retrofit. For building retrofit appeal, individual householders needs to know they are not alone, and they have a peer group they can learn from and with whom they share information and concerns.

BASIC seeks to explain for householders, portfolio holders, and consumers, what a baseline retrofit for a minimum integrated and costed solution looks like. For many this can then become a reliable minimum ask with a guaranteed delivery service and cost, appropriate for their contribution to the planet. For others, it would be a springboard for further enhanced retrofits and perhaps integrated with other home amenity upgrades.

BASIC also seeks to explain to the energy retrofit industry what they need to do to deliver on the cost, programme, and guaranteed energy performance, consumers should be expecting for this level of financial commitment in their homes. **BASIC** also takes advantage of locally based retrofit implementation teams to enable a continuous local workflow for team members with minimum downtime between job sites, and minimum advertising and marketing costs, to reduce overhead costs.

2.4 Inadequate consumer protection

Unlike almost any other major purchase, a householder gets no performance guarantee for an energy retrofit of their home. It is almost impossible for them to hold to account those implementing the retrofit. This has bred an industry culture that too often pays only lip service to what it says on the tin and hides behind the split responsibilities of the multiple parties involved in most whole-dwelling retrofit projects. The lack of consumer protection propagates the fragmented industry that, to use the car analogy, supplies the client with wheels separate from the motor and expects someone else to get them to run together. It has spawned an industry that thrives on media claims and counterclaims from which it is virtually impossible to decern reality from marketing hype.

This lack of clearly defined performance guarantees compounds the householders' doubt that they are getting what they paid for and erodes their trust of those providing the retrofit deliveries. Without a clear energy performance comparison of 'before' and 'after' retrofit, a householder cannot hold the industry to account for non-delivery.

Energy Performance Certificates (EPCs) are the official current metric for existing homes based on a RdSAP site assessment and SAP modelling software[24]. While in the past this has provided an adequate overview snapshot of the national stock, it is proving inadequate for individual whole-dwelling retrofit assessment, and certainly not for providing consumer protection. Smart energy meter data now shows large discrepancies between EPC ratings and actual energy use (Figure 2.4).

The starting point has to be responding to householder concerns

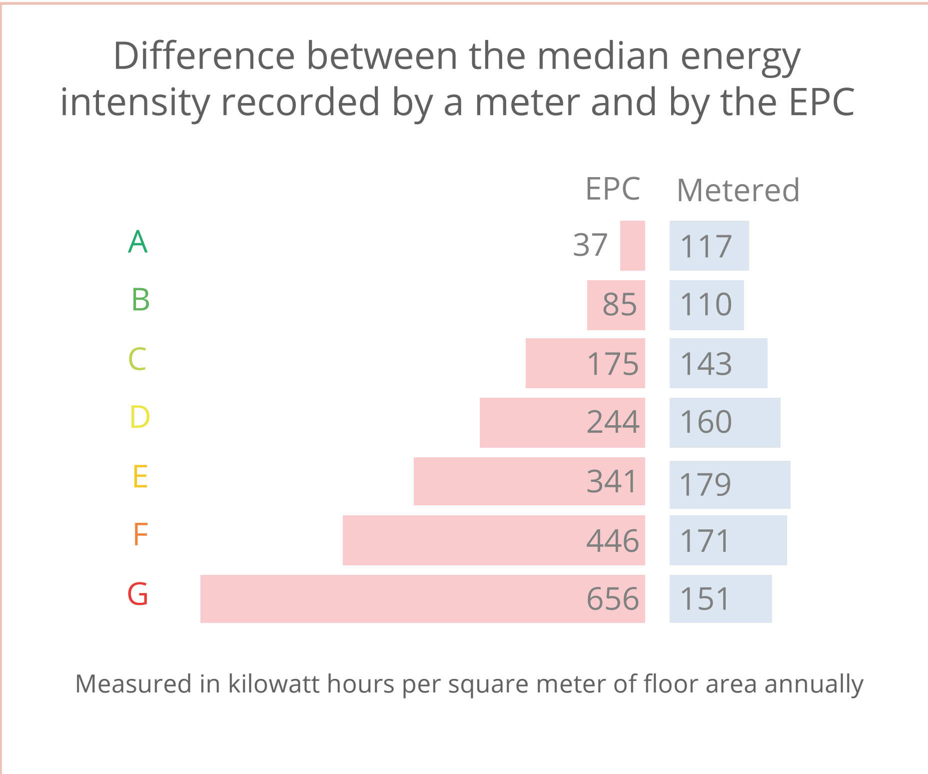


Figure 2.4
EPC predicted energy use compared against meter measured energy use. For uninsulated homes the actual energy use tends to be far less than the EPC assessment, while very well insulated homes actually use more than the EPC prediction. Data from CarbonLace.

This is particularly prominent for older uninsulated housing stock where, unlike new-build, occupants tend to operate at lower temperatures. Incremental improvements to homes are also not accounted for. For instance, the airtightness may be significantly better than the RdSAP survey assumption, which is based on building standards when the home was originally built. These discrepancies are significant for retrofit because claimed energy saving are difficult to deliver if that energy was not being used in the first place.

We must learn from parts of the industry that have a good track record of delivering predictable energy retrofit performance. The EnerPHit retrofit process is one[18] such example where trained personnel carefully survey the home before retrofit and then measures the performance afterwards to provide reliable and predictable outcomes.

BASIC requires more accurate pre-retrofit energy use measurement (see Chpt 3.5) and performance verification post-retrofit[25] This allows far more robust selection of the most appropriate and cost-effective combination of energy efficiency measures, along with more accurate and smaller sizing of heat pumps. It also provides a transparent way for consumers to see what the retrofit has delivered in energy performance improvement terms, as well as an effective way for industry to gain feedback and improve their retrofit delivery.

2.5 Rollout mix of retrofit levels

Having identified the characteristics and scale of the national retrofit gap, the output of the UK housing stock model (see Annex F) was used to assess the likely number of different retrofit levels needed to reduce the UK home heat demand by half.

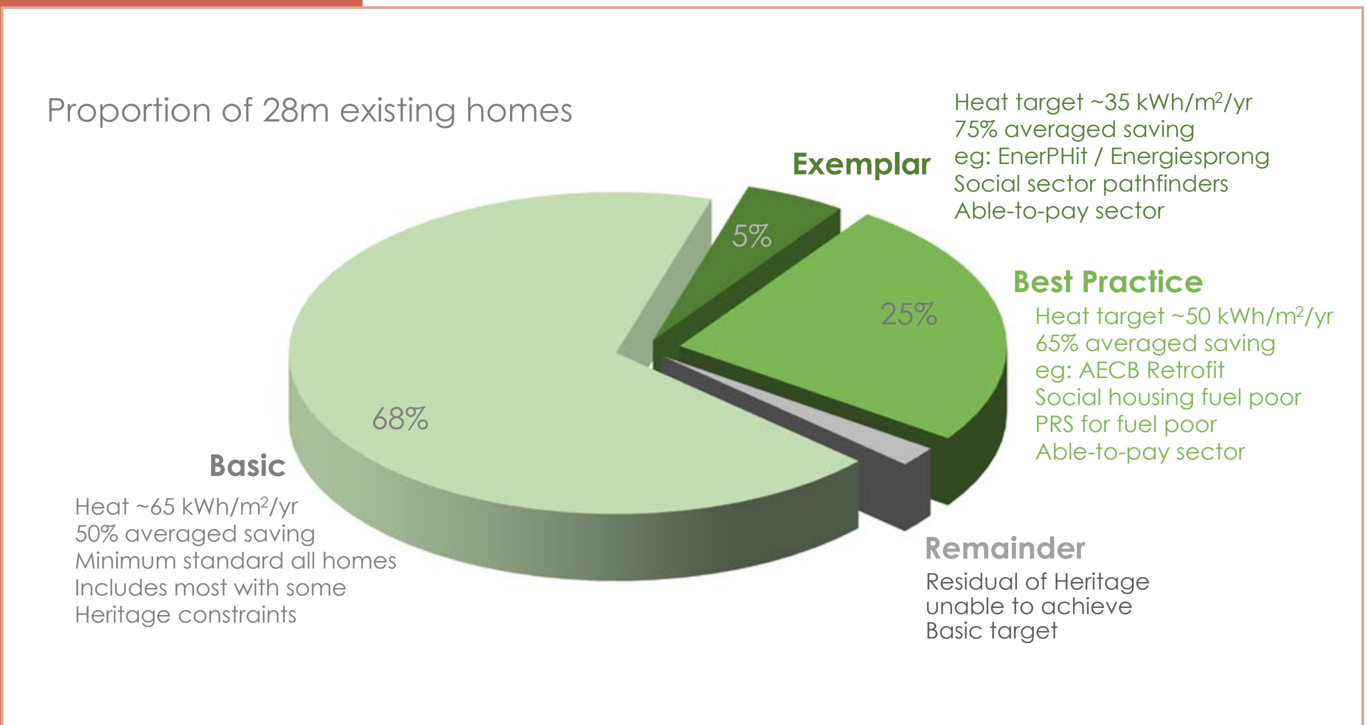
In practice, there is a number of different potential combination of solutions, each governed mainly by the chosen policy framework. There is a preference for the fuel poor to gain most benefit, which would also increase the financial savings available to then help fund the wider retrofit rollout. Although policy tools are relatively blunt instruments, **RETROFIT-AT-SCALE** has identified the key policy framework (Chpt 7).

A shortlist of likely combination of retrofit levels was identified and tested at the stock level. This testing included matching the overall implementation costs against the financial resources identified (Figure 5.8). The **BASIC** retrofit level was costed for a typical installation (Annex E) using the illustrative example alongside best practice and exemplar levels previously defined in the LETI Climate Emergency Retrofit Guide (CERG)[26].

The heat savings delivery target included differing Performance Gap and Comfort Takeback allowances for each level of retrofit (Annex F).

Figure 2.5 shows the national mix of retrofit levels to meet national energy, carbon, and cost targets. This assessment suggests a very significant scale-up of current best practice and exemplar retrofit levels, alongside **BASIC** for filling the mass market gap.

Figure 2.5
Proportions of different retrofit levels to achieve national 50% reduction in home heat needs. The heat target is the heat output of the home heating system. Includes Comfort Take-back and Performance Gap influences.



Chapter 3

The new BASIC retrofit

Chapter key takeaways:

- *There is a lack of options for a low cost retrofit to halve our heating bills for the average typical home*
- *What might a Basic ~£20k retrofit, including fabric and heat pump, look like?*
- *Understanding the householder and owner needs*
- *A one-stop-shop approach with single point of responsibility*
- *Understanding the building to identify the best combination of measures*
- *How do we ensure we include the key elements of a best practice retrofit*

Doing energy retrofits better, and more than halving their cost

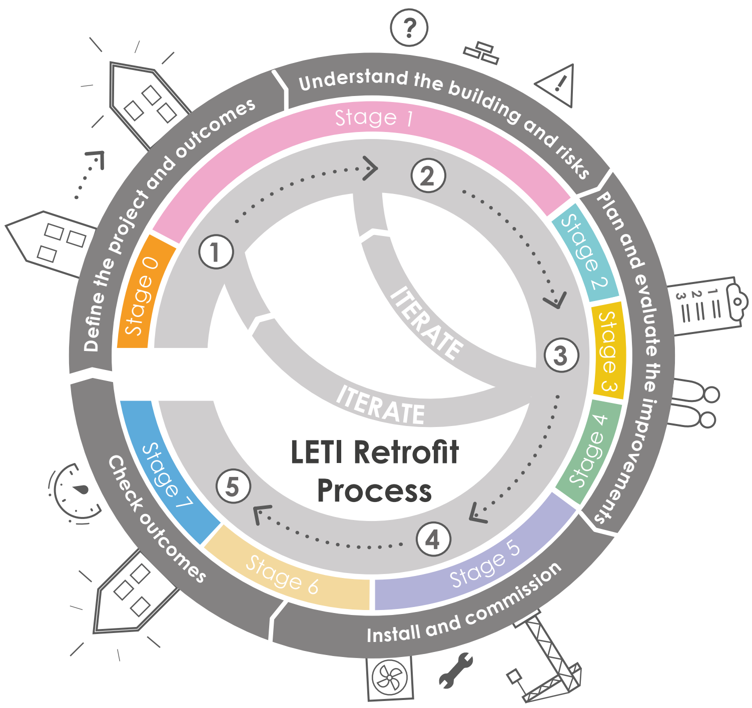
Chapter 3: The new BASIC retrofit

This chapter introduces the new BASIC retrofit, and what it needs to address if it is to deliver a 'whole-dwelling' minimum level of energy retrofit for the identified gap in the market (Figure 1.1). BASIC is forward looking and proposes various products and processes for improving delivery productivity. RETROFIT-AT-SCALE is a call to industry to develop such products and processes.

BASIC aims to deliver a 50% heat demand reduction averaged across the stock for a cost that is a third of typical current best practice (Chpt 5), and be applicable to two thirds of UK homes. This is key for delivering a rollout that is 'net-zero' added cost on our route to net-zero carbon (Chpt 6) .

BASIC is intended to be a performance standard and not a set of proscriptive retrofit measures (Chpt 4). **RETROFIT-AT-SCALE** seeks to illustrate, by way of a detailed illustrative example, how **BASIC** can be achieved when applied to homes currently perceived to be complex-to-decarbonise (Annex B). It shows how our industry can deliver the social benefits of reduced fuel poverty, improved health and wellbeing in the home (Annex A), alongside our net zero-carbon, all at a nationally affordable cost.

Figure 3.1
A retrofit should have a Retrofit Plan prepared beforehand and have it recorded in the Building Passport (Figure 5.5 in ref [1])



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

BASIC: new processes and new products, geared to deliver a very quick site turnaround.

3.1 BASIC - the requirements

BASIC is focused on the need to reconcile and satisfy both local – bottom-up, and national – top-down, objectives. Hence, sufficient energy savings are needed to address fuel poverty on one hand (Annex B.2), while generating sufficient infrastructure and other cost savings to fund this wider retrofit on the other hand (Chpt 5).

BASIC aims to be applicable to about two thirds of the housing stock (see Annex F). For the other third, including those targeting higher energy saving standards, those with non-standard construction types, or with extensive defects to be rectified, **BASIC**'s simplified process may not be appropriate. These are expected to need additional specialist input, both for assessing the extent and type of retrofit measures, and for site implementation skills (Annex B.3). While most heritage buildings should be able to achieve **BASIC**, some, mostly individual listed heritage buildings, may find Basic's simplified process inappropriate (Annex F.4).

BASIC is very deliberately focused on the average housing stock with its specific constraints and does not try to solve all the special cases. Some of the proposed **BASIC** productivity and costs gains could be applicable for wider application, perhaps as the first stage of a phased implementation of deeper energy retrofits. These are not specifically explored in this **RETROFIT-AT-SCALE** research.

Figure 3.2
BASIC retrofit – key headlines

- Focus on reducing heat demand for the big energy bill wins, together with the switch to heat pump.
- 65 kWh/m²/yr space heating demand as a practically achievable demand target (heat pump output). This is a 50% heat demand saving for an average UK home.
- 75% reduction in heat pump electrical peak demand, so avoiding dwelling electric upgrades, reducing local grid upgrades, and reducing national grid future overall capacity needs by 25%.
- Two thirds cost reduction (£/kWh saved) for a 'whole-dwelling' retrofit. This enables a mass retrofit rollout cost to be within the 1% GDP whole UK cost target for getting to net zero carbon.
- Make retrofits better appeal to householders and remove the perceived barriers to retrofit.
- More indepth surveys to fully understand existing dwelling for matching best solutions and then afterwards verify the retrofit works is as intended.
- 7-day site turnaround using new products and processes to minimise disruption and gain the productivity step change.
- Integrated 'fabric-first' and M&E approach, using the cost sweet-spot of 'just sufficient' fabric upgrades with a limited kit-of-parts.
- Robustly addressing moisture and air quality issues using mechanical background supply and extract ventilation.

3.2 Good practice retrofit

RETROFIT-AT-SCALE focuses on aspects of retrofit that can contribute to a retrofit productivity step-change. For guidance on wider technical good practice the reader is recommended to consult resources such as:

- National Retrofit Hub is establishing a library for retrofit good practice and skills information https://nationalretrofithub.org.uk/
- EnerPHit Passivehaus Trust on exemplar retrofit standard https://www.passivhaustrust.org.uk/
- Association for Environment Conscious Building (AECB) on CarbonLite best practice standards https://aecb.net/
- Energeispong energy retrofit and finance process https://www.energiesprong.uk/
- LETI CERG on standards and overview https://www.leti.uk/retrofit
- BSI - PAS 2035:2023 on process and risk management https://www.bsigroup.com/en-GB/search-results/?q=PAS%20 2035%3A2023

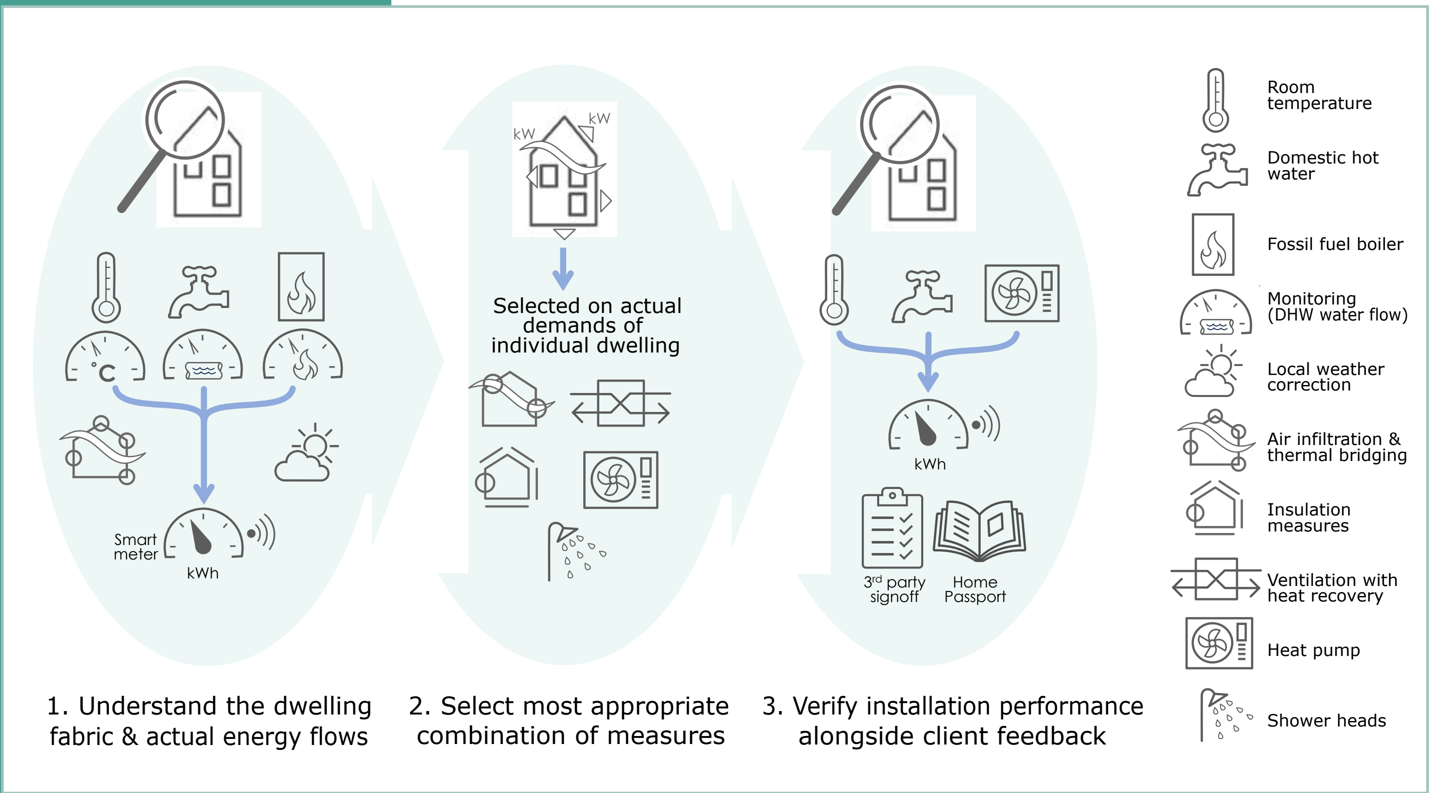


Figure 3.3
Leading clients through the process

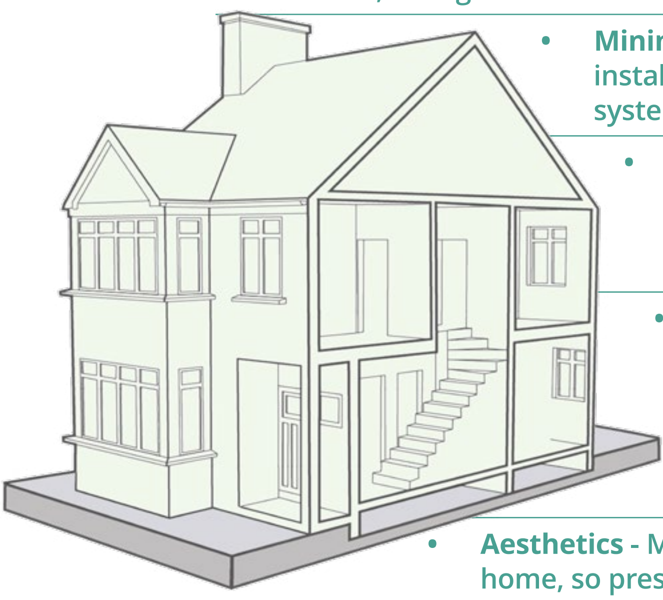
'Every house is different' is a turn-off and needs to become a recognisable **BASIC** kit-of-parts delivered with a one-stop-shop guarentee

3.3 Understanding householder and owner needs

The reluctance of householders to take on energy retrofits is a major blocker to retrofit mass rollout (Annex A). Issues for the householder typically include the high level of disruption to their home, high costs and a lack of trust in a smooth delivery process, albeit these are headlines from a longer list (Figure 2.3). For all to engage, home retrofit needs to better appeal to the majority. A mass rollout must address and solve these issues. This means identifying better means of engagement, being able to offer alternative options, guarantees on delivery, and much clearer articulation of the benefits for them as occupants and owners. A retrofit mass rollout means the relationship with most householders or clients will be different. They are unlikely to be eco-enthusiasts.

A community-based approach is a proven route for introducing retrofit to a wider selection in society who otherwise have limited experience working with a retrofit delivery team or of 'whole-dwelling' retrofit. This community approach should include local trades people and retrofit enablers, who via local networking are more likely to gain the trust of individual householders[27][28]. A community-based approach also allows a sequence of homes to be programmed back-to-back to avoid costly downtime for trades people between individual homes. A smooth, predictable, and quick retrofit process is a key component for greatly reducing the costs (Annex E.2) as well as making it more appealing. Warranties on delivery and energy performance need to be provided and a follow-up service available. A feedback process is needed to allow the retrofit team to learn and improve their client facing service. Co-designing, namely working with householders / client to agree the level and type of retrofit (Figure 3.4), is an essential component of the retrofit process and for getting their buy-in (Annex A.3).

Figure 3.4
Engagement with householder and owner



- **Predictability** - The 'every house is different' offering is a turn-off and needs simplifying into a recognisable BASIC kit-of-parts delivered by way of an integrated service, with guaranteed costs and warrantied energy outcomes.
- **Minimum disruption** – Measures should be chosen for rapid installation with least impact on the existing fabric and systems, and the occupancy.
- **Reduced cost** – Tight and predictable processes and technical solutions, coupled with clearly defined price point options for different levels of energy efficiency performance. Ringfence maintenance & betterment.
- **Preserving space** – The majority of homes are space-constrained, at least as perceived by occupants. Losing space for heat pump hot water cylinders, or internal wall insulation is often be a showstopper. This often extends to heat pumps outdoors. There must be a no loss of space option.
- **Aesthetics** - Most people have a level of visual affinity with their home, so preserving the front façade tends to be a priority. This also enables BASIC retrofit to be appropriate for most heritage situations.
- **Trust / guarantee** – Local community involvement allows engagement householders are more likely to trust. They can offer independent third-party feedback and build confidence by way of locally based retrofit teams.

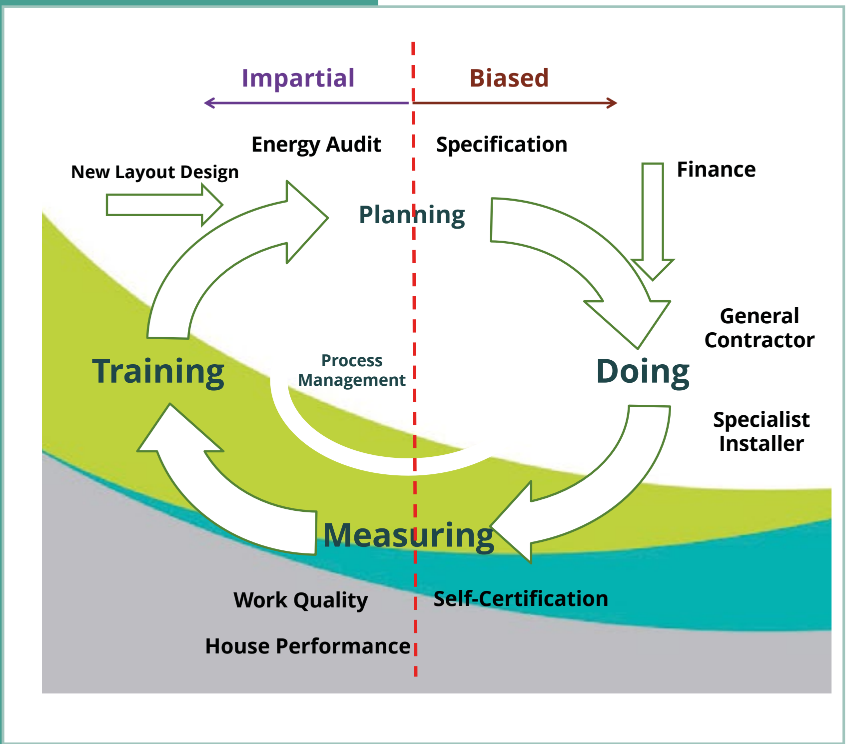
One third of all retrofit costs are related to overheads

3.4 Managing the process

The **RETROFIT-AT-SCALE** elemental cost analysis, together with reviews from a number of retrofit practitioners, identified considerable duplicated and non-productive costs buried within typical retrofit practices. More than a third of conventional retrofit costs were found to be related to overheads costs (Annex E.1).) By focusing on the less complex and more straightforward majority of the retrofit sector, the **BASIC** retrofit aims to eliminate these duplications.

Much of these inefficiencies relate to contractual sub-divisions within the retrofit delivery team (Annex E.2). Instead, **BASIC** recommends all trade contractors, and the associated professionals, should be within a single contractual specialist retrofit organisation to avoid the typical fragmented separate contracts and duties. This means there can be a single point of contact for the householder and a single party bearing the responsibility for the entire retrofit project.

Figure 3.5
Separating out the impartial functions as part of ensuring best value for the retrofit client (Parity Projects).



In practice this is likely to mean a team led by the Retrofit Coordinator as defined in PAS 2035:2023[29] fronting a single delivery contractual entity, with responsible for moulding together an integrated team and coordinated delivery service. The Retrofit Coordinator would be responsible for providing guaranteed overall costs to the householder. They would take responsibility for doing a single site survey visit instead of the plethora of site surveys normally done by each individual trade specialists within the team. This allows, for instance, the heat pump installer's selection of plant size to be based on the same information used to define the insulation scope, and then to have it available for installation at the same time the insulation is being installed. Such a site critical path programme is illustrated in Figure E.2.

Combining the individual site surveys needed by the multiple trade specialist opens up the opportunity to adopt new emerging technologies, such as 3D Lidar scanning and digital thermal imagery to achieve further time and data-gathering savings in future.

The importance of the Retrofit Coordinator and Retrofit Assessor

The Retrofit Assessor, as defined by PAS 2035:2023, is the one contractually independent party whose role is to provide the third-party check on behalf of the householder / client. The Retrofit Assessor would also be responsible for initially assessing the suitability of the property for a **BASIC** retrofit and establishing the associated contractor and professional skill level needs. This reflects the need for an impartial duty separate from the commercially bias delivery team (Fig. 3.5)

The Retrofit Assessor would also be responsible for ensuring the post-retrofit verification processes have been completed, the Home Passport / Logbook updated (Figure 3.1 & Figure 3.3), and the client has signed them off.

A good survey drives out over-sizing and duplication costs

3.5 Understanding the existing building

BASIC energy retrofit at the very least should be considered for all UK homes, even if the extent of measures may vary by home type, condition, features, and context. A good dwelling site survey is essential if the most cost-effective combination of measures is to be identified.

Figure 3.6
PAS 2035: 2023
Retrofitting dwellings for improved energy efficiency – Specification and guidance

The survey should be guided by the PAS 2035:2023 recommendations[29] The survey must be sufficient to determine if the dwelling is suitable for the **BASIC** level of retrofit, or if additional and different levels of technical skills are required (e.g. heritage, construction complexity, non-standard construction).

The survey should also identify if there are building fabric and system defects that would inhibit energy efficiency and compromise improvement measures. Putting right these defects is a pre-requisite to doing any energy efficiency measures. This includes water penetration and damp, and openable windows for purge ventilation (Annex B.3).

Beware that certain survey tools like RdSAP[30 31] make broad assumptions on the construction and details simply based on what was national typical construction at the time it was built. This means the survey overlooks many details that may have been originally built differently, as well as the myriad of alterations typically made to individual dwellings over time. As such, RdSAP surveys should not be relied upon for determining the most cost-effective combination of energy efficiency measures. Likewise, EPC ratings (Energy Performance Certificates) are simply based on RdSAP surveys and have very limited value at the individual home retrofit level (Annex B.3). Figure 2.4 shows there can be a large disparity between actually measured heat use and EPC asset rating assessments. See Annex B.3 for more detail. Figure 2.4 shows there can be a large disparity between actually measured heat use and EPC asset rating assessments.

Plugging air leakage heat loss is very cost effective – if you know where the leaks are.

Surveys should include the following:

- **Establish the actual heat demand using the HLC test (Annex D.1 case study) or equivalent, supplemented by room temperature and actual domestic hot water flow information (Figure B.1)**
- **Air leakage pressure test, complete with identification of air leak size and locations[32]**
- **Thermal image survey to identify significant thermal bridges and damp.**
- **Layout and other information sufficient to avoid the need for subsequent survey visits by individual trade contractors.**

How to reduce the size of your heat pump by two thirds

Instead, the survey should produce an actual heat energy use metric in kWh/m^2/yr with its associated actual heat loss in W/°C based on direct measurement of the dwelling and how it is currently used. Alongside this, the theoretical asset rating in kW/m^2/yr with its associated W/°C, based on its theoretical occupancy, should be used as a comparison to identify how much the pre-retrofit home is underheated (or overheated). Understanding the difference between these is important because an underheated home, whether due to fuel poverty or otherwise, means the retrofit will deliver less energy savings than the theoretical target.

A typical BASIC retrofit:

Community based engagement	Increases access to, and gains trust of householders and owners. Allows multi-dwelling programming flexibility to suit householders / clients Provides continuity of work for different trades between local sites.
Identify existing constraints	Identify defects and maintenance issues to be resolved before energy retrofit. Check heritage and household constraints / preferences. Is the energy retrofit to be coordinated with other dwelling betterment works? Decide if the dwelling is suitable for the **BASIC** retrofit or does it need additional technical input or does householder want even better energy standards.
Single Integrated Delivery Team	Delivers the complete retrofit delivery process with better cost certainty. Provides single point of contact and responsibility. Closely coordinated programming (typical 7-day site works) and integrated site working to reduce overhead costs.
Know your building	Pre-retrofit site survey and assessment. Includes measuring actual heat use, air leakage (& locations), thermal imaging for thermal bridges, and moisture/ventilation of ground floor void. This data helps identify the best suited and most economic combination and accurate sizing measures for the particular dwelling. All survey work needed for each trade specialist combined and done together.
Retrofit offer	Prepare Retrofit Plan for householder / owner. Agree scope of works, costs and programme. Provide energy performance guarantee and cost guarantee.
Fabric–first	Just-sufficient fabric improvement measures aimed at overall retrofit cost sweet-spot. Typically, this allows the existing radiator and pipework system to be retained unaltered to operate at the lower water temperatures of a heat pump. Allows room interiors, fitted furniture and other furnishings to be left in place. Usually Involves the fabric-first measures targeting room heat loss reductions of about 50%. • Enhanced air leakage reductions are particularly cost effective. Using kit-of-parts (Figure 4.3) targeting 3 air changes per hour (@50Pa test pressure) enabled by providing a simplified MVHR system. • External wall insulation (EWI) is often preferred over internal wall insulation (IWI) as it delivers higher overall insulation efficiency, reduced thermal bridging, reduced moisture risks, no loss of room area, no disruption of existing heating and electrical systems, avoids disturbing existing fitted furniture, so less overall disruption and site programme time. EWI focused on the largest uninterrupted wall surfaces as it is easiest to install.

Figure 3.7
Retrofit process to aid discussions with clients

Cont/...

Fabric–first (continued)	EWI tends to be most cost effective on flank walls with fewer windows and edge detailing. Avoid front façade EWI to address addresses householder loss of character concerns and for listed building and conservation area constraints. • Insulate the ground floor for reduced heat losses in ground floor rooms. Suspended ground floor sprayed insulation using a remote-control robotic installer has cost effectiveness potential due to quick installation time and less disruption (see Case-study D.4). Needs installing to Agrément Certificate with moisture and ventilation pre-install test criteria for both above and below. For solid floors, installing EWI down to foundation level may be an alternative, or top-laid vacuum insulation panels plus appropriate protection, subject to added disruption, site programme time and costs. • Overhaul the existing double-glazing typical of most existing homes[33]. Replacement hinges and handles where necessary is key to allowing the frames to resettle onto the original gaskets to recovery the original air tightness. Generally, it is not energy/cost effective to replace double-glazing part way through their service life. Instead, the Home Passport / Retrofit Plan to include recommendation to upgrade to triple glazing at the end of the window normal service life as part of the maintenance replacement.
Ventilation	Install simplified MVHR system (see Chpt 4.5) to deliver reliable air quality and permit enhanced dwelling airtightness measures. Lowering winter humidity levels and condensation risk enables more lenient thermal bridge treatment. Constant volume Building Regulations Part F ventilation air flows[34] delivered by surface mounted ducting within stair and hall areas, with ceiling mounted flat MVHR (Figure 4.5) so loss of floor area and cupboard space is to be avoided.
Heating & heat pump	Existing radiators and pipework system reused without modification. Air source heat pump wall mounted where outdoor space constrained, sized at 75% smaller capacity than normal using amended sizing methodology (Chpt 4.6). Smaller sizing reduces peak and annual electrical demands and avoids electrical supply upgrades inside property and for local network.
Domestic hot water	PCM heat battery (Chpt 4.7) heat store sized to go into the space vacated by wall mounted combi gas boiler using existing pipe connections and electrics. New connections to outdoor ASHP via vacated existing flue opening. Hot water efficiency measures like 6 l/min shower heads used to reduce hot water demand. Heat battery reheat control spreads it at intervals up to 6 hours.
Performance guarantee	Third party verification - Post-retrofit monitored heat demand performance using the SMETERS (Annex B.3) energy meter interface. Performance delivery warrantee to build consumer confidence and provide feedback for retrofit team continuous improvement. Updated Home Passport / Logbook provided.

Figure 3.7 /cont.

Chapter 4

BASIC fabric and systems

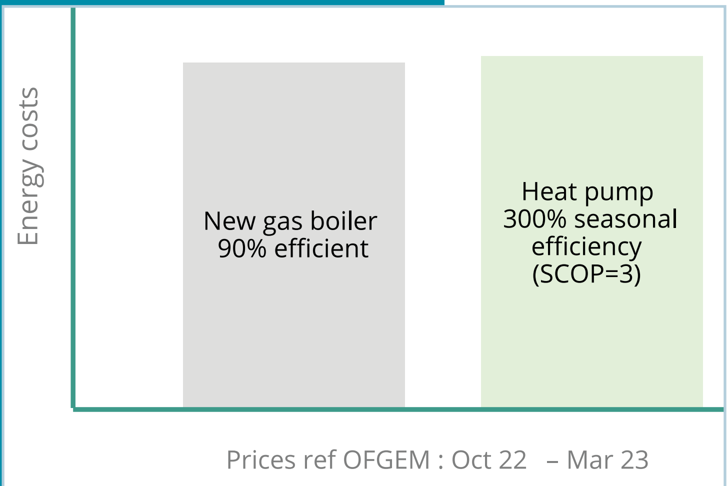
Chapter key takeaways:

- *An illustrative example of how far to go with light touch fabric-first and heating and ventilation replacement to meet the Basic retrofit standard*
- *Identifying where measures in combination deliver more energy saving than the individual measures*
- *How a seven-day site turnaround informs the proposed measures*
- *New products and process innovations needed to increase retrofit implementation efficiency and greatly improve productivity.*

Chapter 4: BASIC fabric and systems

BASIC retrofit is a 'whole-dwelling' approach that integrates fabric, systems and processes to harness combinations that deliver more energy savings, at least cost, than individual measures are able to do. For instance, a lesser extent of 'fabric-first' is possible if a simplified mechanical ventilation heat recovery (MVHR) system is installed. This chapter presents an illustrative example with both fabric and systems showing how the solutions are interwoven. For more detailed background on the detailed illustrative example see Annex B and Annex C.

Figure 4.1
Switching to a heat pump without better insulation typically does not reduce the heating bills



4.1 Fabric interventions

Improving home thermal insulation is absolutely key for meaningful energy bill savings to address fuel poverty. Simply switching a boiler using relatively cheap gas to a more efficient heat pump consuming expensive electricity does not significantly reduce energy bills (Fig 4.1).

This fabric-first approach is also more effective at reducing winter peak electrical demands, hence avoids home electrical system upgrade costs, as well as reducing peaks for the cables in the street and the pressure on the future decarbonised grid system capacity.

The challenge of fabric-first is knowing how far to go with fabric improvements. The **RETROFIT-AT-SCALE** sandbox research identified various key decision points:

Want more technical detail? See Annex B and C

Key fabric decision points

- **Provide only sufficient fabric improvements to allow all radiators to be retained for the switch to a heat pump. This minimises room disruption and shortens the site programming and costs.**
- **Avoid internal wall insulation due to the extent of room disruption and extended site programme costs.**
- **Focus external wall insulation where it gives maximum benefits for least cost. Windows and edge details are complex and so ideally EWI should be used on flank and similar walls with maximum area and least windows.**
- **Enhanced airtightness is particularly cost effective (down to 2 - 3 air changes), enabled by MVHR for background ventilation.**
- **Reduced thermal bridging treatment enabled by the MVHR especially in cooler habitable rooms.**

Building Element	Element Type	Retrofit option	£/kW	Comments	Selected
External walls	Solid wall	IWI	££££	Internal disruption / added M&E costs / longer programme	✗
	Solid wall	EWI	£££	PIR best performance but watch condensation so link to MVHR	✓
Front	Solid wall	EWI	£££	Extent of edge details / board cutting. Large visual change. Heritage issues.	✗
Flank	Solid wall	EWI	££	Large uninterrupted areas with minimum cutting / edge details / 1wk scaffolding	✓
Rear	Solid wall	EWI	£££	An option but higher costs cutting /edge details/ downpipe / facia board detail	✗
	Cavity	Fill / EWI	££	Significant across stock. Fill, or maybe flank EWI due to added performance/cost	✗
Roof	Timber rafter	Warm	££££	Suitable only if roof replaced for non - energy reasons.	✗
	Timber loft joists	Cold	£	Max insulation depth in loft space / inc eaves vent & wind wash detail	✓
1st floor perimeter	Timber	insulation	£££	Disruption / programme. Needs airtight detailing due to joist condensation risk	✗
	Timber suspended	lift & insulate between joists	£££	Lift all floors, carpets, floating floors / disruption / replace finish cost	✗
	Timber suspended	Q-Bot or similar	££££	Small access needed. Short programme / less disruption. airtight	✓
	Solid	VIP	££££	Disruption / limited thickness / performance	✗
Windows & doors	Double glazed	Triple glazing	££££	Instead replace with triple glazing at end of life	✗
	Double glazed	Overhaul	£	Replace hinges to recover gasket airtightness	✓
Thermal bridging	Door /window reveals	Strip to brickwork & re-line	£££	Internal disruption / dust / debris on floors / redecorating / programme	✗
	Door /window reveals	Insulated board lining	£	Surface applied self -finished PVC foamed (facia) board	✓
	Misc other		££	Constant MVHR to reduce all rooms RH, hence reduce condensation risk	✓
Airtightness	Surfaces	Spray / sheet membrane	£££	In practice only with IWI. Disruption / wall linings / redecoration / programme	✗
	Wall/floor	Skirting treatment	£	PVC strip + mastic. 10 -year life. Redo with redecoration / second stage retrofit	✓
	Doors/hatch	Jamb battens	£	Inc gasket attached.	✓
	Windows	Replace window hinges	£	Replace hinges to recover gasket airtightness. Reveal boards sealed to window	✓
	Services entries	Seal service entries	£	Airtightness test identifies where. Inc below bath & letter box seal	✓
Notes:	Cost indication for each measure includes influence on overhead and programme costs				
	Holistic assessment with services. PCB heat battery to avoid cylinder BWIC. No vent ducts in floor voids. Undercut doors for return air.				
	Fabric -first measures to be just sufficient to allow reuse of existing radiators at half output at ASHP water temperatures.				
	Simplified MVHR system used to allow relaxation on fabric -first measures / guarantee fresh air				
	Kit-of-parts to be expanded to include options for differing archetype and site specifics				

Figure 4.2
Fabric measures considerations with cost drivers as identified via the sandbox research for the illustrative exemple meeting the BASIC energy and cost targets.

Figure 4.3
Typical fabric measures found to be sufficient for airtightness, thermal bridging, and thermal insulation for the illustrative example to meet the BASIC energy target.

Add robust ventilation air supply and air extract

The fabric and airtightness measures found to contribute to the most cost-effective combinations are shown on Figure 4.2 on p34 and illustrated in Figure 4.3 on p35. More detailed and performance data is tabulated in Figure 4.4 alongside examples of best practice retrofits. The cost savings against business-as-usual typical deep retrofit are show in Figure 5.2, with more detailed information in Annex E.

4.2 Moisture considerations

Dwelling moisture management is crucially importance as emphasised by PAS 2035. **BASIC** retrofit is based on the robust approach of providing a whole home MVHR ventilation system (Chpt 4.5 and Annex B.5) as the key component for moisture management. Its constant warmed fresh air supply has a higher moisture pickup ability compared with extract only systems (Fig 4.4). This reduces room humidity levels and the mould potential and reduces the extent of thermal bridging remedial works and level of site disruption.

Condensation and moisture approach:

- **Ensure the site survey identifies moisture trouble spots and there are no faulty water handling components.**
- **Do establish a robust means of moisture extraction and maintaining constant lower humidity levels, particularly for unheated or cooler rooms.**
- **Do have a constant running MVHR system delivering warmed air to habitable rooms & extracting from moisture generating rooms.**
- **Do not rely on occupants to open windows or trickle vents especially during colder weather.**
- **Don't install new or increase existing trickle vent sizes to comply with Part F :2021 as doing so likely invalidates existing window warranties, besides being practically difficult.**
- **Do have a constant warmed air supply to reduce room relative humidity, and so surface & fabric interstitial condensation risk.**
- **Do have air leakage and thermal bridging kit-of-parts measures for where the surveys identify key issue areas (Fig 4.3).**

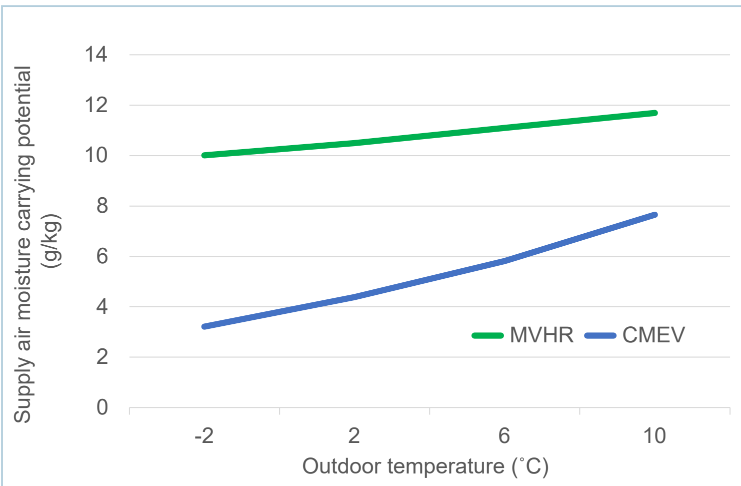


Figure 4.4
Diagram illustrating higher moisture pickup capacity of heat recovery MVHR supply air compared with the colder air intake through trickle vents of a CMEV system (see Chpt 4. 5 & CIBSE ref [129]).

Retain, reuse, reduced stripping out and waste

4.3 Materials environmental impact

Low environmental impact materials and systems were investigated as part of the **RETROFIT-AT-SCALE** research for **BASIC**. This is a rapidly evolving field (see Annex B.6) with the construction mass market expected to progressively adopt lower impact materials as they become available at scale.

The **BASIC** strategy is to minimise the amount of new material needed by adopting a light touch retrofit approach. This maximises the continued reuse of existing serviceable materials and systems, and thereby reduces the environmental impact and the embodied carbon footprint of the overall retrofit works (Fig 4.5).

RETROFIT-AT-SCALE found most specifically low environmental impact materials still have a higher cost for the same thermal performance. Others have potential supply chain future capacity constraints that limit availability for scaling up sufficiently for the intended mass rollout.

Where new materials are selected, their proven longevity in use, compatibility with the retained fabric and systems, potential to increase retrofit productivity, reduce site programme time and cost effectiveness are also priorities.

Whatever the chosen materials, there must be cost transparency with the client as their environmental impact can have a significant effect on the overall retrofit costs. For **BASIC**, due to the urgency to scale up and a brief to identify costs that would enable such a scaling up, low environmental impact materials, if more costly, are considered a specific client option over and above the **BASIC** retrofit.

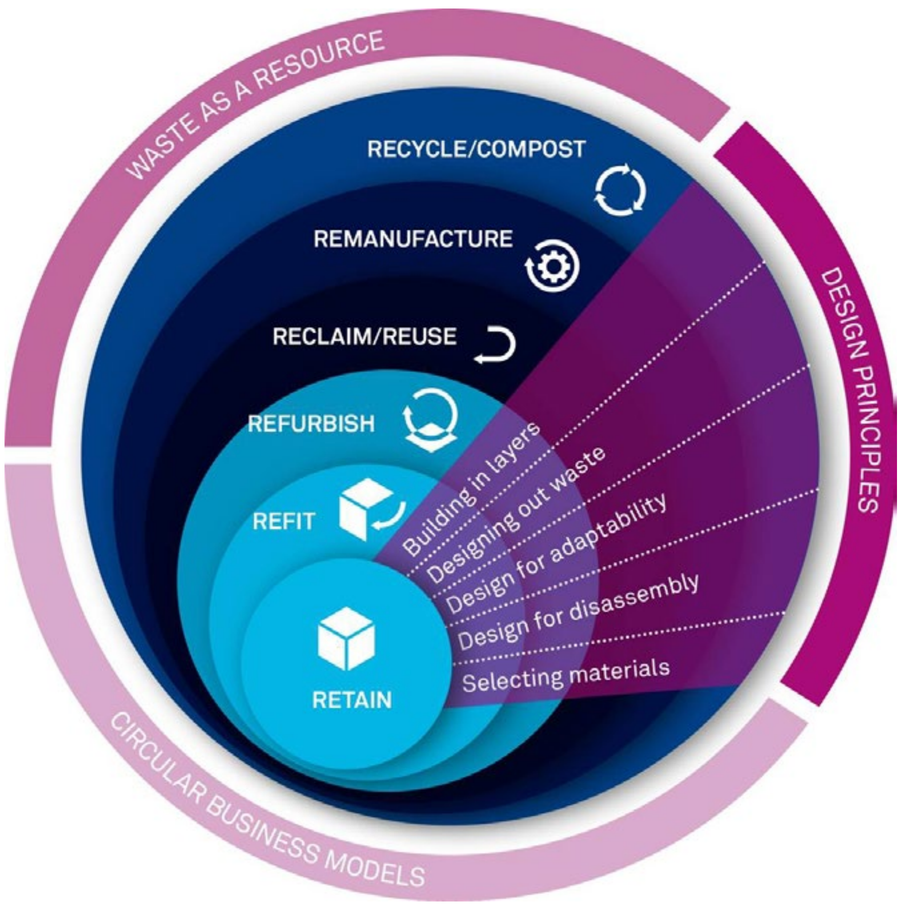


Figure 4.5
Prioritising the response to materials environmental impacts, source Dave Cornish AECOM

	UK baseline typical 85m² archetype	**Exemplar** eg: EnerPHit (elemental), LETI Exemplar
Target heating output kWh /m² /yr	**130**	**35**
Saving against UK av heating demand	Existing average	-73%
Fabric:		
Loft insulation	none/25/50mm	400mm + eaves vent former + re-laid tiles/ felt/ facia/gutter
Front wall	225 solid no insulation	100mm mineral fibre IWI + all reveals + below 1st floor
Back wall	225 solid no insulation	200mm mineral fibre EWI
Flank wall	225 solid no insulation	200mm mineral fibre EWI
Ground floor	suspended no insulation	200mm mineral fibre batts
Windows	10yr old basic casement DG	new TG high performance inc frames
Doors	DG	new TG high performance inc frames
Airtightness:	10ach @50Pa	1ach @50Pa
Ground floor		new chipboard/equal floor
Intermediate floor		taped around joist ends
Loft	25mm insulation	New loft hatch + ladder
Services entries		All new seal to approved details
Ceiling roses and power outlets		service void in front of membrane
Windows	10yr old loose hinges	New windows sealed using approved details
Around doors		New doors sealed using approved details
Testing before & after		After only
Thermal bridging	untreated	
Windows / doors		All reveals + jambs, lintel, etc stripped back
Eaves		loft to wall insulation meet detail
Ground floor		Take EPS EWI down to footings
Intermediate floor depth		IWI continues into floor depth
Ventilation:		
System configuration	Trickle vents + local extract	MVHR 92% eff, PtF+50% flow, summer bypass
Equipment location	Through room wall	MVHR in roof with health & safety access facilities
Ductwork	None	concealed dual 90mm dia flex to each room
Heating + hot water		
Heat source	Combi boiler	Outdoor ground mounted ASHP
DHW plant	Instantaneous from combi	210 Litre thermal store in new cupboard
Ancillaries	Integral	Expansion vessel
Heat emitter / pipe system	radiator system MSC sized	All new
Electrics:		Complete new installation + controls (& their integration)
Drainage:		For ASHP and thermal store safety value / drain. MVHR drain from roof
Builders' work in connection (BWIC):		
Scaffolding		Scaffolding all facades for programme duration
For services		New cupboards for thermal store and MVHR. MVHR air in/out through external wall. ASHP pipes to outside. ASHP base. New heat/DHW pipes/new electrics/wall services cavity
Redecorating		extent - throughout
Overheads		
Professionals		Architect M&E consultant Retrofit coordinator + project manager Retrofit assessor - building surveyor 3rd Party certifier PAS2035 completion sign-offs / due diligence
Trade contractor surveyor visits:		- Windows installer - EWI installer (inc pullout tests) - IWI installer - ASHP installer - MVHR installer
Period on site for H&S etc facilities:		9 months

Figure 4.6 (sheet one)
Typical measures for each level of retrofit, alongside those RETROFIT-AT-SCALE found to be most appropriate for satisfying BASIC. See Annex E for the cost assessment for each

Best Practice eg: AECB CarbonLite, LETI Best Practice	**Basic retrofit**
50 -62%	**65** -50%
400 mineral fibre + internally installed eaves vent former 100mm mineral fibre IWI + all reveals + below 1st floor 150mm mineral fibre EWI 150mm mineral fibre EWI 150mm mineral fibre batts new TG high performance inc frames new TG high performance inc frames	400 mineral fibre + internally installed eaves vent former + eaves wind shield None None 150mm PIR + EWI render on uninterrupted flank 150mm PIR Q-Bot (tapers at DPC edges) Replace hinges on retained double-glazing Retain and add jamb battens with deep draught strip + letter box seals + lock cover
2ach @50Pa new chipboard/equal floor taped around joist ends New loft hatch + ladder All new seal service void in front of membrane New windows sealed New doors sealed After only	3ach @50Pa Existing floor sealed by Q-Bot, Skirtings sealed to PVC carpet underlay strip Retain hatch + add jamb battens with deep draught strip Existing openings located, sealed and tested Mastic seal cable/pipe entries Replace window hinges to recover gasket sealing Add jamb battens with deep draught strip Before (to identify leaks locations) & after
reveals strip back to brick, insulation & plasterboard reduced insulation thickness continuity Take EPS EWI down to dpm IWI continues into floor depth	18mm uPVC self-finished foamed core 'soffit-board' installed on window / door reveals Room side EPS large coving added Q-Bot installation seals' floor No treatment
MVHR 90% eff, PtF+50% flow, summer bypass MVHR in roof with health & safety access facilities concealed dual 90mm dia flex to each room	Basic MVHR 80% eff, Pt:F flow rate, no summer bypass Flat MVHR unit exposed ceiling mounted Exposed self-finished flat uPVC rectangular
Outdoor ground mounted ASHP 210 Litre thermal store in new cupboard Expansion vessel All new	Outdoor wall mounted ASHP <5kW PCM Heat Battery (6kWh,128L equivalent) installed in combi boiler space to existing pipes/elect 6 L/min EWL 'A' rated shower head Reuse existing radiators and pipework
Largely new depending on IWI etc + controls (& their integration)	Reuse existing + new MVHR spur + filter alarm + ASHP controls wiring + SMETER DHW & temp sensor
For ASHP and thermal store safety value / drain. MVHR from roof	For outdoor ASHP + MVHR drain inside bathroom
Scaffolding all facades for programme duration New cupboard for thermal store and MVHR. MVHR air in/out through external wall. ASHP pipes to outside. ASHP base. New heat/DHW pipes/new electrics/wall services cavity extent - throughout	Scaffolding to flank wall only of 2 week duration Reuse existing flue hole for pipes/elects to ASHP. MVHR new air in/out through external wall. Indoor air ducting holes ~1 per room None as no IWI, & MVHR + ducting surface fixed.
Architect M&E consultant Retrofit coordinator + project manager Retrofit assessor + check PAS2035 completion sign-offs / due diligence - Windows installer - EWI installer (inc pullout tests) - IWI installer - ASHP installer - MVHR installer - Contractor PAS2035 completion sign-off 6 months	Retrofit Assessor - 3rd party pre & post inspection Single multi-role Surveyor for: - Retrofit Coordinator - Assessing building is PAS2035 Risk 'A' - Identify out-of-scope latent defects - Client coordination - Project manager - Site surveying for EWI, ASHP, MVHR, pre infill test, Q-Bot, window refurb, thermal bridging, etc - PAS2035 completion sign-offs / due diligence - SMETER year-after monitor performance check 7-day works on site - programming in parallel: - EWI to flank wall = 3 days - Boiler replaced with ASHP+PCM = 2 days - MVHR installed and ducting installed = 2 days - Q-Bot installation = 1 day - Airtightness measures = 2 days - Thermal bridge treatment = 2 days

Figure 4.6 (sheet two)

4.4 M&E interventions

RETROFIT-AT-SCALE introduces the new **BASIC** minimum standard retrofit, delivering an averaged 50% heat bills reduction for a cost that is almost two thirds less than current practice. This is an essential part of the proposals for scaling up a mass rollout. By focusing on the less complex and more straightforward majority of homes, BASIC is intended to be a kit-of-parts approach, reducing site time, the works extent and complexity, and greatly improving productivity. It is a 'whole-dwelling' approach, using 'just sufficient' fabric-first measures enabling all radiators to be retained, and allowing a smaller, simpler heat pump installation and an overall cost sweet-spot. A key component is installing a simplified MVHR system to allow reduced fabric-first measures and provide reliable air quality and moisture management.

RETROFIT-AT-SCALE used a sandbox research method to identify products and processes for improving delivery productivity that are not yet used or tailored for the retrofit market. It is a 'call to action' for industry to develop such products and processes. The significant cost difference between best-in-class deep retrofit and BASIC is harnessed to enable a mass rollout.

Whatever the retrofit level delivered, each should provide a warranted performance, even if they do not all claim the same levels of sophistication. BASIC is intended to define a minimum level any householder should expect. With the initial installation of a heat pump and MVHR, this leaves future upgrade options when normal service life replacement occurs.

While BASIC has been developed using the UK's most prevalent housing archetype, the principles and targets are expected to be suitable for most other types. A block of flats, for instance, with a centralised boiler replaced with a heat pump, can also be coupled with fabric-first measures just sufficient to allow the existing heat distribution and emitter system reuse.

BASIC retrofit - The M&E key requirements

- **Reuse of unaltered radiator system to operate at heat pump temperatures. Just sufficient fabric-first measures reduce space heating demand by 50% in each room.**
- **Fabric thermal performance verified so avoiding adding margins into heat pump sizing.**
- **Solutions that do not use any dwelling floor area, cupboard space or outdoor ground area.**
- **A simplified MVHR to allow enhanced dwelling airtightness energy savings and to reduce condensation / thermal bridging treatment.**
- **More accurate heat pump sizing, with amended controls, to reduce its required capacity by some 75%.**
- **2-day heat pump installation, includes thermal store into space vacated by gas-boiler, within 7-day overall retrofit site programme.**
- **Annual SCOP and energy use guarantees provided to householders, alongside pre-retrofit measured energy use.**
- **Improved productivity (i.e. delivering more retrofits for less cost per retrofit), with rapid turnarounds delivering more retrofits**

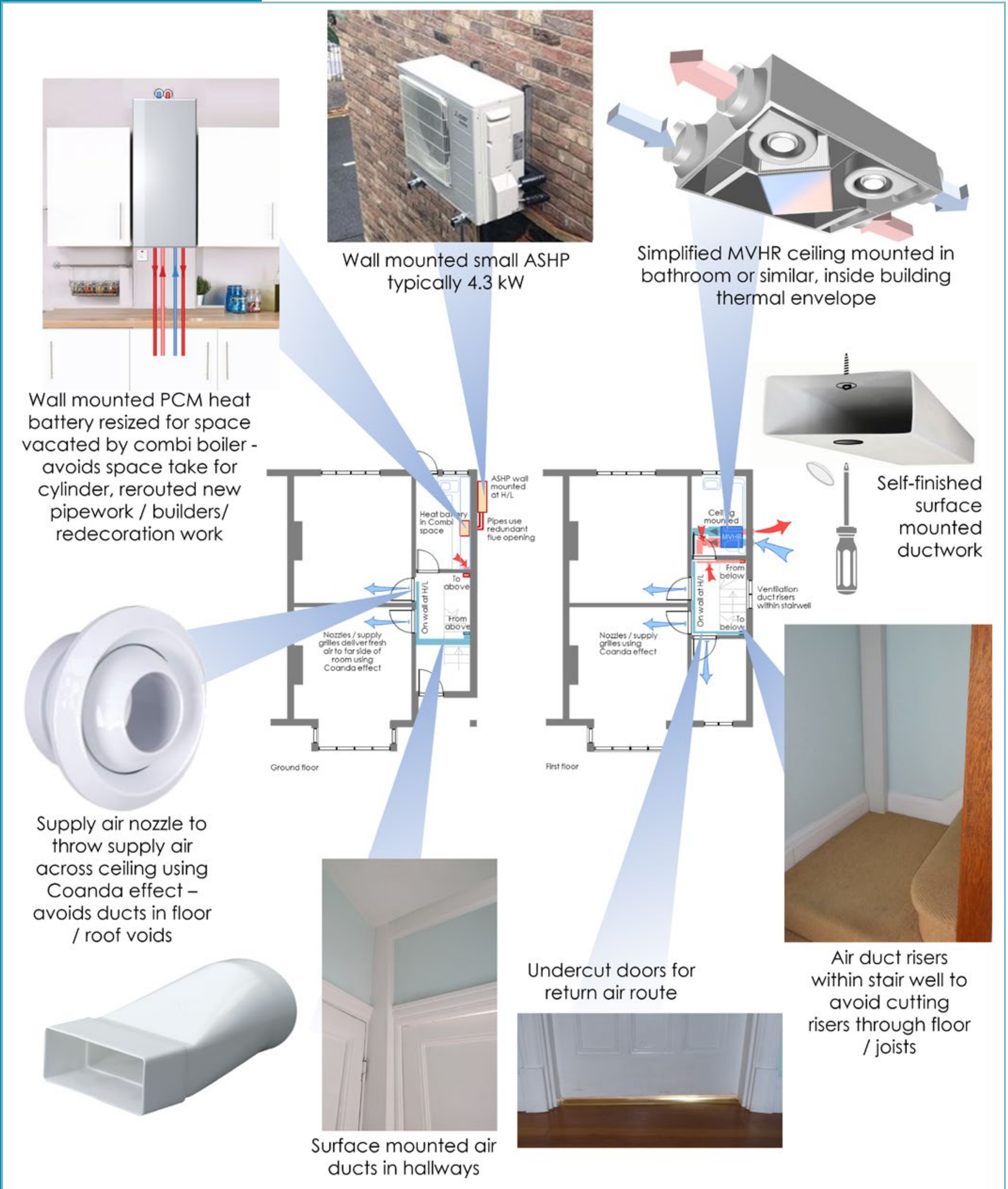


Figure 4.7
Typical heating and ventilation retrofit measures found to be sufficient for the illustrative example to meet the BASIC energy target.

4.5 Ventilation

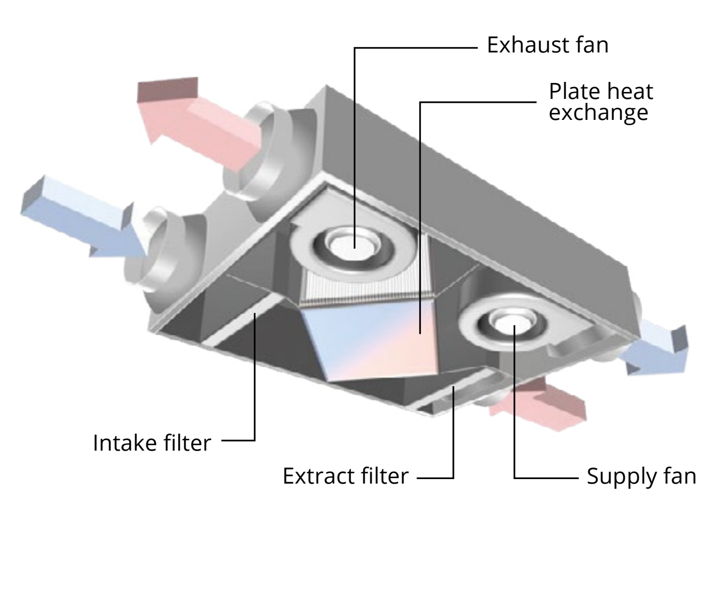


Figure 4.8
Simplified MVHR unit. Typical of mass market 'Air Quantity Unit' products in China.

Improving dwelling airtightness is a highly effective low-cost energy saving measure, down to 3 air changes if with test verification (Fig 4.2 & Annex B.5). At these air leakage levels the building regulations[35] require some sort of minimum background balanced fresh air supply and extract, as can be provided by an MVHR system. MVHR also provides improved fabric moisture management for reduced condensation and mould risk, as its prewarmed and constant air supply absorbs more moisture (Fig 4.4) than the alternative untempered trickle vent air supply of a central mechanical extract system (CMEV). These lower room humidity levels particularly help in underheated rooms where condensation is been found to be prevalent. This use of MVHR enables a more lenient and cost-effective approach to treating thermal bridges as the target minimum indoor surface temperature factor can be potentially relaxed.

BASIC requires only simple MVHR functionality with fresh air and exhaust fans, heat recovery unit and filters (Fig 4.8). It can run at constant volume, delivering Building Regulations Part F minimum fresh air volumes into habitable rooms, with extraction from moisture generating rooms (Fig 4.10). A summer bypass is not required because it has limited benefit for overheating avoidance (Fig 4.9 & Annex C.5). Hence, the MVHR unit can be physically smaller while also consuming less fan energy annually.

For ease of installation the unit can be ceiling mounted in a room inside the dwelling thermal envelope. This avoids avoid losing floor area or cupboard space and avoids enlarging the loft access hatch, health & safety (H&S) access across the loft space, and electrical and drainage provision into the loft. **BASIC** could use surface mounted self-finished UPVC rectangular ducting located at high level in hallway circulation areas and uses the staircase corners for risers (Fig 4.10 & Fig C.10).

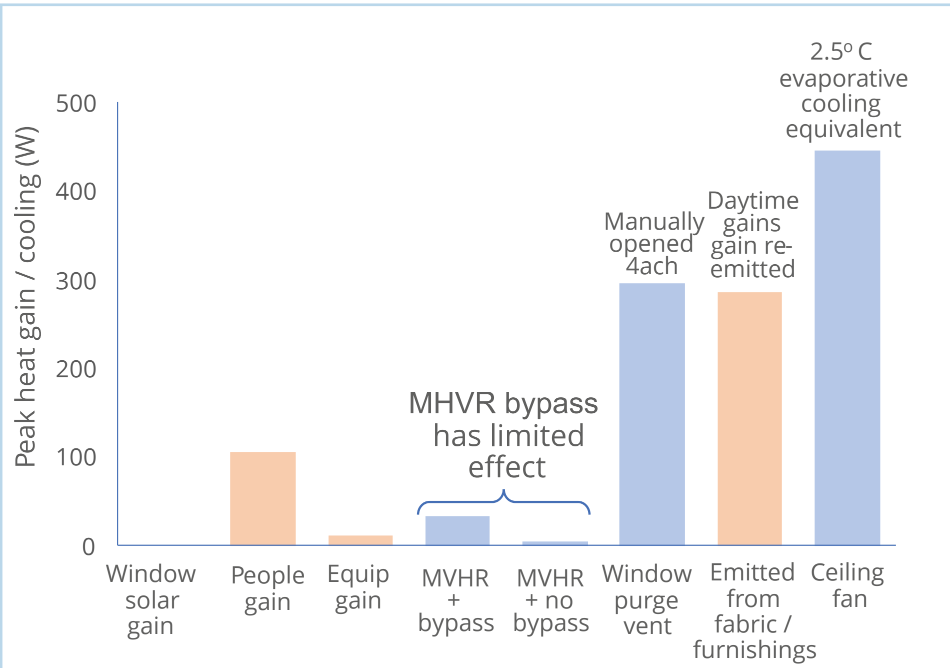


Figure 4.9
Overheating influences for hot summer night. The heat balance shows MVHR summer bypass has far less benefit than window ventilation or ceiling mounted fans (Annex C.5)

Optimised the systems with the fabric-first measures

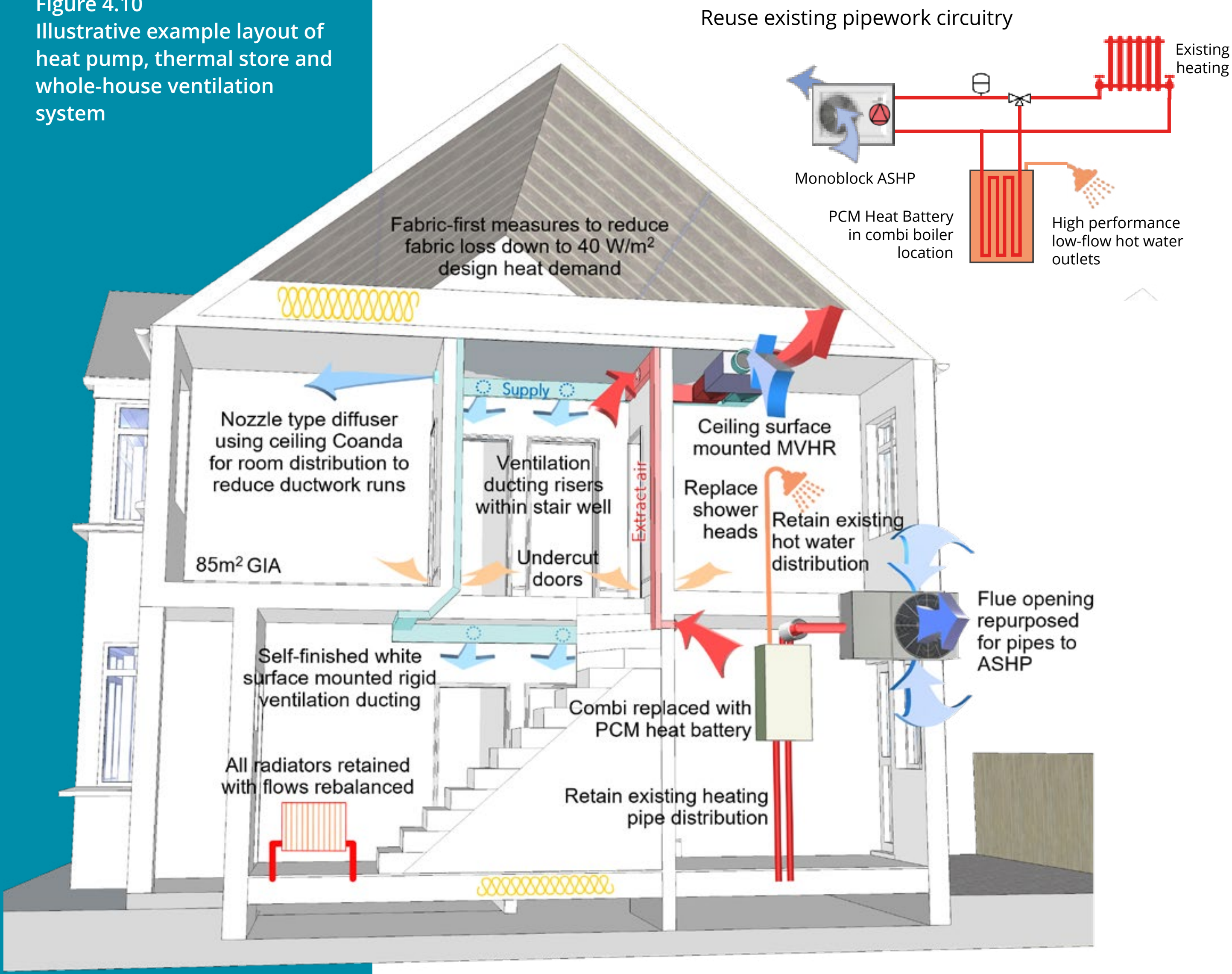
4.6 Heating system

The **BASIC** fabric-first energy efficiency measures typically target 40 W/m^2 'design day' peak heat loss to keep the annual space heating demand from the heat pump under 65 kWh/m^2/yr (Annex C.2). This peak heat loss is typically sufficient to allow the existing radiators and piped distribution to be reused without modification for the switch to a heat pump.

The **RETROFIT-AT-SCALE** research used dynamic simulation modelling (DSM), to investigate dwelling heat losses for sizing the heat pump. The results indicated that a heat pump of only about half the size suggested by the industry standard MCS method would be sufficient (Annex C.2), in addition to the **BASIC** halving of fabric heat loss. This peak demand of 40 W/m^2 means an average 85m^2 sized home would need no more than 3.4 kW of heat pump capacity for space heating. The additional heat pump capacity for DHW thermal store reheat is only 25% added to this (Chpt 4.7).

In installation terms the new systems should aim to use the standard domestic heating system layout and avoid the need for any thermal buffer or headers. With the required capacity reduced, the air source heat pump should be of a size to be easily wall mounted. This addresses the lack of outdoor space identified in most space constrained UK dwellings (Annex A).

Figure 4.10
Illustrative example layout of heat pump, thermal store and whole-house ventilation system



Making it happen: a common sense approach.

...an average 85m² sized home would need no more than 3.4 kW of heat pump capacity for space heating. The heat pump capacity for DHW thermal store reheat only adds 25% to this.

RETROFIT-AT-SCALE - what would a typical dwelling need?

Monoblock ASHP:

- 3.4 kW space heating plus 0.85 kW DHW thermal store reheat
- Sizing for space heating at 95% design day conditions (hence allows for thermal inertia, heat gains, thermal store diversity, 24/7 design day operation) thereby reducing size by 25%
- Sizing for 6 hr reheat of hot water thermal store. Avoids heat pump sizing being driven by hot water peaks.
- Controls that harness the diverity between hot water reheat and space heating priority on the coldest day
- 60-65°C output temperature - ideally R290 natural refrigerant
- Inverter driven, so avoids buffer vessel
- ~120 x 60 x 30 cm small physical size for small gardens / acoustic positioning
- Wall mounted to avoid ground space loss

Ceiling mounted flat MVHR + attenuators:

- Whole-house MVHR ventilation system
- MVHR unit ceiling mounted in low acoustic sensitivity room
- Avoids loss of householder valued cupboard or floor space
- Part F compliant constant air volumes
- ~80% heat recovery efficiency would be sufficient
- Summer bypass not required, so allowing smaller MVHR unit
- Fans selected on low speed to minimise acoustic treatment
- Uninsulated ducts as inside dwelling insulated envelope
- Duct located in stair/hall areas needing no floor void access

PCM thermal store / heat battery:

- Sized to occupy space vacated by combi boiler in kitchen wall unit
- Reuse existing pipe connections
- Provides instantaneous hot water
- Capacity ~6 kWh PCM (phase change material) for 3-bed home

DHW demand reduced by ~30%:

- Change shower heads is highly cost effective
- EWL rated 6 L/min at mains pressure

4.7 Domestic hot water

Thermal store reheat adds just 25% to heat pump sizing instead of 50% – 100%.

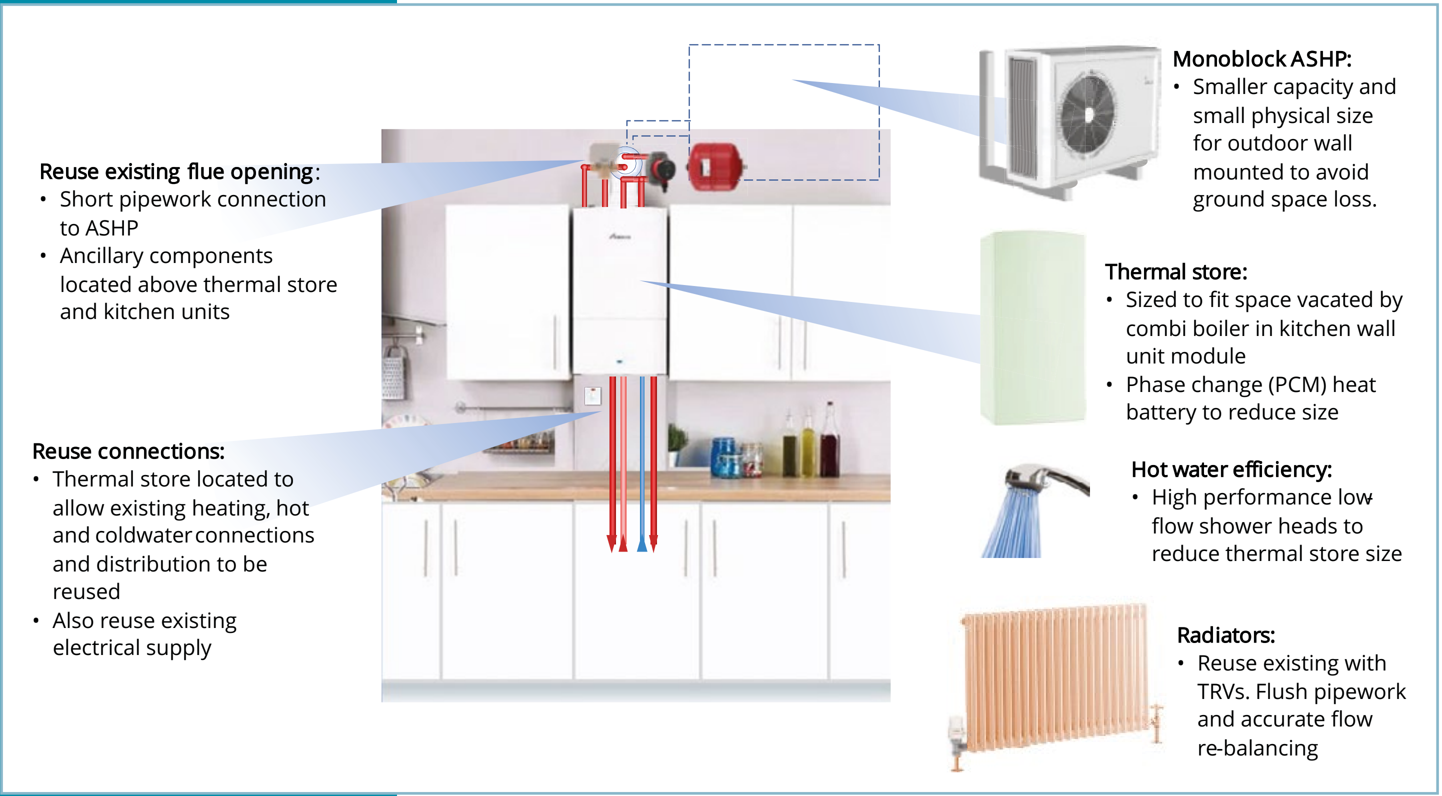
Unlike the instantaneous high output hot water supply of a combi boiler, a heat pump provides a much lower steady supply of heat that requires a thermal storage vessel to gather and store it to be availability for the tap peak draw-offs. Finding a location for this thermal store (Fig C.7) is one of the main reasons many UK homes have limited suitability for heat pumps (Annex A). A solution to resolve the space issue is the use of a PCM heat battery, sized to fit the space vacated by the combi boiler (Fig 4.11), coupled with DHW efficiency measures. The easiest efficiency measure is installing, high-performance low-flow shower handsets typically 6 l/min EWL rated[36] or equivalent, which can be expected to reduce hot water demand by as much as 30%.

A PCM heat battery uses a 'phase change' storage medium that holds a lot more heat than water, meaning the storage vessel can be considerably smaller (Annex C.4). PCM heat batteries are readily available products, yet so far have not been tailored to the needs of the retrofit mass market. They need to be made available in new sizes and dimensionsbetter suited to space constrained homes.

Installing a PCM heat battery in the space vacated by the combi boiler reduces the complexity, disruption, and time of the switchover to a heat pump as all the existing hot water and heating pipework, and electrics already terminate at this location. This also removed the builders' work and redecoration time and costs associated with providing an alternative DHW storage vessel cupboard or similar location. Additionally, the existing flue opening could provide a ready-made pipework route directly to the outdoor heat pump.

There is the opportunities available to improve the thermal store reheat control strategy to reduce the required heat pump capacity. Current practice often results in inflating the heat pump capacity by 50-100%, whereas a staged reheat together with peak time diversity controls can reduce this to as little of 25% (Fig C.2).

Figure 4.11
Simplified heat pump switch over installation



Smaller heat pump avoids electrics upgrades

4.8 Electrical installation

The switch from gas to electrically run heating can have a major impact on the electrical systems. Added to this is the future likelihood of the switch to electric cooking, and for some households the addition of electric car charging. As part of a mass rollout this is also likely to impact on the local electrical distribution and wider grid capacity, particularly during winter peak heating demand periods.

BASIC aims to avoid needing to upgrade the home electrics, even if the current supply is the historical 60 Amp capacity. This is achieved by:

- **Reducing peak winter space heating demand by 50% using fabric-first measures**
- **Sizing the heat pump, and hence peak capacity, using diversified winter day design conditions**
- **Using a diversified DHW storage reheat control strategy, which further reduces the heat pump size by an additional 25%.**

Overall, the **BASIC** retrofit standard heat pump electrical peak demand is expected to be 75% reduced compared with a typical heat pump installed without fabric and systems enhancement (see Annex C.2). This helps address the emerging issue of lack of local electricity grid capacity.

4.9 Innovations

RETROFIT-AT-SCALE is a call-to-action for industry to develop products and processes for improving retrofit delivery productivity to enable a scaling up for a mass retrofit market.

Examples of products and processes retrofit needs:

- Integrated one-stop-shop retrofit implementation teams and processes (Chpt 3.4)
- Local network of enablers and implementors (Chpt 3.3)
- Funding packages offered alongside the technical package (Annex D.5)
- Double glazing overhaul service, instead of replacement presumption[37] [38]
- Mass rollout of suspended ground floor sprayed insulation using remote control robotic installer (Annex D.4)
- Simplified MVHR system and controls, together with complete simple airtightness package (Annex C.5)
- Small capacity wall mounted air source heat pumps with outputs down to less than 4.3 kW for average retrofit dwelling and down to 1.5 kW for new-build dwelling (Annex C.2)
- More accurate sizing methodology for smaller heat pumps, in simple form for everyday use, with predicted energy use warrantees (Annex C.2)
- Controls that take advantage of diversity between hot water and space heating (Fig C.2)
- Heat battery (PCM) heat stores sized to fit into the space vacated by a standard combi boiler (Annex C.4)
- High performance rated low-flow shower heads (Annex C.4)
- Examples of the many new tools needed specifically for retrofit:
  - multitool saw for 10mm ventilation undercut without door removal (Annex C.5)
  - Heating pipe water flow & temperature difference measurement meter for use on existing radiators / underfloor heating (Fig B.4)

Chapter 5

Affordable mass rollout

Chapter key takeaways:

- *Why retrofit costs need to be reduced by about two thirds*
- *Learnings from other industries on cost-quality assessment for the cost sweet-spot*
- *How retrofit is ripe for major productivity gains*
- *Delivering a mass rollout without adding to the cost of the UK getting to new zero carbon*
- *Funding mass retrofit from avoided infrastructure investment and from retrofit cost benefits*

Affordable mass rollout

Chapter 5: Affordable mass rollout

The current advice to government is that for the whole-life least-cost route to a net zero carbon UK, it is cheaper per tonne of carbon saved to build wind turbines, rather than to retrofit our homes (Chpt 6).

This chapter looks at the costs of doing home retrofit, how these could be significantly reduced for the bulk of typical UK housing, and how a mass rollout can then be funded at net zero extra cost to the UK.

This **RETROFIT-AT-SCALE** investigation has identified a cost sweet-spot. By changing the way retrofit is done, home heat demand savings of 50% can be achieved, but at 65% less cost compared with typical best practice. A mass rollout at this level would reduce the future National Grid peak capacity needs by about 25% (Figure 5.5). Redirecting such infrastructure investment savings, along with other co-benefits, and better enabling those able-to-pay, provides the funding for the retrofit mass rollout.

A summary of the mass rollout cost and the funding sources is shown in Figure 5.8.

5.1. The cost of carbon savings

The Climate Change Committee (CCC) has outlined what it judges to be the most cost-effective roadmap to achieving net zero carbon for the UK and how for all sectors it collectively should not cost more than 1% of GDP up to 2050 (Chpt 6). 1% of GDP between now and 2050 is just over £1 trillion for delivering net zero carbon for the whole UK. By way of comparison, if all this budget for all UK sectors were to be spent solely on retrofitting our 28 million homes, this would equate to just £35,000 per home.

For this reason, the current national policy instead favours building more wind farms, and only spending an averaged £9k per home to retrofit them to about EPC rating ‘C’, with the inclusion of a heat pump or equivalent (Chpt 6.1). Put another way, doing a typical deep retrofit rolled out across the UK, at £65,000 average per home (Annex E), would cost more than six times the retrofit budget the CCC suggests is the most cost-effective pathway to net zero carbon.

The CCC suggests switching most homes to a decarbonising electric supply grid with just 12% average efficiency improvement to our homes. This fails to address the issue of who pays for the UK’s route to net zero carbon. It effectively puts the bulk of this cost onto those households least able to pay by way of their higher energy bills[39] forcing too many into fuel poverty[40] [41]. But, this is by no means the only route to net zero carbon.

RETROFIT-AT-SCALE proposes an alternative route that switches the emphasis to deeper reductions in energy demand by way of home retrofits, so needing less energy peak supply capacity, while keeping within the 1% GDP overall cost.

The **RETROFIT-AT-SCALE** alternative looks at this at a system wide level. By reducing the demand for decarbonised grid green electricity, this also reduces the cost of decarbonising the grid. It also makes available spare future green energy, for export and as a revenue earner for the UK (Chpt 5.13). Collectively with other system-wide cost benefits, this starts to move the balance towards demand-reducing retrofit instead of just energy supply investment.

However, this only works if the cost of retrofit to deliver this level of national energy demand reductions is also reduced significantly. **RETROFIT-AT-SCALE** identifies how this can be done.

Retrofit is ripe for big productivity gains and cost reductions

5.2 Reducing retrofit costs

There is a lot the retrofit industry can learn from other industries where productivity has improved by as much as 75% over the last 30 years, compared with our industry where it has hardly changed (Figure E.2). The flip side of this is that our industry has many untapped opportunities for productivity enhancement. **RETROFIT-AT-SCALE** was able to gather together professionals with experience from other industries and abroad, as well as the retrofit industry, who offered their contributions as non-aligned individuals, not as commercial employees, meaning that productivity solutions could be explored independent of commercial and vested interest.

To fill the retrofit market gap (Chpt 2) the aim was to develop a new **BASIC** retrofit standard pitched at a level that gained most of the benefits but at minimum cost – hence finding the sweet-spot. For identifying the best cost-value, Figure 5.1 illustrates the typical relationship between costs and quality. Avoiding going for best-in-class was a conscious decision. There are already established standards for delivering Best Practice and Exemplar retrofit standards[42 43 44 45], but the identified market gap needs a lower cost-point 'Good Practice' standard. However, this standard needs to be of a sufficient level to be able to deliver the energy savings needed to generate the national co-benefit costs savings and hence the funding sources for a national retrofit rollout.

A series of inter-related sweet-spots were identified. These included:

- **Optimising the cost per kWh/yr saved, at the bottom-up site level**
- **The market mix of differing retrofit levels, each with their differing costs, energy saving levels and performance gaps**
- **For the national top-down, the level of energy demand savings necessary to trigger infrastructure savings and funding sources sufficient to fund the retrofits.**

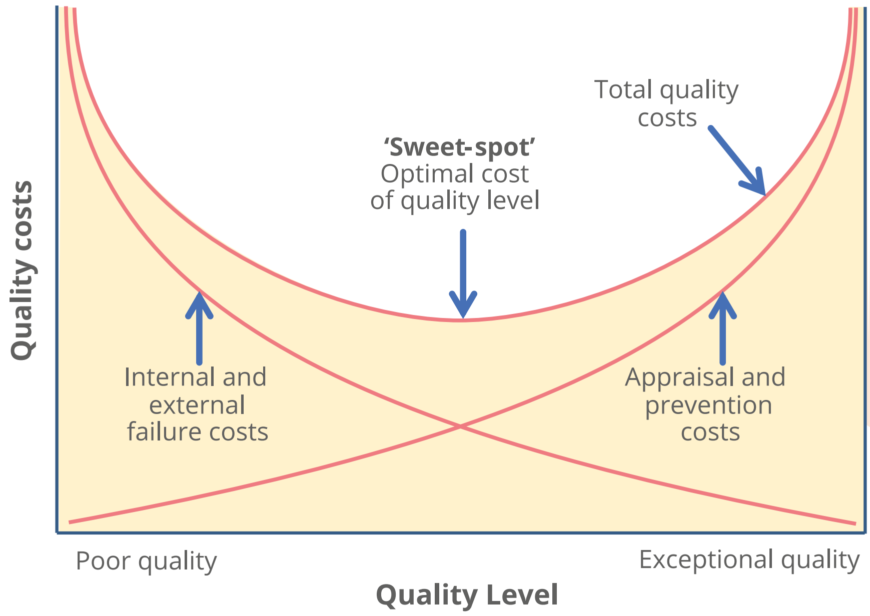


Figure 5.1
Cost of quality curve[46].

How can the retrofit process become more efficient

These had to be aligned with each other. The sweet-spot analysis showed it was the bottom-up peak demand minimum cost per kW saving, not annual energy demand, that best aligned with maximising the top-down grid capacity costs savings. This is perhaps a pointer to the future, where home winter peak demand becomes more important than annual energy demand when it comes to delivering on the national net zero carbon target.

The alignment of the top-down target with the bottom-up target established the **RETROFIT-AT-SCALE** aim of 50% heat reductions and 65 kWh/m^2/yr target for the **BASIC** retrofit standard. The housing stock model identified this standard would be required for 68% of dwellings across the UK, with the remainder being to higher standards or conversely more relaxed for heritage reasons (Annex F.4)

The typical retrofit measures needed to achieve this target are those illustrated in Chapter 4. These are shown related with their costs in Figure 5.2 showing where the costs are driven down compared to a typical best practice deep retrofit. Further cost details and breakdowns are provided in Annex E.

5.3 Allocating energy savings to retrofit oversight

Identifying an accurate cost 'sweet spot' required the allocation of a proportion of the energy savings to the retrofit preparation, design, supervision, management, and verification overhead tasks. This is rarely done in practice, where energy savings are allocated purely to the installation of the energy efficiency measure. This means these overhead tasks tend to be cut because they apparently do not deliver energy savings. This can be a major false economy resulting in the delivered energy saving measures falling short by a performance gap that is almost wholly down to inappropriate oversight provision. This performance gap can be as much as 40% loss of intended energy efficiency improvement and in some cases considerably more[47]. Meanwhile the evidence shows[48 49] that the more skilled the oversight, the closer the retrofit is likely to be to achieving its intended energy performance and in turn the occupant and client level of satisfaction. **RETROFIT-AT-SCALE** uses this evidence to identify a cost-effective level of oversight provision. It neither aims for best-in-class or for simply arbitrarily cutting overheads (Annex E).

5.4 New products and installation methods

The **BASIC** retrofit approach enables new innovations in ways of working and new products to be applied that are not yet generally available in the UK. Wall mounted heat batteries appropriately sized for the constraints of our existing mass market housing, is an example, as are smaller wall mounted ASHPs. Another is the simplified MVHR units that are available abroad but no longer in the UK. The contractually integrated delivery team also opens up new more efficient ways of site implementation, with potential big productivity improvements. The cost analysis focuses on examining

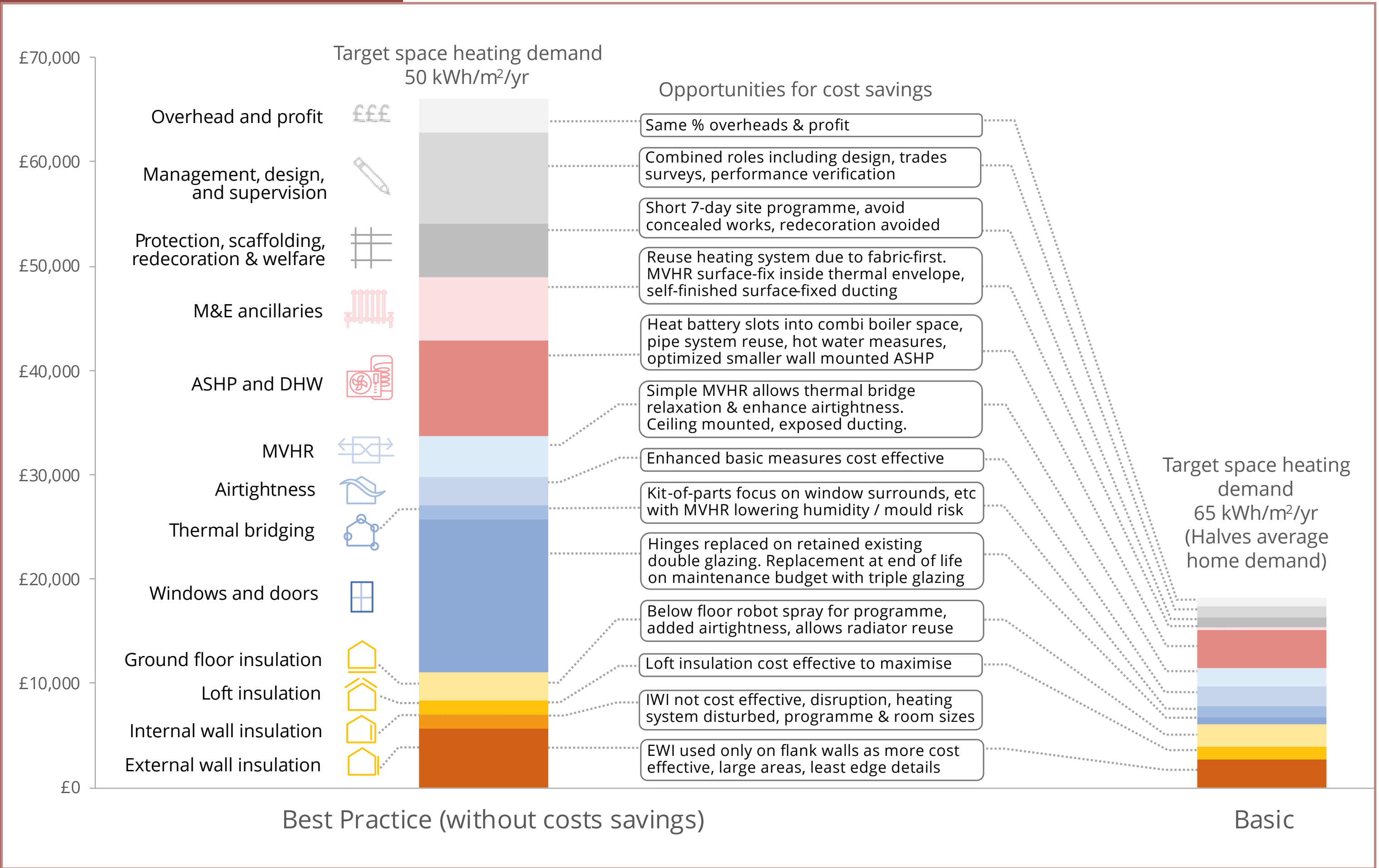


Figure 5.2
The RETROFIT-AT-SCALE illustative example showing productivity and cost savings.
Assumptions:
- **Cost basis early 2022.**
- **Exc VAT.**
- **Based on 26-wk vs 7-day site works programme.**
- **Team / site work continuity between local job sites.**

these to estimate the time and material savings likely if included in a retrofit mass rollout. Beyond the initial development cost hump, economies of scale and market competition drive costs down at differing rates for differing types of products and services. A simplistic mass scaleup cost factor has not been used. Instead, actual costs, extracted from other situations where such innovations are already used at scale has been sourced. Annex E explains these in more detail and how they inform the assessment of future costs of a mass rollout.

5.5 Other cost benefits

There are other overhead cost savings achieved by a contractually unified retrofit implementation teams working on many local homes together, in each street for example. Various of these relate to operating on a local community basis with good community engagement. It tends to be difficult to separately identify and quantify most of these because they are location specific. What has been included is ensuring there is continuity of work for all personnel – in other words there is no associated non-productive time to be paid for between working on individual dwellings.

5.6 Paying for it at a national level

The **RETROFIT-AT-SCALE** funding strategy involves a combination of the following measures:

- **Baseline homes retrofit budget already included in the CCC 6th Carbon Budget**
- **Enabling the 'Able-to-pay' sector, including capturing a proportion of asset value increase**
- **Redirected investment due to reduced energy supply infrastructure needs**
- **Increased employment tax revenue**
- **Redirected portion of healthcare and societal savings**
- **A portion of energy bill savings**
- **Renewable energy profits supplementary tax**

The following chapter sections provide a synopsis of each, drawn together as a summary in Figure 5.8. More detail is provided in Annex G.

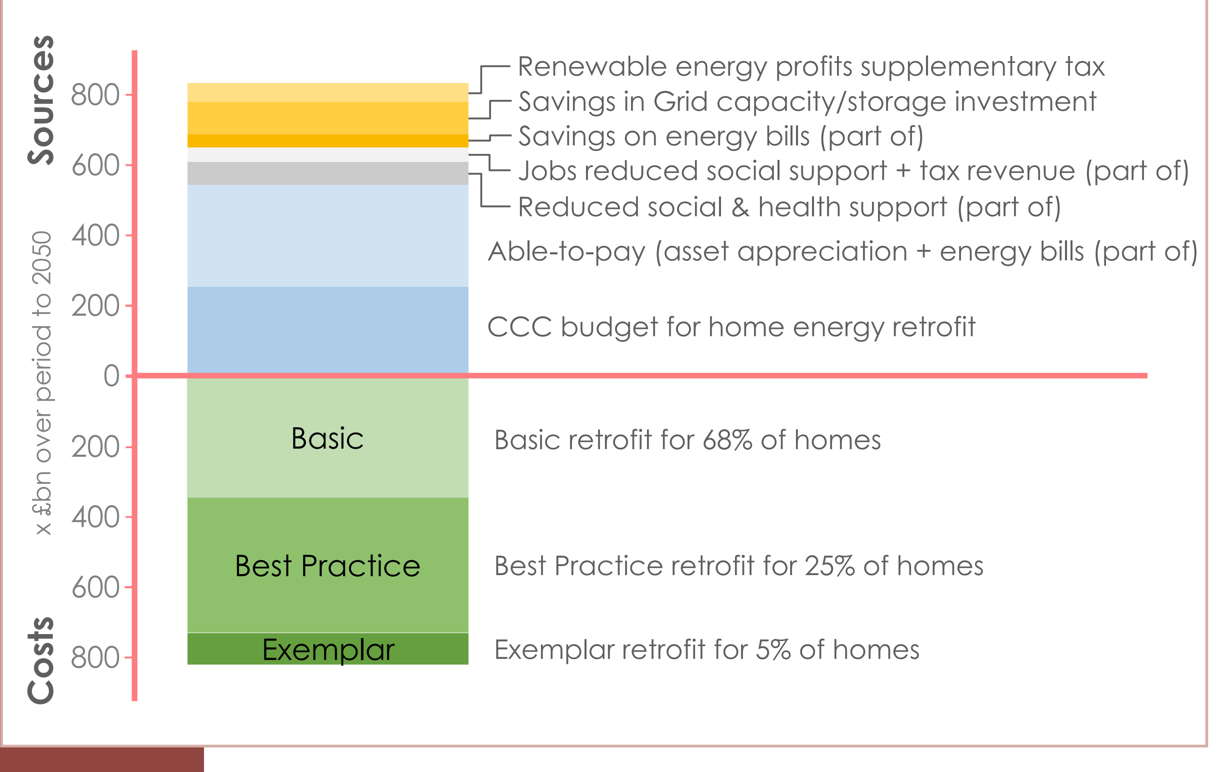


Figure 5.3
How home energy retrofit should be funded.

Figure 5.4
Overview of funding sources for a retrofit mass rollout. Adapted from ref[50]

Redirecting investment from energy supply into demand reduction

5.7 CCC baseline retrofit allowance

The CCCs 6th Carbon Budget includes an allowance of about £9k per home for energy retrofit within the 1% of GDP overall cost for getting the UK to net zero carbon by 2050.

For the retrofit to become a mass rollout delivering a 50% cut in heating, other funds sourced from within the 1% GDP need to be used. It is proposed that the £9k/home sum is supplemented as described in the following sections. Figure 5.4 provides an overview, Figure 5.8 a numerical summary, and more detail is in Annex G.

5.8 Able-to-pay sector contributions

The number of householders with no mortgage is deemed to be an approximation for those who are able to pay for most of their own energy retrofit. This is a very large sector of the market, and with appropriate policy support it is expected to take a major part in a mass retrofit rollout (Annex G.4). Those having paid off their mortgage are deemed to have freed up sufficient disposable income to pay for the energy retrofit costs themselves – as these would be a very small fraction of the property capital value.

While the non-mortgage indicator provides a useful scale of this market sector, it is not expected to preclude those with mortgages who feel they also are able to join this market sector. They all directly gain the benefit of added property asset value as well as reduced bills. Retrofit for this sector is assumed to be spread evenly between **BASIC** retrofit and Best Practice retrofit levels. To help motivate this potentially massive market sector, and help mature the supply chain, in financial terms each retrofit should receive support of some £5k, preferably as a tax credit, or as a discount rate loan or similar.

5.9 Redirected investment due to reduced supply infrastructure

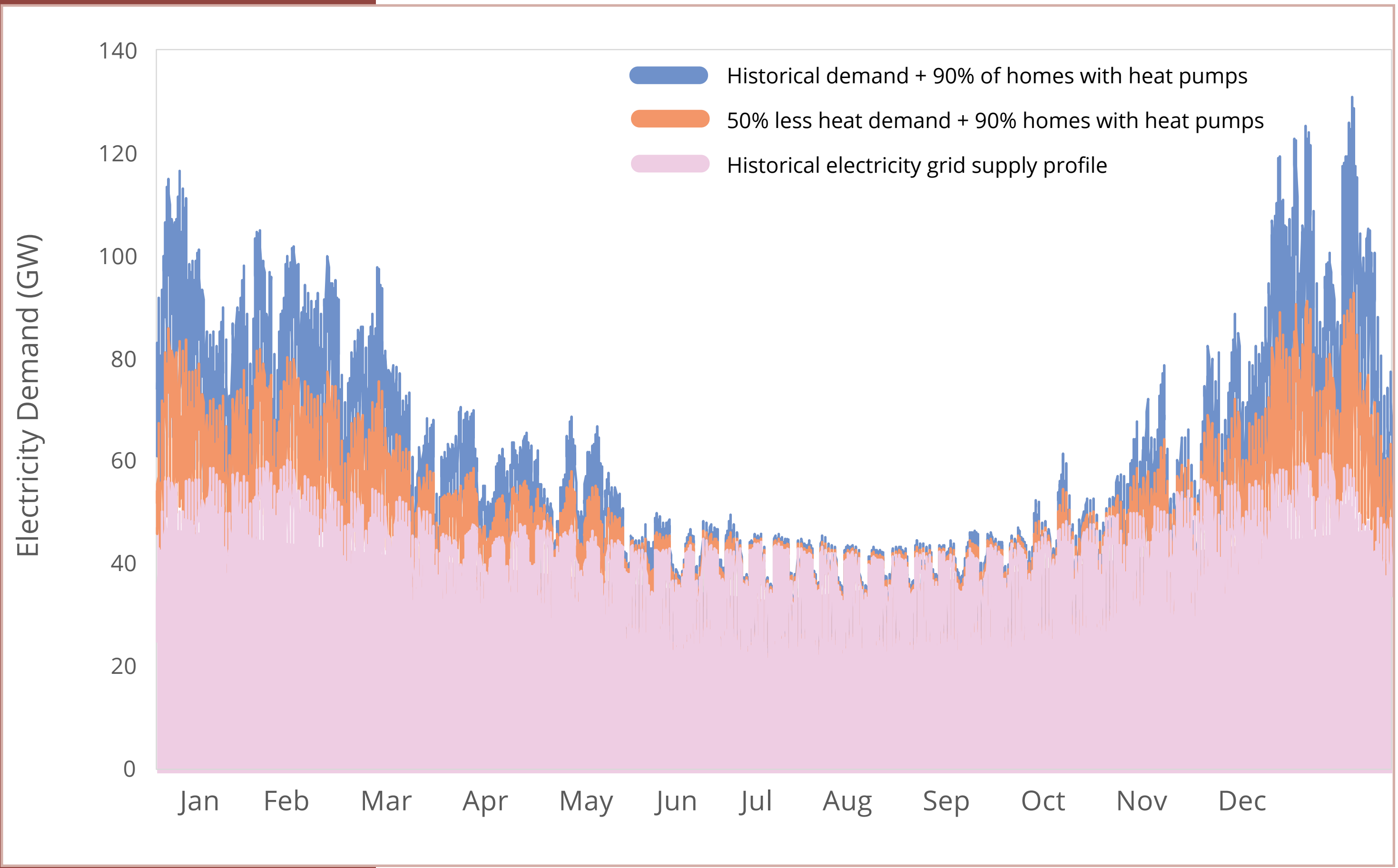
The UK's winter peak energy demand is largely due to the heating demands of homes. Currently this is dealt with by fossil fuelled gas power stations that can be turned on and off to meet this peak demand. However, this ability to quickly ramp up energy supply to meet instantaneous large peaks will become very much more difficult for a system based on renewable energy (and nuclear) generation. A key future challenge will be the storage of significant quantities of generated energy, at a grid managed level, until this energy can then be used during peak demand periods[51]. In addition, this peak capacity will need a matched high-capacity grid to be able to deliver this peak supply.

Consequently, the cost of delivering net zero carbon energy for heating not only includes the cost of energy generation, but also the poorly utilised peak grid capacity, as well as energy storage required from periods of surplus supply to periods of peak demand. Much of this is expected to use technologies like DAC, BECCS, hydrogen, and CCS (see Glossary, Annex G.5) that are currently unproven technologies, or without appropriate supply chains, with uncertain scaleup abilities, and with little capital and running cost predictability.

A key benefit of reducing peak home heating demand is the avoided grid infrastructure costs, and the removal of much of the risk associated with using insufficiently developed large scale technologies. This frees up capital that can be better redirected towards home retrofit. The scale of this avoided peak grid capacity is some 25% of the currently anticipated future grid capacity (Figure 5.5). The cost of providing this extra grid peak capacity has been assessed at £91bn (Annex G.5).

In practice these numbers may well be an underestimate of the potential grid capacity savings. Other research[53] shows how increasing the level of thermal insulation also enables the natural thermal inertia of dwellings to come into play, thus allowing heat pumps to be switched off for a few hours during the winter peak demand periods to reduce pressure on the supply grid.

Figure 5.5
Infrastructure capacity savings. Switching from gas heating to electric heat pumps more than doubles the peak demand on the electrical grid. Halving of residential heat demand using retrofit reduces the peak capacity demand on the grid by about 25% and hence there is a cost saving by not paying for this additional infrastructure (this includes a combination of transmission, distribution, storage, etc) - adapted from research by James Price[52]

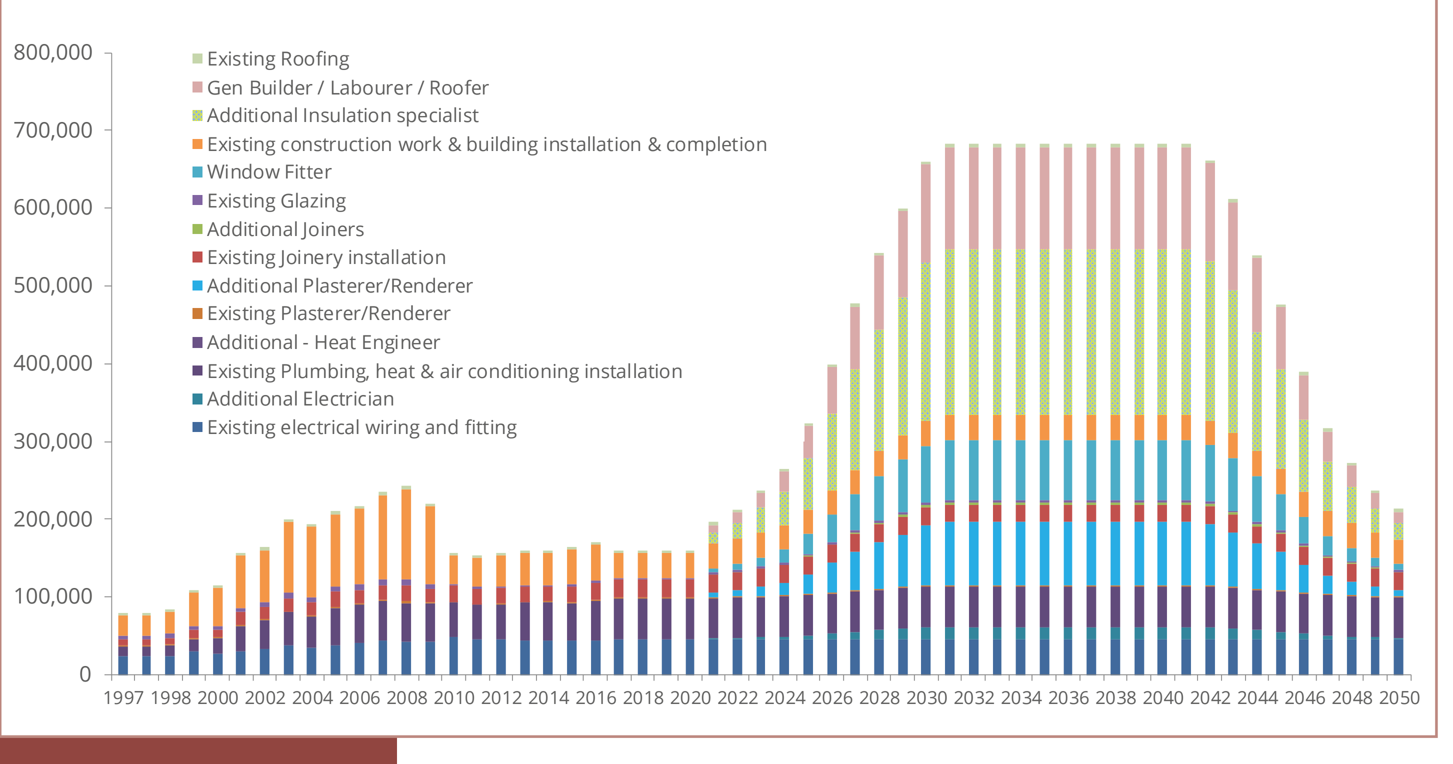


5.10 Increased employment tax revenue

Retrofit of homes is an ideal means of increasing employment and skills across the country, including those regions of the UK in need of 'levelling up' support. This additional employment generates new tax revenue contributions towards a retrofit rollout programme. It also increases GDP levels and thus the sum available from the 1% of GDP target for delivering net zero carbon UK. Figure 5.6 illustrates the scale of additional employment expected based on an adaptation of the National Retrofit Strategy (Annex G.2).

Any resulting additional VAT receipts have not been considered as potential tax contributions towards retrofit funding, because **RETROFIT-AT-SCALE** supports the policy of removing VAT from energy retrofit costs where they are delivered to verified performance standards.

Figure 5.6
Profile of skilled workforce for RETROFIT-AT-SCALE mass rollout programme by comparison to statistic in recent years (adaptation from CLC National Retrofit Strategy figure, adapted for deeper retrofit to more homes coupled with higher productivity).



Yes, healthy homes can reduce NHS costs, but that money is so sorely needed elsewhere within the NHS that none is likely to be freed up to pay for home retrofits

5.11 Redirected portion of healthcare and societal cost savings

The UK has the worst housing stock conditions in Western Europe (Annex B) and as a consequence very large health and social support costs of the order of £18bn per year attributable to poorly insulated and ventilated homes (Annex G.1). Halving the heating needs of the housing stock across the UK is expected to significantly reduce these costs.

However, in acknowledgement that these public services are already under severe cost pressures, only 33% of the health and societal potential cost savings have been deemed to be available to contribute towards home retrofit costs. These focus on the elimination of the current Warm Homes Discount and similar direct social support savings. Availability of these funds shown in Figure 5.8 are assumed to ramp up as the retrofit programme gets rolled out (Figure G.1).

Keeping energy bills high to pay for lengthy paybacks is not a compelling reason to invest in retrofit.

• 5.12 A portion of energy bill savings

At a purely theoretical level the savings from reduced energy bills can pay for the proposed **RETROFIT-AT-SCALE** mass retrofit rollout over 35 years. However, this assumes that the bills are not lowered to address fuel poverty issues, but instead simply switched to retrofit repayment costs.

In the net zero costs calculation in Figure 5.8, only 3-years of average energy costs savings have been included as contributing towards the retrofit cost, because of the high priority of reducing occupant energy bills. Keeping current bills artificially high to pay back the retrofit costs would not deliver this. This 3-year period represents a reasonable expectation of payback period for a typical householder. On the other hand, for the proportion of homes assumed to use the Exemplar retrofit level using the Energiesprong model, the complete retrofit cost is expected to be recovered using a cost model that recovers this from fuel cost savings, typically over a thirty-year period.

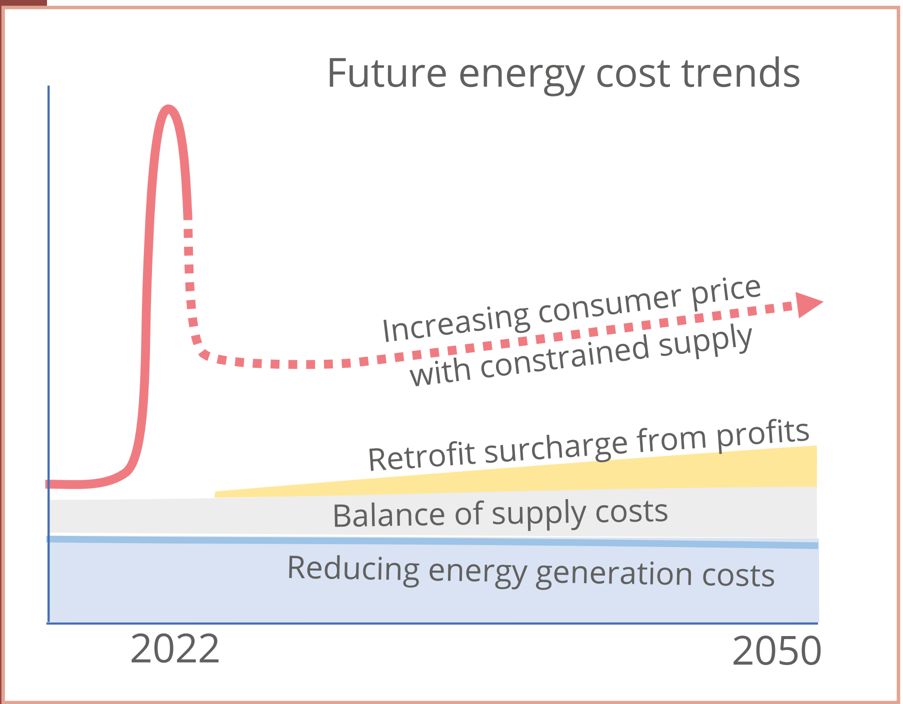


Figure 5.7
In formulating their net zero carbon trajectory recommendations, the CCC assumed energy prices would fall from 2019 to 2050 as generation costs fall. In practice, after the 2022 spike, retail prices are likely to settle at about double this level and steadily rise in real terms, largely based on supply constraints, and independent of generation costs. Data sources Ofgem, CCC, Cornwall Insights, and beyond 2030 based on 1% over inflation [165 166 167].
Excludes EPG subsidy (see Glossary).

Home retrofits free up wind power for green exports - a cut of these profits should help pay for these retrofits

5.13 Renewable energy profits supplementary tax

The CCC 6th Carbon Budget assumed the cost of renewable energy generation would fall during the period between 2019 and 2050. Instead, consumer prices rocketed, demonstrating the impact of a constrained energy supply, largely independent of the cost of generation. While this peak in consumer prices is expected to subside, it is currently anticipated to settle at about double the 2019 levels (see Figure 5.7) by 2030, even though this is not a result of a doubling of generation costs. For the medium term, with most countries on a trajectory to net zero carbon, it can be reasonably expected that carbon free energy will be a continuously constrained supply, meaning that there will be constantly increasing consumer price pressure running well ahead of generation costs. This has not been considered as part of the CCC 6th Carbon Budget scenarios, or for its impact on UK domestic energy consumer bills.

There is a great funding opportunity emerging from the success of UK renewable energy generation rollout, driven by its relative abundance compared with most other European countries. While the cost of constructing wind power has rapidly fallen over the years, the consumer price of energy is more likely to be governed by international demand influences, including the ease of switching delivery to alternative markets based on the highest bidders. This potential is expected to expand given the planned increases in electrical interconnector capacities between the UK and the European electrical grids[54].

This increased difference between generating cost and retail price provides the opportunity to redirect a modest slice into funding retrofit to reduce the UK demand, without unduly influencing the investment needed for the next generation of floating offshore wind. Indeed, reducing domestic demand on the back of retrofit enables more of the UK generated renewable energy to be made available as a valuable UK export and an addition to the UK future GDP.

The means for accessing this finance source would mirror the existing Supplementary Tax and Ring Fence Corporation Tax applied to North Sea oil and gas[55]. This has a similar situation where production costs are relatively low and steady compared to the international market defined consumer prices.

How is Net zero carbon retrofit for net zero cost paid for?	To 2050
• Baseline of CCC retrofit costs already included in 1% GDP cost of ZC:2050 - Average per dwelling of £9k	£252 bn
• Savings in healthcare and social support due to better housing - Based on accessing 33% of savings - given other competing funding needs. Saving heat support grants (as of Oct 2019)	£85 bn
• Energy bill savings - Based on: 5yrs of energy savings generally, except 30yrs for Exemplar Retrofit as Energiesprong payment model	£79 bn
• Able-to-pay increase in asset value (effectively increases GDP) - Based on householder proportion who are mortgage free and assumed to implement Best Practice Retrofit	£218 bn
• Additional green local jobs to service expanded retrofit - Additional national tax income	£60 bn
• Reduce decarbonised peak energy storage costs savings - Based on home heating being the major part of this peak.	£91 bn
• Top-slice of wind energy generator increasing profits - Based on consumer price of energy rising while CCC projections of generating cost are expected to continue to fall	£32 bn
Total funding sources:	+ £820 bn
BASIC retrofit applied to 19 million homes:	- £343 bn
Best Practice retrofit applied to 7 million homes:	- £385 bn
Exemplar retrofit applied to 1.4 million homes:	-£91 bn
Net zero carbon retrofit for net zero cost:	**zero**

Figure 5.8
Summary of costs and funding for deep retrofit mass rollout of 28 million homes

Chapter 6

Policy target has to change

Chapter key takeaways:

- *The Climate Change Committee recommends only 12% retrofit efficiency savings in their advice on policy to government*
- *Why they need a credible alternative from industry to be able to change this to prioritise retrofit*
- *How this needs to work within the national 1% GDP cost target for getting to new zero carbon in 2050*
- *How this informs the step-change proposed by Retrofit-at-Scale with its new Basic retrofit standard*

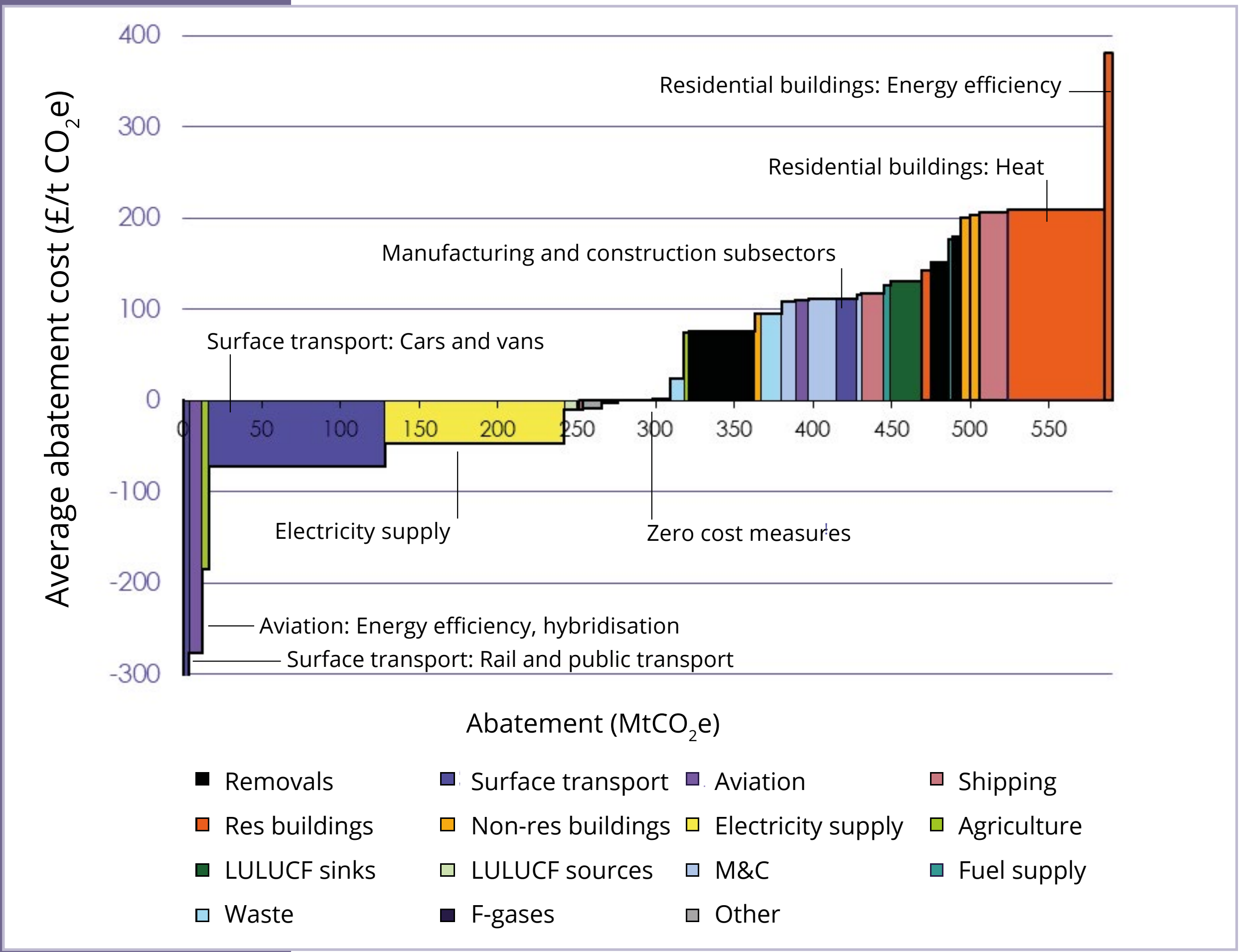
Chapter 6: Policy target has to change

The current CCC advice to government is that for the whole-life least-cost route to a net zero carbon UK, it is cheaper per tonne of carbon saved to build wind turbines than it is to retrofit our homes. To unlock an alternative strategy, it is necessary to understand the context of this current policy position.

The Climate Change Committee (CCC) is an independent, statutory body established under the UK Climate Change Act 2008. Its purpose is to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of climate change.

The CCC has outlined a roadmap to net zero carbon for the UK[56] and how it should cost no more than 1% of GDP up to 2050. This roadmap identifies allocations of energy / carbon savings for the different sectors of UK society (Figure 6.1). This is in effect the strawman for each sector to work on, and to adapt as appropriate, to accord with the overall national roadmap. The property / construction industry and its customers, householders and portfolio holders have a spectrum of very specific and differing characteristics compared with other sectors, which need addressing for it to be able to fully contribute to the Net Zero Carbon roadmap.

Figure 6.1
Diagram from the CCC 6th Carbon Budget analysis showing average cost of carbon emissions abatement across the UK major sub sectors in 2050.

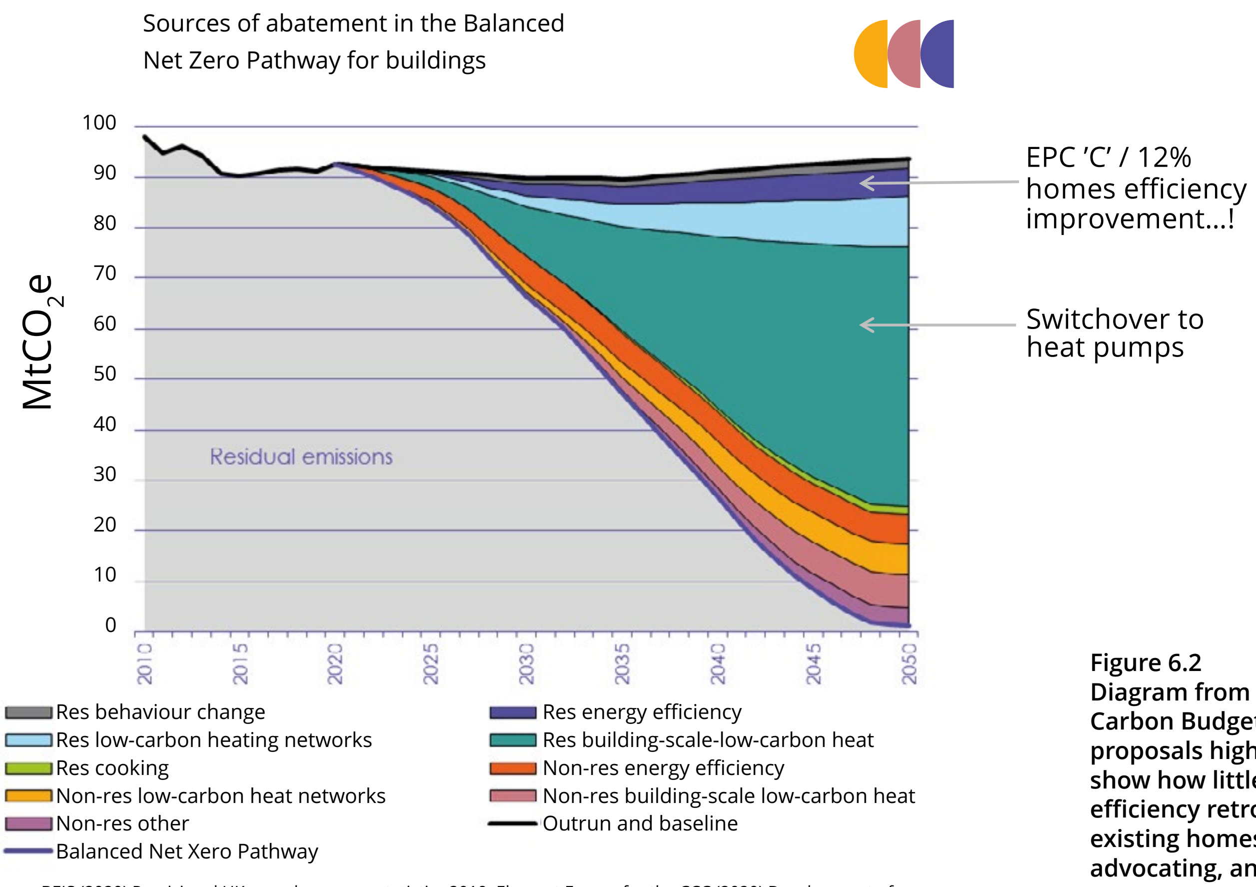


The CCC is driving the policy for low retrofit investment

6.1 Climate Change Committee strawman

Heating and hot water for homes make up 25% of UK total energy use[57] and 18% of the UK territorial greenhouse gas emissions[58]. CCC proposes an average of 12% energy efficiency improvements, together with the switch to electric heat pumps or equivalent (Figure 6.2). The current government target of EPC 'C' retrofit level is roughly aligned with this. For the mass rollout CCC anticipates costs averaging at about £9k per home including the heat pump installation.

The CCC's proposed roadmap to 2050 is based on analysis that minimises the whole life cost, but does not consider whether this cost is equitable across the nation or not. It does not address what is now expected to be the energy bill impact on householders. The CCC projections assumed that electricity costs will reduce in the future from a 2019 baseline as the cost of building wind farms continues to fall. Yet since that date the consumer cost of energy has more than doubled – largely based on international constrained supply (Figure 5.7). This is exactly the situation that is likely to be applicable for the wider international switch to 100% decarbonised energy supplies. A doubling of domestic energy bills means householders will in effect be paying the equivalent of the complete sum needed for all sectors of the UK to switch to net zero carbon, just from the extra they will be paying in bills between now and 2050.[59]



Source: BEIS (2020) Provisional UK greenhouse gas statistics 2019; Element Energy for the CCC (2020) Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget; CCC analysis. 6CB Fig 3.2.a
Notes: Residential low -carbon heat includes some efficiency associated with new homes. Non -
also includes some behavioural measures. Non -residential other includes catering and other non -heat fossil fuel uses.

Figure 6.2
Diagram from CCC 6th Carbon Budget proposals highlighted to show how little energy efficiency retrofit of existing homes is advocating, and instead assessing it is cheaper to build more wind turbines and install larger heat pumps to save carbon.

Building wind turbines is far cheaper than doing retrofit

6.2 6th Carbon Budget

The CCC advises the UK Government on how to deliver its legally binding emissions targets. It creates carbon budgets in five-year intervals and provides recommendations to the Government on how to reach them.

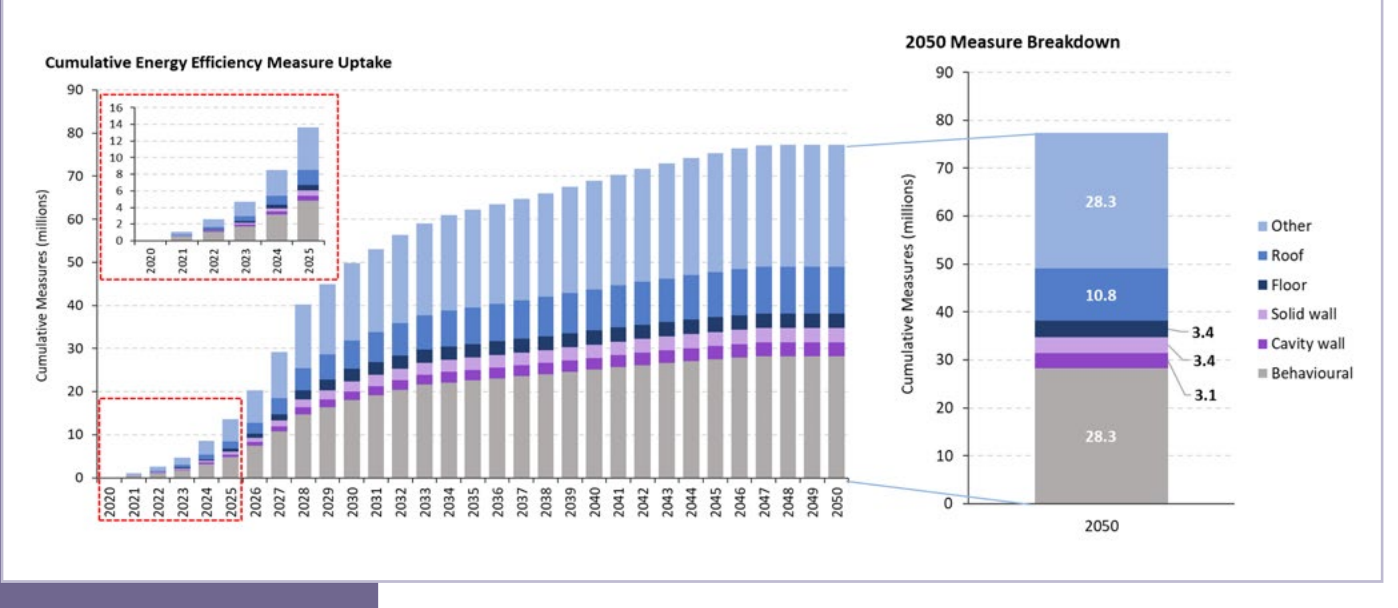
Government chooses whether to formally adopt the budgets into law or not, and then identifies which portions of their recommended pathways become actual policies. The Balanced Pathway that the CCC included in its 6th and most recent carbon budget is therefore not a formal policy, but one possible trajectory towards net zero carbon and a useful indication of the decarbonisation levels sought for different parts of the economy.

The CCC uses average abatement costs for decarbonisation to make comparisons across different areas of the economy. According to this methodology, energy efficiency measures in homes are among the most expensive decarbonisation options (Figure 6.1).

The CCC methodology includes some of the positive knock-on effects of energy efficiency such as enhanced health and well-being, reduced fuel poverty, regeneration, job creation, and improved energy security.

Even with these adjustments, the CCC Balanced Pathway recommends only a 12% energy demand reduction across the entire housing stock. Most of that is delivered through behavioural change, for instance turning down thermostats, and light touch measures like draught stripping and 'other' in Figure 6.3. There are very few insulation measures and virtually no deep retrofits included within the recommendations for the majority across the stock, other than for fuel poor, quantified as 12% of households using the now grossly out of date information from 2019 (Annex A.2).

Figure 6.3
CCC assumed energy efficiency uptake trajectory[60].



The construction industry failed to engage

The CCC limits the average cost of energy efficiency works per home to about £1000, plus £9,000 as an early rollout cost for a heat pump, or equivalent, for the switch to zero carbon fuel. Essentially, the judgement is that at a national scale it would be cheaper to waste low carbon heat supplied by wind than it is to reduce home energy demand. Moreover, the CCC does not consider the running costs for the home, nor the risk of energy price increases. See Annex H for more detail.

In 2019 this logic was flawed, in 2024 it is outright wrong. The CCC originally assumed that separate policy measures could be used to ensure a just approach, protect the most vulnerable, and reduce fuel poverty. In early 2023, fuel prices were triple what the CCC had used in their model, and at the end of 2023 almost double. With half the country approaching fuel poverty, by various sources[61], the assumptions behind the CCC's Balanced Pathway must be fundamentally revisited.

The difference between the Balanced Pathway's 12% demand reduction and **RETROFIT-AT-SCALE BASIC**'s 50% amounts to bill savings of nearly £1000 per year for the average home at early 2023 fuel prices

6.3 Challenge of construction industry engagement

It is important to understand why the CCC stakeholder engagement pointed them toward policy recommendations that included little in the way of homes retrofit. In formulating the 6th Carbon Budget, the CCC engaged both with householders through their Citizens' Panel on home energy decarbonisation, and otherwise with relatively few parts of the construction industry and its supply chains.

The CCC conclusion drawn was that householders were not prepared to accept much change intervention in their homes and the construction industry likewise had little interest in retrofit. This conclusion is more a reflection of the industry's fragmented nature and not a reflection on what it is capable of delivering.

For those seeking to engage with the construction and property industry on developing policy and regulations, there are major challenges in doing so. This is particularly the case when compared to other sectors like energy supply. Consequently, past energy retrofit policies and regulations have gained poor traction, largely down to not considering the extent of industry and client fragmentation in their formulation. This has been reinforced by national building policy initiatives that have repeatedly been dropped after a year or so, to the frustration and subsequent non-engagement of most of the industry.

Our industry has relatively few people in larger organisations with the resource to put over their particular viewpoints when engaging in developing policy and regulations. Overall, our industry can be characterised by reference to:

- Some 98% of our people are in SMEs with 78% in micro organisations
- Our client base is likewise fragmented with limited energy retrofit knowledge
- There is an increasing information 'overload' with most of it being partial / commercially driven
- The industry lacks a unifying structure to allow engagement
- Largely driven by clients who want the lowest initial cost, and the industry responds accordingly
- Much of the regulatory framework is informal / outsourced, meaning there is a lack of accountability
- The vast majority of people have limited training, and with limited access or incentive to upskill
- Construction components are mostly sold as individual bits, not as whole functional assemblies
- Outturn functioning of complete assemblies or buildings is not a commercial driver
- Very little verification of delivered performance
- General lack of trust on behalf of the wider public.

Considering all this, the energy retrofit rollout policy and supporting regulations must be tailored to suit these characteristics. By definition this means that they need to be multiple-level and multi-facetted to gain traction across all the fragmented parts of the industry. One size does not fit all.

The construction sector must be onboard with the scale of our retrofit challenge for meeting net zero carbon. As the vast majority of the construction sector are micro-enterprise practitioners, and those working in home renovation and repair are often small local builders, a long-term place-based approach is needed to develop the needed skills and trust. This will need to include free training opportunities for existing practitioners, case study and showcase demonstrator projects (with pre- and post- retrofit data) and local partnerships to develop learning, practical training and implementation programmes. Building control and planning teams must be trained and sufficiently resourced to oversee safe retrofit mass rollout. Where making good is required, trusted partnerships with insurers and funders can assist, accepting that pioneering work of whole-dwelling retrofit incurs some risk and that it can be shared. Every opportunity in the supply chain must be taken, for instance using the information dissemination potential of builders' merchants, of surveyors, finance providers and estate agents, to trigger discussions on energy efficiency, with builders, plumbers, electricians and heating engineers, to incentivise and equipped them to offer quality-assured advice to end consumers.

6.4 RETROFIT-AT-SCALE counterproposal

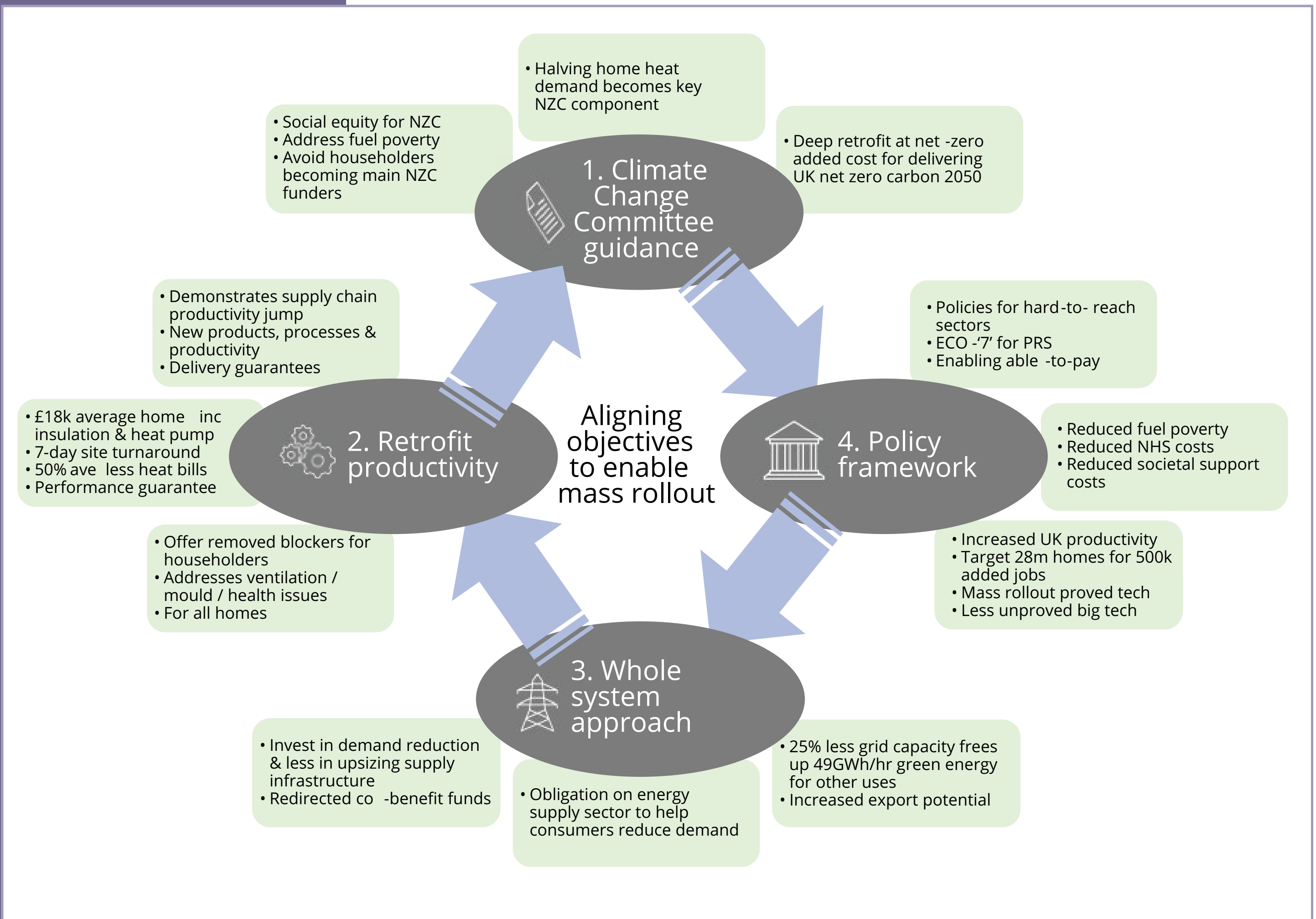
As a structured response from our fragmented industry, RETROFIT-AT-SCALE has drawn on wide cross-industry support and experience to propose an alternative strategy for retrofitting our existing homes, with a far greater emphasis on reducing energy demand and reducing the utility bills for our clients, the end consumers.

There has been a sea change in public opinion since the UK Climate Change Act adoption of the net zero carbon target, and the numerous Climate Emergency declarations. The majority in society are now beginning to understand the reasoning for needing radical change, they now need to know how to do it and feel they are not being ripped off.

To draw together a fragmented industry in helping their many client types navigate a new route forward, needs a comprehensive set of integrated policies and structured support that operates together from both national top-down and site bottom-up.

Figure 6.4 summaries the alternative **RETROFIT-AT-SCALE** strategy and its four constituent parts:

Figure 6.4
The four key interdependent components with their linkages



1. Providing well-grounded mass retrofit proposals to give the CCC confidence to change their retrofit policy recommendations from a 12% efficiency target to a halving of heating demand
2. A site level productivity step-change improvement allowing mass retrofit at net-zero extra cost as a key part of CCC plans for delivering net zero carbon
3. A whole system approach that allows savings in energy supply infrastructure and other co-benefits to be redirected as investment into mass retrofit
4. A national policy suite to enable support, development and funding for a retrofit mass rollout for the whole housing stock

The **RETROFIT-AT-SCALE** proposed new **BASIC** retrofit standard is pitched at a level to address all the above interlinked issues (Figure 6.5). It focuses on improved productivity and practical delivery of far more retrofits with quicker site turnarounds, as the foundation for the mass rollout. It fills the existing homes retrofit missing yawning gap with a well-grounded answer to the question of **'How many, how deep and at what cost?'**

Figure 6.5
Comparison between CCC Balanced Pathway proposals for home retrofit and RETROFIT-AT-SCALE alternative of halving heat demands for no more cost to the UK.

Climate Change Committee 6th Budget Balanced Pathway summary:	RETROFIT-AT-SCALE alternative:
• Delivery of NZC for 1% of GDP by 2050	• Delivery of NZC for 1% of GDP by 2050
• 12% home energy efficiency improvement average across the stock + switch to decarbonised grid powered heat pumps (or equivalent)	• 50% home heat energy efficiency improvement for all homes + switch to decarbonised grid powered heat pumps.
• Winter peak demand met by combination of green energy imports and energy storage of yet to be defined format or technology combination.	• Specifically addresses 'complex-to-decarbonise' home issues.
• Home efficiency improvements include behavioural change measures like reducing room temperatures, and 'pre-heating', despite there being no real-life evidence for either in UK uninsulated and leaky homes.	• Reduces winter peak demand by 36 GW using proven technologies - avoids need and cost of as yet undefined storage technologies or poorly utilised grid capacity.
• 'Complex-to-decarbonise' homes greatly limits extent of efficiency improvements	• Reduced UK home heat needs makes available 60,000 GWh/yr of high value zero carbon energy export to less renewable endowed countries, with an associated increase in UK GDP.
• No consideration of future ever increasing energy bills for householders	• Reduces householders' heat bills by about 50% with a heat pump when compared to the gas boiler bills.
	• Takes account of particular built environment characteristics, including Comfort takeback, Performance gap, delivery verification, etc.

Chapter 7

Policy support

Ultimately, all policy proposals must seek to create a functioning consumer market for retrofit provision.

Chapter 7: Policy support

The current policy context is a major obstruction to home retrofit mass rollout. This is compounded by a construction and property sector that is inherently fragmented and uncoordinated. Without a clear policy framework, competition and market forces do not operate in the best interests of consumers or householders. While in the past policy initiatives and incentives have come, they invariably disappear before they could mature into real change. At each change of policy direction, industry investment has been lost and confidence in delivering change undermined.

Industry needs a reliable long-term clear policy direction. Reassurance that this will be adhered to is required before investment and preparation can start to flow. The industry's disparate stakeholders (from sole traders to PLCs, material suppliers to tradespeople, funders to estate agents, householders to portfolio holders) need a coordinated set of differing policies, each then crafted to address differing housing types (dwelling form and tenure), and consumer types (those in fuel poverty, differing household size, life stages and financial means).

Ultimately, all policy proposals must seek to create a functioning consumer market for energy retrofit provision. This will need a mix of tailored information, supply models, finance and consumer protection, and regulatory shaping, all configured to ensure alignment between carrots and sticks.

This policy support chapter has been structured on the four key interdependent issues previously identified:

1. Updating Climate Change Committee (CCC) national policy recommendations to government
2. Support and encouragement for all parts of industry to deliver a productivity step-change Support for bringing about a retrofit delivery productivity step-change
3. A national whole energy system approach to ensure supply investment savings and associated financial benefits can be redirected into retrofit energy demand reductions
4. A national policy framework that supports locally driven initiation and delivery of retrofit

7.1 Climate Change Committee policy recommendations

Increase the priority given to energy efficiency as part of the roadmap to net zero carbon. While the previous push for decarbonising energy supply is supported, the future challenge is reducing home energy demand. This should focus on minimising peaks alongside far greater annual demands.

Who pays for the switch to net zero carbon emissions. The current expectation that residential consumers pay for much of the switch to net zero carbon needs to change. In particular, it should consider how those least able to pay in society should avoid paying a disproportionate contribution via their home energy bills. An alternative lowest whole life cost model would put more emphasis on reducing energy demand instead of the 6th Carbon Budget now discredited assumption that energy costs would fall.

Set homes retrofit as a net zero carbon priority sector. Propose at least a 50% average heat demand reduction, instead of the current 12% efficiency improvement averaged across the UK stock. Specifically, this demand reduction relates to the building's heat needs, not the energy input to heating appliances. This is to ensure the consumer energy bills are reduced, so they do not lose out by switching to the higher cost energy used by heat pumps.

Convert targets for buildings sector to energy demand reductions instead of using carbon metrics. The majority of UK current decarbonising is in the upstream energy supply system, largely unrelated to actions taken in buildings. Presented as carbon targets this demotivates stakeholder engagement. For better traction, building contributions to the national net zero carbon trajectory should be in terms of the energy they demand from the energy supply system. Put simply, building stakeholders, including occupants, respond better to the granularity of meter readings than hard to visualise national carbon targets.

Remove the recommendation for hydrogen and district heating to serve the existing housing stock. This is to halt the trend of putting off retrofits on the basis of these future silver bullets. Clear direction is needed now on the unsuitability of hydrogen as a natural gas alternative for home heating. Likewise, for district heating and heat networks, the current and likely future financial viability is simply not there for connecting the vast majority of the existing stock. Unfortunately, without clear direction, market forces mean big business elements pushing these onto consumers who pick up the bigger bills.

7.2 A national policy framework that supports locally driven initiation

Develop a comprehensive strategy for heat decarbonisation in the UK. This should prioritise energy efficiency, as well as the switch to energy sources with a baked in trajectory to net zero-carbon. A robust detailed timeline for the pathway to full net zero must be prepared, with full appreciation of the need for staged rollout and the multi-speed lead-in times required for a fragmented construction industry to fully mobilise. It should also emphasise the role of reducing building energy demand for consumer energy bills affordability. The term 'Low carbon heat' should be retired as this is now being used for lock-in to carbon emitting heat systems.

Develop Local Area Energy Planning (LAEP) to focus on demand reduction, and less on energy supply. LAEPs will be a useful tool to help local authorities develop retrofit rollout programmes, harnessing local people, businesses, and communities. Currently most LAEPs focus on energy supply, largely driven by the commercial interests of larger companies involved in energy supply. With the national grid supply already decarbonising, the focus should instead be on energy demand reduction and the processes for delivering this.

Adopt mandatory energy standards for existing homes that combine energy efficiency and the switch to zero-carbon trajectory heating. Some 80% of the 2050 housing stock already exists and will become one of the largest consumers of our future decarbonised energy supply. The need to manage this demand requires mandated standards to be rolled out. This involves a trajectory of future tightening standards, enforceable and incentivised at trigger points such as sale, rental and major renovations or extensions requiring planning permission. This will need to consider each home in 'whole-dwelling' terms and not just energy terms, for example, by ensuring that moisture/mould control and ventilation are included.

Develop Leasehold arrangements which end the split incentives and responsibilities. This is to make it cost effective for building owners to implement whole-building energy retrofits and enable tenants to operate them efficiently. In rental properties, through Section 11 responsibilities the landlords must already maintain and replace all heating system components. For most shorthold assured tenancies, the tenant have no capacity to interfere with the heating system or help initiate improved performance.

Develop a comprehensive strategy for where funding for a home retrofit national programme should come from. This should cover all parts of the housing sector, including a plan for reducing the currently growing social costs, for enabling those able-to-pay, the role and extent of market based financial mechanisms, and how to help the private rented sector (PRS).

Provide financial incentives to encourage the able-to-pay sectors to adopt whole-dwelling measures. For example, Stamp Duty and Council Tax that consider the dwelling's energy performance level and zero rate VAT for energy retrofit works where they deliver certified energy retrofit standards such as **RETROFIT-AT-SCALE Basic**. Consider allowing the cost of certified (& verified) retrofit to be offset against occupants' taxable income as, for instance in France.

Support market based financial mechanisms such as Green Finance grants and low or zero interest loans to reduce the upfront cost of retrofits to households (including particularly those targeted at the fuel poor segment of society)[62]

7.3 Support for bringing about a retrofit delivery productivity step-change

Develop a support framework for industry to change how it delivers home energy retrofit. These should focus on the delivery of 'whole-dwelling' integrated packages tailored to the properties and end users. There are massive potential productivity gains and retrofit cost savings. Local community-based mechanisms are particularly important at the organisational level, as well as increasing local employment, and for motivating householder engagement.

Upgrade existing homes Energy Performance Certificate (EPC) labelling system. This is to better reflect individual dwelling situations using newer survey methods, hence informing more cost effective whole-dwelling retrofits, instead of isolated insulation measures. The Future Homes Standard proposals[63] inadequately consider existing homes, the inaccuracies of RdSAP building data gathering, or the need to mandating performance verification as part of consumer protection.

Prioritise good quality and defined minimum standards for design and installation, and ensure training is available to help the industry meet those standards. This is to grow the skills base and supply chain in the UK to facilitate the market growth. Much of current training is for single measures and has yet to address integrated teams delivering single point of contact with single point of responsibility for consumers. Training programmes should avoid being driven by single-measure commercial entities. Standards need to be enforceable by the consumer, and so requires guaranteed energy performance targets coupled with post-retrofit performance verification.

Help move research knowledge from academia into practical industry rollout. Retrofit would especially benefit from new knowledge as its industry is particularly fragmented, making it difficult to circulate and scale up new knowledge, processes and products. Processes like real-time assessment of existing dwelling heat loss (eg HLC) and using smart meters for transmission of measured data (SMETERs, etc.) have the potential to improve pre- and post- retrofit energy verification, consumer trust, and assist industry continued improvement. Likewise, more commercially non-aligned academic research would help, for instance for understanding actual domestic hot water consumption, to counter current industry over-specification.

Launch a campaign to develop trust between local builders and householders. Incentivise local partnership action groups to include trainers, industry bodies, local employers, and local authorities. Involve those builders who act as project managers and will have to coordinate the different trades needed for retrofit. This can lead to local retrofit opportunity promotion in every builders merchant and in local advertising spaces. This needs to include highlighting the benefits of new ways of working.

Provide tailored advice and support. for each type of households, covering appropriate energy efficiency and zero-carbon trajectory heat measures. This should identify the incentives and other available support, how to access financial assistance, identification of certified suppliers able to advise on whole-dwelling retrofit. Currently there is on-line information overload, with conflicting and commercially biased information, with little on how to do **BASIC** level energy retrofit, or for guiding people through the complete whole-dwelling retrofit process.

7.4 Whole energy system approach to ensure benefits can be harnessed

Incentivise the energy supply sector to prioritise consumer energy and peak demand reduction. This should become part of a whole system approach to national energy management. So, instead of energy supply company profits being simply related to selling more energy, reducing demand and hence reducing supply system investment costs, should be of equal benefit for them. This sector has particular roles it is well suited to when it comes to certain types of consumers that otherwise policy has difficulty reaching.

Expand the Energy Company Obligation (ECO). This is so it provides integrated packages of demand reduction measures coupled with the switchover to zero-carbon heat. So instead of single measures, it delivers a single point of contact, **BASIC** whole-dwelling verified performance retrofit, together with its funding. ECO would expand beyond is current narrow definition of client affordability, to include the Private Rented Sector (PRS) and certain unable-to-pay sectors. Its funding by the energy supply sector reflects their considerably reduced grid peak investment costs, both at the national and local network levels resulting from the mass rollout of homes energy retrofits.

Move away from a system of wholesale markets pricing electricity based on the most expensive generator setting the grid price. Instead, ensure that the lower generating costs of renewable energy generation are reflected in consumers bills. In addition, better represent the higher supply costs of peak electricity in the bills, initially as an introduction to the future issues of grid maanagment, and progressively as an incentive for householders to initiate demand reduction and peak demand management.

Eliminate the disadvantage of switching to greener grid electricity by removing the Social and Environmental Obligation Costs from electricity and incrementally adding a climate change levy to fossil fuels as an added incentive to switch away from them.

Annex

A

The social dimension

Annex A: The social dimension

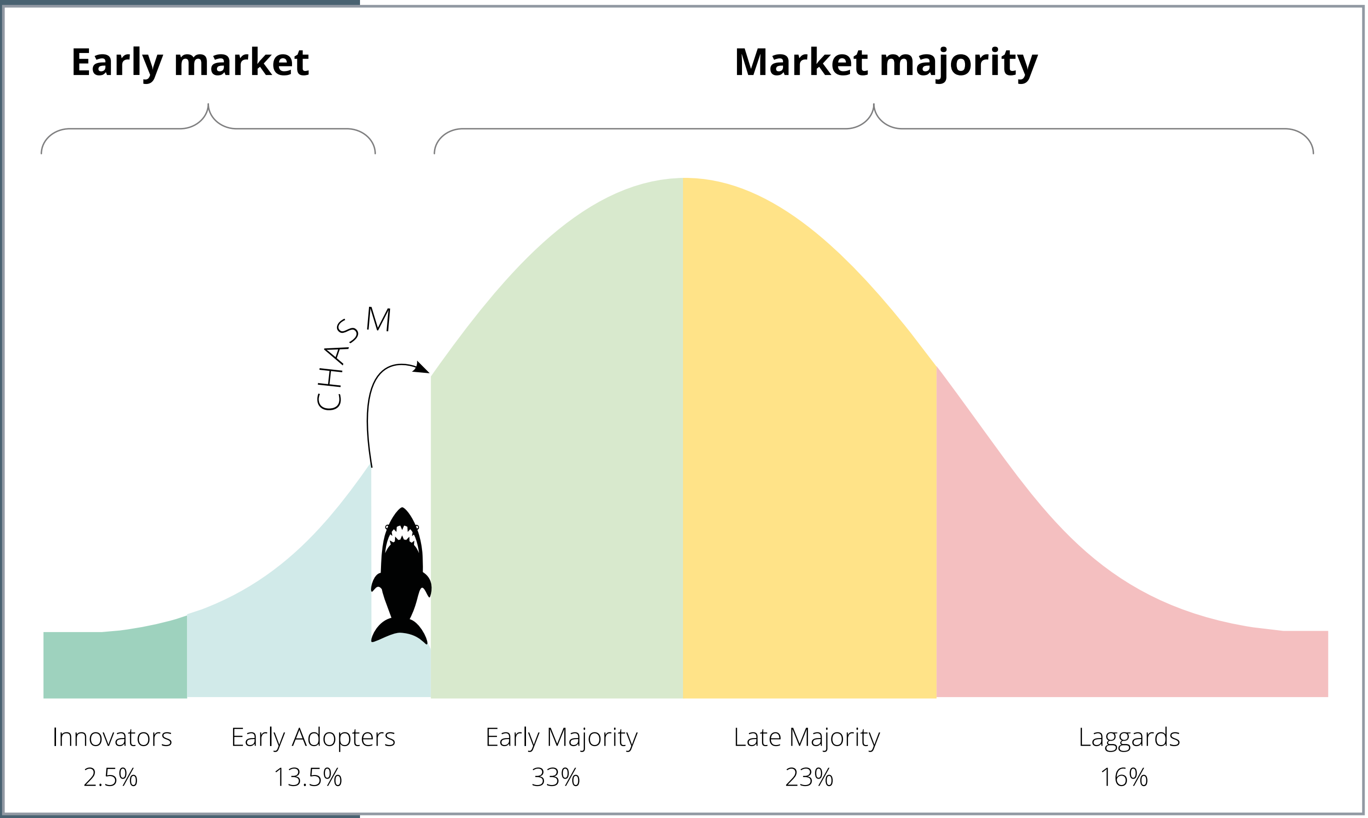
Most people in society feel unable to engage in, or consider, energy retrofits to their homes. There are significant differences between engagement for the majority compared with the early adopters, reflecting the challenges seen more generally in innovation adoption (Figure A.1). This Annex investigates the key retrofit 'blockers' for the majority, and so what BASIC needs to address to allow retrofit mass rollout to appeal to the majority in society.

A.1 Blockers to retrofit

First and foremost is the fact that few people have done it before, and personally know of no one else who has, so this is a new world for them. A boiler replacement is regarded as a simple maintenance task, not an energy upgrade. This tends to come as a distress purchase with disruption and an unexpected large cost. Replacing a kitchen on the other hand is regarded as practically and visually adding amenity and value. It is driven by wide exposure in the media and knowing someone else who has already been through the process and proudly displays it. Fundamentally such home interventions must provide tangible benefits and appeal.

Energy retrofitting a home, whether you live in it or not, is not a simple decision to make, and for most does not appeal. Any retrofit plan should outline the implementation steps to consider, but before this, there is the need for establishing the initial contact and making energy retrofit appealing. Different households will have different needs, priorities,

Figure A.1
For a mass rollout, understanding how the drivers and barriers for the market majority differ from the early adopters has to be understood[168].



constraints, and desires. Designing an appropriate retrofit necessitates a good understanding of these specific needs and preferences, and must reinforce this appeal. This is where a community based initial engagement process is key, getting likeminded locally known people to make the initial contact and providing a trusted local advisor throughout the process. Basic must be able to communicate its benefits in simple terms that can be understood by layperson in this initial engagement process.

BASIC must anticipate occupiers' and owners' concerns, many of which were identified by those involved in the Green Deal, as well as by independent research[64], with key concerns shown in Figure A.2. Responding to these, every home in the UK should be able to expect the Basic level of retrofit, at the very least. This is important for economic and social equity, so making energy bills more universally affordable and reducing fuel poverty. The aim is to achieve this by lowering energy demand and increasing amenity, rather than by energy bill subsidy payments. However, such laudable objectives must be put into layperson terms, of lower bills, low disruption, does what it says, adds home value, communicated via people the local's trust.

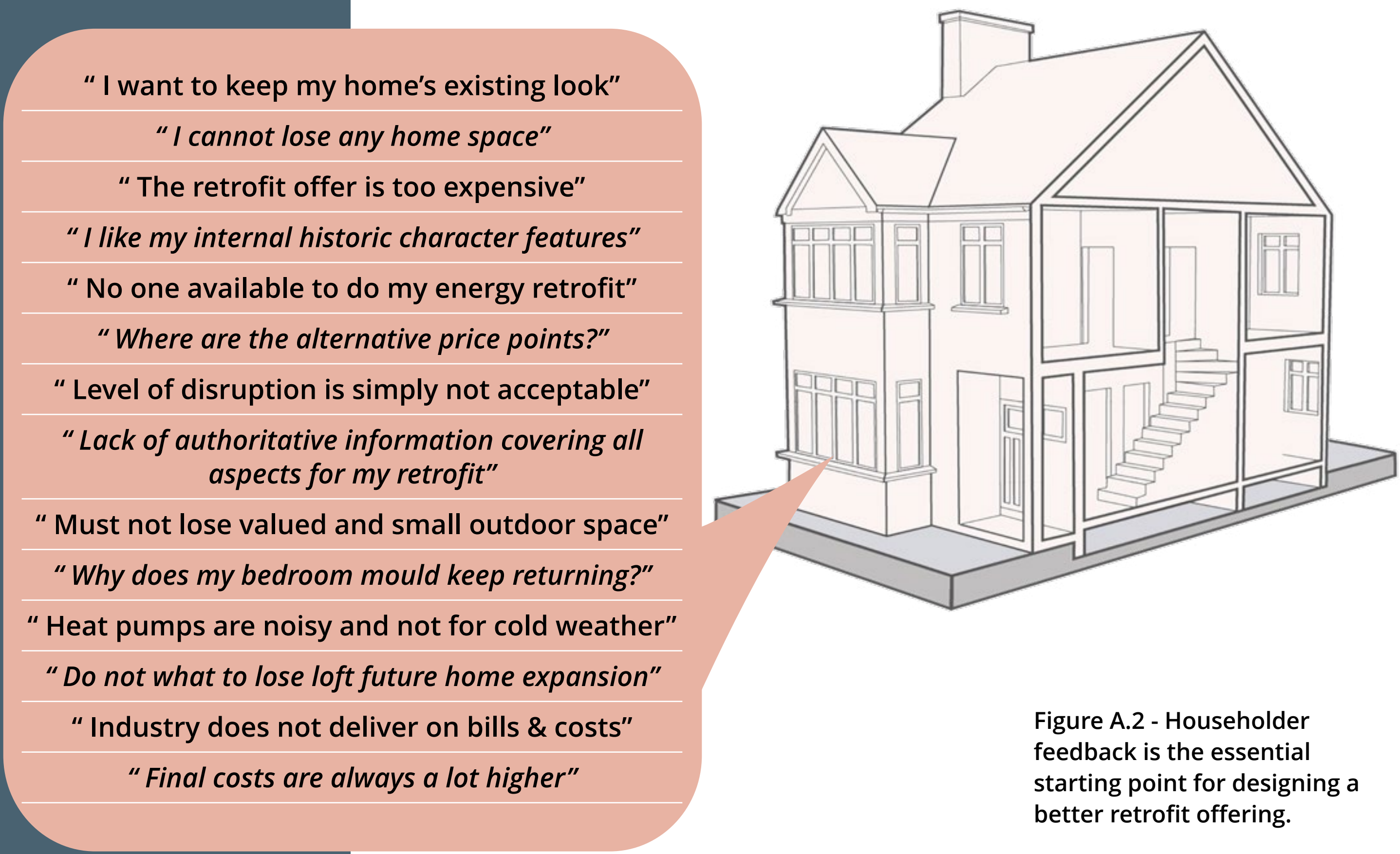


Figure A.2 - Householder feedback is the essential starting point for designing a better retrofit offering.

A

“The retrofit is too expensive, where are the alternatives?”

“I cannot lose any home space”

“Must not lose valued limited outdoor space”

COST

This is one of the most important barriers for residents whether renting or as owners. A simple ‘payback’ on utility bill saving may not be their primary concern. After all, during a ‘payback’ period there is no reduced bills, simply bills redirected to pay back the capital cost.

The total cost of the retrofit is typically a critical factor. Just as when contemplating the purchase of a car or similar scale of investment, a homeowner or owner, or perhaps portfolio holder client, should be presented with the full range of options. These options should encompass varying levels of specification, spanning from **BASIC** to the top-of-the-range, each presented with its complete cost. The majority of the current market offerings to householders are on the basis of only single measures, such as a heat pump or window replacement. Consequently, the benefits of even some modest fabric insulation enhancement or a windows overhaul [65], to say, reduce the size of the heat pump and eliminate radiator replacements, are simply not offered. It is essential to explain the full range of options as most householders and clients have limited knowledge of the full range. Where budget constraints exist, the approach is to begin with the baseline model and subsequently incorporate different upgrades as needed and when deemed suitable. The **BASIC** baseline needs to be able to deliver a reasonable level of amenity at the minimum price point - complete with a performance guarantee. The provision of a mechanical ventilation system, for instance, initially offered as surface mounted, could be encased for visual concealment either initially or at a later stage, for a cost upgrade.

Locating the funding for upfront cost is often problematic. The retrofit technical offers should come with a tailored financial offer, also with options. This is part of providing a single point of contact for the complete retrofit implementation, and should cover all aspects of the works, seeking to avoid later cost surprises. When attempting something they have never done before, people will be particularly keen on getting reassurance that they are achieving ‘value for money’. This is one of the most important perceived barriers for householders, even if they have access to the necessary funds. Ensuring the client has access to alternative independent advice is crucial for providing trust in this regard. Hence the need to have a Retrofit Coordinator who is part of the integrated delivery team, but also having a contractually independent Retrofit Assessor third party.

SPACE

To scale up for the majority of the market, space constraints in the typical home become a major issue. This is largely because of the hot water storage space required by a new heat pump system.

While early adopters may be prepared to lose space, this does not extend to the majority. The space constraint was frequently cited by retrofit practitioners as a reason why previous Green Deal[66] and similar initiatives ended up discouraging householders from proceeding with a retrofit. This tends to be the case particularly for householders of smaller and of most average sized houses, and of flats, who feel they do not have this space to lose. There are many home types, particularly those more than 40 years old, that originally had space for a hot water cylinder in an airing cupboard. However, with the switch to combi boilers with their instantaneous hot water, those spaces have generally been lost and typically repurposed as new shower rooms or for required storage space. The need to surrender

A

“Do not want to lose loft [for] future home expansion”

“Level of disruption is simply not acceptable”

“I want to keep my home’s existing look”

this repurposed space coupled with its associated disruption tended to be a complete blocker to retrofit implementation.

Previous research for CCC[68] also identified this space constraint issue. For analysis simplicity CCC research defined the extent of constrained homes as a simple function of floor area to occupancy ratio. The **RETROFIT-AT-SCALE** research explored this in more detail with retrofit practitioners, particularly in regard to householders’ reasons for not wanting to embark on retrofit. This feedback indicated that the extent of perceived lack of space was for a far larger proportion of homes than the floor to occupancy ratio would suggest. Almost any householder has an aspiration for home upsizing to gain more perceived space. More recent anecdotal feedback suggests that Covid has further enhanced this perceived floor area value, now extended to cover outdoor and garden spaces for most modest sized homes.

As a consequence, to allow **BASIC** to be applicable for mass rollout, **BASIC** should be able to offer a technical solution that avoids reducing the home floor area and avoid losing valued outdoor space

DISRUPTION

The inconvenience for the majority of the market should not be underestimated. It is an altered state of living for the occupants for not only the period of the works, but with elements of lifestyle adjustment thereafter.

Disruption during the retrofit process may have a greater negative impact for some residents than to others. Elderly residents might have lower tolerance for or be less able to cope with disruption. These residents may require additional support. Those who work from home may also find disruption challenging. It is important to provide clarity and manage residents’ expectations. Common questions include: when will the work start; for how long; what is required from residents beforehand; in what state will the place be left; how noisy will the works be; will there be dust, smells, etc (especially for people with allergies); what happens to my furniture and possessions? **BASIC** must aim must be to minimise the extent of all disruption to the resident.

A high priority for this is reducing the duration of the site works. This reduced site time also directly reduces the retrofit teams’ costs (Figure E.2) and improves productivity, and so reduces the overall retrofit price. Minimising site time, and with this the need to reduce the risk of site unknown snags, increases the importance of obtaining comprehensive and reliable pre-site works survey information. Reducing the extent of stripping out and disturbance to the existing fabric and systems also helps in this regard.

APPEARANCE AND HERITAGE

In older buildings (pre-1940) residents, and owner-occupiers in particular, typically have some personal attachment and gain value from the heritage aspects of their homes. This is regardless of whether these buildings are officially designated through listing, conservation areas, or follow traditional construction designations (e.g. heritage being pre-1919). The heritage value affects the types of retrofits that residents would enact. External wall insulation is generally unacceptable to residents in buildings with stone façades or decorative masonry. Internal insulation may lead to concerns about space reduction, disruption, and damage to internal features with heritage value. Residents with original windows may also value the character of traditional glass and want to retain it. Secondary glazing and shutters may

“I like my internal historic character features”

“Heat pumps are noisy and not for cold weather”

be required. Residents with original shutters often highlight their benefits both for heat retention in winter and for preventing summer overheating.

Residential buildings constructed pre-1940 are about 35% of the housing stock (Annex F). However, residents and owners often remain inactive because they believe there are no viable solutions available. They may be aware that retrofit measures suitable for buildings with heritage significance might be more expensive. Sometimes they may be prepared to pay the price or wait until they can afford adaptations that will not harm the significance of the building. A range of retrofit offers need to be made to these residents addressing their specific needs, for them to become engaged in the process.

Occupants may also be attached to certain visual aspects of more modern properties. While it may be less challenging to fit retrofit measures such as external insulation and new windows, cost constraints similar to the rest of the majority market are likely to be applicable.

As a consequence, the **BASIC** space heating target has been pitched at a level that allows opportunities to mean it with measures appropriate for heritage and older properties (Annex F.4) as well as for more modern properties. Not requiring external or internal wall insulation to the front façade is one example.

INFORMATION

While there have been big political statements, there is a lack of joined up consistent narrative from these on how they relate to the multiplicity of individual household situations. At a more detailed level, many retrofit technologies, heat pumps included, have been the subject of much misinformation. Cost expectations may also be unrealistic (in either direction) – hence the importance of trustworthy information.

Information needs to be both **specific** as well as **trustworthy**. Householders want to understand how X will work in **my** house and for **my** lifestyle. Referring to typical savings isn’t sufficient, people have very varied energy and heating practices, influenced by their different perceptions of comfort, costs, occupancy patterns, age and health. It is necessary to understand people’s specific needs to specify appropriate solutions and to be able to provide assurances on the retrofit benefits. Any occupant experiencing fuel poverty or financial difficulties tends to use less heating in their home, making the extent of savings on utility bills less than a typical home, albeit of more significance to them. On the other hand, the impacts on improvements in health and comfort aspects are likely to be greater than the average.

It is also important to meet residents on their level. Some will have only a **rudementary** understanding of how their homes function and of technical issues. Some, however, will have spent significant time researching retrofit and have a detailed and technical understanding of their buildings. Professionals should be prepared to give residents the level of information that they want or need. While you may be the expert in retrofit, residents are the experts when it comes to managing their homes and articulating their preferences and needs. Residents are concerned about being ‘sold’ specific solutions that may not be appropriate or the best option for their home or their lifestyle. It is therefore essential to offer them various options and clearly outline the advantages and potential difficulties associated with each one. This approach helps residents comprehend the basis for the recommendations they receive. People learn experientially and are also

"Lack of authoritative information covering all aspects for my retrofit"

"No one is available to do my energy retrofit"

"Why does my bedroom mould keep returning?"

likely to trust the experience of peers, so opportunities to see similar retrofit projects in the local situation is invaluable. Equally, be prepared to work with other players if there is a need to help dissuade residents from insisting on risky or ineffective measures.

CONSUMER PROTECTION & QUALITY ASSURANCE

The energy efficiency market traditionally has a history of falling short of meeting the expectations of homeowners and occupants. Poor experiences with tradespeople can discourage residents from pursuing additional measures. Moreover, residents may become disheartened if their input is disregarded or if essential information about their home is overlooked. The quality of cleaning, touching up minor faults and making good defects before completion of the job is critical for residents' satisfaction, as well as the provision of guidance on how new systems will work. Equally important is the availability of neutral third-party advice sources, as well as ensuring there is the means of providing consumer protection, including guarantees the retrofit will function as intended and as the resident expected.

CAPACITY

The time capacity to investigate and make the decision to retrofit is another barrier. Finding the time and drive to start a likely complex process and understanding the initial steps to take, as well as being able to continue to negotiate the process of retrofitting to a successful conclusion, is a barrier to many. Communicating clearly with householders and understanding the other demands on their actual time and thinking time is important. This may be a particular barrier for people with intense jobs and/or young children.

Depending on the extent of the works required, the effort, time, and physical labour required to clear spaces for the necessary works to take place may not be trivial. In addition to time capacity, spatial capacity for storing the technology may also be of concern, such as the placement of heat pumps and thermal stores. **BASIC** needs to focus on demystifying the retrofit process, and on providing simple, predictable and reliable technical solutions, so the householder and other occupants can understand and buy into the process.

It should also be borne in mind that some 40% of the population are not confident using smart phones[67]. Once again this is a considerable proportion, which is probably biased towards the majority market. To serve this sector **BASIC** should be able to offer technical solutions that do not depend on sophisticated smart controls. There is always the option to enhance the **BASIC** retrofit, although it should be noted that occupants may move out within the service life period of most of these smart systems and so subsequent occupants need to be considered.

VENTILATION AND INDOOR AIR QUALITY

Many homes in the UK suffer from poor indoor air quality, damp and/or mould[68]. This is the case even where the occupants are not in fuel stress. Where cold and bills are an issue, the problem is often worse because of the perception that ventilation adds to energy costs. However, it is the inadequate ventilation provision that leads to issues of damp and mould, and so to unhealthy conditions as well as discomfort.

Improving the affordability of warmth can improve ventilation, as occupants may be more tolerant of ventilation heat loss when they are confident of being able to afford their heat. However, though this may make the conditions better, many retrofit measures also reduce infiltration – so improved energy efficiency alone cannot be relied upon to deliver satisfactory ventilation.

To achieve a worthwhile standard of energy efficiency and comfort, a retrofit should aim for high airtightness. Not least, enhancements to standard draughtproofing tend to be remarkably cost effective (Figure E.1). However, a reliable means for supplying fresh air must be provided, and there is growing evidence that trickle vents through windows or walls do not deliver this. In particular, occupants often do not associate trickle vents as the permanent fresh air supply component for the correct functioning of mechanical extract systems as required by Building Regulations (Part F for England), and consequently tend to keep them closed[69]. To ensure consistently good indoor air quality, good airtightness should be accompanied by the installation of a whole house ventilation system.

A whole house MVHR system is strongly recommended for all **BASIC** retrofits as it provides consistent and reliable minimum background ventilation into all living spaces, without heat loss or discomfort. As with any means of providing ventilation, it is important to verify that these fresh air rates are actually delivered, because research shows many homes have insufficient rates, albeit particularly where whole house ventilation systems are not provided[70].

High humidity encourages mould and dust mite growth, which can lead to allergic reactions and respiratory illnesses[71]. Ideal indoor relative humidity (RH) level ranges between 30-50%[72]. Higher humidity also increases the concentration from pollutants[73]. Over-occupancy is common in the UK, and is associated with increased moisture production, making the avoidance of cold spots and the sizing of ventilation with the higher moisture capture of the warmed supply air of an MVHR system doubly important.

A.2. Understanding clients

Successfully engaging with the homeowner implies knowing the client. Homeowners, be they the occupants or not, require communications that are tailored to them as individuals. Understanding the identity of the client and motivations for retrofitting their home is crucial, along with the essential information to prompt their decision. It is important to recognise that for different clients there will be different incentives and obstacles.

DECISIONS SURROUNDING RETROFIT

When presenting options and explaining the costs and benefits it is advantageous to understand the factors that influence decisions related to costs, whether they are financial, disruption-related or time-related. Based on existing research, the decisions made by the client can be significantly influenced by their adaptation level, diminishing return and loss aversion[74]. These are overlays on the more recognised influences.

Factors influencing the sentimental importance of retrofit for clients:

- Adaption level: People evaluate based on a neutral reference point - their status quo, or the outcome they expect or feel entitled to. If a choice will put them in a situation better than their reference point, it will be a gain to them; otherwise, it's a loss. What you perceive as retrofit benefits may not be how your client perceives it.
- Diminishing return: With a whole-house approach, some measures of the retrofit plan would present more benefits or more downsides (real or perceived) than others. Be cognisant of how you present the retrofit measures, especially those that would be more cost-effective to be installed together.
- Loss aversion: People weigh loss (cost, time, convenience) more than gain, even if the apparent amount is identical. In other words, even though the monetary values are the same; the psychological values are not.
- Income level: For much of the population their disposable income has been falling. Thus, more people see a larger income proportion being committed to essentials, with less for discretionary retrofit expenditure.
- Tenure type: When tenants are responsible for covering the utility bills, landlords often lack the incentive to undertake retrofitting projects due to the slower and less apparent return on investment. Moreover, multi tenure blocks pose an additional challenge as it raises the question of who will coordinate the retrofitting works and manage interactions with the various tradespeople involved.
- Lifestyle and life stages: This can vary from pensioners, and families with young children, who spend most time at home, to young professionals who may be less settled with less commitment to the property. There may also be occupant health concerns, and other vulnerability classifications.
- Attitudes to innovation: according to research, about 50% of the population tend to be risk averse and more likely to hold sceptical views of new technology and approaches that disrupt the status quo. About 25% of the population are not smart phone enabled.
- Building status: This includes of Listed or historical significance. For many, personal preference for retaining historical or cultural details are also important.

FUEL POVERTY

The Resolution Foundation[75] has estimated that 1/4 to 1/3 of all households risked falling into 'fuel stress' by the end of 2022 (using the definition of the household needing to spend more than 10 % of income on heating). There is a prediction that 20% of households in EPC A-C rated homes will be in 'fuel stress'. Other sources quote similar rising trends[76] with more recent sources suggesting almost 10 million, hence 1/3 of UK households, are now living in cold damp and poorly insulated homes[77]. For anyone in either average or below-average dwellings (EPC ratings E, F, G) or on a below-median income there is a more than even chance of being in 'fuel stress'. A large number of people are potentially affected by fuel stress, so retrofit designers should assume that the occupant of the dwelling could become someone in fuel stress, even if the current occupants are not.

TEMPERATURE OF UNHEATED DWELLINGS

For any dwelling likely to be occupied by someone in financial stress, consideration must be given to the 'fall back' temperature if occupants disconnect their heating and hot water for a day, a week, or longer. In the UK in 2022, people are turning off their heating in increased numbers. Low temperatures are dangerous to health, particularly if young children, elderly people, or residents with a disability or long-term health condition are present. A lack of heating also means the conditions expected to propagate condensation and mould growth are far more likely to occur.

VULNERABLE POPULATIONS

Disabled people often have exceptionally high energy needs because:

- **They are at home nearly all the time**
- **They have reduced appetite and therefore low metabolic rate;**
- **They may be are advised to heat to 22oC (in particular, people with a spinal injury),**
- **They need to do extra laundry**
- **Medical/care equipment also consumes energy (e.g. mobility aids, etc.) which means they are acutely vulnerable to energy price increases**

People with dementia are also extra vulnerable to cold (high rate of excess winter deaths). Certain segments of the population are more sensitive to environmental changes. The comfort afforded by energy retrofit measures will therefore be particularly beneficial to their health and wellbeing.

Children are more vulnerable to temperatures that are too warm or too cold. Older adults (65+) and people with pre-existing cardiovascular, respiratory, or mental health conditions are also more vulnerable[78]. Children are also more susceptible to poor indoor air quality. Similarly, older adults and anyone with cardiopulmonary conditions are more sensitive to subtle changes in indoor air quality (IAQ)[79].

A.3. Discussion points with occupants and clients

If the homeowners are not the occupants of the property, encourage them to engage with the occupants, as they are the ones who will directly experience the disruptions. Identify the primary concerns of your clients and the occupants and establish ways to alleviate potential challenges before starting the site works. Consider and communicate the risk of any energy efficiency measure that may negatively impact the property.

“Final costs are always a lot higher”

Communicate the rationale and benefits of specific sequences of energy measures to be carried out. It is important to consider how each component may affect another and the order these measures are carried out. Some need to be done in a specific order to avoid future problems and to minimise the disruption and discomfort to the occupants. For instance, if the retrofit plan involves the installation of both insulation and a new heating system, the insulation should take place first as this will allow the selection of a smaller simpler heating system, as well as reduce the bills – whereas a simple switchover to a heat pump instead of a new gas boiler will not.

It is important that the needs and concerns of the occupants are communicated to those physically carrying out the retrofit as they will be the ones in contact with the occupants on a more intimate basis. Establish that any contractors and workers employed have a well-documented history of reliability, with positive feedback via local third parties known to the client being particularly good for cultivating an atmosphere of trust.

Be transparent and upfront about costs – especially those having to do with existing fabric defects, and their early detection to reduce subsequent uncertainties on timescales. Communicate scenarios and prepare the homeowners on the possible scale of work and costs these scenarios may incur. Additionally, provide clients with an understanding of the range of stakeholders involved in ensuring that the retrofit project is completed within the set timescale and budget, such as approvals from local authorities and other statutory bodies.

Breakdown and be clear about the different costs: Range of Capital costs, Running costs, ‘hidden’ or soft costs such as professional fees. Ensure that total outturn costs are presented to ensure transparency for all concerned, and particularly those unfamiliar with commissioning building works.

WHY DO PEOPLE RETROFIT?

Clients often hold expectations about retrofit that may not align with reality. These expectations can vary, with some being overly optimistic and others lacking awareness of the full possible scope.

Manchester’s Carbon Co-op work with ‘early adopter’ owner occupiers identified a range of priorities among the people they worked with, including an environmentally motivated wish to reduce GHG emissions, desire for a more comfortable or a healthier home, lower bills or more commonly, a buffer against potential increases in energy bills. Offering low-cost finance and grants may also both incentivise people and shape priorities.

Many owner occupiers are now aware of the government drive for low-carbon heating and may have an idea that a better-performing fabric works well with a low carbon, low temperature heat source. This group may be approaching retrofit with a degree of caution or scepticism. However, especially in areas not connected to the gas grid, owner occupiers may still have an interest in learning about potential improvements for their property.

There is an incentive to comply with regulations on ‘decent’ and energy efficient housing. Landlords may be aware that increasing the energy efficiency of rental properties can reduce rent arrears, vacant properties and protect the fabric of the building. A number of social landlords have ambitions to address fuel poverty and improve the wellbeing and life chances of their tenants, as a part of their social mission and/or for commercial reasons related to the long-term value of their property portfolio.

ENCOURAGING THE OWNER OCCUPIER

Before beginning to draw up individual plans, it is important to discuss a client's motivations and drivers to tailor retrofits to residents' needs and to help convince them to make additional changes which will help to reduce carbon. This is a two-way and iterative process that can't be short-cut. This enables the designer to better judge what would work well. Learning about new possibilities from the designer may lead to new priorities, desires and ambitions on the part of the client.

The benefits that can encourage owner occupiers:

- **Improved comfort** – Improving levels of comfort in a building such as making it warmer or reducing external noise. Residents may wish to address specific comfort issues such as dealing with draughts, cold areas or elements (e.g., floors) or user-unfriendly heating systems.
- **Reduced financial costs** - Residents able to pay for their own deep retrofit should not expect a rapid financial payback, but security against future energy price rises is usually a common motivator. Residents may wish to take advantage of time-limited and action-specific subsidies and grants, influencing the measures they prioritise.
- **Reduced environmental burden** - People may be keen to reduce their carbon footprint or to improve their individual energy security. Different drivers include joining peers in 'doing their bit' to save the planet, or feeling a responsibility to future generations.
- **Improved quality and convenience** – Retrofit can provide opportunities to improve the useability of space, make changes to layouts, improve the quality of finish or update décor. Occupants may wish to upgrade elements with cold surfaces that attract condensation and mould. In buildings with heritage interests' residents may also have a desire to reinstate or preserve traditional features. Off-gas residents may wish to end the inconvenience and insecurity of needing to arrange fuel deliveries.
- **Dealing with damp** – Residents may wish to maintain their properties dealing with ongoing issues, such as preventing water ingress from leaky roofs, reducing overheating or fixing heating systems. There may be concerns about the health issues related to moisture or poor indoor air quality, particularly if there are allergies or other health conditions in the household. Residents may also wish to improve the longevity of their buildings.
- **DIY** - Some residents may derive a sense of accomplishment from this. They may have long-term aspirations for renovating their residence, or they might engage in such activities sporadically as they identify areas for improvements.
- **Improvements around sale** - Residents may have recently bought their property and wish to tailor certain aspects to their needs. Conversely, they may wish to make improvements to a property prior to selling it to increase its value.

Examining their current motivations will assist in determining the extent and nature of the alterations that they are prepared to consider. When already making changes to a building it is an excellent opportunity to encourage energy retrofit. For example, if they are fixing roof defects to prevent moisture ingress, insulation could be added at the same time. Even if changes are not currently possible, it is a good opportunity to discuss/provide retrofit passports/plans for future upgrades and staged measures. The likelihood of future regulatory change may also be a motivating factor for some residents.

Advocating for the benefits of a whole-dwelling retrofit is crucial to encourage residents to engage in a cohesive retrofit. Residents need to understand the importance of a coordinated approach and the risks of neglecting various aspects[80]. It is necessary to start from where they are and consider their motivations and barriers as part of a process of getting them to make greater changes, rather than starting from where they 'should' be.

STAGING AND MINIMUM STANDARDS: WHAT DO OCCUPANTS NEED?

This document describes a comprehensive energy retrofit as a single dedicated event. But, energy retrofit generally has to fit round all kinds of other events, requirements and constraints in the life of the building, the occupants, the owner – and national and local initiatives and requirements. Thus, the process may not be completed in one go, but be staged. **BASIC** has the potential to be the first of various stages.

THE PRINCIPLES OF STAGING A RETROFIT SUCCESSFULLY INCLUDE:

- **A Whole House Plan with the stages set out in advance is the best way to ensure that changes now do not skew the pitch for changes later.**
- **While leaving an opportunity for later actions, the first stage must leave the building in a safe condition where it could stay indefinitely, should further progress be stalled.**
- **Ensure early changes should not worsen, and in almost all cases, should improve conditions for occupants, in terms of comfort, health and energy bills.**
- **Where the occupants are tenants, the interventions should bring the dwelling up to at least the minimum standards for health, safety and affordability**

THERMAL PERFORMANCE AND BILLS

No energy retrofit should increase running costs, unless this is the result of the first stage of a staged retrofit, and this has been explicitly requested and agreed by the client (and householder, if different).

With a more comprehensive fabric upgrade, higher heating system efficiencies are easier to achieve, and running cost savings should be secured for occupants. The goal of a retrofit for a dwelling occupied by a vulnerable person and/or someone in financial stress, is that the household achieves thermal comfort while also spending less on energy than before

“Industry does not deliver on bills and costs”

(or, spending comfortably less than 10% of their income on energy). The retrofit should be able to provide energy bill guarantees, and retrofit total cost assurances, reflecting consumer protection expectations.

VENTILATION AND OVERHEATING

Different levels of ventilation are needed for different purposes, with minimum requirements given in the Building Regulations[81]. Extract ventilation is needed from rooms with concentrations of local indoor pollutants, for instance for removing excess moisture where moisture is generated, or odour control in sanitation and cooking rooms. A continuous ventilation supply must also be provided for delivering fresh air for breathing and more general air quality. Occasional purge ventilation, typically provided by adequate window openings, must be provided to enable passive cooling of the dwelling in hot weather and occasional pollution events, for instance after room painting. Further discussion on overheating is included in Annex C.5 and guidance available from CIBSE TM59[82], so with care the overheating risk to be minimised or avoided altogether.

Ventilation rates need to be appropriate for the room size and use, and occupancy level. Occupants must be well informed on the importance of all elements of the ventilation strategy, including MVHR for background fresh air, mechanical extract for pollution control, and their manually controlled window purge ventilation for minimising summer overheating risk.

ACOUSTIC COMFORT

Even a moderately low level of noise at 40 dB(A) can negatively impact health depending on the background ambient noise levels. Higher levels of noise (>55 dB(A)) are associated with heart diseases[83]. Noise intrusion is often the main reason for occupant dissatisfaction. It can be a physiological stressor especially if the noise prevents occupants from sleeping[84]. Building airtightness will not only improve energy efficiency but will also improve acoustic comfort for the occupants where outdoor noise is prevalent. Particular care is needed with indoor noise sources, such as mechanical ventilation to ensure the selected fan speed and noise level is sufficiently low, otherwise the occupants may be tempted to switch it off. Similar care is needed with the heat pump selection to ensure its sound level is appropriate.

INDOOR AIR QUALITY – SOURCE CONTROL

Many household products, as well as building components and furniture, release volatile organic compounds into household air. Some of these compounds are irritant, some are toxic or even carcinogenic[85 86 87 88]. Replacing solid fuel heating and gas cooking with low carbon central heating and electric (induction) cookers reduces the generation of these indoor pollutants. Airtightness and filtered, whole-dwelling ventilation reduces the ingress of these pollutants from outside, while helping to remove any indoor generated chemicals. Good ventilation is however an enhancement to source control, not a substitute.

Annex

B

Fabric retrofit

B

Annex B: Fabric Retrofit

This annex provides further information on how the new BASIC retrofit standard was developed out of the sandbox research, with its testing against a 'complex-to-decarbonise' housing type illustrative example. This helped identify the level of information required from individual properties feeding into the assessment of 'fabric-first' extent needed.

The **RETROFIT-AT-SCALE** top-down analysis identified the need for a low-cost alternative retrofit standard to sit within a mix of standards for a national rollout (Chpt 2). The starting point, given the poor state of the national stock Figure B.1)[89], means that a mass rollout of deep retrofit using conventional retrofit standards is not capable of being financed for anything like the limited scale of budget anticipated for getting the UK to net zero carbon (Chpt 6 & Annex H). Radical new ideas are needed to make mass retrofit cost viable. The householder and owner concerns that make retrofit so unappealing for them must also be addresses (Annex A).

For any substantial reduction in retrofit costs, the focus has to be on improving overall productivity, at both the component and process levels. This in turn needs a 'whole-dwelling' approach to the retrofit. This considers the building as an interlinked and interacting system of elements, and so not as a set of individual parts independent of each other and of occupant practices and lifestyle. Applying energy efficiency measures singularly without consideration of these interactions has been shown to be the cause of many renovation failures[90]. The 'whole-dwelling' approach seeks to identify the most appropriate mixture of measures that is important. The 'whole-dwelling' approach does not mean all possible energy efficiency measures should or need to be implemented.

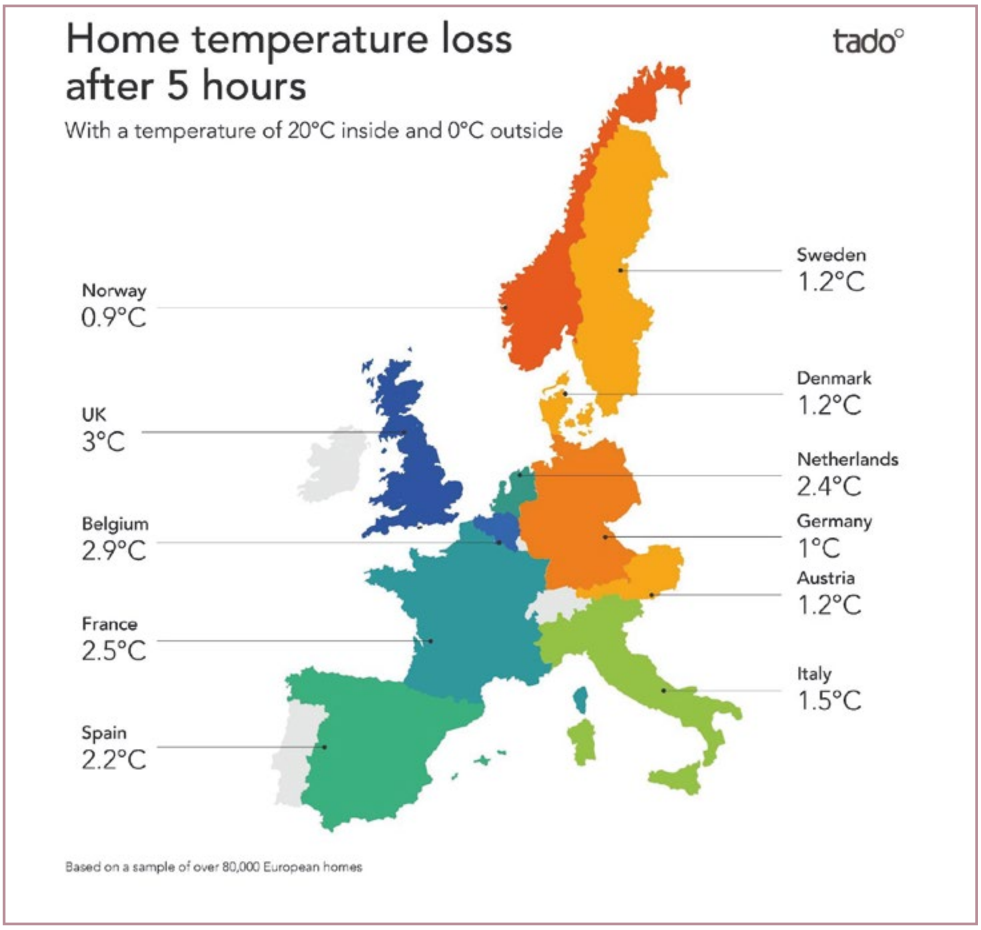


Figure B.1
The UK has the worst performing housing stock in western Europe. Image source[91].
The Building Research Establishment (BRE) found that the UK has the oldest housing stock in Europe, with 38 per cent of the homes built before 1946, which compares to 29 per cent in France and 20 per cent in Italy.

B

What BASIC seeks to achieve

PULLING TOGETHER THE OBJECTIVES GENERATED BY THE SANDBOX RESEARCH

1 Halving of space heating demands and halving its bills to address fuel poverty:

- Allows typical home heat pump size to be reduced by 75% (Annex C.2)
- Avoids upgrades to home electrics and reduces impact on local grid system.
- This size of reduction across the stock allows national grid peak capacity savings of about 25%, hence of a scale to enable investment to be switched to funding retrofits (Chpt 5).

2 Two-thirds retrofit capital cost reduction (£/kWh):

- The focus is on a far more effective process of delivering individual retrofits.
- Includes the switch from fossil fuel to electric heat pumps.
- Brings retrofit costs down to about the same cost as new wind turbines (Chpt 6) countering CCC's current advice, based on least cost, of only needing 12% home improvement (Chpt 6.1).
- Can be rolled out across the UK without adding to the UK cost of getting to net-zero carbon.

3 Delivers a typical individual dwelling retrofit in less than 7-days on-site:

- Reduces disruption, waste and duplication, and improves cost predictability.
- Significantly reduces direct and indirect overhead costs (Annex E.2)
- Maximises reuse of already expended embodied carbon and minimises new embodied carbon.
- Makes best use of expected limited workforce availability (Annex G.2)

4 A new optimum for the extent of fabric-first:

- Integrated 'whole-dwelling' approach that harnesses services to reduce fabric interventions.
- 'Just sufficient' sweet-spot also reduces services sizing and simplifies installation.
- Identifies where new and evolved products and systems are needed specifically for retrofit.
- A PAS 2035 compliant process.

5 Making retrofit appeal more to the mass market of householders (Chpt 2.3) including:

- Reduced disruption to their home, particularly indoor disruption.
- Addresses space constraints for average and smaller homes (Annex A.1).
- Retains home character, including front façade and internal features.
- Greatly reduces, with more predictability, both the capital and running costs.
- Guaranteed performance for site delivery, and for energy consumption.

6 Key innovations needed for mass rollout:

- One-stop shop integrated team for delivering the complete retrofit.
- Onsite non-intrusive method of measuring home actual heat demand (Annex D.1)
- Fabric-first only as far as is needed to allow unmodified radiator system reuse.
- Remote control insulation application for ground floor ventilation void (Annex D.4).
- Simplified MVHR and ductwork system to half its overall costs (Annex C.5).
- Heat storage vessel sized to fit the space vacated by the combi boiler (Annex C.4).
- Small capacity wall mounted ASHP using new sizing methodology (Annex C.2).
- New heat pump demand control, and heat storage reheat control system (Annex C.2).

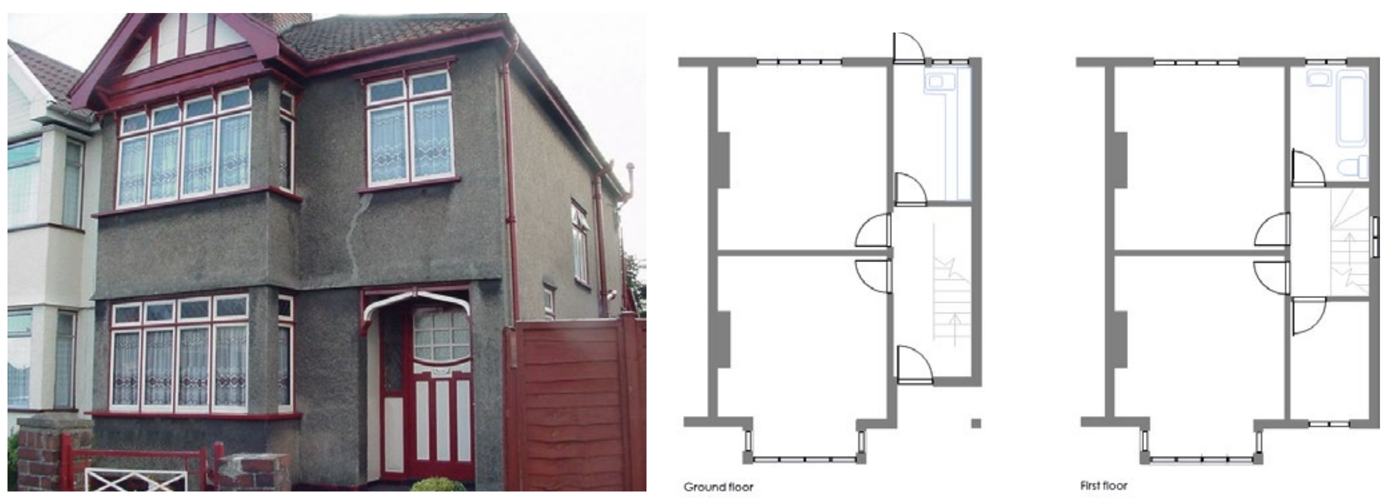
B.2 Testing BASIC on a 'complex-to-decarbonise' archetype

The sandbox methodology identified proposals for pragmatically satisfying the proposed **BASIC** retrofit standard. The LETI stock model (Annex F) was used to identify the features of the UK's most prevalent housing archetypes. The UK dwelling average floor area and a Birmingham UK mid-location were applied. The work done for the CCC on 'complex-to-decarbonise dwellings[92] was used to define the characteristics that are typical barriers to retrofit. The selected illustrative example archetype is an 85m^2 end of terrace / semi-detached of 1930's vintage with solid brickwork walls.

The householder blockers identified by the **RETROFIT-AT-SCALE** societal workstream (Annex A) were included as design criteria for the selected illustrative example. These included the residents' perception that their homes are space constrained and hence the retrofit should aim for no loss of floor area or cupboard space. It also accepted that a significant number of the target sector householders have aspirations for living area expansion into roof spaces and so this should not be cluttered with retrofit plant. Also accepted is the avoidance of any over-cladding of the front façade, for reasons of heritage, architectural and householder preferences. There is assumed to be a marginal condensation issue as a result of normal activity-based moisture generation, coupled with ineffective ventilation likely due to undersized / missing trickle vents and inadequately functioning local extract fans. The English Housing Survey indicates some form of damp problem in some 4% of homes [20]. Any rising damp, rain ingress or water conveying system faults were assumed to be rectified as retrofit prerequisites.

In systems and component terms, to represent a typical home, the archetype has double glazing to align with 87% of UK homes[93] with at least a third of the window service life remaining[94]. It has a ventilated ground floor void as have 10 million of our homes [95]. It has central heating as have 95% of homes[96], gas fuelled as 78% are nationally. It has a mains pressurised hot water system heated by a combi type boiler reflecting the 80% boiler replacement data[96], with the other 20% of conventional boilers being likely installed in larger homes that are not the main focus of the **BASIC** retrofit.

Figure B.2
Archetype for the illustrative example testing of BASIC, selected as representative of the most common challenges of the UK housing stock.



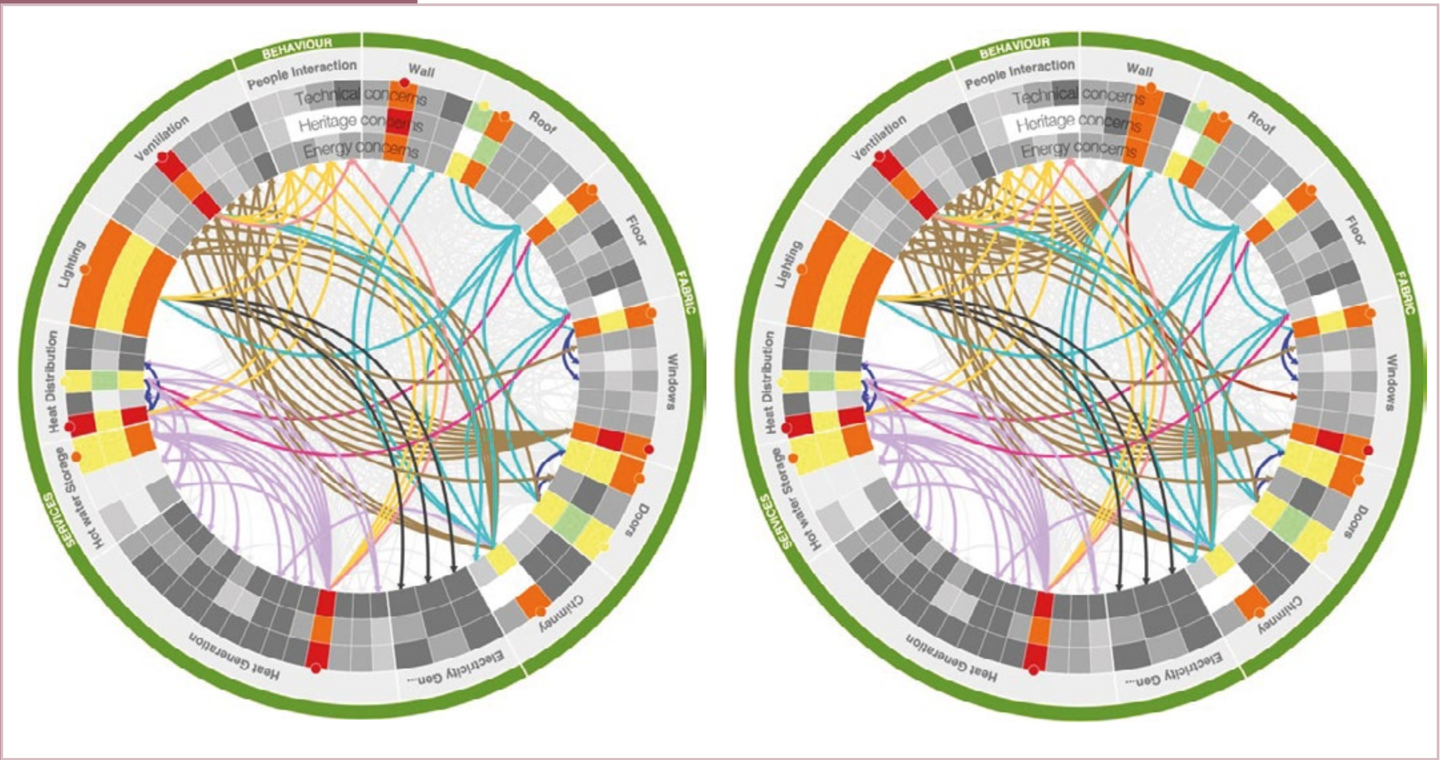
This composite approach allowed the chosen illustrative example to have characteristics that reflect most of the major constraints and challenges to be expected of UK existing houses, including many of those converted into flats, or similar dwelling forms. Nonetheless it is likely that many of the **BASIC** retrofit components have potential for use in other housing archetypes and other retrofits standards.

The focus for **BASIC** is on reducing heat demand because this is the dominant part of the typical energy bill (Figure 1.2), and so provides the most potential for bill savings. Besides this, this is where the vast majority of homes will also need interventions for fossil fuel to electricity switchover on route to net-zero carbon (Annex H). **RETROFIT-AT-SCALE** disregarded hydrogen as a decarbonisation option [101][97]. Likewise, district heating is simply not practical for the vast majority of existing homes[98].

To examine options, a dynamic thermal simulation model (Annex C.2) was used to extract detailed information on the breakdown of peak heat-losses, not only at the whole-dwelling level, but also for individual rooms. This modelling allowed the analysis to examine aspects not normally considered in individual housing retrofits, such as building thermal inertia, beneficial internal heat gains, and the switch to trickle-charge heating systems. These helped identify the 'just sufficient' options for energy efficiency measures.

The Sustainable Traditional Buildings Alliance (STBA) online Responsible Retrofit Guidance Tool (Figure B.3) was used for checking the inter-relationship of components in the modelled scenarios[99]. As illustrated, the operation of adding insulation to walls, roof and floor and incorporating airtightness measures will have associated major consequences for the ventilation strategy. This accurately represents the complexity of inter-relationships when investigating retrofit options, together with the necessary associated risk mitigations.

Figure B.3
Use of the STBA retrofit Guidance Wheel for checking interdependence between scenarios.
It highlights the dependence on ventilation strategy for identifying the optimum solutions.



From all the scenarios, it was identified that various main fabric elements needed some level of improvement in an uninsulated property. A follow-up iterative process examined to what degree and extent these main fabric elements needed upgrading. The scenario with no improvement to the ground floor was also tried but failed to meet the energy target or allow reuse of the existing heat emitter system in ground floor habitable rooms.

Different scenarios with combinations of different insulation materials, U-values and envelope airtightness were analysed. The mechanical services alternatives were developed in parallel to identify where there could be combined benefits. A shortlist of scenarios were costed right down to the elemental level to single out which clusters of measures were most cost effective. These were benchmarked against conventional deep retrofit costs (Figure E.1). A separate analysis looked at where overhead costs that would not normally be allocated against a particular energy saving had potential to be reduced, particularly where there was duplication and programming time and sequencing issues. Accessing these often-substantial overhead savings fed back into the choice of energy efficiency measures, with the result that the most economical combination often did not use the cheapest individual measures.

In parallel, a subset of the scenarios was applied to the national housing stock (Annex F) to establish the level of national peak and annual energy demand reductions that would result. This feedback on the energy supply side investment reduction fed into the wider analysis of where funds could be redirected into a retrofit mass rollout (Annex G), and hence how far the costs for each retrofit needed to be reduced. To ensure the retrofit technical solutions developed for the illustrative example were more widely applicable, a lighter touch review of the other main dwelling archetypes listed in LETI's Climate Emergency Retrofit Guide (CERG)[100] was also fed into the process.

This iterative process ended up pinpointing a retrofit cost sweet-spot for an individual home, with the maximum heat savings being delivered for least overall cost. This ends up being where fabric-first energy efficiency measures are only applied for each room as far as is needed to allow the existing radiator system to be reused unaltered. The radiators operating at the lower ASHP water temperatures then have sufficient heat output to match the lower heat loss resulting from the fabric-first measures (Annex C.3). In essence, the fabric-first measures only need go as far as halving space heating demands. In parallel with not needing to disturb the radiator system, fabric measures that likewise had least disturbance on the room interiors tended to be part of the most cost-effective solution. Minimising the duration needed on site was particularly cost-effective, as was the set of minimum intrusion airtightness measures (see Fig.4.3, Fig 5.2, Fig.E.1). While the option of operating a heat pump at higher temperatures without fabric measures was investigated, this simply increased the householder's heating bills. It is the fabric measures and their halving of heat loss that directly relates to the halving of heating bills.

B.3. Understanding the existing building

To allow a quick and smooth retrofit, and gain the cost benefits of a short site programme, the building context and condition needs to be clearly understood beforehand. The aim is to have no surprises during the site works. A good survey allows the right combination and extent of measures to be identified before arrival on site, permitting each trade to bring the correct materials in the right sequence for a straightforward installation.

Good design preparation informed by a good site survey ensures site programmes are driven by simple physical logistics (Figure E.3) and not by information and mobilisation delays. Too often it is the lack of this information that prompts pessimistic presumptions, over-provision, preparation work delays, and the waste of both time and materials.

In line with PAS 2035 recommendations[94] ,heritage, outstanding maintenance, and unconventional construction must also be identified in the pre-retrofit survey process. At this stage the suitability of a **BASIC** level of retrofit for the individual home should be confirmed. It is expected that perhaps one out of three UK homes (Annex F) may need additional professional and/or tradesperson skills for which **BASIC** and its quick site turnaround may not be the best solution. CERG provides detailed information on alternative approaches best suited for these.

The survey must identify if there are building fabric and system defects that would inhibit energy efficiency and compromise improvement measures. Water penetration and damp must be addressed, with the building fabric properly dried out before retrofit work can begin. Structural defects (e.g. significant cracks) and poor pointing of masonry must also be identified and rectified. Likewise, the survey should assess whether or not the ventilation provision complies with the Building Regulations (e.g. Part F for England), for instance, sufficient opening windows are available for purge ventilation. Putting right these defects is a pre-requisite to doing any energy efficiency measures.

Where the **BASIC** retrofit is deemed appropriate the energy survey will need to provide building specific data of sufficient depth. Beware that survey tools like RdSAP[101] make broad assumptions on the construction and details based simply on what was typical construction at the time it was built. This overlooks differences that have major energy implications, as well as misses the myriad of alterations typically made to individual dwellings over time. As such, RdSAP surveys should not be relied upon for determining the most cost-effective combination of energy efficiency measures.

Energy Performance Certificates (EPCs) may be useful at a portfolio level but have very limited value for the individual home. Their recommendations on individual energy efficiency measures are generic and do not consider the interaction between measures or the failures that can consequently occur, for example, if ventilation is not also considered. The EPC A-G ratings are generally based on the RdSAP survey method with its inherent inaccuracies noted previously, onto which it overlays other factors like out-of-date fuel costs and fuel carbon content. Beware that gaining a high EPC rating can be misleading, for example, if there is cheaper gas heating with a larger PV array, this can hide poor fabric insulation standards. Smart energy meter data is now beginning to show the large disparity between actually measured energy use and EPC asset rating assessments (Figure 2.4). The inadequacy of EPCs for predicting retrofit performance is also highlighted by the English Social Housing Decarbonisation Fund (SHDF) retrofit programme. The initial funding waves are providing post implementation monitoring feedback showing delivered performance can be typically 1 band worse than the targeted level[102].

We can learn from the parts of industry that have a good track record of delivering predictable energy retrofit performance. The EnerPHit[103] retrofit process is one example where careful surveys before and after retrofit provide reliable and predictable energy performance. **BASIC** draws on this experience to require more accurate pre-retrofit measurement and then the verifying of energy performance post-retrofit (Figure 3.3).

BASIC focuses on the survey components that have most impact on the selection of efficiency measures. In addition to actual dimension and material survey data gathering, the following surveys are recommended:

Surveys should include the following:

- **Measured space heating demand.** Typically, this would be the HLC test (Annex D.1 case-study) or equivalent, using metered energy use in association with room temperature monitoring and weather data. A smart meter[104] or similar is used to remotely download data for off-site analysis.
- **Measured domestic hot water (DHW).** Typically, a temporary small strap-on flow and temperature meter is used (Figure B.4). This is important because it is the hot water reheat rates that can oversize a heat pump by as much as 50% (Annex C.2)
- **Building air leakage pressure test.** As well as the overall leakage rate, this needs to identify leakage locations and approximate sizes, so measures to seal the significant ones can be scheduled before site works commence.
- **Thermal image survey.** This is used to identify the extent of significant thermal bridges and damp. Any damp remedials needed with drying out should be completed pre-retrofit. The size and locations of thermal bridging allows measures to be scheduled before site works commence (Chpt 3.5 & Annex B.3)
- **Layout and other information needed by all individual retrofit trades.** This should be sufficient to avoid them needing to do subsequent separate surveys. This would also detail the full extent of builder's work.

The dwelling survey should aim to produce an actual heat energy use metric in kWh/m^2/yr with its associated actual heat loss in W/°C, based on direct measurement of the dwelling and how it is actually used. Alongside this, the same metrics need to be formulated for the theoretical asset rating in the same units of kW/m^2/yr with its associated W/°C, based on its theoretical occupancy. The comparison of actual versus theoretical energy use identifies how much the pre-retrofit home is underheated (or overheated). Understanding this difference is important for delivery of a retrofit performance guarantee because a home using less energy due to underheating pre-retrofit, whether due to fuel poverty or otherwise, means the subsequent retrofit will deliver less energy savings than the theoretical target.

Once the retrofit is completed the energy use measurement is repeated to verify that the retrofit has delivered the overall fabric and systems performance required. This is an essential part of providing warranties and confidence to the individual householder/client, and for the wider mass retrofit rollout cost/value assessment. It also provides all the delivery parties involved with the contractual motivation to deliver a verified performance as intended – something our industry has in the past often fell short of (Annex A.1). This feedback provides the means for the supply chain to identify continuous process and product improvements.

Use of the SMETER[108] energy measurement method is recommended, using a smart meter or equivalent to access the actually used heat before, and then after, the home retrofit. Pre-retrofit, this provides gas use with room temperature data that can be converted into a building heat transfer coefficient using local weather data (Annex D.1 case-study). It is also recommended that actual hot water use is monitored (Figure B.4) because of the large influence this has on heat pump sizing (Annex C.3). Post-retrofit, the installed heat pump is linked back to the smart meter, to provide data from which the heat use and its energy use can be verified against the predictions, as part of providing this performance warranty to the householder.

Figure B.4
Strap-on flow and temperature meters to measure domestic hot water use are becoming relatively cheap and easy to install. Quantifying actual hot water use is expected to become increasingly important as space heating demand is reduced. It also provides evidence for developing better heat pump control strategies that extend hot water store recharge schedules, given its large impact on heat pump sizing.

B.4 Materials selection

The challenge of applying 'fabric-first' is identifying how far to go with the fabric improvements where there are diminishing returns. This Retrofit-as-Scale research introduced a further set of criteria driven by the potential of significantly greater cost benefits; namely, what level of performance from one component allows cost savings in another? This will be familiar to those involved in integrated design. A product may be more expensive but if its implementation saves site time, or enables greater savings in another measure, there could be clear benefits in using it. So, switching to a higher performing insulation, but using the same manpower and programme can deliver more benefit. Understanding how the overhead costs are allocated is also useful, for instance, taking apart the external wall insulation costs highlighted the lower costs of doing walls uninterrupted by windows. Likewise, implementing an MVHR considerably reduced the extent of thermal bridging measures.

Figure B.5
Fabric and systems proposed by the Sandbox research for meetings Basic compared with typical measures for CERG Exemplar and Best Practice standards.

			LETI exemplar	LETI best practice	BASIC
Building element		**Retrofit actions**	**All retrofit types**	**All retrofit types**	**Minimum standard**
Walls	Cavity	External, cavity or Internal insulation	0.15 W/m^2.K	0.18 W/m^2.K	Partial area EWI 0.15 W/m^2.K
	Solid uninsulated	External or Internal insulation	0.15 W/m^2.K	0.18 W/m^2.K	
	Timber frame	External or Internal insulation	0.15 W/m^2.K	0.18 W/m^2.K	
Roofs	Cold	Insulate	0.12 W/m^2.K	0.12 W/m^2.K	0.12 W/m^2.K
	Warm/flat	Insulate	0.12 W/m^2.K	0.12 W/m^2.K	
Floors	Suspended timber	Insulate between joists	0.15 W/m^2.K	0.18 W/m^2.K	0.15 W/m^2.K
	Solid uninsulated	Excavate and insulate below	0.15 W/m^2.K	0.15 W/m^2.K	
Windows and doors	Windows	Replace	0.80 W/m^2.K	1.00 W/m^2.K	Replace hinges on retained double glazing
	Doors	Replace	0.80 W/m^2.K	0.80 W/m^2.K	
General envelope	Thermal bridging	Mitigate where possible	0.08 W/m.K	0.10 W/m.K	Window reveals
	Airtightness	Draught proofing, sealing of chimneys and vents	1.0 ach@50Pa	2.0 ach@50Pa	Comprehensive draught stripping measures 3.0 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	Simple MVHR
	Lighting power	Replace lamps and fittings	100 lm/W	100 lm/W	5 W/m^2 reduced size ASHP
Hot water	Hot water tank	Increase insulation or replace	1.5 W/K	1.5 W/K	1.5 kWh/pers reduced size heat store
	Primary pipework	Insulate all pipework	90% of pipework insulated	90% of pipework insulated	6 litres/min reduced demand shower heads
	Shower demands	Low flow fittings	16 litres/pers.day	16 litres/pers.day	
	Other demands	Low flow fittings	9 litres/pers.day	9 litres/pers.day	Reuse all existing pipework & radiators
Renewables	Photovoltaic generation	Rooftop installation	40 % of roof area covered in PV panels	40 % of roof area covered in PV panels	Future upgrade

Typical of the output of this approach was the recommendation to implement low-cost air tightness measures to deliver some of the largest energy savings, enabled by installing the simplified MVHR system. This was found to save considerably more energy through the reduced fabric air leakage than the MVHR saved in recovered energy. But added to this, the MVHR allowed reduced thermal bridging treatment costs, because its warmed air supply delivered to the colder rooms increase moisture pickup and removal (Figure 4.4). More details on the recommendations for MVHR are included in Annex C.5 and how it contributes to the lowest cost option is included in Chapter 5 and Annex E.

This integrated design process questioned the logic of allocating energy savings only against the normal installation costs of an energy efficiency measure, as is normal in the industry. There are a set of additional overhead costs that are separately costed, but which are intrinsically linked to delivering the outcome performance of the energy efficiency measure. These include the initial site survey work, the planning for which combination of measures should be applied, site supervision and coordination, and verification the measures have been properly installed and are operating correctly (Figure 3.3). Without these overhead items, the energy efficiency measure is highly unlikely to deliver anything like its theoretical performance. Instead, there is a clear logic in allocating a proportion of the energy savings to these overheads. So, if no verification of delivered performance is included in the cost of these measures, then the efficiency measure should not claim the theoretical performance. Put another way, an energy efficiency saving should be specifically allocated against the verification process, as well as, for example, site supervision and the initial survey.

Having identified the different thicknesses for each insulation type to achieve the **BASIC** thermal performance, the options suggested in CERG were followed to compare two main installation arrangements, their moisture performance, and their architectural consequences: one with external wall insulation (EWI) and a second with internal wall insulation (IWI). The same measures were applied to the previous two CERG retrofit levels of Exemplar and Best Practice (Figure 4.6) in order to compare the efficiencies across the three, with the two material types and two different installation methods. The further iteration removed EWI from the front façade, driven by householder pushback against visual changes, the need to make retrofit more compatible with conservation areas, and the higher EWI front façade costs given their numerous window openings.

Thermal bridging options were tested separately using condensation as the driving concern. For these the heat loss is a second order issue, unless the surrounding insulation levels are already to very good or Best Practice standards

B.5. Moisture and airtightness considerations

Dwelling moisture management is crucially importance as emphasised by PAS 2035. Installing individual energy efficiency measures can make an existing moisture management problem far worse. The STBA online Responsible Retrofit Guidance Tool (Figure B.6) is useful for helping to identify the interrelationship between retrofit measures and moisture management.

The feedback from practitioners was, that for the typical archetype, condensation largely fell into two categories; localised in the main moisture producing rooms, or moisture moving towards the coldest surfaces in other colder rooms. Permutations of the retrofit measures used in Best Practice and Exemplar retrofits (CERG) were considered, albeit much of this was achieved by substantial interventions like window and reveal replacement and the installing of membrane arrangements as part of new indoor wall insulation.

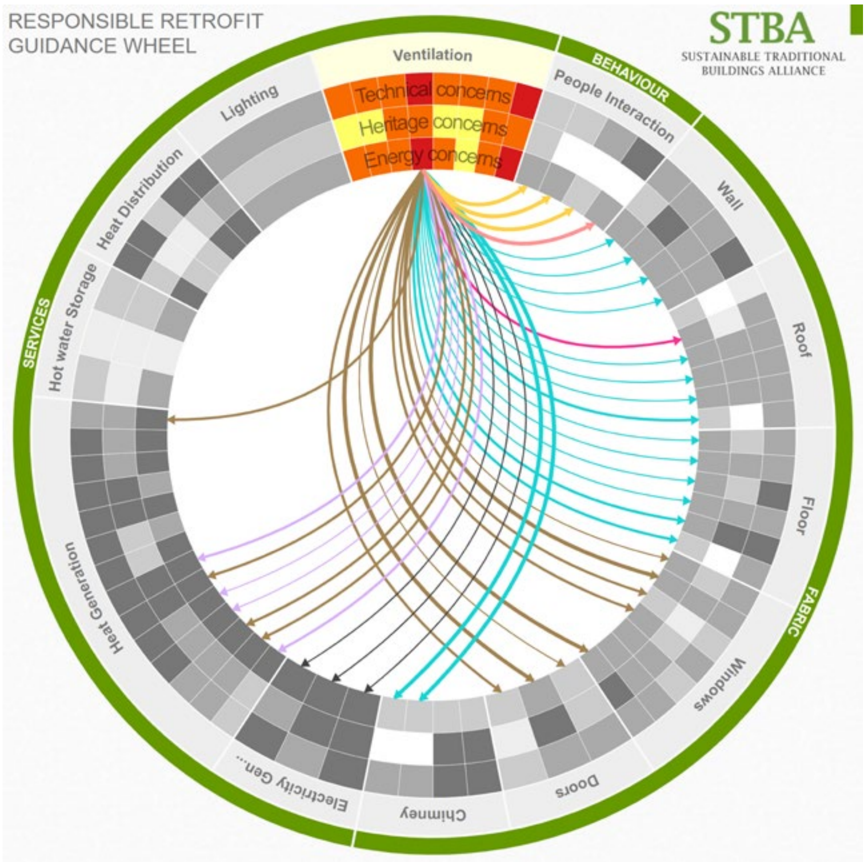


Figure B.6
STBA Guidance Wheel illustrating the interdependence between ventilation and most fabric-first measures[101]

Separate to these, practitioners provided alternative ideas, like separately treating window reveals using off-the-shelf insulated boards (Figure 4.3 and Annex D.3). Options explored included better harnessing of the ventilation to lower general dwelling humidity levels, so permitting lower room surface temperatures without increasing the condensation risk. This works best with a heated fresh air supply, particularly for the cooler bedrooms in passive clothes drying scenarios. From this a brief for a stripped down 'whole-house' MVHR and easy to retrofit ducting system was developed (Figures 4.7 & 4.10) to provide a constant background tempered air supply to all habitable rooms, as well as extract from the main moisture producing rooms. This meant avoiding having to retrofit into existing window frames the larger trickle vents now needed for compliance with the Building Regulations[105], or the installation of new separate fresh air supply trickle vents.

Large heat loss reductions can be delivered by enhanced levels of airtightness, as Best Practice and Exemplar retrofits demonstrate. With practitioner' input, as an alternative, a range of quick to implement airtightness measures were identified and then shortlisted to those that have minimum disruption and can be implemented as a package in a 2-day site programme. Suitable background fresh air provision is then ensured by the MVHR. Centralised mechanical extract ventilation (CMEV) was rejected because it provides higher room humidities, and higher heat losses with its cold air intakes in each habitable room (Annex C.9).

B.6 Materials environmental impacts

The **RETROFIT-AT-SCALE** research investigated the use of specialist low environmental impact materials. Almost all had a higher cost for the same thermal performance. Some materials like wood fibre insulation also needed additional care for selecting where and how they could be used in relation to moisture, thereby prompting the need for additional services of specialists with an associated cost uplift. Others like sheep's wool or recycled newsprint have material sourcing limitations, meaning limited potential to supply a mass retrofit rollout. For more conventional materials, various suppliers stated they anticipated reducing their production environmental impact and carbon emissions in line with UK targets. While these are indicative of an evolving market, for selection of materials to be installed now, it is the embodied environmental impact now that is relevant as opposed to future intent.

The holistic design approach influenced the position taken to minimising embodied carbon. Simply selecting materials with the lowest embodied carbon content resulted in significantly increased costs, largely due to relatively immature supply chains. However, if considered more holistically, including the embodied carbon avoidance of reusing, and leaving undisturbed as much of the existing fabric and systems as possible, a lower overall embodied carbon solution can be arrived at. This allowed the selection of certain individual materials that did not have the lowest embodied carbon available. Although challenging to put numbers against, reducing the site programme period, the increased site productivity, the reduced personnel time, sourced locally with associated travel savings, all contributes to reducing the overall embodied carbon and environmental impact of each **BASIC** retrofit.

Heat pumps and particularly their refrigerants were identified as having potentially high embodied carbon impacts. Where possible refrigerants with lower global warming potential (GWP) should be chosen as they now become more common (Annex C.2).

For clients and occupants wishing to further explore materials with lower environmental impact, information is available from the LETI CERG, as well as for issues like fire safety and indoor air quality[106], and on embodied carbon[107] [108]. The information and application knowledge on materials is rapidly evolving. A mass rollout is likely to bring a new intricacy to defining a particular material's future sustainability, as well as acting as a potential driver for developing lower impact alternatives for wider application.

BASIC does not exclude the use of low embodied environmental materials, indeed it supports the transition to these. However, whatever the considered material options, any discussions with clients must provide transparency on the cost implications as this can have a significant impact on the overall retrofit costs. For **BASIC**, due to the urgency to scale up and a brief to identify costs that would enable such a national scaling up, low environmental impact materials are considered a specific client option over and above the **BASIC** retrofit cost.

B.7 Staging retrofit

BASIC has been developed to provide the minimum cost and best value retrofit standard, making the best use of the expected limited workforce availability. It is offered as the minimum retrofit standard all can expect for their homes. **BASIC** can be enhanced if clients wish and become a stepping stone to higher energy retrofit standards. Alternative implementation strategies, including staged implementation of **BASIC**, were investigated.

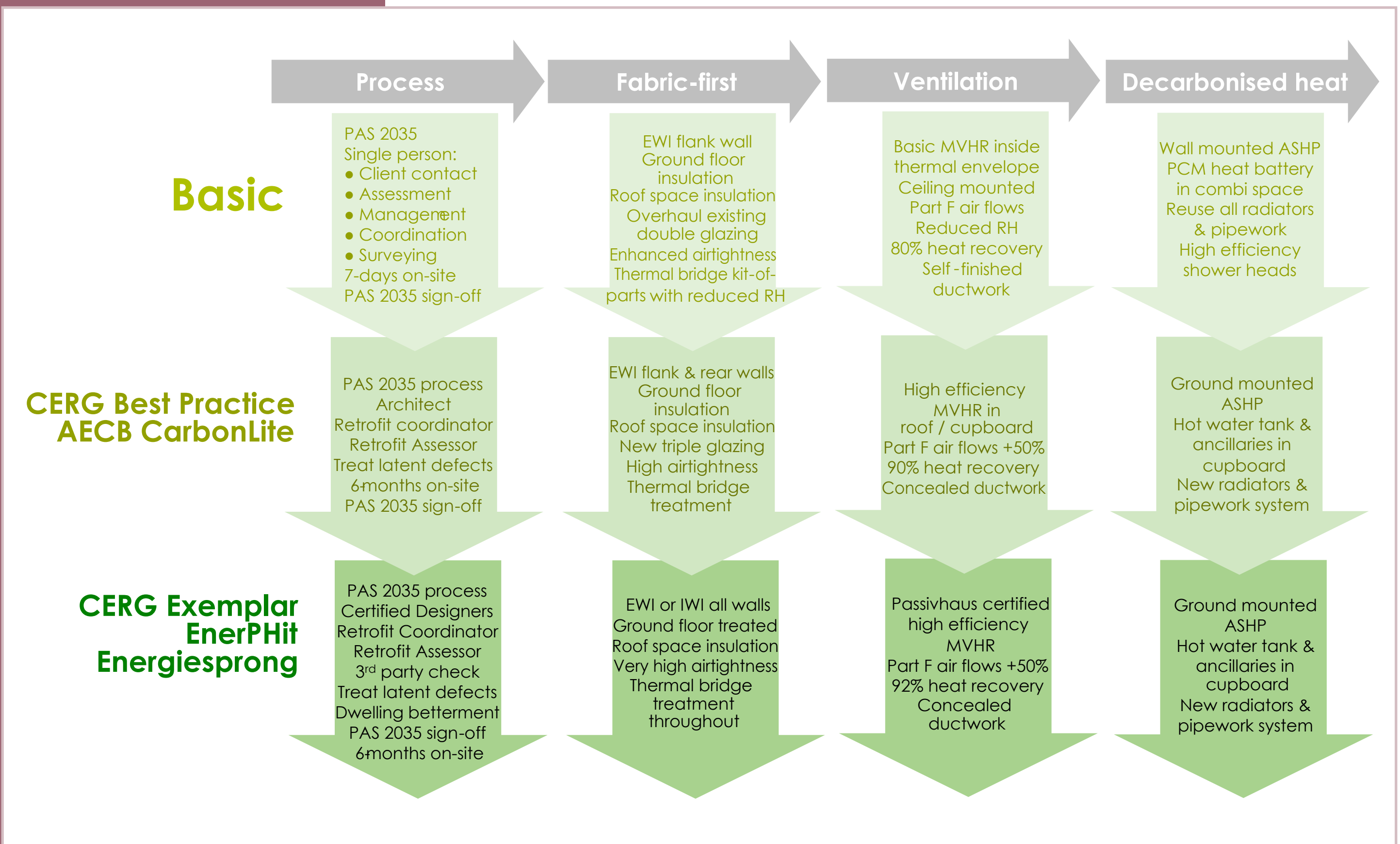
Staging the **BASIC** retrofit, in whatever order, was found to increase the overall retrofit costs significantly. The option of first installing the heat pump and then following this later with fabric improvements results in a larger heat pump and typically no energy bill savings. This option is also not appropriate for the many space-constrained home types and those with condensation issues. Where this approach is taken, installing fabric measures for a second stage is probably best done when the heat pump is due for normal replacement in some 15-years' time.

Installing the **BASIC** fabric-first measures as a first step and later installing a heat pump is also an option. Particular care is then needed to ensure the ventilation measures are installed with the fabric measures to avoid potentially increasing the condensation risk dramatically.

Either of these stepped approaches are likely to need more specialist technical support as each will have its own challenges to be addressed. Consequently, the overhead costs increase with staged implementation.

For staged energy retrofits Figure B.7 shows how **BASIC** aligns with other deeper levels of energy retrofit, and provides an indication of what typical enhancements are needed for each level.

Figure B.7
Alignment between alternative retrofit levels allows a step-by-step phased approach



Annex C

M&E systems

C

Annex C: M&E Systems

This annex provides additional background for Chapter 4.4, in support of a new BASIC retrofit standard.

C.1. Key aspects

Summary:

- A new BASIC energy retrofit standard appropriate for the more standard housing stock
- The halving of utility bills for heat
- Based on a two-thirds cost reduction compared with deep retrofit current practice
- Whole-dwelling approach with integrated fabric and systems measures
- A one-stop-shop integrated team to deliver big productivity gains
- Fabric measures heat reduction of 50% allows smaller and simpler heat pump installations
- Reduced heat pump size suits homes with smaller electrical feeds and for reducing grid capacity issues
- Whole-dwelling simplified MVHR system allows good airtightness and condensation measures
- Quick site turn-around using products tailored to the mass retrofit market
- Better plant sizing to enable the provision of energy performance guarantees
- Offers a recognised minimum standard any householder should expect and can enhance if so desired
- The goal is to make the whole process far more householder friendly.

The retrofit mass rollout will require a range of retrofit cost points, with **BASIC** being a minimum baseline for the majority of the market, with higher and best-in-class standards for more specialist needs. All of these different retrofit levels should come with a combined fabric and systems performance warranty for the householder.

The cost sweet-spot identified for **BASIC** (Annex B1) is where ‘fabric-first’ energy improvement measures are just sufficient to avoid needing to change any of the heating radiators and distribution system. These fabric-first measures may vary with different home archetypes, but overall the aim is to reduce space heating demands down to a 65 kWh/m^2/yr (heat output of heating system) and a peak of 40 W/m^2 averaged across the stock. Rolled out across the housing stock this is a halving of average demand. These retrofit works are intended to take no more than 7-days per dwelling, including 2-day heat pump and MVHR installations (Figure E.3). For this, the systems and their installation arrangement for the average home must be much simpler than is the current norm.

The **RETROFIT-AT-SCALE** analysis highlighted that fabric-first measures are generally more cost-effective than the retrofit of M&E systems. Also, there is very significant cost saving potential between the best-in-class and more **BASIC** plant, their arrangement, and components. For instance, a simplified MVHR unit could cost about two thirds less than a Passivhaus certified best-in-class, and the ducting system cost halved if floors do not need lifting (Annex C.5). The recommended fabric-first measures (Figure E.1) are typically an order of magnitude less costly (per kWh saved) than the marginal efficiency improvements of providing say, a best-in-class MVHR heat exchanger.

For more accurate systems sizing, actual energy use of the individual homes is first measured using the SMETERS approach[109], so avoiding typical current approximation methods. The performance of fabric enhancements can then be fully relied upon for system sizing coupled to the coordinated contractual responsibilities of having a fully integrated retrofit delivery team. The choice of heat pump sizing method and its controls can also significantly reduce the capacity needed as the **RETROFIT-AT-SCALE** research has identified (Annex C.2). These allow almost all the typical sizing margins, to be omitted entirely.

The **BASIC** retrofit aims to convert all the homes to be heat pumps and MVHR futureproofed. Whilst the initially installed plant may not be of the highest efficiency and sophistication, these can be upgraded when replaced at the end of their useful service life, so typically after 15 years. By this time the market and options should be more mature.

RETROFIT-AT-SCALE is a 'call to action' for industry to improve our retrofit offering, with its delivery productivity and costs to consumers. Various of the products proposed may be available, albeit from other countries (e.g. simplified MVHR), and not yet in the UK. Others like the heat battery are available but not yet in a dimensional format to suit the lack of space in medium and small UK homes. The controls will also need developing to harness the benefits of sizing diversity between heat pump, heat battery and immersion (Annex C.2).

C.2 Heat Pump

Various heat sources and plant configurations were investigated by **RETROFIT-AT-SCALE** for the **BASIC** retrofit standard. Hydrogen boilers, or hybrid alternatives, were disregarded as being unsuitable and fuel availability unlikely for the vast majority of homes[110]. District heating was likewise discounted due to lack of availability[111], high connection costs, high on-going service charges, as well as its unclear route to net-zero carbon. Ground source heat pumps were generally unsuitable, limited by their high installation cost, outdoor space and access constraints for average and smaller homes, and their greater potential for disruption. Direct electric heating (radiant, immersion or convective) resulted in significantly higher energy bills and grid peak capacity issues, and so was also disregarded. Individual monobloc air source heat pumps provided the best match for the majority of homes in a mass roll-out.

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The **RETROFIT-AT-SCALE** workstream carried out extensive thermal modelling, using PHPP, SAP, MCS, and DSM (Figure C.1). The DSM dynamic simulation modelling allowed analysis of beneficial heat gains, thermal inertia and alternative plant maximum sizing criteria. For the tested archetype, this identified that the industry standard MCS 'steady state' sizing could result in heat pumps being oversized by more than 50%. This suggests there is considerable potential to reduce capital costs, as well as improve running efficiencies with less starts and stops, and reduced mechanical wear and tear.

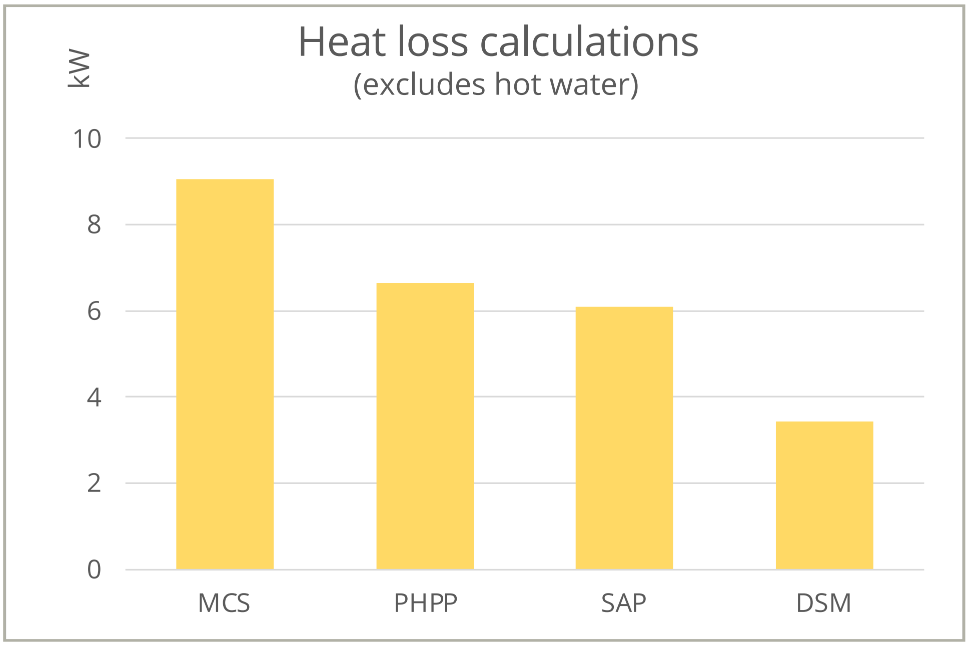


Figure C.1
Scope for reducing heat pump size. Shows the variation in heat loss calculated by different methods.

MCS = Microgeneration Certification Scheme,

PHPP = Passivhaus Planning Package,

SAP = Standard Assessment Procedure,

DSM = Dynamic Simulation Modelling (IES).

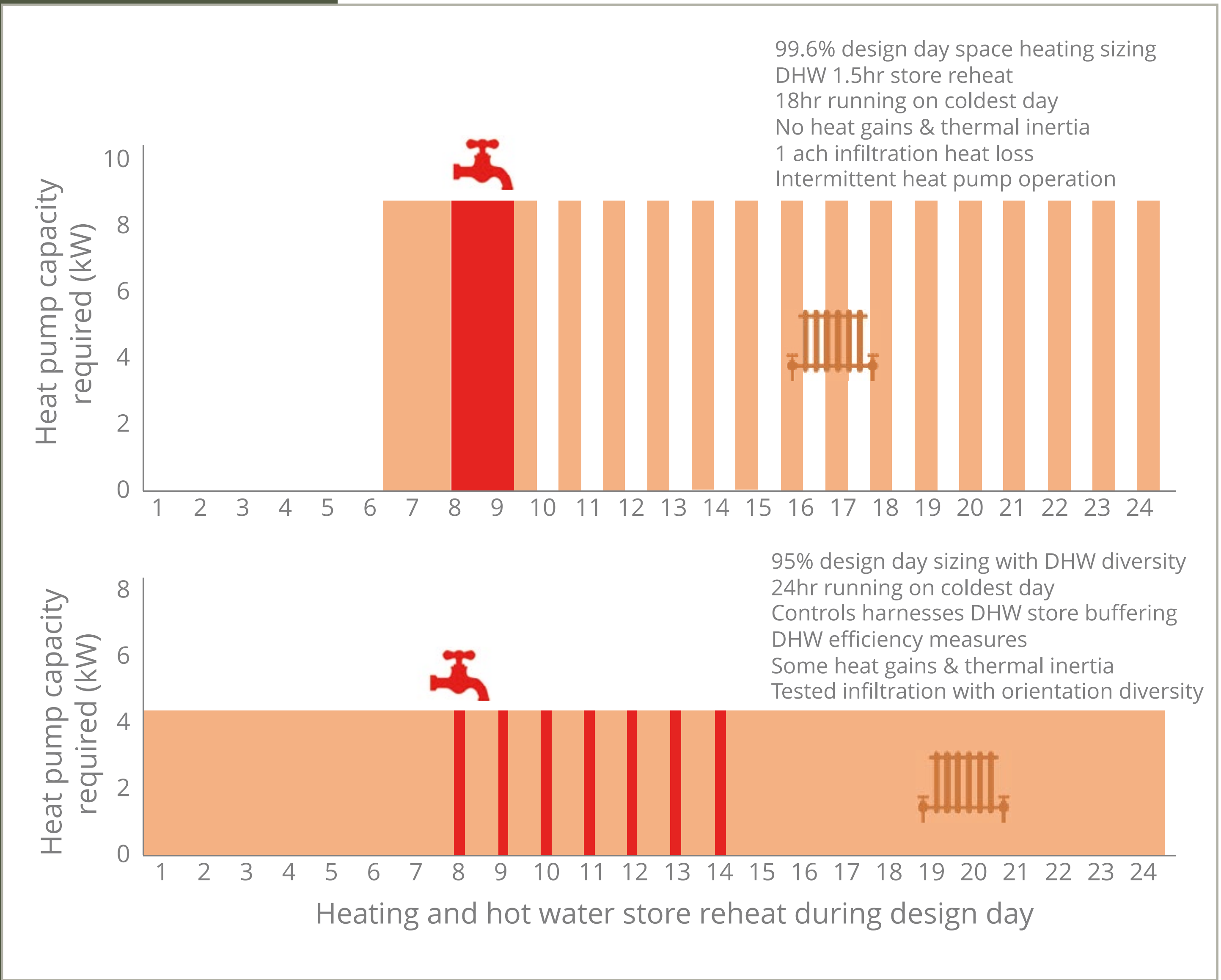
Having implemented the recommended fabric-first measures for bringing the heat demand down to 65 kWh/m^2/yr, the space heating peak capacity needed from the heat pump is only 40 W/m^2 of floor area. This assumes a modest MVHR heat recovery efficiency of 80% and includes some dwelling thermal inertia and heat gains. For the average 85 m^2 illustrative example dwelling this would require a heat pump capacity of no more than 3.4 kW for space heating, instead of the more typical 8 kW.

Added to the above heat pump sizing, is the capacity needed for reheating the domestic hot water (DHW) storage vessel. The storage sizing advice in BS 6700[112] tends to result in large sizes, reflecting gas boiler conventions of the past. It also does not include any allowance for water efficiency measures like high-performance rated low-flow shower heads[113] as now included in SAP10[114]. It is noted that the MCS guidance on how much heat pump capacity to add for DHW is also ambiguous[115 116], suggesting instead sizing agreement should be secured in advance with the householder. As the householder normally has little idea of what is a reasonable size, the result is today's typically oversized storage vessels. In the absence of clear guidance, many experienced installers instinctively go back to boiler conventions of short reheat periods, which tend to result in oversizing particularly for heat pumps (Figure C.2). There needs to be an updated sizing method for DHW storage vessel volumes, and clear recommendations for smoothing out the reheat period to make them compatible with smaller heat pump sizing.

Unlike a combination boiler, a heat pump system inherently has the opportunity to reduce the peak capacity needed by using the diversity between space heating and DHW storage reheat. Put another way, this means on the very coldest days, if the heat pump is short of space heating supply, it can use some of its DHW reheat capacity, because the DHW is unlikely to also be on its peak demand on the same day. There is also further diversity available because the DHW storage anti-legionella immersion heater could be enabled to provide DHW backup on this worst day. Control systems that allow the heat pump to take advantage of this diversity are not generally available and need developing.

In parallel, DHW reheat control algorithms need to take advantage of the storage buffering effects, and so spread the reheat period into discrete intervals spread over many hours (Figure C.2). This takes advantage of the storage volume being typically 24-hours of normal DHW use, so it is highly unlikely the full storage volume is needed immediately after a high draw-off. The controls must be able to identify when there is a sustained hot water draw-off, not to wait until the DHW vessel is largely empty of heat. Then, the heat pump can manage space heating priorities and decide how fast to reheat the DHW vessel. Not only does this reduce the size of the heat pump, but it also reduces electrical demand during grid demand peak periods.

Figure C.2
Heat pump sizing optimising can reduce the capacity needed by 50%



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REVIEW OF HEAT PUMP SIZING

The current MCS method (version 1.10), as generally used for sizing (often a grant funding requirement), has significant limitations and a tendency to significantly oversize. It uses a simplistic steady-state method (EN 12831) and is not underpinned by a dynamic model to better represent the non-linear heat flows in a home.

Figure C.3 – Review of opportunities for reducing heat pump sizes

Summary of the main issues identified as contributing to heat pump oversizing:

- No diversity included for parameters used for establishing the 'design' worst-case day.
- Assumes simultaneous worst-case for both space heating and for hot water peak demands.
- No acknowledge of inherent backup potential of immersion in hot water storage for worst case day.
- Air infiltration assessment is highly inaccurate, sometimes as much as 10-fold error.
- Beneficial internal heat gains are not considered, given its increased significance in well insulated homes.
- Building fabric thermal inertia is not sufficiently considered - even lightweight properties have a thermal delay.
- Thermal bridging is not sufficiently considered, given its increased significance in well insulated homes.
- No options for hot water demand reduction measures, given it is now included in SAP.
- Assumes hot water storage sizing (BS 6700:2006+A1:2009) as developed for boilers, which generally oversizes, and hence has large heat pump capacity impact. Expectation that uninformed client takes sizing responsibility.
- Insufficient guidance for reheat periods for hot water cylinders, and so default is tendency for short reheat periods and hence large heat pump capacity impact.
- No consideration of how to quantifying defrost cycle impact.
- Incentivises further oversizing, by explicitly and implicitly saying it is the installer's responsibility to mitigate sizing risk.
- For annual energy use assessment uses the Degree-Day method, but with no baseline gains adjustment, given its increased significance in well insulated homes.
- The method limitations are compounded. Much of supply industry does not provide heat pump capacity data that relates to UK design conditions.

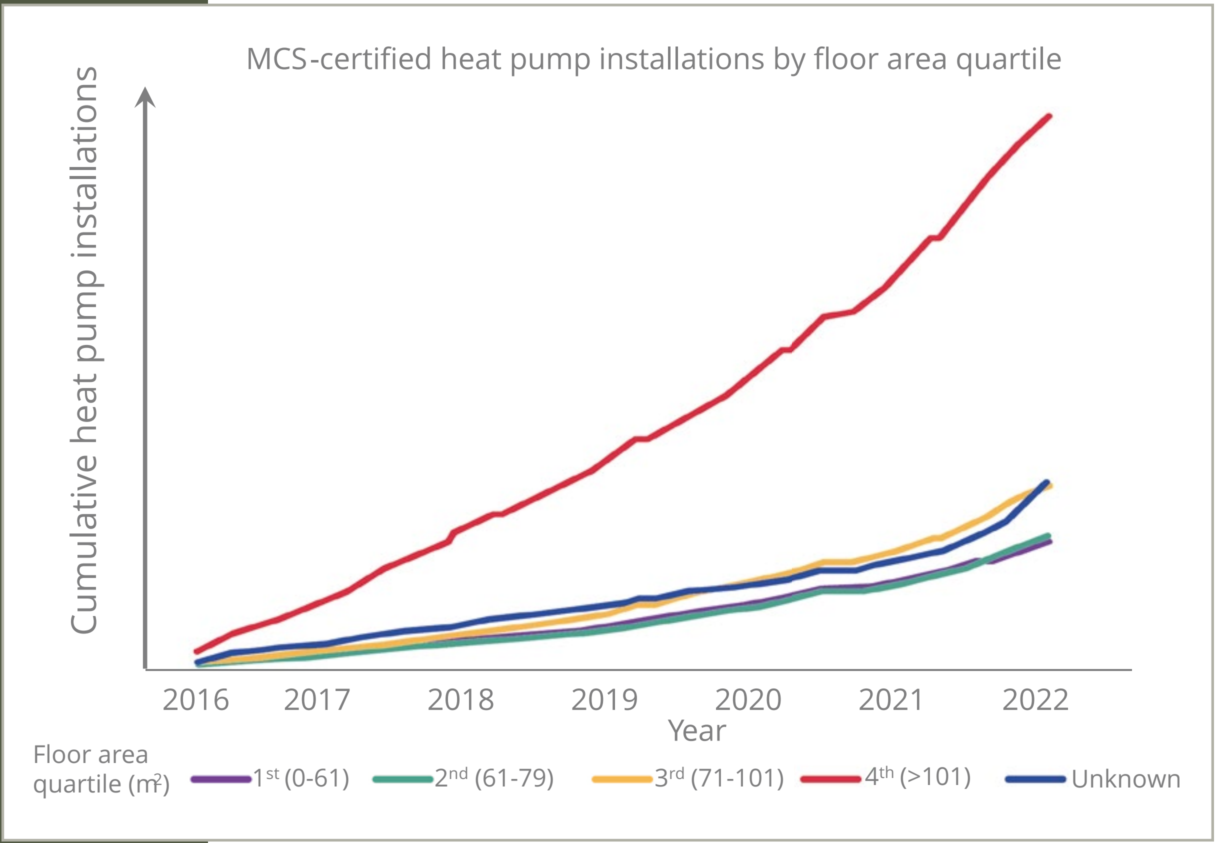
RETROFIT-AT-SCALE also proposes using 95% design-day external temperature condition exceedance criteria for sizing the heat pump, instead of the current 99.6% advice[121]. This is a simple way for the above-mentioned diversity to be included for heat pumps with a DHW vessel. Typically, this has the effect of reducing the capacity needed of the heat pump by about 25%[117]. All heat pumps should also have weather compensating controls, so the design-day radiator water temperatures are lowered in milder weather when less heat is needed, and so allow more efficient heat pump operation.

With appropriately configured controls, the **RETROFIT-AT-SCALE** investigations indicates the DHW reheat capacity need only be 25% or 10 W/m^2 additional capacity added to the reduced heating demand, giving an overall heat pump output of 50 W/m^2. For the illustrative example this would be a 4.3 kW output heat pump, and given this is the UK average sized home, this suggests the industry should start supplying heat pumps smaller than this for smaller homes, just as it could do for new homes (Figure C.4).

This optimised heat pump sizing should allow the heat pump outdoor unit to be physically smaller and so allow it to be wall mounted, as is normal practice for commercial individual AC/heat pump units. This particularly addresses the concerns of smaller property householders for avoiding the loss of their valued outdoor space (Annex A.1). It should be noted there are also Planning limitations on located the heat pumps[118].

Figure C.4

To date, a disproportionate number of heat pumps installations have been in bigger properties and hence of larger heat pump capacities. Smaller properties requiring smaller heat pumps are far less well served.[119]



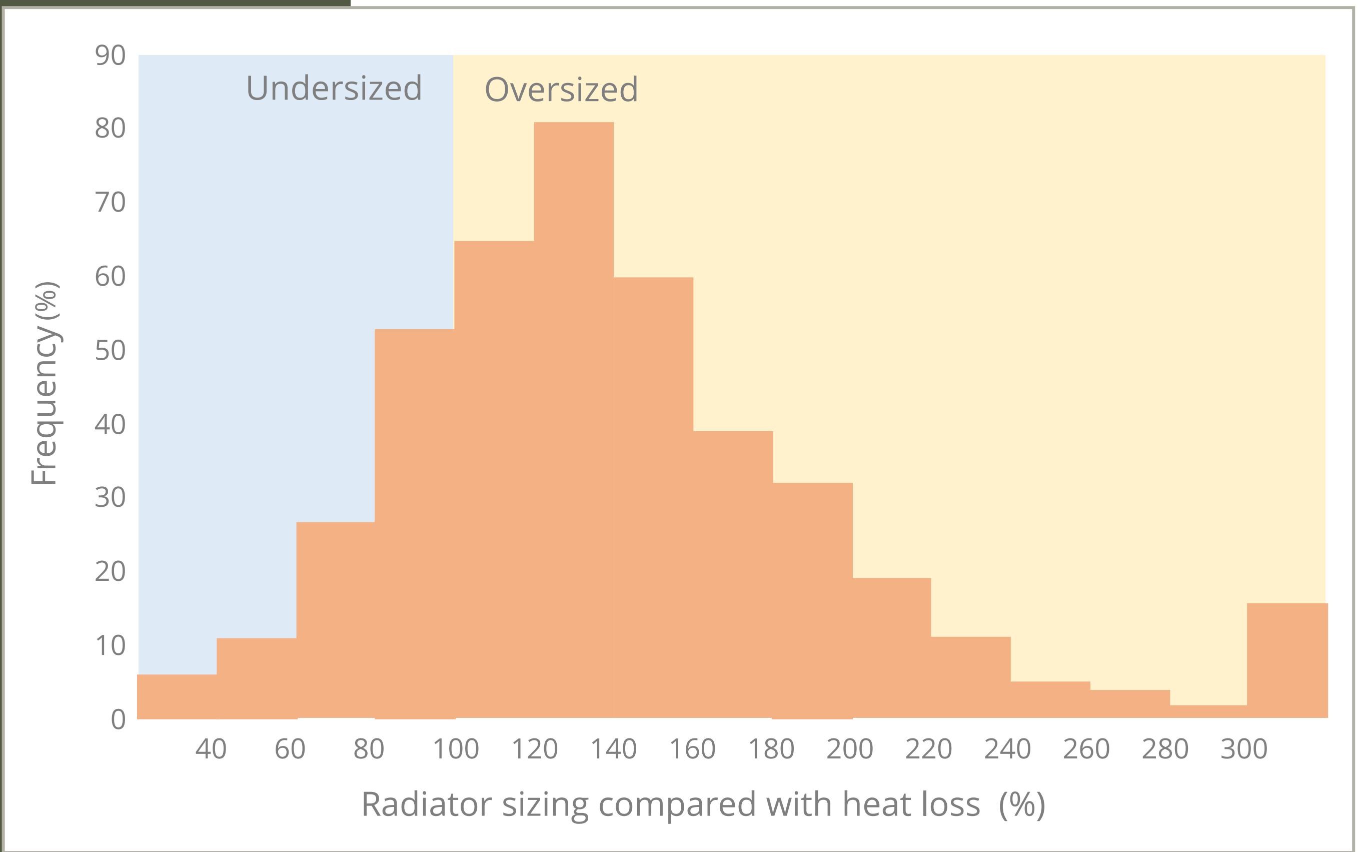
These optimised smaller heat pumps also reduce the size of the electrical power supply needed to below 13 Amp, so reducing electrical upgrades within the home, as well as avoiding the need to upgrade the incoming mains, even where it is still at the old 60 Amp rating. The reduction in heat pump size also reduces the likelihood that the neighbourhood DNO electrical network would need upgrading. It also supports the **RETROFIT-AT-SCALE** proposed 25% reduction in future needed capacity of the national grid transmission and distribution systems, and hence enables this investment to be redirected into retrofit (Chpt 5.9 & Annex G.5).

C.3 Radiator system

The **BASIC** retrofit aims to reuse the existing radiator system without modification to make the switchover to heat pumps quicker and easier. Radiators have been traditionally sized with 50°C temperature difference between the room and the radiator, with water temperatures typically 80-70°C. They are also assumed to provide an oversizing margin to allow rapid heating boost, reflecting the practice of switching boilers off overnight. Typical oversizing has been confirmed in research for DLUHC (Figure C.5).

For heat pumps, the radiator temperatures are ideally 45-40°C, although higher temperatures are possible at lower efficiencies for colder days. Figure C.6 shows the traditionally sized radiator heat output halves when switched from a boiler to these lower heat pump temperatures. This established the target of halving room heat losses using the fabric insulation measures. Heat pumps in insulated homes can also be operated in a trickle-heating mode across 24 hours each day and so avoid the need for the additional boost heating margin.

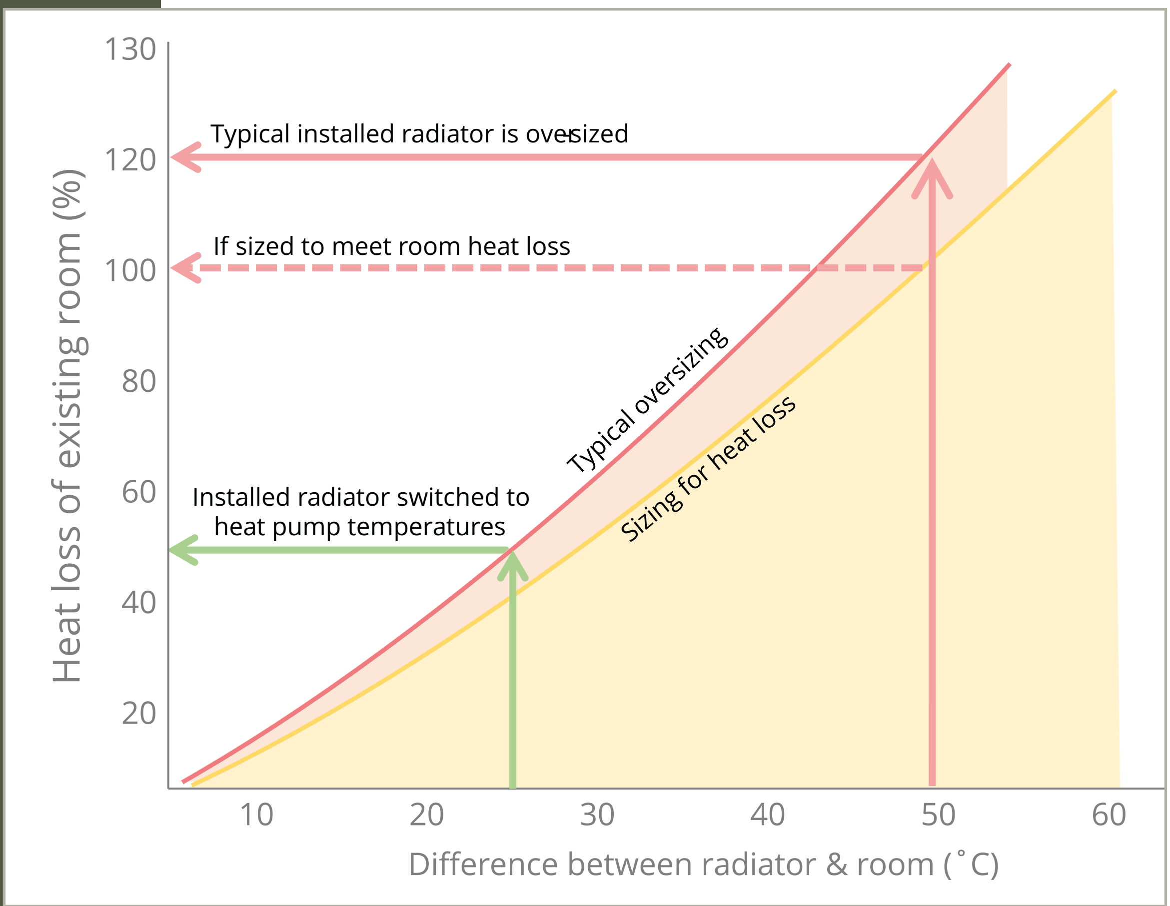
Figure C.5 – Distribution of typical radiator oversizing in UK dwellings[120].



For retaining the existing circulation pump, the heat pump smaller flow/return temperature difference would about double the required flow rate for the uninsulated home. However, with the insulation halving room heat loss, the pre-retrofit flow rate and the same pump can be reused, whether it is microbore or conventional pipe sizing.

For modest sized homes, to avoid the need to add a buffer vessel, the heat pump should have an inverter driven compressor to vary its output, typically down to about 25%.

Figure C.6
Existing radiators are generally sized for 50˚C temperature difference between room and water, then typically installed with next size / oversizing margin. A 50% heat loss reduction using fabric energy efficiency improvements allows reuse of existing radiator system with the reduced water temperatures of a heat pump system.



C.4 Domestic Hot Water system

Heat pumps require a DHW hot water storage vessel to be able to deliver peak hot water demands (Figure C.7). Most householders in the UK regard their homes as space-constrained, and this is a key barrier to adopting heat pumps across many homes (Annex A.1).

Even those homes that previously had a hot water cylinder, have mostly lost this space to other uses after the switch to combi boilers. The **RETROFIT-AT-SCALE** proposed solution for this is to install a 'phase-change material' (PCM) heat battery in the space vacated by the combi boiler (Figure C.8).

PCM heat batteries work by passing the hot water from the heat pump through pipes buried in PCM. This causes the PCM to 'melt' and it will stay in its liquid state until DHW is needed. When a tap is turned on, the liquid PCM releases its heat into the tap water supply, and consequently changes back into a solid (becomes 'frozen'). Because the PCM can hold almost three times more heat than water at a given volume, the device takes up significantly less space than a traditional hot water cylinder or a conventional heat pump hot water vessel.

PCM heat batteries are already available on the market of an appropriate capacity for the average home (typically 6 kWh, comparable to a 128 litre hot water cylinder), but no products are currently available of the shape needed

Figure C.7

Typical DHW hot water storage vessel for a heat pump © Eco Installer and Service LTD and ground mounted air-source heat pump © Chris Twinn TSI to replace a wall mounted combi boiler. While heat batteries tend to cost more than a hot water storage vessel, the reduced size of a slot-in unit and the significantly reduced site works mean a reduction in overall cost.

PCM heat batteries have a phase change temperature of typically 58°C, which has needed specialist higher temperature air source heat pumps to be able to deliver water at 63°C for reheating them. However, the newer generation of propane (R290) refrigerant heat pumps introduced for their low GWP (global warming potential) and zero ODP (ozone depletion potential)[121], have the ability to operate at this reheat temperature, albeit as for all heat pumps, at a marginally lower efficiency than supplying radiators at 45°C.

Installing the PCM heat battery in the space vacated by the combi boiler makes use of all the existing boiler pipework and electrical connections. PCM is typically heavier than water so just as with past wall mounted cast-iron boilers, it should come with a mounting spreader plate, and for unconstrained wall heads, a wall restraint bracket for fixing through to ceiling joists, or similar. As the PCM heat battery does not contain heated water, a hot water expansion vessel can also be avoided[122].

The switch to a PCM heat battery sized to replace the combi boiler, requires hot water efficiency measures to be implemented to reduce the 24-hr storage volume needed. The most cost-effective means of achieving this is by replacing the existing shower heads with high-performance low-flow shower heads (e.g. EWL green/A rated showerheads). With shower water demand being typically as much as 80% of total hot water demands, showerheads rated at EWL 6 l/min[118] or equivalent, are likely to reduce hot water demand by more than 30%. Such demand reductions directly feed through to reduced household heat and water bills, alongside reduced hot water storage and heat pump size and costs, as well as addressing the wider environmental concerns of reduced future water availability.

Figure C.8 – Simplified heat pump switchover installation.

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C.5 MVHR

The table below summarises the reasoning for **BASIC** including a simplified MVHR system, with various of these being further elaboration in the following paragraphs. The wider context is explained in Chapter 4.

Logic for simplified MVHR unit and its system:

- **Airtightness -** Building regulations requirement a dedicated air supply for airtight homes[169].
- **Moisture removal -** MVHR warmed and drier outdoor supply air is able to remove more moisture more reliably from mould susceptible cooler bedrooms than alternative systems like CMEV systems (Fig. C.9).
- **Thermal bridging –** Constant running MVHR lowers room relative humidity, so allowing a lower surface temperature factor (fRsi) and hence reduces extent of thermal bridge remedials.
- **Avoids trickle ventilators –** Alternatives need cold air trickle vents (of increased size for Part F:2021) to be cut and inserted into existing double glazing (with loss of existing window warranties) or equal openings.
- **Constant speed operation -** keeps controls simple, less likely to be heard and overridden by occupants, and provides fresh air 'reservoir' effect for intermittent higher occupancies.
- **Simplified controls -** Only occupant interface needed is time switched prompt for filter cleaning. Simplified controls – so no temperature sensors and no return relative humidity sensors.
- **Heat recovery efficiency –** Only needs 75-80% compared with top-of class 92% as better energy cost-benefit from fabric-first measures (typically less than 2.5% of total dwelling heat loss).
- **Summer bypass can be omitted -** UK 's relatively mild climate allows other more cost effective and user intuitive passive cooling, like ceiling mounted fans that use less year-round fan power.
- **Cost -** BASIC MVHR units can be purchased for some 70% less cost than top-of-the-range (Annex E)
- **Acoustics –** Low speed MVHR selection (lower fan impeller tip speed) lowers noise, so with matched attenuators this avoids acoustically lined ducting allowing more visually acceptable rigid rectangular ducts.
- **Located inside thermal insulation –** If within the dwelling thermal insulation envelope, most of the ducting thermal insulation can be eliminates (except for short MVHR to outdoors connection).
- **Reduced Health & Safety requirements for MVHR maintenance –** Avoid the costs of enhancing loft flooring, access and hatch Health & Safety requirements for MVHR maintenance, together with routings for new loft drainage, electric and controls, if loft can be avoided for locating the MVHR.
- **Avoid space loss –**Locating the MVHR in the bathroom (ceiling mounted), or kitchen (eg over cooking hood) avoids losing valued dwelling floor/cupboard space.
- **Ducting –** MVHR air ducting can be off-the-shelf, white self-finished, surfaced mounted, 'Flat Channel' type, using stairwell for risers and halls for vertical distribution.
- **Supply grilles –** selected to harness the ceiling Coanda effect and so avoid the need for routing ducts to remote sides of rooms, and avoiding ducts needing to be inserted inside floor and loft voids

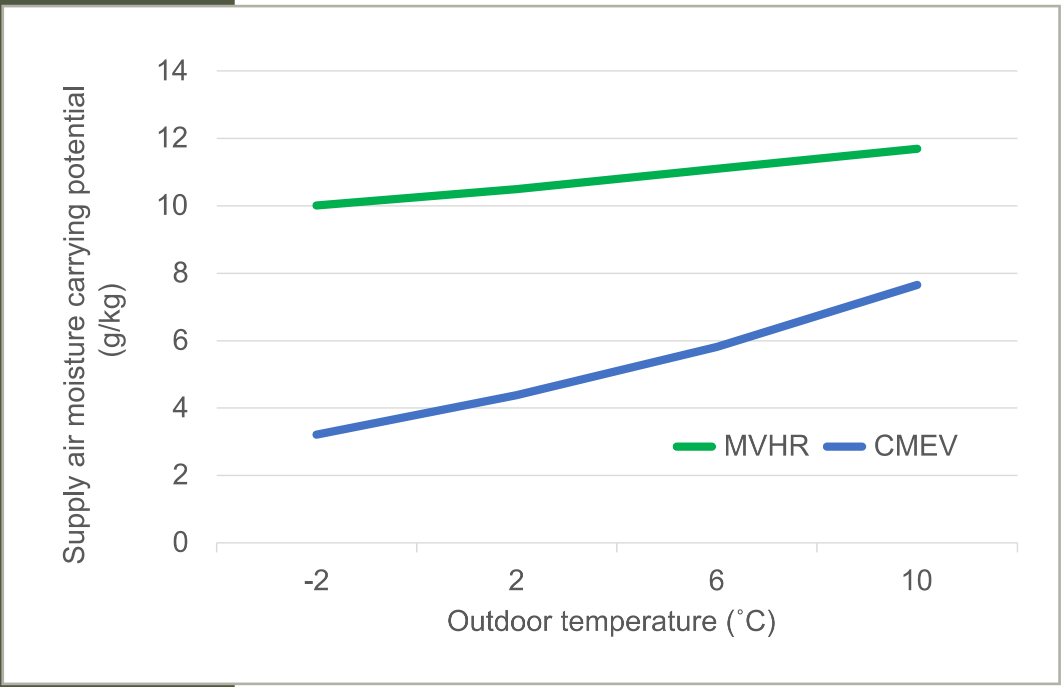
Dwelling airtightness improvements have been identified by **RETROFIT-AT-SCALE** as a low-cost highly effective energy saving measure. Simple measures as illustrated in Figure 4.3, can deliver airtightness levels of 3 ach or lower at 50Pa test pressure (Annex D.3 case-study). From experience, existing dwelling measures tend to be imprecise, and so the air leakage can end up being lower, particularly with the quick learning curve informed by before and after testing. At these airtightness levels the building regulations[128] require a balanced fresh air supply as well as the extract, as is inherently provided by an MVHR.

Alternatives using centralised mechanical extract ventilation systems (CMEV) require untreated outdoor air to be introduced into the habitable rooms, with an increased risk of cold draughts and occupant override. Many existing properties have inadequate window trickle ventilators either for natural ventilation or for CMEV, and where they have been installed, are undersized and would need increasing to comply with the recent changes to Building Regulations (as Part F for England). Inserting new or increased sized trickle ventilators into existing windows is to be avoided, not least because of the time and disruption, but also because of the practicalities of getting adequate vents sizes into windows, and since it invalidates pre-existing window warranties. Installing a simplified centralised MVHR system avoids all these issues.

In room moisture terms, an MVHR system delivers consistently lower winter humidity levels, particularly in cooler bedrooms where moisture condenses on the coolest surfaces, having migrated from the wet rooms (bathrooms, kitchens, etc). While CMEV can effectively extract moisture from these wet rooms, it is less effective in other habitable rooms the residents choose to operate at lower temperatures, and yet these are where they often expect to leave washing to dry.

The higher moisture pickup potential of MVHR air supply (Figure C.9) and hence the lower supply air relative humidity (based on CIBSE data [126]) allows it to remove more room moisture, and so lower room air humidity levels which in turn lowers the condensation risk on thermal bridges. This permits

Figure C.9
Diagram illustrating higher moisture pickup capacity of heat recovery MVHR supply air compared with the colder air intake through trickle vents of a CMEV system
(see Chpt 4. 5 & CIBSE ref [126]).



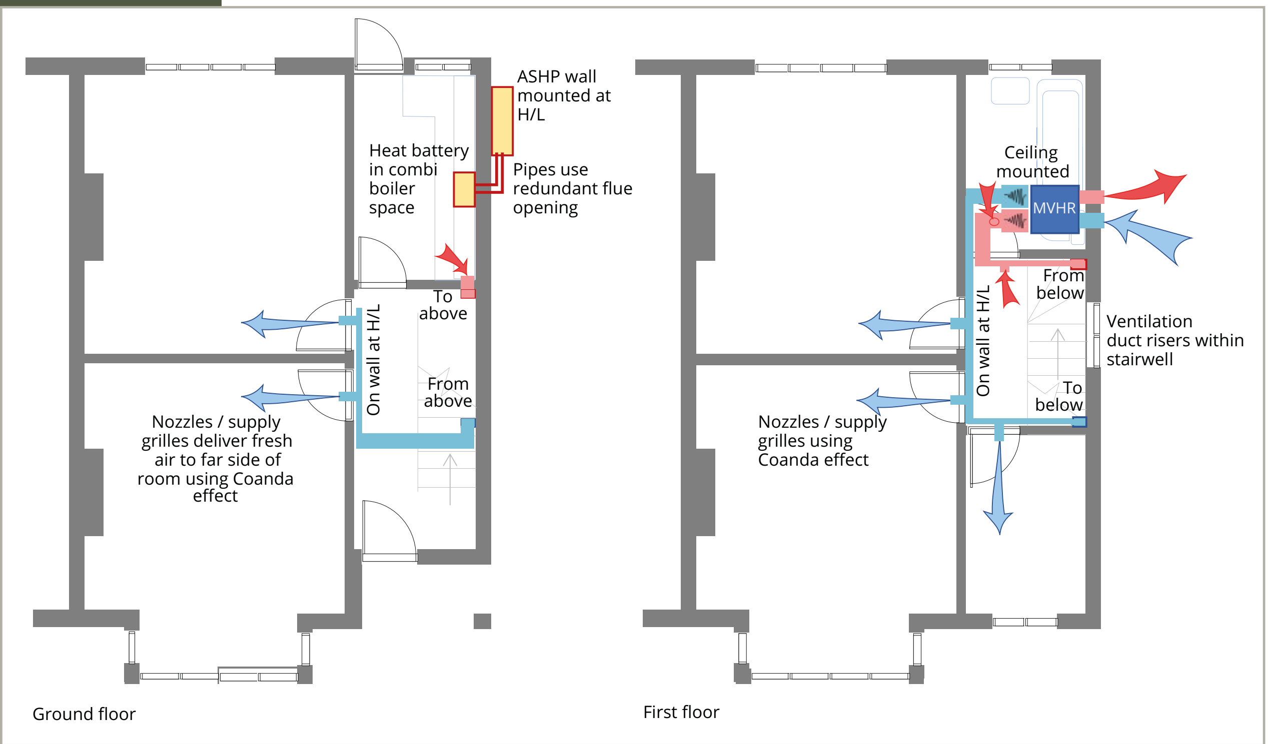
a more relaxed surface temperature factor (fRsi) to be considered and so reduces the extent of thermal bridge remedials and their costs (Annex B.5)

In air volume terms, **BASIC** uses an MVHR system sized to deliver the Building Regulations (ie Part F for England) required air quantities, operating at constant volume. This simplifies the controls and needs no humidity or temperature sensors and no fan variable speed or real-time demand controls. Running the MVHR at constant volume inherently provides an element of fresh air spare capacity by harnessing the buffering room 'reservoir effect'. By continually changing the room air during unoccupied periods, they are charged with a full reservoir of fresh air for subsequent periods of higher-than-normal occupancy. This helps avoid the complexity of real-time humidity sensing and controls to retrospectively trigger boost ventilation, together with the associated oversized system, and avoids the occupant noticed changes in noise levels.

The air ducting for the MVHR system would be off-the-shelf, white self-finished, 'flat channel' type (Figure 4.5), installed in a surface mounted arrangement. The duct layout lengths are minimised by locating the MVHR in the bathroom and using the stairwell corners and high-level ground and first floor hall space for risers and distribution (Figure C.10). Boxing these in or installing them in concealed location would be an upgrade from the **BASIC** retrofit. Simple nozzle type supply diffuser grilles that harness the Coanda effect (Figure D.7), channel the supply air jets across the ceiling, providing room air distribution without needing any ducts routed to the far side of the rooms. Having surface mounted rigid ducts eliminates the contortions of concealing them inside the existing building fabric, so reducing flow pressures, increasing predictability, and allowing better fan size matching.

With no cutting of floorboards, lifting of floating floor finishes, no hopscotch with concealed joists, and no loft ducting going through the dwelling airtightness/insulation barrier, the builders' work associated with the new ventilation system is significantly reduced. It mainly becomes a simple predictable single duct entry to each room typically above the room entry door, with the doors undercut as is normal for the return air. Among other

Figure C.10
Air ducting layout confined to stair well and hallways within typical archetype.

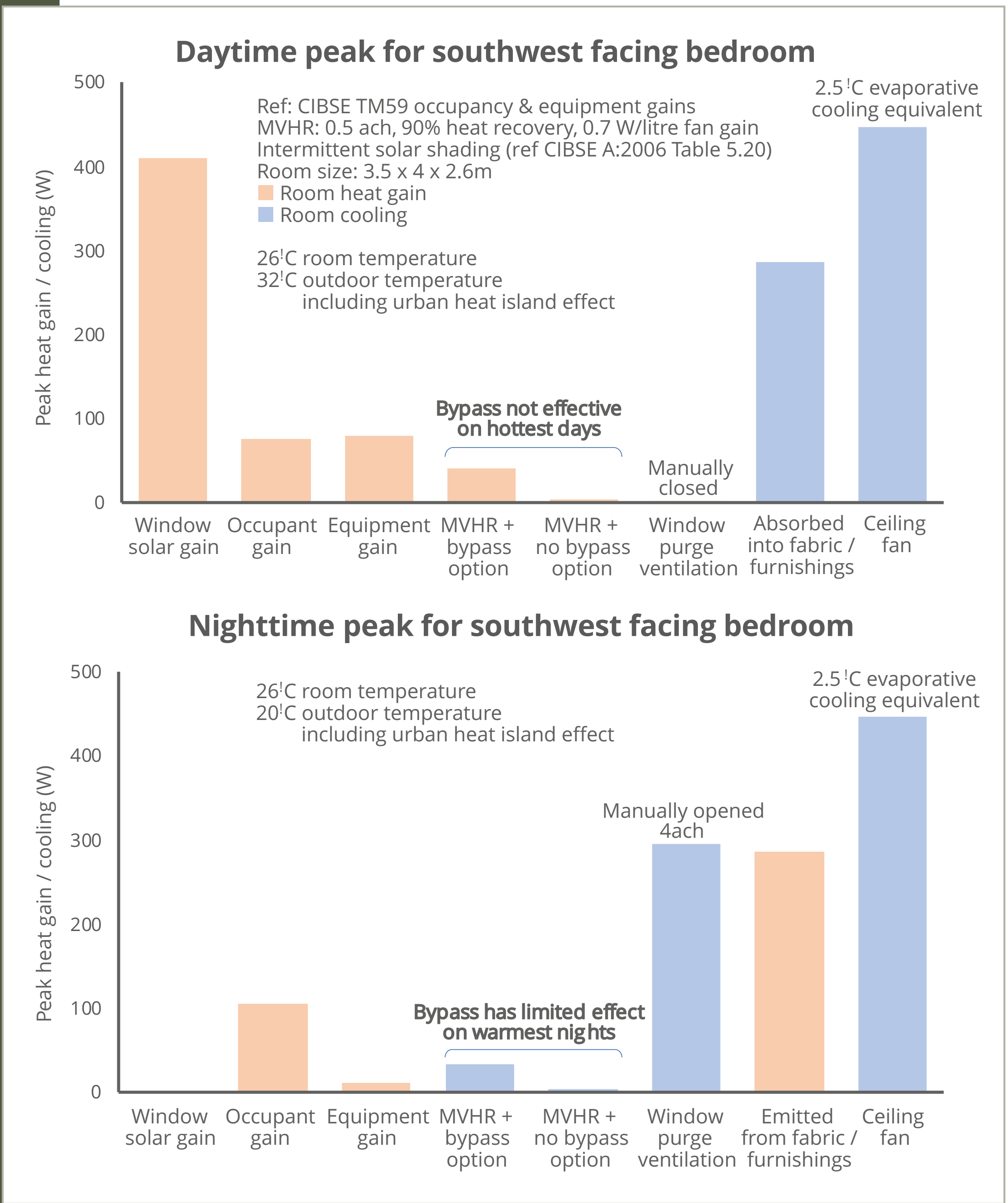


productivity improvement suggestions, practitioner feedback noted the lack of simple tools that can cut 10mm off the bottom of an existing door, without having to take it off its hinges.

SUMMER OVERHEATING

Summer overheating risk was studied by the **RETROFIT-AT-SCALE** team before recommending that a simplified MVHR need not have a summer bypass for the UK climate (Annex C.5). Figure C.11 illustrates the key outputs from the analysis for both daytime and nighttime peak summer overheating conditions, illustrating the scale of influence for the major overheating components. It shows that having a bypass has no benefits during daytime periods when the outdoor air is warmer than indoors. During nighttime the bypass has some benefit by introducing cooler outdoor air, but its effect is dwarfed by the cooling effect of purge ventilation via the windows.

Figure C.11
Scale of overheating peak influences. Shows MVHR summer bypass has an order of magnitude less impact than either window purge ventilation or ceiling mounted fans.



Although not part of the **BASIC** retrofit remit, the **RETROFIT-AT-SCALE** team did investigate what cooling means might be appropriate if a dwelling had inherent overheating issues, and for future climate change. Drawing on experience from abroad where climates are already of the temperatures expected for the future UK, retrofitting ceiling mounted fans, using the room existing light wiring, was identified as by far the simplest and most cost-effective means of providing up to about 2.5°C of cooling[123]. For the nighttime cases the cooling effect of retrofitting ceiling mounted fans was found to be more than 10-fold larger than for the MVHR bypass, and its cooling effect remained at this scale during daytime when the bypass benefits dropped back to zero (Figure C.11).

The following are observations drawn from the overheating study:

- **The BASIC measures for halving of dwelling heat loss tended to reduce room summertime peak temperatures, largely due to less infiltration and increased thermal insulation, particularly the loft insulation.**
- **The MVHR ventilation rate of 0.5 air changes per hour is only an eighth of the window purge ventilation rate also required by the Building Regulations[128], and hence the MVHR's relatively small influence on room temperature conditions. This is applicable for mid-season overheating risk periods, as well as in peak summer.**
- **Under conditions when unwanted heat was recovered from the MVHR exhaust air and put into the supply air, the temperature difference across the heat exchanger was so small that very little heating of the supply air occurs.**
- **If the particular dwelling has outdoor noise issues that deter use of opening windows, then the overheating could not be solved by having an MVHR bypass, and so other cooling measures would be required anyway.**
- **At a more general analysis level, although DMS thermal modelling is a powerful analysis tool, it lacks transparency for showing the order of magnitude of each of these subsidiary heat flows.**

C.4 Electrical systems

The aim is to minimise and ideally avoid upgrading the dwelling's incoming supply and distribution by keeping heat pump peak demands low enough to preserve adequate capacity for the switchover to electric cooking and future electric vehicle charging. By halving the fabric heat demand, using design-case diversity, and managing the DHW reheat schedule, the heat pump output capacity is expected to be as much as 75% less than a heat pump installed into an uninsulated home. Given the context of a mass retrofit rollout, this also helps protect the local area electrical network where there tends to be limited capacity. As transport and heating in general switch to all-electric, the local area network is likely to start expecting smoothing and lowering of peak demands from consumers in return for avoiding high time-of-day tariffs. This type of demand management is likely to become an increasing feature of the electrical supply as it also helps minimise the increasing peak loads feeding back into the wider UK electrical distribution, transmission, and generation system.

An electrical load assessment was carried out on the illustrative example archetype to demonstrate that no electrical supply upgrade would be required, and so remove the potential additional retrofit task and the unpredictability involved in interfacing with the local electricity infrastructure provider. For the illustrative example this is assumed to be 60 Amp as the smallest typical domestic connection size. The heat pump peak demand for this average sized dwelling with the application of a **BASIC** retrofit would be below 2 kW.

Summary of electrical capacity assessment:

- **BASIC aims to avoid any need to upgrading the dwelling electrical supply.**
- **The assessment considers the electrical loads related to cooking, heating and hot water generation and some future trends, such as Electric Vehicle Charging Points.**
- **EVCP (car charging point) assumed to be 7.4 kW capacity - they are expected to have a smart system in future that understands when there are other priorities in the house.**
- **Induction hobs fed by 13A (avoid hobs having 7 kW rating) and a 2 kW oven.**
- **Introduction of an MVHR supply (1.5A), reuse of the boiler supply for the small heat pump (13A), a heat battery assumed to have a 1.5 kW backup immersion heater that is rarely used because legionella sterilisation is not necessary for PCM.**
- **Smaller heat pump sizing related to fabric improvements, better sizing method and improved DHW trickle recharge controls.**

In addition to the **BASIC** retrofit with its focus on heating, the dwelling Retrofit Plan should inform the householder about other energy retrofit opportunities that could be included as a retrofit option at the same time, or as part of later phased implementation. Among these is the recommendation to switch all light fittings to LED illumination lamps. A switch to all-electric cooking would also allow the gas meter to be entirely removed and the monthly gas standing charge bill to be saved. This need not be done during the initial retrofit, but when most convenient for the occupant, probably at the time of the next kitchen refit. It should be suggested that the replacement electric hob is of the lower energy induction type now their prices have rapidly fallen. Any induction hob installed is recommended to be no more than 2.8 kW capacity as this not only reduces the wiring costs, but also maintains sufficient future capacity for EV charging.

Smart control systems are not a requirement for **BASIC** retrofit, which aims to keep the controls simple, cost effective and as a **BASIC** kit-of-parts applicable for most dwellings. **BASIC** is cognizant that currently some 40% of the population have limited 'smart phone' literacy[124]. The assumption is that no additional controls are needed other than those that come integral with the individual heat pump, DHW store and the MVHR. Adding an additional layer of controls is viewed as unnecessary and adds to installation time and commissioning complexity. Advanced controls also have a short useful service life and supplier support period - a lot shorter than the 15 years expected of other M&E components and the even longer life of fabric measures. For certain householders there may be a role for Wi-Fi enabled thermostatic radiator valves to provide room by room heating schedules instead of a central thermostat. Such controls need careful user support because the heat pump system operates with a night setback, and not as an ON/OFF system with an assumed large boost capacity.

Solar photovoltaic (PV) renewable power generation can also be recommended but may not happen with the initial **BASIC** retrofit package. PV tends to have less energy bill reduction potential for a home with a modest sized or non-ideally orientated roof compared with fabric-first measures. For certain market sectors, like those able-to-pay, PV may be attractive as it can deliver further energy bill savings in return for the extra investment. Similarly for the social housing sector, separate long-term third-party finance could be accessed to be able to include these as part of reducing energy bills for the fuel poor.

Battery storage is an option that could be coupled to a PV installation. Currently it typically does not make economic sense as part of an initial retrofit for non-technically able householders. But should the electricity tariff system develop with simple automatic controls to harness time-of-day variable tariffs this could be considered for a second stage of retrofit. Of course, this battery may be more cost effective if it is part of an electric vehicle (EVCP) with the ability to feed electricity back into the home.

Such additional energy retrofit measures should be discussed with the client as part of the retrofit process, since there maybe economies in doing the works at the same time, for instance if scaffolding is in place for works to the external walls or roof.

Annex D

Innovation case studies

Annex D: Innovation case studies

The following case studies focus on aspects of the cost, time and space saving opportunities identified by RETROFIT-AT-SCALE, and contributing to the BASIC retrofit standard. They aim to provide real life examples of how these constituent parts can be applied.

D.1 CASE STUDY
Measuring actual heat loss

Figure D.1
Case study Victoria semi-detached home

Case study:	Short-term monitoring to establish actual energy use[125]
Location:	Bristol
Completion:	2019
Feature:	Three-week monitoring period using smart meter and online calculation tool
Retrofit Coordinator:	SOAP Retrofit Ltd
Monitoring specialist:	Build Test Solutions
Energy use:	Actual heat loss found to be about 45% less than the RdSAP/SAP assessment:
SAP design prediction	HTC = 709 W/K
HTCSmart measured:	HTC = 392 W/K

SUMMARY

To gain a better assessment of actual heat demand and allow better selection of retrofit options, this Victorian semi-detached property in Bristol was fitted with simple temperature monitoring sensors linked to an online tool.

KEY FEATURES:

- Three-week pre-retrofit monitoring of actual energy from existing meter.
- Use of online SmartHTC tool to convert this into heat loss information.
- Direct comparison with RdSAP/SAP assessment.
- Allowed heat pump installation of almost half normal size and the reuse of most of the radiator system.
- Post-installation verification of actual energy use of the retrofitted dwelling and heat pump system.

MONITORING METHOD

Measurements of internal temperature and metered energy consumption were used to inform the SmartHTC on-line tool. Readings can come from existing smart home systems or a small number of temporary, discrete sensors. During the three-week measurement occupants can continue to use the property as normal. The online tool includes corrections for weather and occupant factors to provide an indication of the true performance of the building fabric. This can be directly compared with normal alternative predictions.

IMPACTS ON DESIGN

Using monitored data removes many of the inaccuracies inherent in normal site surveys and in the standard RdSAP assessment method. These inaccuracies typically stem from inaccurately assessed thermal bridging, material U-values, and airtightness, where unmeasured default inputs are often used.

The measured data and SmartHTC tool showed the actual energy use to be significantly lower than SAP predictions. The measured Heat Transfer Coefficient (HTC) for the property was assessed as approximately 400 W/K compared to SAP estimates of greater than 700 W/K. This allowed a significant reduction in ground source heat pump (GSHP) size, and reduced the number of boreholes from four to three (~100m each).

Figure D.2
Examples of temporary Wi-Fi data-logging sensors

Figure D.3
SmartHTC 3-Week Rolling Average HTC Samples and Cumulative Average from 24/11/19 to 01/04/20

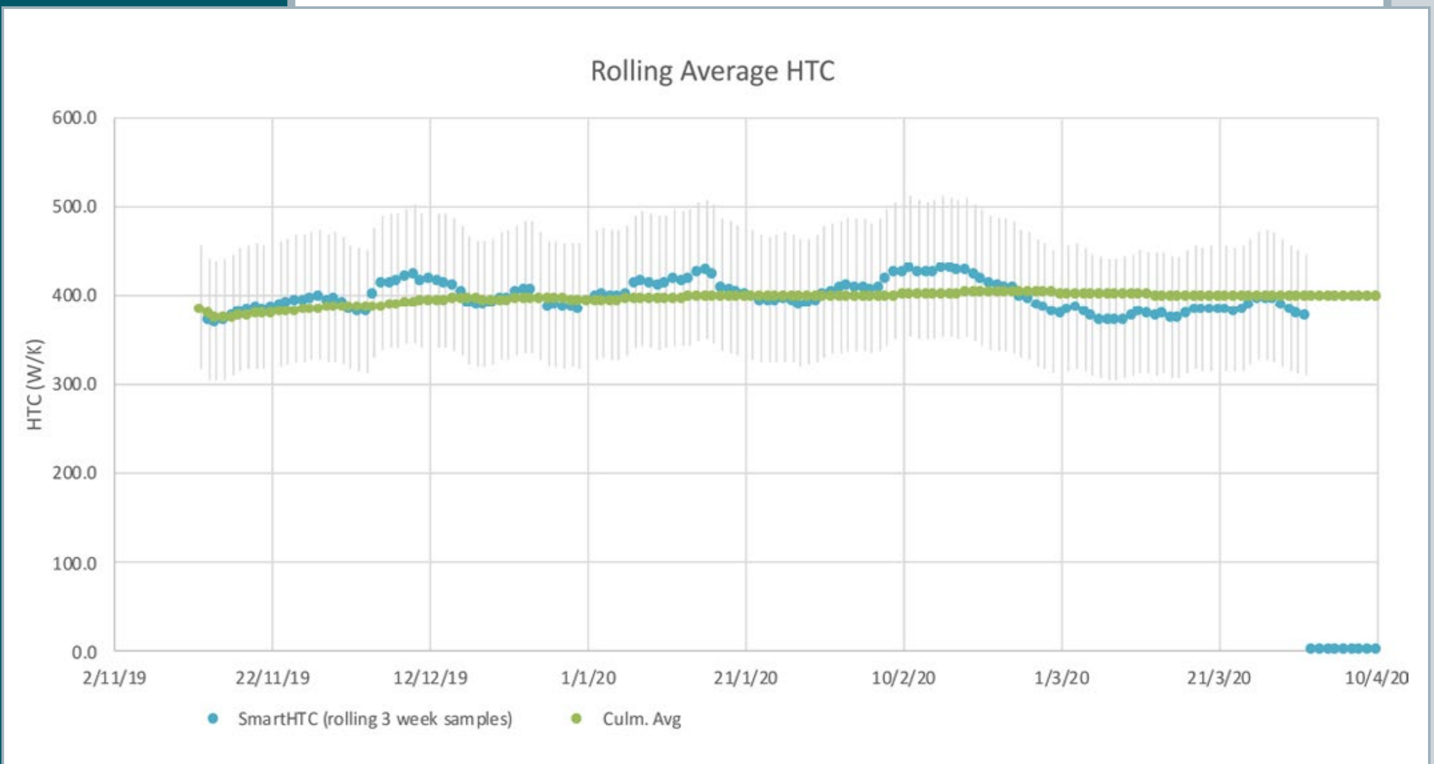


Figure D.4
Extract from SAP – Heat Loss and Heat Transfer Coefficient (HTC)

BENEFITS

There was a capital cost saving due to a smaller heat pump and reduced number of boreholes, providing a better system cost effectiveness (reduced payback period). The avoidance of an oversized heat pump installation also reduces potential inefficiency during low/part load operating conditions. There was also less site disruptive works and associated costs.

SAP Heat Loss (W/K)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fabric	463	463	463	463	463	463	463	463	463	463	463	463
Thermal Bridges	69	69	69	69	69	69	69	69	69	69	69	69
Ventilation	195	183	187	183	187	169	172	165	162	169	169	179
HTC	727	715	719	715	719	701	704	697	694	701	701	711
SAP Average HTC	**709 W/K**											
SmartHTC	**HTC: 392 W/K-67 (-ve Cl)+ (+ve Cl)**											

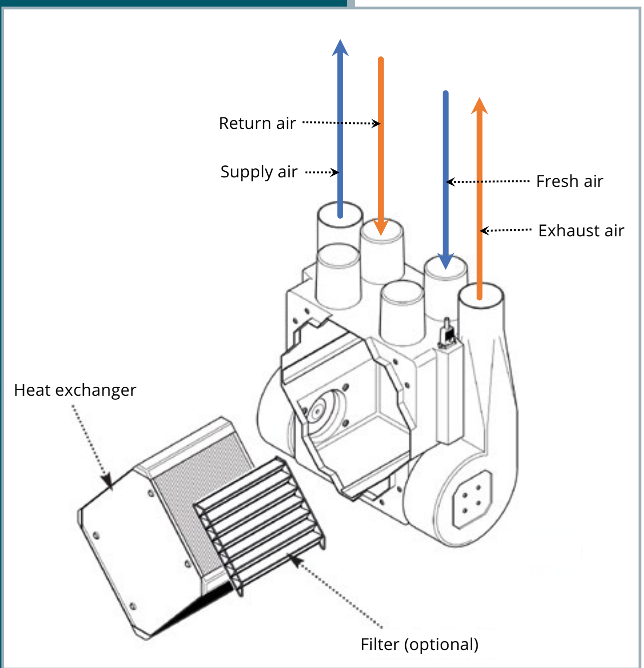
POST RETROFIT MONITORING

The same approach was taken after retrofit to verify the performance of the heat pump installation and other efficiency measures installed. Heat pump output data is also helpful, allowing separate identification of the heat demand component within the electricity meter readings. Overall, these provide confidence that the performance gap has been minimised and assists the industry in its move into providing performance warranties.

D.2 CASE STUDY Simplified MVHR

Figures D.5 and 6
Simple MVHR unit with plastic heat exchanger

Case study:	Retrofit application of simple (MVHR)
Location:	Woodford Green, London
Operation period:	21 years
Specification:	Part F air flow rates. Sized on low speed for acoustics. No summer bypass. Casing of fire-retardant moulded polythene
Heat recovery:	Polymer PVC heat exchanger, 65% heat recovery (estimated)
Ductwork:	Mostly rigid plastic
Controls / sensors:	None – constant speed
Manufacturer	Baxi WH400



SUMMARY

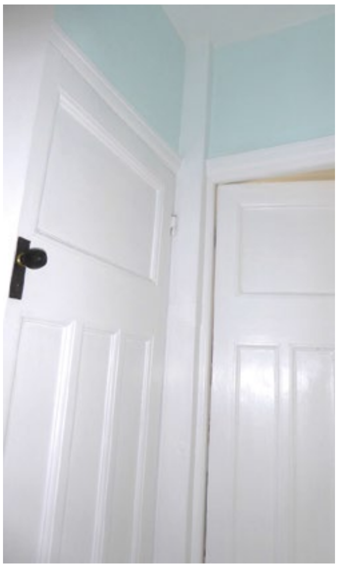
An MVHR system installed into a 1930s semi-detached home, as part of a staged retrofit programme. It has been operating for more than twenty years. Drivers for the installation included:

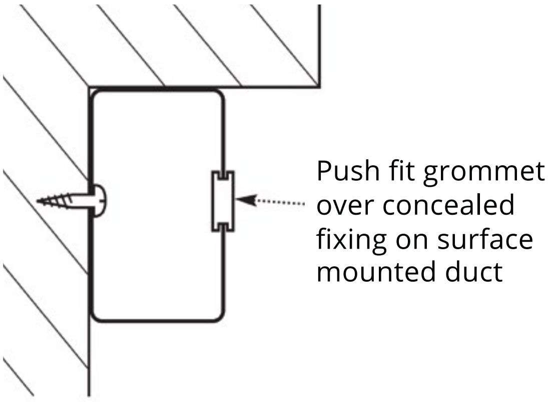
- Pre-existing condensation issues.
- To improve air quality and comfort levels.
- To allow enhanced airtightness energy savings
- Exposed ducting given space and disruption constraints
- An uncomplicated largely fit-&-forget MVHR system.

MVHR UNIT

The simple MVHR unit was an off the shelf unit made in the UK by Baxi to a design by ADM. It consists of a moulded polythene enclosure for the heat exchanger and centrifugal supply and extract fans. The heat exchanger is of uPVC plate format, an early version similar to most other MVHR units now on the market. The unit came with a separate insulated covering and had an optional EU3 fresh air intake filter.

The fans were 240v AC with tappings inside a transformer unit, allowing speed adjustment during commissioning. External switching between two





Top left & centre: Surface mounted ducting

Top: Coanda effect supply grille

Above: Concealed fixing for surface ducting

Left: Undercut door for return air routing

Figures D.7
Air distribution details

speeds was possible although an external control switching arrangement. o

WHOLE HOUSE VENTILATION SYSTEM

The system provides tempered fresh air to living rooms and bedrooms, and extract from kitchen, dining, bathroom, shower room and toilets. The MVHR unit was installed in the loft. Separate duct risers served most individual rooms.

As the MVHR unit was located immediately above a bedroom it is mounted on anti-vibration pads. Two metre acoustically lined ducting lengths are installed on the supply and extract duct connections. In acoustics terms, the most important aspect was ensuring the ducts and MVHR unit were sized to allow operation at low fan speed.

AIR DISTRIBUTION

Most ducting is rigid uPVC providing a smooth air flow surface and hence minimising fan power. Most risers, including exposed ducting, are of uninsulated self-finished rectangular format, typically of 220x90mm size or 110x54mm for individual rooms. Some circular soil vent type pipes were used as risers inside redundant chimney stacks, but these proved awkward to install.

Air ducting was not installed below floorboards because of the disruption it caused. Besides, the joists voids only allowed single direction routing, and with frequent cross noggin blockages. The desire to retain existing ceilings and cornice details precluded a new duct void below ceilings.

Instead, surface mounted rectangular duct risers were introduced into selected first floor room corners to serve the ground floor below. Locating risers in stairwell corners can also avoid the all too common floor joist blockages that then required duct offsets.

FEEDBACK

The continuous MVHR air supply has delivered consistently good background ventilation. The condensation has gone. The tempered supply air has eliminated the draughts from the previous window trickle openings.

Initial use with humidity switching to higher speeds was abandoned after occupants tended to notice the fan speed switchover - even though it satisfied all the sound level targets. Subsequently, there has been no condensation using the single low fan speed. Energy monitoring showed that DC motors, had they been available, would save about 75% of the fan energy use.

Off-the-shelf air valve grilles worked well for extract, but occupant feedback indicated they tended to dump supply air. This was solved by changing to grilles shaped to push the air supply across the ceiling using the Coanda effect, thus achieving a better mixing with room air. Locating the MVHR unit in the loft was perhaps not ideal due to extra ductwork insulation / condensation measures, the extended routing for drainage and electrics, providing safe walkways over deep insulation, and having to increase the loft access hatch size.

Having no summer bypass has virtual no impact on peak summer temperatures. Monitoring showed little heat transfer across the exchanger in hot weather due to low supply/return temperature differences. In practical cooling terms, the MVHR air volume is smaller, by about 10 times, than that provided by the operable windows. If additional cooling is needed in future, room ceiling fans could be more economically added with the wiring already available to central light locations.

Filter cleaning is typically six-monthly with two-yearly replacements. Buying filter fabric by the roll avoided sourcing the bespoke sizes that after a few years were no longer available. A coarse EU3 filter was found to be generally sufficient, the telltale being avoiding supply grille dust accumulations. An auditable filter alarm, rather like those on smoke detectors, would have been a useful addition to what is otherwise a fit-&-forget system.

D.3 CASE STUDY
Implementing BASIC level retrofit measures

Case study:	Trialling thermal efficiency measures suitable for BASIC level of performance
Location:	Woodford Green, London
Phased retrofit period:	1993–2023
Client & retrofit lead:	Anna and Chris Twinn
Airtightness testing:	Paul Jennings
Pre-retrofit heat fuel use:	164 kWh/m²/yr (metered)
POST-RETROFIT:	
Airtightness:	2.6 ach @50Pa (measured)
Heat fuel use:	84 kWh/m²/yr (metered)
Space heat loss:	60 kWh/m²/yr (estimated)
EPC rating:	82/B (before various measures)

SUMMARY

The retrofit of a 1931 semi-detached house within an 'Area of Special Character' and Article 4 planning restrictions. The retrofit was phased with the client doing most of the work themselves. The retrofit acted as a test bed for energy efficiency measures, in particular measures that reduced disruption for what was a continuously occupied family home.

KEY MEASURES INCLUDED:

- Roof insulation
- Suspended ground floor insulation
- Partial external wall insulation (EWI)
- Partial internal wall insulation (IWI)
- Extensive airtightness measures
- MVHR installation (see Annex D.2 case-study)
- Double glazing with 20-year overhaul
- Thermal bridge and condensation treatment

LEARNING BY DOING (AND MONITORING)

Pre-retrofit monitoring and detailed observations allowed measures to be applied specific to the needs of the building. Post-retrofit monitoring helped identify which measures tended to fall short of their claimed performance. Monitoring involved a combination of meters, thermal imaging and thermal monitoring, and direct user feedback. For example, the initial installation of double-glazing triggered high CO_2 and condensation issues. prompting the installation of whole house ventilation - illustrating the need for a more holistic approach.

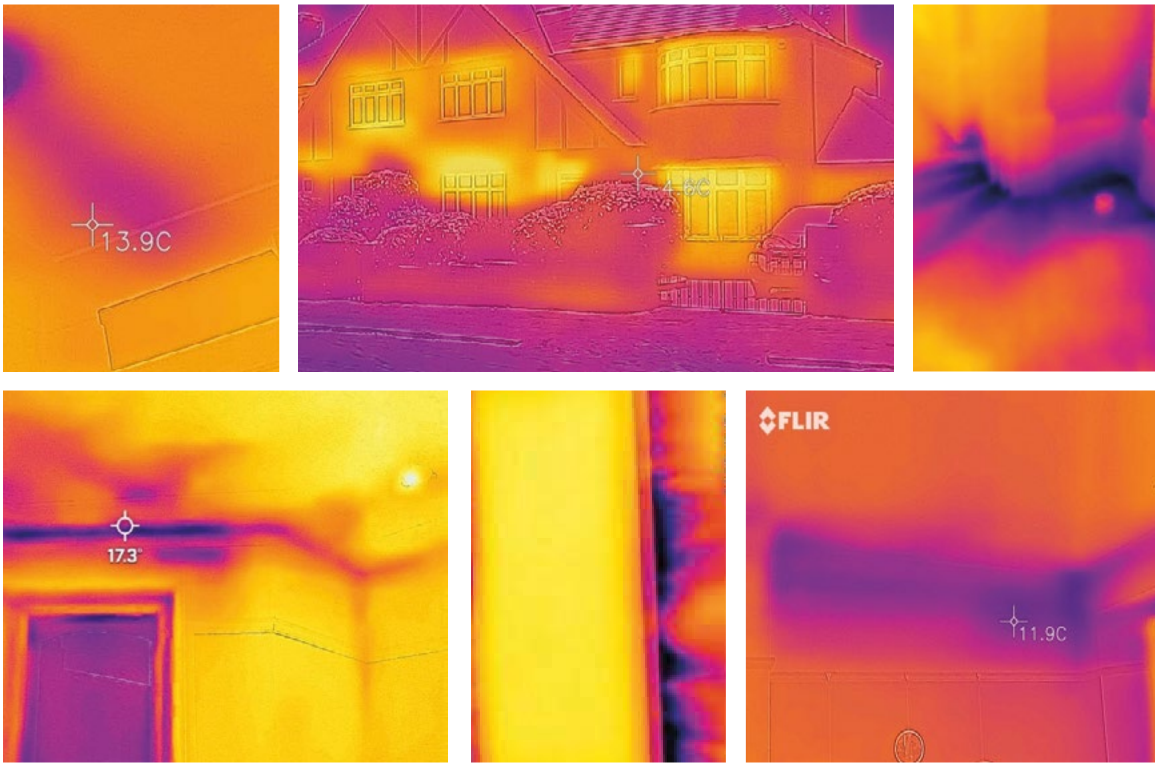


Figure D.9
Thermal imaging for locating heat loss

THERMAL INSULATION

The fabric-first measures initially focused on thick roof insulation, and ground floor and internal wall insulation. Their thermal performance initially fell short of expectations, although this was subsequently largely addressed by coupling them with **BASIC** airtightness measures.

The disruption to an occupied family home was sometimes difficult, particularly installing IWI, lifting floorboards, and resolving clashes with fitted cupboards, doors and period features, plus the omnipresent dust. In effect these were only appropriate when combined with room remodelling, not for just energy measures. Eventually the switch was made to pebble dash finished EWI, with facing brick areas remaining uninsulated.

AIRTIGHTNESS AND VENTILATION

The decision to install a simple MVHR system was made early in the retrofit process. This removed the uncertainty about eventual infiltration air leakage being sufficient for air quality. It also solved high bedroom CO_2 levels, as well as mould in the north facing bedroom.

Early investigations identified air infiltration was generally at floor to wall joints and not through the traditional wet plaster. Services openings were also significant. A selection of low impact remedial measures were used. These included generous mastic sealing to tops and bottoms of skirtings (Figure D.10), a ground floor polyethene underlay, and supplementary seals for external doors, loft hatch, and doors to below stair services openings.

Over the years Increased double glazing air leakage was noted with loosening hinges specifically identified. With hinges replaced, the gasket sealing was then recovered. The house was recently airtightness tested and achieved a rate of 2.6 ach (at 50Pa), this is in spite of most of the airtightness measures now being many years old.

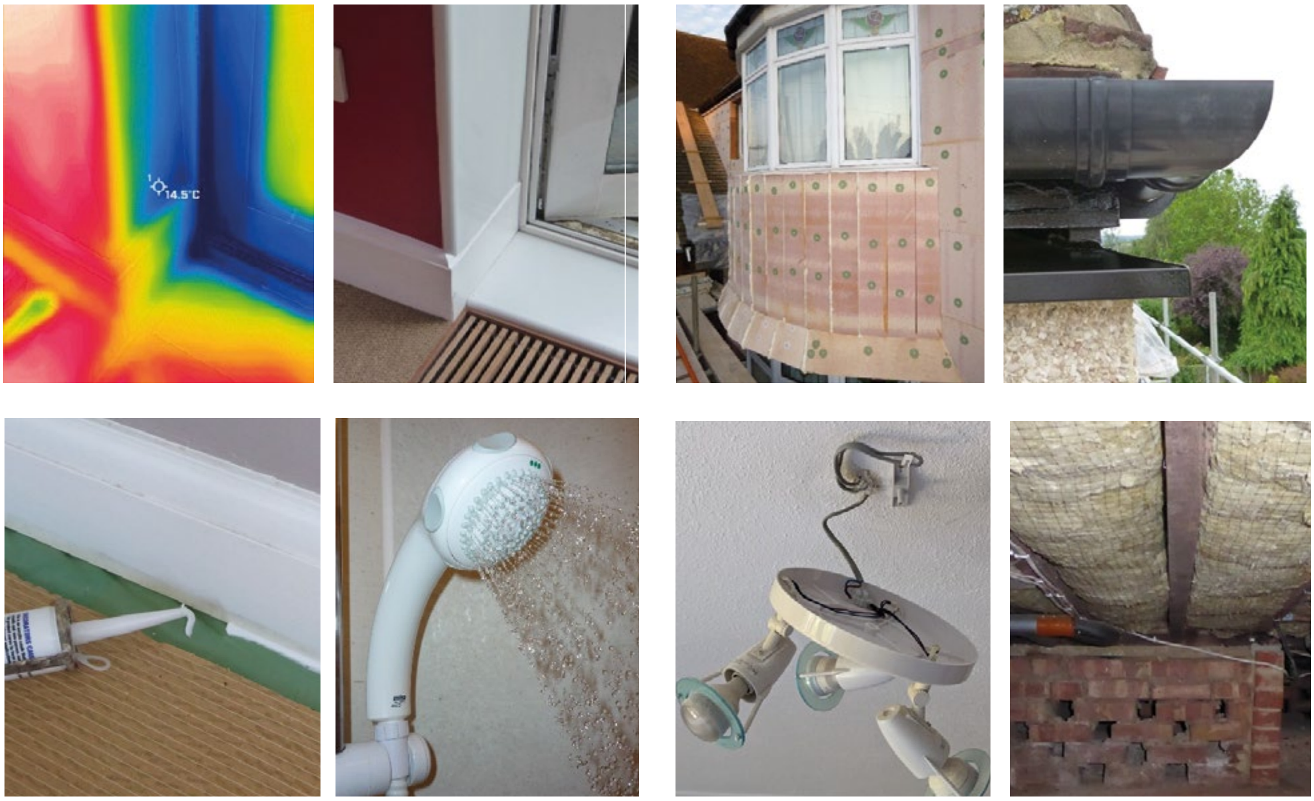
THERMAL BRIDGE TREATMENT

Thermal imaging was used to identify and prioritise treatments. Various details were developed, such as 18mm foamed uPVC (fascia) boards on the more moisture attracting window reveals (Figure D.10) and EPS covings in rooms exposed to eaves thermal weak points. It was disappointing to find that the EWI introduced added thermal bridging, particularly for the detailing around complex bay window forms, at wall head aluminium flashing details, and above existing flashing details, all of which could have been designed out.

HEATING SYSTEM

The previous gravity circulation gas boiler system was upgraded to microbore condensing boiler some years ago. All the original 1970s radiators have been retained. Hot water demand has been reduced by some 40% by installing low-flow shower heads served from the retained 110 litre cylinder. The heating flow temperature has been set at 50˚C for recent winters, providing confidence for a future heat pump switchover.

Figure D.10
Details of energy efficiency measures



Clockwise from top left: Thermal camera used to identify thermal bridging. Same detail with foamed UPVC facia board installed on reveal. Complexity of EWI on front facade. Thermal bridging capping detail unfortunately introduced at top on EWI. Airtightness sealing of skirtings onto PVC sheet strip overlapped with carpet underlay. Low water flow shower head. Sealing electrial wiring below loft. Insulation to suspended ground floor.

D

D.4 CASE STUDY
Low-disruption below floor insulation

Figure D.11 Example home with floor insulation

Case study:	180 homes[126]
Technology:	Installation of suspended ground floor insulation using remote control robot
Scope of works:	
Pre-survey for moisture and cavity condition Forming access hatch and spray application BBA/KIWA Certification and Works warranty Post-installation performance monitoring	
Installations to date:	More than 3500
Typical insulation thickness:	120 mm
Energy use:	Actual heat loss found to be about 45% less than the RdSAP/SAP assessment:
System developer:	Q-Bot

SUMMARY

Case study of 180 different homes from across England and Scotland retrofitted with spray thermal insulation below their suspended ground floors, applied using a small remote-controlled wheeled robot. This provides both high levels of thermal insulation and airtightness to the underside of the floor while maintaining the functionality of the ventilated cavity below. The results show that this measure reduces heat loss by 77% through the floor and cold draughts by 1/3 for the whole house.

A key feature is the reduced disruption to the rooms above and its quick installation time. It illustrates the potential for use as part of a quick turnaround whole house package of fabric and systems upgrades.

THE INSTALLATION SYSTEM

The application system consists of a four-wheeled remote controlled spray applicator, controlled via an umbilical cord by a manual control, with dedicated specialist software. A comprehensive pre-installation survey checks for any existing moisture and ventilation defects, so they can be rectified before application of the insulation.

The layer of high-performance foam creates a hydrophobic barrier between the floor and void. The material used is a closed cell spray foam, supplied by BASF called Elastospray which is tailored to this application. This thermal insulation is intended to raise the temperature of the floor structure and reduce the risk of condensation.

By reducing uncontrolled outdoor air infiltration via the floor, it is important to check there is adequate alternative ventilation inside the home. Agrement certification outlines the checks for this, as well as the existing fabric moisture levels that are needed. The system has been developed in the UK with the support of BEIS and InnovateUK. It is an approved ECO funded solution and has had its results verified by the Energy Savings Trust, and is fully accredited by BBA, PAS and TrustMark.

Figure D.12 Remote control applicator in use

CASE STUDY

The case study is based on a wide range of housing types, different ages and sizes from Camden Council, Abri Group, The Guinness Partnership, Curo Group, Dane Housing, Hexagon Housing association, Castlehill Housing Association, Argyll Community Housing Association, Langstane Housing Association, Stonewater, Flagship Group, Aston Group, Oxford City Council, Osborne Energy, Link Housing Association, and Midas Group.

The U-values for both pre- and post-installation conditions, were calculated using actual measurements of the floors, vents, perimeter walls and physical site conditions for the 180 homes (in accordance with ISO 13370:2007). The pre-installation U-values for the floors were, on average, 0.84 W/m^{2}K and post-installation were 0.19 W/m^{2}K, hence the 77% improvement.

Occupant feedback was good, with 100% saying they were 'Satisfied' or 'Very Satisfied' with the installation in terms of disruption, and 90% scoring 7 or higher for likelihood of recommending the system (where 1 stood for 'not at all' and 10 for 'highly recommend').

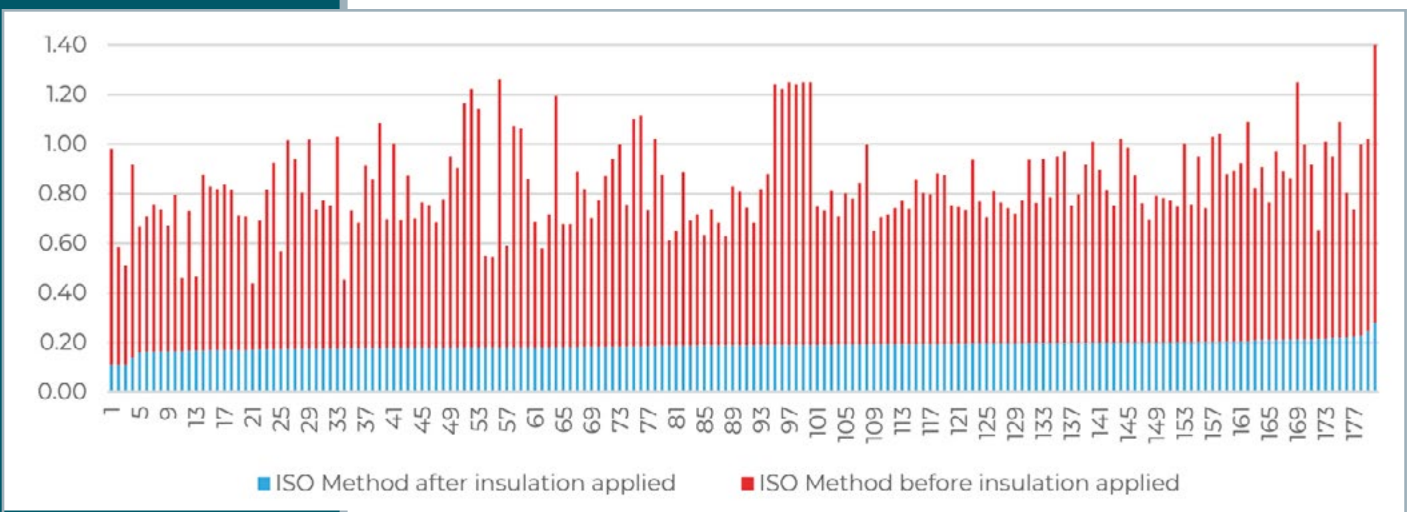


Figure D.13 measured floor U-values before and after installation for the 180 homes

FUTURE POTENTIAL

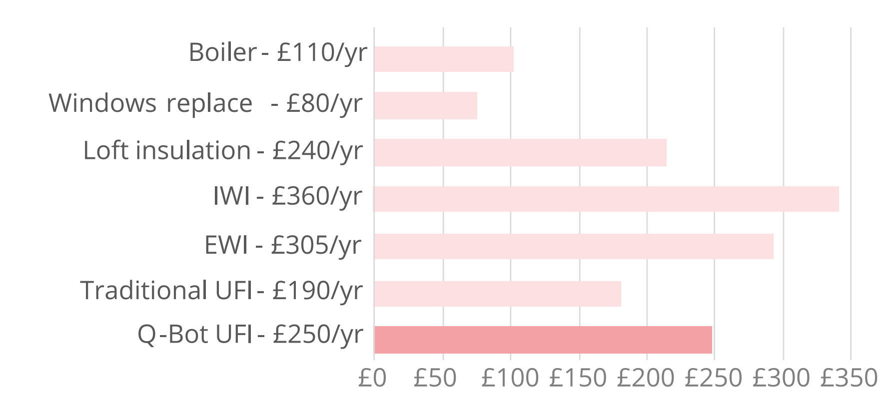
The Q-Bot technology is relatively new, but with considerable potential to scale up. Currently, an installation team would typically treat one house per day. If the installation was integrated into the work of a single whole house retrofit team, with a continuous stream of local sites, there is the potential of using this system on as many as four home installation per day. This would significantly increase productivity, reduce retrofit overheads, and pull down the overall costs.

Figure D.14
Key Outcomes From The Programme of Works

Measurement	Floor heat loss (U-Value) W/m².K	Draughts (Air Permeability)* m³/m².h @50Pa	Space Heating Requirement kWh/yr
Before (average)	0.85	15.6	12,170
After (average)	0.19	11.0	10,260
Reduction (ave.)	77%	30%	16%

*An average was used when specific results were not available

Figure D.15
Average Annual Energy Savings (£ saved/year)



D.5 CASE STUDY
One-stop-shop retrofit programme

Figure D.16
Image © Arturs Budkevics/Dreamtime

Case study:	One-stop-shop retrofit service[127]
Location:	Republic of Ireland
Roll out:	2022 start
Extent:	25% of national housing stock by 2030
Energy target:	BER rating

Scope of works:

- Initial assessment survey and report
- Grants and finance options
- Management
- Fabric and systems upgrades
- Quality assuring the work

SUMMARY

A complete retrofit start-to-finish solution for the householder, through a government certified list of 'One Stop Shops' subsidised by generous grants. Homes built before 2010 have to commit to achieve a deep upgrade, getting the property to a minimum energy standard. Estimated costs to upgrade are €14,000 - €66,000 per home.

This government programme aims to deliver 500,000 home energy upgrades to Building Energy Rating (BER) B2 standard, by 2030. This is approximately 25% of all Irish homes (numbering 2,130,000) or to put this in perspective, equivalent to 100% of all Irish homes built before 1970 (Figure D.18).

Twelve One-Stop-Shops (OSS) dotted around Ireland are either main-contractors in their own right or organise 'subbies' (subcontractors) to do the work to standards set and audited by a regulator called the Sustainable Energy Authority of Ireland (SEAI).

They offer three elements that are currently missing from the UK retrofitting landscape: clear standards of what's allowed and how to do it; financial support for those who cannot afford changes on their own; and reassurance on whom to hire so the work is done properly. Homeowners typically receive up to half the cost as subsidy, though that percentage has fallen to 40 per cent because of inflation. The poorest households do not pay anything.

These One-Stop-Shops carry out an Energy Assessment, typically costing €600, offset by a €350 government grant (from SEAI).

The Energy Assessment covers:

- A Building Energy Rating (BER) assessment - similar to UK EPC.
- A full technical report on the energy efficiency of the home.
- Details on the energy upgrades needed to get the home to a B2 rating or better.
- A heat pump technical assessment detailing the energy upgrades required to make your home suitable for a heat pump.
- A report explaining how the recommended energy upgrades will improve the comfort of the home and help to reduce energy bills.
- An estimate of the costs of the recommended energy upgrades.

The One-Stop-Shop is contracted to deliver the energy upgrades. They take care of everything, including applying for grants, procuring, managing and coordinating the contractors who complete all the work, quality assuring the works, commissioning and handover of the project for the householder.

Figure D.17
Schedule of available grants by dwelling type

	Private Homes			
Measure	Detached	Semi-Detached / End Terrace	Mid Terrace	Apartment
Heat Pump	€ 6,500			€ 4,500
Central Heating System for Heat Pump	€ 2,000			€ 1,000
Heat Pump Air-to-Air	€ 3,500			
Heating Controls only	€ 700			
Launch bonus for reaching B2 with a Heat Pum	€ 2,000			
Ceiling Insulation	€ 1,500	€ 1,300	€ 1,200	€ 800
Rafter Insulation	€ 3,000	€ 3,000	€ 2,000	€ 1,500
Cavity Wall Insulation	€ 1,700	€ 1,200	€ 800	€ 700
External Wall Insulation	€ 8,000	€ 6,000	€ 3,500	€ 3,000
Internal Wall Insulation	€ 4,500	€ 3,500	€ 2,000	€ 1,500
Windows (Complete Upgrade)	€ 4,000	€ 3,000	€ 1,800	€ 1,500
External Doors (max. 2)	€800 per door			
Floor Insulation	€ 3,500			
Solar Thermal	€ 1,200			
Solar PV	O to 2 kWp €900/kWp 2 to 4 kWp €300/kWp			
Mechanical Ventilation	€ 1,500			
Air Tightness	€ 1,000			
Home Energy Assessment	€ 350			
Project Management	€ 2,000	€ 1,600	€ 1,200	€ 800

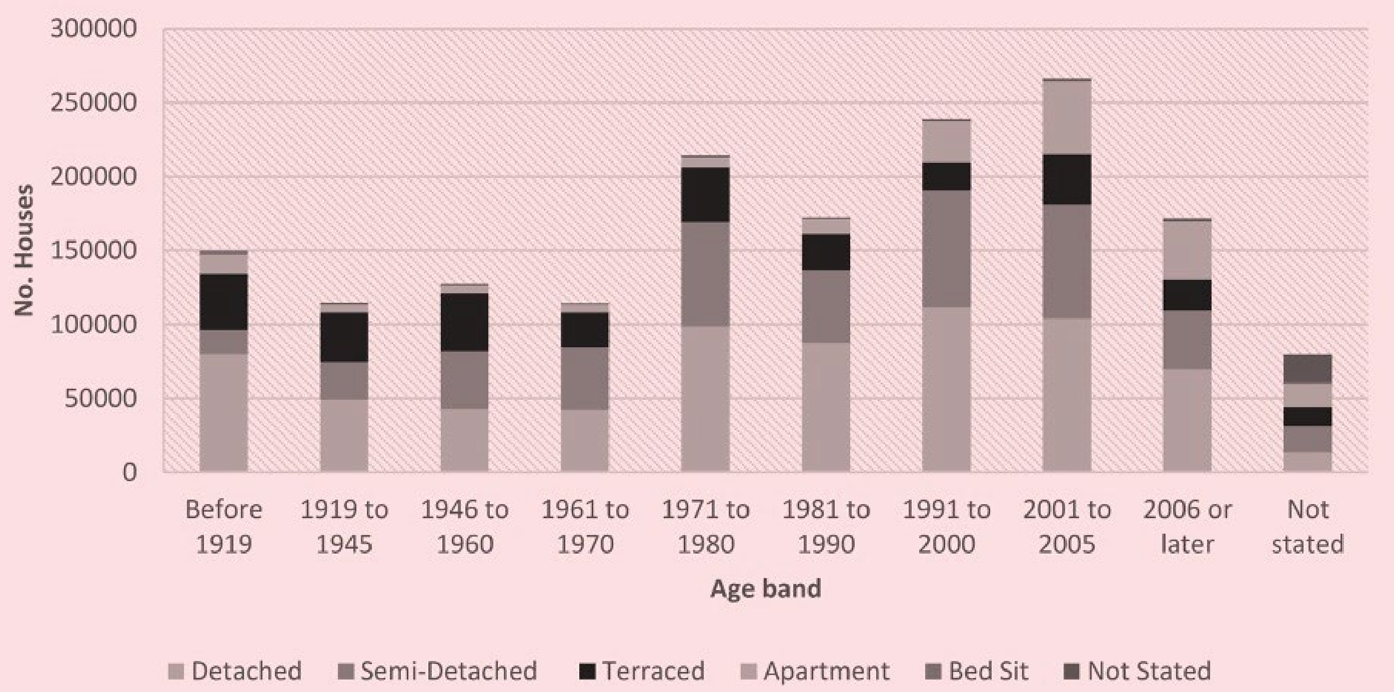
The government grants available are paid to the One-Stop-Shop to offset the cost of the work. A mid-terrace could receive €25,800, while a semi or end of terrace could receive €30,000.

If an Air-to-Water heat pump is used, then the grant contributions for achieving the B2 rating include, upgrading the central heating, roof and ground floor insulation, EWI, windows, 2 doors, mechanical ventilation, and airtightness. Additional grants are available of €1,200 for a 4kWp PV array and €1,200 for solar thermal (Figure D.17).

On finance options, the One-Stop-Shops help, and also give advice through finance partners. All Irish banks discount loans by 1% for Home Energy Upgrades. There are 100% grants for people on benefits, called the 'Warmer Homes Scheme'.

The Government programme is paid for from the National Budget and the Carbon Tax Fund. The national carbon tax is a levy of €48.50 /tonne of carbon emitted from 12 Oct 2022. The carbon tax was introduced in 2010 and is designed to progressively rise to €100 /tonne by 2030.

Figure D.18
Irish national profile of existing housing stock



Annex

E

Driving down costs

Annex E: Driving down costs

This annex explains the scope of the RETROFIT-AT-SCALE cost investigations, a summary breakdown for the various levels of retrofit, the productivity benefits identified, and a summary of the key cost findings. It also includes the BASIC 7-day site implementation programme used in the costings.

E.1 Summary of findings

Feedback following the CERG publication[128] pointed to the need for an additional low-cost alternative whole-dwelling retrofit model. The **RETROFIT-AT-SCALE** national (top-down) policy analysis indicated the retrofit cost per tonne of carbon mitigated needed to be reduced to a level comparable to offshore wind turbines for retrofit to meaningfully contribute to the UK minimum cost route to net zero carbon. Current deep retrofit costs are about three times this level.

RETROFIT-AT-SCALE assessed in detail the costs for a typical retrofit with its energy efficiency measures (Figure E.1) using the illustrative example. While the industry normally provides measure by measure cost information, this study went deeper and took apart the costs within individual measures to understand how they could be reconstituted. This helped inform a new set of optimum cost solutions (Chpt 4). It allowed a range of duplications to be removed, identified synergies to deliver greater benefits for less cost, and greatly helped the focus on how to increase productivity gains.

The cost analysis ran in parallel with, and gave a cost structure to, fabric and system design decisions. The cost input shaped the nature of these solutions, rather than simply costing the solutions that were developed. This annex lists the key opportunities and questions provided to steer and help the technical team develop solutions that represented best value for money (Figure 4.2). Overall, with these **BASIC** achieved a 70% reduction in costs (£/kWh of energy saved) compared with good practice deep retrofit (Figure 5.2).

Many of the potential cost saving opportunities affect overall system efficiency, and therefore needed an iterative process of testing to identify the best overall combinations to meet the energy saving target. This can present challenges for many in our fragmented retrofit supply chains, where the focus tends to be only on their own specific measures, with the perception that deep retrofit only requires the highest performance standards for all components. The overall cost optimum tended to involve lower standards used in combination with other complementary measures (Figure 5.1).

The focus was on identifying process improvements and product enhancements, to gain overall improved productivity. Some recommended products for **BASIC** are not currently available in the UK, and were cost benchmarked using data from countries where they are available. These were cross checked using cost-experience curves (Figure E.4). For new adaptations of already available products, the costs were benchmarked against comparable products. For certain measures where productivity benefits were identified, the labour processes and costs were examined separately from the materials costs.

Key cost findings:

- More than a third of conventional retrofit costs are in overheads, much of it buried at individual trade level.
- Costs are often not linear with energy performance. Hence upgrading from EPC ‘E’ can cost less than upgrading from ‘D’.
- The cost of measures largely relate to their extent or area, not their thermal performance.
- There are big costs gains by focusing on a very short site programme.
- Ease of installation dominates the costs, not the minimum cost of the individual measures.
- Measures to be avoided are those that open up the existing fabric and create site and programme disruption. This includes avoiding the lifting of floorboards or disturbing of the existing electrics.
- Avoid measures that require builders’ work and redecoration.
- A good initial site survey reduces the risk of unexpected site works and delay costs.
- Arriving on site with the right predetermined materials avoids site delays and reduces surplus material / waste disposal costs.
- Removing duplication and non-productive working delivers big cost savings.
- Target good plant efficiency, instead of the best. It is the fabric-first that substantially reduces the energy bills, not an additional few percent efficiency on a particular piece of plant.
- The cost sweet-spot is where the fabric-first measures go only sufficiently far to reduce heat losses to allow the existing heating pipework distribution and radiator system to be left untouched.
- There is considerable cost benefit in retaining and overhauling existing double glazing.
- An optimised heat pump switchover can be comparable to boiler replacement costs, eg avoiding: radiator and pipework changes; heat pump oversizing; electrics upgrading; a new hot water storage cupboard.
- The UK market lacks suppliers off small heat pumps and simplified MVHR units.

		Exemplar				Best Practice				Retrofit-at-Scale Basic			
Ref Nr.		Quantity	Unit	Rate (£)	Total (£)	Quantity	Unit	Rate (£)	Total (£)	Quantity	Unit	Rate (£)	Total (£)
1.00	**WALLS**												
1.01a	External wall insulation - front elevation	10.64	m²	0.00	0.00	10.64	m²	0.00	0.00	10.64	m²	0.00	0.00
1.01b	External wall insulation - side elevation	40.46	m²	87.00	3,520.00	40.46	m²	75.00	3,014.00	40.46	m²	66.00	2,650.00
1.01c	External wall insulation - rear elevation	23.80	m²	128.00	3,046.00	23.80	m²	112.00	2,654.00	23.80	m²	0.00	0.00
1.02a	Internal wall insulation - front elevation	10.64	m²	129.00	1,370.00	10.64	m²	129.00	1,370.00	10.64	m²	0.00	n/a
1.02b	Internal wall insulation - side elevation	40.46	m²	0.00	n/a	40.46	m²	0.00	n/a	40.46	m²	0.00	n/a
1.02c	Internal wall insulation - rear elevation	23.80	m²	129.00	n/a	23.80	m²	129.00	n/a	23.80	m²	0.00	n/a
2.00	**ROOFS**												
2.01	Insulation to joists	42.30	m²	41.00	1,734.00	42.30	m²	32.00	1,332.00	42.30	m²	30.00	1,248.00
3.00	**FLOORS**												
3.01	Insulation to joists	42.30	m²	72.00	3,046.00	42.30	m²	65.00	2,728.00	42.30	m²	51.00	2,157.00
4.00	**WINDOWS & DOORS**												
4.01	Windows	27.10	m²	473.00	12,819.00	27.10	m²	473.00	12,819.00	27.10	m²	20.00	542.00
4.02	Doors	4.00	m²	473.00	1,890.00	4.00	m²	473.00	1,890.00	4.00	m²	40.00	158.00
5.00	**GENERAL ENVELOPE**												
5.01	Thermal Bridging	85.00	m²	20.00	1,658.00	85.00	m²	15.00	1,233.00	85.00	m²	13.00	1,063.00
6.00	**AIRTIGHTNESS**												
6.01	Advanced draughtproofing etc.	85.00	m²	33.00	2,805.00	85.00	m²	33.00	2,805.00	85.00	m²	23.00	1,913.00
7.00	**MEP**												
7.01 +02	ASHP + DHW	85.00	m²	108.00	9,157.00	85.00	m²	108.00	9,157.00	85.00	m²	43.00	3,645.00
7.03	ANCILLARIES	85.00	m²	71.00	6,053.00	85.00	m²	71.00	6,053.00	85.00	m²	3.00	253.00
7.04	MVHR	85.00	m²	46.00	3,901.00	85.00	m²	46.00	3,901.00	85.00	m²	20.00	1,734.00
8.00	**ANCILLARY PROJECT COSTS**												
8.01	Temporary protection	85.00	m²	3.00	255.00	85.00	m²	3.00	255.00	85.00	m²	3.00	255.00
8.02	General redecorations [or not required]	5.00	days	560.00	2,800.00	5.00	days	560.00	2,800.00	0	days	560.00	0.00
8.03	Management + design + surveys + supervision	50.00	days	250.00	12,500.00	35.00	days	250.00	8,750.00	4.00	days	250.00	1,000.00
8.04	Scaffolding	113.00	m²	14.00	1,588.00	113.00	m²	14.00	1,588.00	43.00	m²	14.00	613.00
8.05	Temporary welfare facilities	1.00	item	950.00	950.00	1.00	item	520.00	520.00	1.00	item	100.00	100.00
8.06	OH&P	5.00%	%		3,455.00	5.00%	%		3,143.00	5.00%	%		866.00
8.07	Contingency (excluded)	0.00%	%		0.00	0.00%	%		0.00	0.00%	%		0.00
	TOTAL				**£72,546.00**				**£66,012.00**				**£18,196.00**
	Assumed site duration:				9-months				6-months				1-week
	Costs current at Q1 2022 prices Costs exclude VAT.												

Figure E.1
Cost breakdown and comparison between Basic retrofit with cost efficiencies applied and CERG Exemplar and Best Practice. (CERG 'Constrained' was not used because compared with Best Practice the costs did not significantly vary).

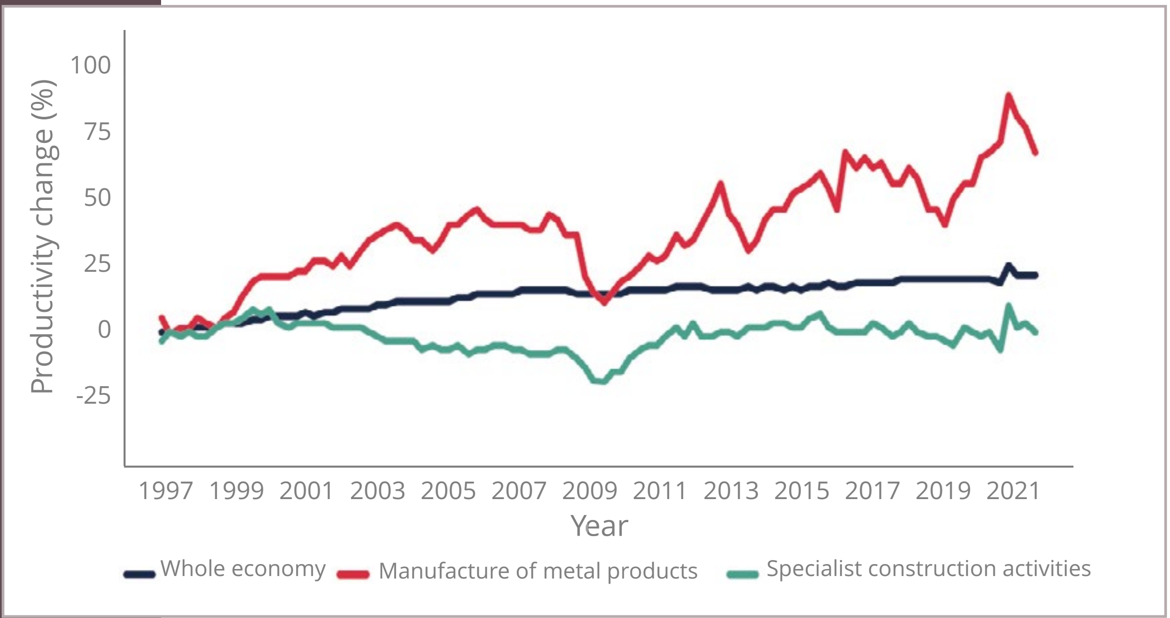
E.2 Industry productivity

Home energy retrofit, as typified by the heat pump installation sector, has not improved its productivity in over 25 years, unlike for instance the manufacturing sector or the wider UK economy (Figure E.2). This suggests there is a large latent potential to improve. Improving productivity means finding different, more efficient ways of installation. **BASIC** aims to demonstrate how increased productivity can be delivered, making the installation simpler, integrated into a coordinated package, including fabric and systems, all with reduced installation overheads. This particularly includes a very short installation period, allowing fewer tradespeople to complete more home retrofits.

Supply chains also need to rapidly evolve for a new mass roll-out market. By way of an example, to date most heat pump installations for single homes have been large units for larger properties (Figure C.4). There are considerably more homes in the UK of average and smaller size with smaller heat demands that would benefit from smaller unit sizes.

There is considerable duplication and non-productive costs buried within normal working practices as identified by the practitioners contributing **RETROFIT-AT-SCALE**. For instance, individual trade contractors would typically send their own personnel to do their own site surveys, done only following the completion of works by the previous trade, hence with delays between one finishing and the mobilising of those following. The inability to change this largely relates to separate contracts, with separate responsibilities and liabilities, between contractors.

Figure E.2
While manufacturing productivity has generally improved, construction installation productivity has not.[129]



Numerous responsibility gaps tend to occur between the contracted parties. For instance, the installer of the heat pump will oversize it because they cannot rely on the thermal insulation performance provided by another trade. Likewise, there tends to be similar fragmentation between the various involved professionals. Each contractual party will also have duplicate management functions for their own marketing, the lining up of the next project, billing functions, etc. The end result of this multi-contract arrangement also includes no single point of contact and responsibility available for the householder. To use the car analogy, we supply the client with wheels separate from the motor and expect someone else to take responsibility for making sure they run together.

Many of the productivity gains are counter-intuitive for individual trade contractors. Hence as examples, reducing the heat pump size and avoiding new radiators by adding some insulation; using a more expensive PCM heat battery so builders' work then becomes unnecessary; or the installation of an MVHR unit to allow simplified fabric measures. What **RETROFIT-AT-SCALE** brought to this was a commercially non-aligned focus for making the complete retrofit extent and works simpler.

The biggest single productivity gain and hence cost saving, came from the site programme duration reductions, as a result of coordinating site tasks and selecting measures that could be implemented in quick succession and in parallel. Also critical for delivering achieving this is ensuring all the information needed by all the site parties is available before arrival at site. This means the site programme is driven by simple physical logistics and not by information flows and mobilisation delays (Figure E.3).

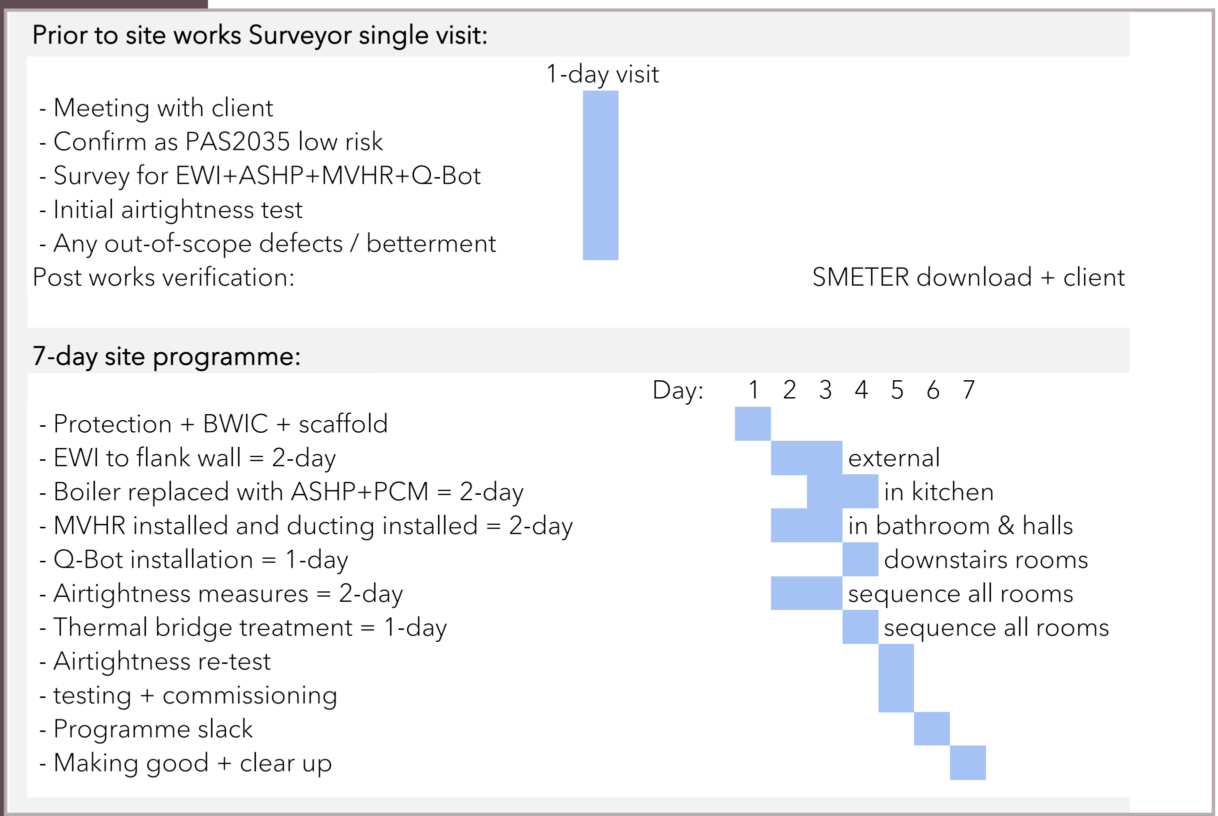


Figure E.3
BASIC 7-day energy retrofit and heat pump switchover site programme.

E.3 Separating maintenance, betterment & energy retrofit

The challenge for allowing energy retrofit costs to be interrogated, is being able to separate them from conventional cost information that includes site works for other purposes. Most case-study cost information, such as those in the CERG Chapter 6 include dwelling 'betterment' of home amenities, in addition to the energy retrofit works. These would often involve room rearrangements, adding floor area, new kitchens, roof covering replacement, fixing the rainwater goods, and the like, that are not directly related to energy efficiency improvements. Consequently, there is the need to be able to identify three separate different categories of retrofit intervention, namely:

1. **Legacy maintenance costs**
2. **Accommodation betterment costs**
3. **Energy retrofit direct costs**

RETROFIT-AT-SCALE specifically focuses on the energy retrofit direct costs. For this reason, an elemental cost breakdown approach was used to separately identify the costs of each, with the case-studies only used for overall benchmark checks. This was done for three different levels of energy retrofit (Figure E.1).

Industry tends to present the associated overhead costs as a combined percentage markup across all the works. Disaggregating these is important because typically there are numerous duplications and avoidable non-productive aspects buried within them. These are significant because more than a third of conventional retrofit costs are typically overhead related, either at the project level, or as a larger proportion if the specialist trade contractor overheads are also considered. In addition, as Annex B.1 outlines, there are serious unintended consequences, in terms of increased performance gap and loss of energy savings, if certain overheads are simply reduced or removed. There is a clear logic in taking a proportion of the energy savings normally allocated to individual measures, and instead allocating them to various of these overheads, including site coordination and supervision, the initial survey, the verification processes, etc. This then allows a cost-value assessment to be made based on how much performance-gap is acceptable in return for how much is invested in overheads. While best-in-class retrofit overheads are high, the performance gap is least. On the other hand, reducing the overheads to a minimum ends up with the measures installed simply delivering perhaps a halve of the energy savings predicted. **BASIC** aims for a mid-value in this cost-value equation (Annex F.2).

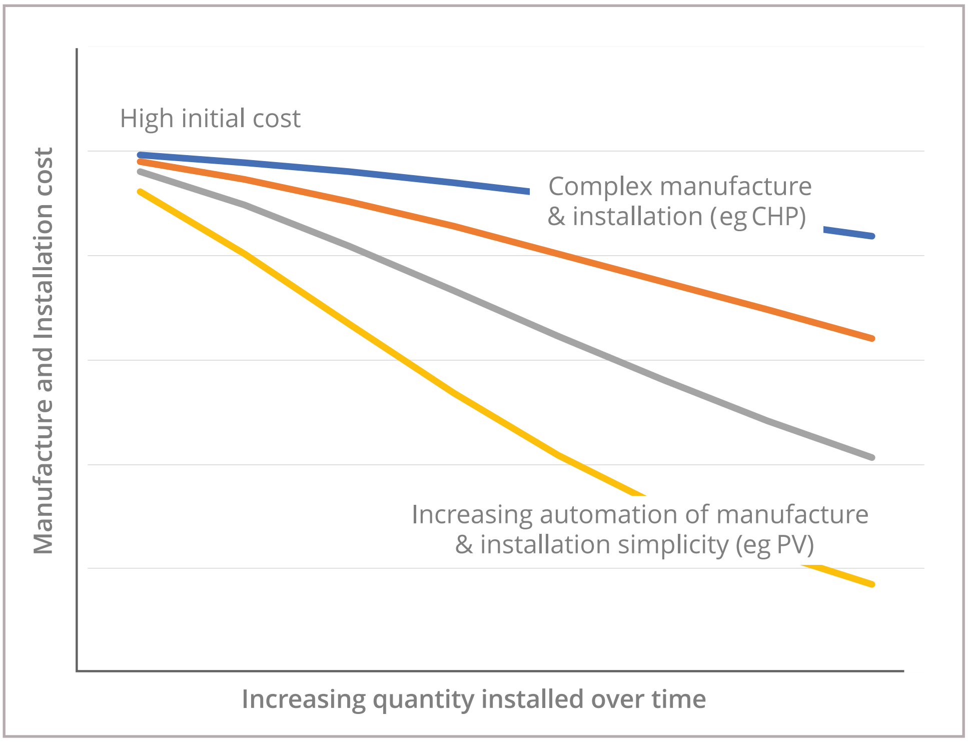
E.4 Assessment of future costs of innovation

Cost Experience Curves are used to gain an indication of how the cost of innovative products and services can be expected to reduce as production scales up and enters the mass market (Figure E.4). This cost reduction profile over time is illustrated in practice by the likes of photovoltaic materials and installations, where their combined cost has fallen by more than 75% in the last 10 years[130]. But not all cost experience curves are equal, and they are also influenced by the market context they are selling into, namely:

- **repetition of fundamentally the same product - in other words ensuring the bulk of the market is geared up to accept a limited range of products, standards, or kit-of-parts.**
- **good product performance feedback process - to allow products and their production process to evolve and simplify, on the back of a sufficiently sized market potential.**
- **a clear long term national policy framework - to provide investment confidence that the market will expand as intended.**

There are different curves for different types of products with different characteristics which drive costs down to different degrees. Curves are available for a wide range of energy products, normally derived from similar product rollouts elsewhere[131 132]. Higher levels of product complexity and limited implementation volumes tend to mean the cost experience curves are flatter, with less cost saving potential. The curve can also be divided into the component for the supply of the product, separate to the installation cost.

Figure E.4
Cost Experience Curve once beyond the initial innovation cost hump and as the quantity reaches mass rollout numbers, the costs tend to fall following a curve reflecting the product complexity.



For new and innovative products where there is little in the way of UK cost data, **RETROFIT-AT-SCALE** has referenced these curves to establish adjusted costs to reflect mass rollout prices beyond their initial innovation and market establishment cost hump. These projected costs have then been robustness priced checked, either as manufactured components or combined with local installation, against other countries where similar products are already available. For the **BASIC** costs these were applied to the products themselves and not the installation labour costs, with the latter already accounted for in the programming cost savings.

E.5 Cost considerations

INPUT FROM SUPPLY CHAINS

- Cost-value breakdown within individual measures
- Costs for key ancillary components instead of industry norms for mass archetype (e.g. edge detail costs separate from area costs for EWI)
- Identify separately costed enabling tasks required by others.
- Specific site period reduction opportunities
- Identify duplicate and process inefficiency costs
- Identify where a measure enables other measures improvements.
- Balance of benefits/costs for whole-dwelling, cost / value sweet-spot
- Make full use of what is existing as this minimises embodied carbon.
- Focus on solutions suitable for the majority of UK homes, including space-constrained homes, not the full deep retrofit solutions.
- Reflect likes/dislikes feedback from householder research.
- Design life of components of about 15 years after which many would be normally renewed, redecorated, and upgraded.
- Avoid most of stripping out and subsequent making good costs.

PROCESS ASPECTS

- Ensure client single point-of-contact and reduced iterations.
- All surveying for all trades to be done by single person to avoid duplication.
- All survey and measures done at one time to minimise costs.
- Multi-skill site operatives, particularly M&E building work in connection (BWIC).
- Combined professional roles (architect, retrofit coordinator, site management, etc).
- Limited kit-of-parts standard solutions with standardised archetype options to select from.
- Greatly shortened site programme has large overheads cost benefit (also eliminates decant costs).
- Minimum whole life cost is achieved when BASIC measures area implemented as a single stage.
- There are added costs for phasing subsequent upgrades to Best Practice in terms of higher management, design, and verification costs.
- Added cost option for adding additional finishes, concealed ducting, etc.
- Clear separation into three different cost categories:
    - Energy retrofit direct costs
    - Legacy maintenance costs
    - Accommodation betterment costs

BASIC costs only consider energy retrofit costs.

FABRIC ASPECTS

- Iterative process with fabric, services, managing and cost workstreams.
- Quickly learn what are appropriate kit-of-parts.

- Testing options for allowing radiators not to need upgrading.
- Maximising roof space insulation thickness is an easy win. Should include eaves vent and wind-wash protection.
- Avoid works that require roof relaying work costs.
- EWI generally preferable to IWI based on cost.
  - IWI has internal disruption and programme additional costs.
  - Use existing fascia overhang and avoid adding EWI flashing.
  - Avoid EWI to front façade with its added detailing and costs (also avoids streetscape, planning, and conservation and associated delay costs).
  - Avoid going below Damp Proof Membrane (DPM) – as ground floor insulated above vented cavity (for solid floors an alternative strategy may include EWI insulation below the DPM)
- Overhaul existing double glazing
  - Replace to triple glazing only at end-of-life at subsequent retrofit stage - costs expected to fall in future).
  - Focus on replacing hinges on existing double glazing to recover as new performance of gaskets.
  - Inserting trickle vents where there are none is problematic in warranty and practicality terms.
  - Inserting the larger trickle vents required by recent Building Regulations Part F:2021 changes is problematic.
- BASIC MVHR for:
  - Assures ventilation with higher airtightness and lower room moisture levels
  - Allows the use of higher performance closed cell thermal insulation.
  - Reduces treatment and extent of specific thermal bridge treatments (returns to party walls, etc.) as room relative humidity (RH) is consistently lower.
  - Allowing the use of lower surface temperature factor (fRSi).
- Big low-cost energy gains with enhanced airtightness – enabled by MVHR.
  - Pre-works airtightness testing identifies hierarchy of leakage points.
  - Light-touch measures to avoid redecoration, BWIC, programme, and disruption costs.
  - Optimum target of 3ach@50Pa test pressure.
  - Post-works testing provides rapid feedback and process improvement and upskilling.
  - Consider the use of simpler pulse test – providing it also includes leak location information.
- Below ground floor insulation:
  - Big insulation gain and airtightness gain.
  - Cost model based on Q-Bot, but on basis of two back-to-back installations a day, for reduced disruption and programme costs compared with alternatives.
  - Big scale up potential needs a competitive market and more back-to-back installations for full cost benefits.
- Added cost for reduced environmental impact materials to be identified separately as extra to BASIC.

SYSTEMS ASPECTS

- Iterative process with fabric, services, managing and cost workstreams.
- Fabric enhancements only as far as needed to allow system reuse.
- Avoid measures that disrupt the existing M&E (eg: IWI need electrics and radiators moved)
- Avoid interventions that need any house electrical installation upgrade:
  - Allow for future electrical cooking switchover, but not part of BASIC.
  - Allow for future car charging (and demand management), but not part of BASIC.
  - Avoid direct-electric heating
  - Focus on reducing peak demand and heat pump sizing.
  - PV, batteries, low energy lighting. etc., assumed to be future upgrade options.
- Reuse existing radiator system and pipework distribution.
- Flush and reuse piped distribution from boiler.
- Include for pipe flushing and flow rebalancing.
- PCM Heat Battery instead of DHW hot water cylinder:
  - Allows installation into removed combi boiler wall space.
  - Avoids space loss, BWIC, pipework, electrics, and cylinder cupboard.

- 128 litre equivalent capacity PCM with integral immersion backup.

- Reuses combi boiler pipe connections and power supply.
- Replace shower head with high performance low-flow type to reduce hot water demand.
- DHW expansion vessel not required because unvented water heater is below 15 litre.
- Avoid damaging existing finishes and redecoration and BWIC costs and added programme costs.

HEAT PUMP

- Air source heat pump most practical and cost effective.
- Sized at ~50% of MCS calculations, with trickle recharge of DHW heat battery.
- Lowered heating bills because of fabric and DHW efficiency improvements. Maximising heat pump efficiency is a lesser issue. Upgrade efficiency at 15-year normal replacement.
- Lack of UK examples small enough so cost assumptions and technical specifications benchmarked against off-the-shelf units sourced from China.
- Monoblock to avoid F-gas working premium.
- Inverter driven so buffer vessel not required.
- Pipes to heat pump through vacated flue opening.
- Wall mounted to avoid losing garden space / minimise pipework.
- '2-day' boiler strip-out + heat pump installation process.

SIMPLIFIED MVHR

- Sized to meet Building Regulations Part F minimum air volumes.
- Ceiling mounted inside thermal envelope to avoid duct thermal insulation and loft health and safety (H&S) access facilities and avoid BWIC for MVHR cupboard.
- Sized at low-speed to minimise acoustic treatments.
- 75-85% heat recovery efficiency
- BASIC unit without summer bypass reduces unit size and cost. Ceiling fans were a cheaper option and delivered more cooling effect, and could be retrofitted separately from BASIC.
- Fit-and-forget constant volume control + filter alarm.
- Cost assumptions and technical specifications benchmarked against off-the-shelf units sourced from China.
- Ductwork standard rectangular white plastic off-the-shelf surface mounted.
- System layout to minimise ductwork length. Nozzle air supply grilles use Coanda effect to avoid ductwork in any ceiling / floor voids.
- Risers inside stairwell to avoid cutting through floors / joist hopscotch.
- Installed system tested to verify Part F air flows.

OVERALL COST ASSUMPTIONS

- Cost baseline is first quarter 2022.
- Excludes VAT. Assumed 0% VAT rate for achieving certified 65 kWh/m^2/yr energy target.
- 85m^2 dwelling as illustrative example archetype.
- Assumes 7-day site-works for BASIC.
- Assumes trade contractors have continuous workstream without downtime between dwellings.
- Where proposed components not currently available, uses comparable products from abroad and benchmarks these using experience curve learning.
- Where proposed components are 'close to' market, uses comparable product costs.
- Comparative costs for CERG Exemplar (eg EnerPHit) and CERG Best Practice (eg AECB CarbonLite Retrofit based on similar elemental cost breakdowns. These do not include BASIC cost savings, albeit some could be adopted by them in future.
- CERG Best Practiced 'constrained' was not considered beyond an initial review as the costs as essentially similar to Best Practice un-constrained, but will reduced energy savings.

E

Annex

F

National stock model

Annex F National stock model

The housing stock model used Retrofit-at-Scale is derived from the Cambridge Housing Model (2011). It also include updates based on subsequent English Houses Surveys and scaling factors appropriate for including Wales and Scotland. The model then clusters similar archetypes to reduce their number from over 14,000 to 486.

The energy profiles of these archetypes were modelled using a modified PHPP methodology. This allowed varying indoor temperatures, reflecting many existing homes not being uniformly heated to expected set-points. This permitted demand predictions to be reconciled against national supply energy data. Alterations to this model have also been made on a stock level to factor in a proportion of empty houses. For more information refer to the LETI Climate Emergency Retrofit Guide (CERG) [133].

F.1 Development of stock model

The CERG further narrowed the stock down and presented targets for five main architypes based on building form. **Retrofit-at-Scale** originally sought to add an additional level of detail to each of these architypes but identified factors other than built form, largely drove retrofit costs. These included the initial energy efficiency condition, heritage factors, indoor/outdoor space needed by heat pumps, and factors driven by occupants' preference (Annex A) and tenure.

While some of these could be factored into the stock model using information from the English Housing Survey with its correlation against EPC ratings and their loosely implied energy use levels, this proved more problematic when using a stock model based on PHPP modelling with its separately defined kWh/yr levels.

It also quickly became clear that the level of effort needed to examine six different architypes down to a level to be able to propose alternative design and cost approaches for each variant (with the non-building form variants), was beyond the resources available to the **Retrofit-at-Scale** team.

Instead, **Retrofit-at-Scale** focused on a single hybrid 'average' architype to which most of the identified difficult-to-retrofit features are added (Annex B.2). This allowed Retrofit-at-Scale to offer a unique perspective with different opportunities by way of the '**BASIC**' retrofit approach, rather than industry standard expectations on design and costing.

Thus, an assumed set of **BASIC** retrofit measures were applied to the stock model outputs. Various deployment scenarios were evaluated for the existing baseline, and for various **BASIC**, Best Practice and Exemplar retrofit combinations. The aim was to find a realistic and cost optimum combination for achieving the 50% reduction in heating demand averaged across the stock.

It is acknowledged there is scope to improve this modelling in future by doing a separate review of retrofit measures and costings for each of a wider variety of architypes and retrofit constraints

Compared with the CERG modelling, the 'Do minimum' option is replaced by **BASIC** with its performance improvement and lower costs. The Exemplar retrofit is roughly equivalent to Energiesprong and the EnerPhit standard 'Component Method'. Best Practice is roughly equivalent to the AECB

Retrofit, albeit AECB Carbonlite now permits a wider target range. The CERG Best Practice 'Constrained' target is omitted because **BASIC** can accommodate most of these at a lower price-point..

Different Performance Gap factors and a Comfort Takeback factor are applied to each level of retrofit at the housing stock level as follows.

F.2. Performance Gap

Differing levels of performance gap factor reflect the level of quality assurance, site supervision, and verification levels applied during the works[134]. This research indicates the gap between predicted energy performance and actually delivered performance varies from as much as 40% expected for Part L implementation without post-works measured verification, through to an average close to zero for Passivhaus and Exemplar retrofits where post-works monitoring is the norm. Using this data to interpolation gives indicative performance gaps as follows that were used in post-processing of the stock model outputs:

- 0% for the Exemplar retrofits
- 8% for the Best Practice, and
- 16% for the BASIC - if includes post-works energy monitoring using SMETERs[135]

F.3 Comfort Takeback

The Comfort Takeback factor reflects the reality that insulating a home tends not to deliver the expected energy savings. There is a natural 'rebound effect' because some of the energy savings are, in effect, taken as increased comfort temperatures. Uninsulated homes are more difficult to heat and lose temperature more rapidly. Hence, occupants tend not to heat them to the ideal temperatures, or for the durations, assumed by the energy modelling tools, most of which were originally developed for assessing well insulated and fully comfortable homes. If the pre-retrofit energy use is low to start with, there is less energy savings that can be delivered post-retrofit. This Comfort Takeback factor tends to increase when fuel costs are high.

To establish a stock level Comfort Takeback average factor, national statistics for actually delivered energy[136] were compared with the stock model PHPP analysis predictions. The modelled analysis was found to over predict energy use for the largely uninsulated national stock by about 10%. Thus, nationally there is 10% less energy being used and hence not available to be saved. This was taken as representative of a Comfort Takeback factor and was applied in the **RETROFIT-AT-SCALE** modelling. It was applied to all retrofit levels because any of these could have been under heated pre-retrofit.

F.4 Addressing Heritage constraints

The CERG identified a UK housing stock comprising some 28 million homes, of which roughly 25% or 7 million are assessed to have heritage or architectural constraints (CERG Figure 3.1). **RETROFIT-AT-SCALE** proposes than many, if not all, could have a **BASIC** level of energy retrofit applied to them. In particular, one of the **BASIC** research outputs is that external wall insulation on the front façade is often unnecessary, so it could be used in many heritage situations, and particularly in conservation areas.

The 25% figure assumes all housing built before 1900 (11.7%) and some homes built after 1900 (13.4%) would be heritage or architecturally constrained, with 10% of these listed or within Conservation Areas. There are 10,000 conservation areas in England with each council having at least one. Some authorities such as Bath, Westminster, Kensington & Chelsea and Islington have more than 50% of their area within Conservation Areas. Not all of these are constrained as evidenced from 'Conservation Area Building Audits', a building-by-building audit being undertaken by Historic England in all Conservation Areas.

RETROFIT-AT-SCALE assessed the other 15% of homes and observed that some were not in their original condition or have some features leading to the constraint classification. The assessment identified opportunities for retrofitting improvements, including measures like internal insulation.

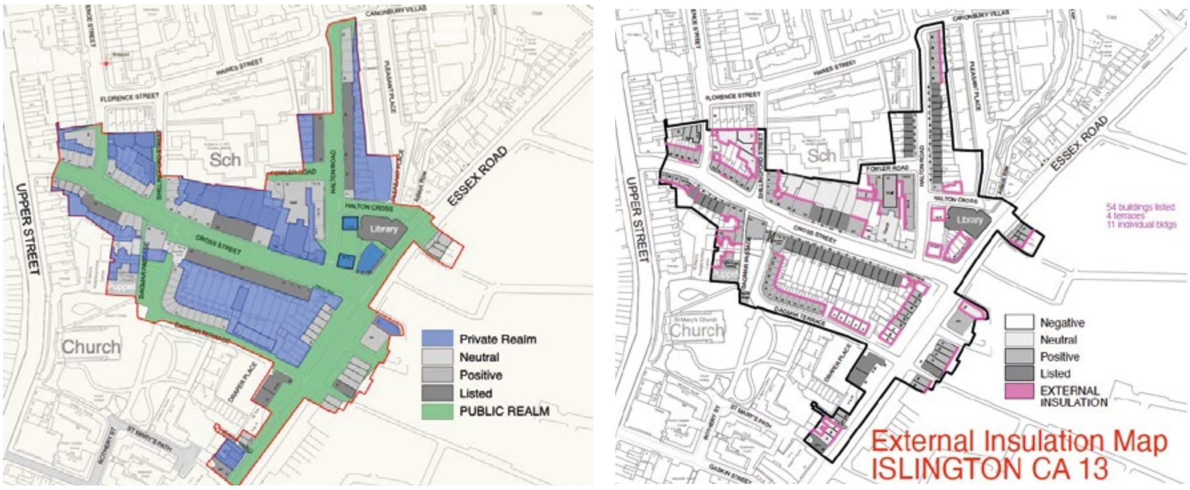
Reviewing the 10% of homes within conservation, not all of these are constrained as evidenced from Conservation Area Building Audits. Historic England has advocated undertaking building-by-building auditing in all Conservation Areas. A few Local Authorities have started using a more accurate assessment system to rate buildings in Conservation Areas as Negative; Neutral; Positive and Listed buildings. This system identified that many buildings in conservation areas are Negative or Neutral with no heritage constraining features. These assessments suggest that retrofitting can be applied to homes that were previously assumed to be constrained.

Conservation Area ACAN case study with 173 buildings found:

- **22% - Unconstrained -18 Negative Buildings, 14 Neutral Buildings, 6 Positive Damaged.**
- **78% - Constrained - 81 Positive Buildings and 54 Listed Buildings.**

The ACAN Climate Emergency Conservation Area Toolkit[137] provides in-depth research into the possible nature of constrained properties remaining. The Toolkit advocates a more detailed Building Element Audit which shows further opportunity for deeper retrofit. Analysis of external walls, windows, roofs, solar opportunities, and projecting features gives more understanding of possible retrofit.

With regard to external wall insulation, an appreciation of Public vs Private Realm is needed. Street Frontage, for example, is in the Public Realm, while the rear can be considered Private Realm and should not be constrained (Figure F.1). The ACAN study conducted actual public and private mapping of walls for the case study area. This found the unconstrained wall area to be 44% of all walls, with 56% of all walls constrained due to listed buildings and fronts of Positive rated buildings. This allows deeper retrofit such as external wall insulation and replacement of windows.



Blue = private
Green = public realm

44% walls are Unconstrained

Figure F.1
Conservation area case study illustratingh the extent of Private Realm, indicative of where energy improvement measures are possible.

The actual window conditions and heritage harm are important factors. Retrofit offers the opportunity to avoid heritage harm while upgrading fabric even for listed buildings. Historic England provides guidance on making changes to windows in listed buildings. One of the principles includes;

"Where historic windows have been replaced with ones whose design does not follow historic patterns. These are unlikely to contribute to the significance of listed buildings. Replacing such windows with new windows of a sympathetic historic pattern, whether single or incorporating slim-profile double- glazing, may provide an opportunity to enhance the significance of the buildings."

So even on listed homes some windows may be replaceable.

Careful analysis of conservation areas such as the ACAN study found that many retrofit elements are indeed possible, and most homes can therefore achieve at least **BASIC** level of retrofit delivering 65kWh/m^2 annual space heating demand. Overall, the conclusion is that all but about 2% of the heritage constrained 25% of homes could achieve this level using a variety of combinations of energy measures. These will likely all need specialist professional advice for ensuring the appropriate combination of energy efficiency measures, and for assessing what heritage components need safeguarding.

The ACAN case study also looked at roof areas and found:

- **31% - of roofs were suitable now for unseen solar.**
- **49% - of roofs were not original with half of these able to have new roofs.**

Current planning policy locally for street visible photovoltaic panels, exterior wall insulation, or window replacements requires planning permission. This can hinder their implementation, even before consideration of its heritage impact[138]. However, policies are evolving rapidly with many councils committed to rewrite Local Supplementary Planning Guides to permit the controlled implementation of such measures.

F.5 Proportions of different upgrade levels for national stock

Deployment rates across the housing stock were assessed for a set of different scenarios. An iterative process was used to test a range of top-down options meeting national targets, together with bottom-up practical ranges of options for scaling up the current deep retrofit levels (Figure 0.1). The stock model was used to understand the likely major construction and tenure constraints, and from this the range of market penetration for which the new **BASIC** retrofit might be applicable.

The investigations into retrofit funding sources also fed into this stock model post-processing. Doing more of the deeper retrofits at their higher costs made it difficult to find sufficient funding, despite more energy being saved. Meanwhile, larger proportions of more modest retrofit, generated less co-benefit cost savings that could be redirected into funding the retrofit rollout.

The bottom-up retrofit cost sweet-spot target of 50% heat demand savings was converted into a grid energy supply quantity based on an average residential heat pump seasonal coefficient of performance (SCOP) of 3 for space heating and 2.5 for domestic hot water. This is on the basis that fabric-first measures allowed the optimum heat pump water temperature of 45°C, with post-retrofit verification monitoring to ensure the installation quality delivered close to this level of performance.

However, for the national stock level assessment, the Comfort Takeback and Performance Gap factors were then applied on the basis that site level targets would have some natural slippage in overall delivered energy savings. So, while a halving of national energy supply would generate adequate funding from reduced infrastructure and a useful revenue source from the freed up exported green energy, the **BASIC** heat saving target of 50% on its own would not deliver sufficient energy savings. Hence, a mix of higher savings, with less slippage, from deeper retrofits plays an essential role in offsetting the slippage in the **BASIC** savings, to be able to deliver a national halving of energy supply.

The outcome of this assessment was proposed market penetrations (Figure 2.5) estimated as follows:

- **5% of homes to have Exemplar level retrofit,**
- **25% of homes to have Best Practice retrofit,**
- **68% of homes to have the BASIC retrofit, and**
- **2% of homes are untouched to represent homes with more challenging heritage constraints**

Annex

G

Paying for mass rollout

Annex G: Paying for a national mass retrofit rollout

Chapter 6 explains the background to why so little home energy retrofit is included in the UK's route map to net zero carbon. The **RETROFIT-AT-SCALE** alternative strategy is introduced in Chapter 1, with its objective of improving retrofit productivity to reduce its cost, so allowing a national retrofit mass rollout to be funded by retrofit co-benefit cost savings. Chapter 5.6 introduces these retrofit funding sources, and this Annex provides further background information, including how much funding could be expected from each source. For simplicity, future costs and savings are presented at present day values.

Figure G.1 provides a summary of the total costs for the retrofit mass rollout together with the sources of funding **RETROFIT-AT-SCALE** has identified for paying for it at a national level. Annex G.1 to G.6 provides an explanation for each of the funding sources.

Figure G.1
Summary of mass retrofit rollout costs and the funding sources

Retrofit costs:	UK totals	Cost per home (1)	National mix (2)			
To Exemplar standard	£91 bn	£65 k	5%			
To Best Practice standard	£385 bn	£55 k	25%			
To Basic standard	£343 bn	£18 k	68%			
Total	£820 bn					
Funded from:						
CCC current for retrofit (3)	£252 bn	£9k/home	£1k/home av	heat pump or equal		
Health, social & heat support cost avoided (4)	£85 bn	£18 bn/yr spend	33% redirected savings	28 yrs worth	50% ramp up (10)	
Added jobs tax income (5)	£60 bn	500 k jobs peak	£6k/job/yr	10 yr peak	ramp up & down	
Heat & hot water bill savings (6)	£79 bn	160 kWh/yr/m^2 av	85 m^2/home av	3 yrs worth	50% heat saving	35p/kWh (11)
Able-to-pay contributions (7)	£218 bn	35% mortgage free	75% use Basic retrofit	25% use Best Practice	£5k support	35p/kWh
Peak grid redirected investment (8)	£91 bn	600 TWh/yr (12)	3.1% slice	28 yrs worth	50% ramp up	35p/kWh
Wind profit surcharge (9)	£32 bn	600 TWh/yr	1.1% slice	28 yrs worth	50% ramp up	35p/kWh
Total	£820 bn					

(1) For cost build-up of different retrofit levels see Annex E and Figure E.1
(2) Proportions of 28 million existing UK homes retrofitted to the different levels.
(3) Retrofit allowance already budgeted for in CCC 6th Carbon Budget within UK 1% of GDP cost for getting to NZC (see Chapter 6).
(4) BRE cold/damp costs, of which 33% deemed to be redirected to retrofit (see Annex G.1). Converted pro-rate homes to UK total.
(5) Assumes a doubling of NRS assumed additional trades people is needed for Retrofit-at-Scale mass rollout (see Annex G.2)
(6) Heating / DHW savings converted to delivered energy using 85% boiler efficiency and heat pump SCOP of 3 / 2.5 (ignores standing charge saving). Less CCC 12% savings already included. 5% that are Exemplar / Energiesprong use 30 years of energy savings for complete funding (see Annex G.3).
(7) Able-to-pay uses proportion of homes that are mortgage free as indicator. £5k grant or similar support is included (see Annex G.4).
(8) Grid transmission / distribution reduced capacity redirected investment, presented as a generated wind power percentage flat rate sum (See Annex G.5).
(9) Surplus wind power for export / other uses, enabled by reduced heating demand, presented as a generated wind power percentage flat rate sum (see Annex G.6).
(10) Retrofit and benefit costs assumed to linearly ramp up over time Wind ramps up, so this is an average, hence the 50% ramp up figure (see Annex G.6).
(11) Assumed electricity cost as future average (social/environ cost switch not included and inflation excluded). Counterfactual gas price used is10.3p/kWh.
(12) FES projected amount of delivered wind generated power (see Annex G.5)
NB Rounding up mean some numbers do not exactly sum.
Retrofit costs base is 1st Q 2022 with VAT excluded (see Annex E.5).

G

G.1 Health, social, heating support cost savings

At governmental level the UK funds considerable healthcare and societal support costs due to the poor thermal performance of our housing. A mass rollout of home energy retrofits would allow much of these costs to be avoided, and a proportion of these saved costs to be redirected into part funding the retrofit rollout.

The Building Research Establishment (BRE) paper of 2010, updated in 2015, 2021 and 2023[139], detail 'The Cost of Poor Housing' in England. The highest added health and societal costs are due to excess cold and dampness in homes. In 2019, there were 2.4 million (10%) of homes in England which fall below standards for housing by having Category 1 Health and Safety hazards. The full NHS and societal costs are of the order of £18.5bn per year. The BRE papers divide this between tenure. Around 1.6 million (10%) owner occupied homes had a Category 1 hazard that, if left unmitigated, would result in an annual cost to the NHS of £783 million. Around 619,000 (13%) private rented homes had a Category 1 hazard that, if left unmitigated, would result in an annual cost to the NHS of £290 million. Around 217,000 (5%) social rented homes had a Category 1 hazard that, if left unmitigated, would result in an annual cost to the NHS of £65 million. The BRE also suggest payback periods for retrofit investment to mitigate the above, ranging from 7 to 13 years. **RETROFIT-AT-SCALE** rewriting these by proposing the retrofit costs can be reduced by more than halve.

While a significant proportion of this relates to direct NHS costs, the majority is related to societal support costs. Any savings for the NHS are expected to be redirected back into the NHS and therefore in practice, not available for redirection into funding home retrofit. Of the societal costs, 33% is assessed by Retroit-at-Scale to be costs that could be saved and redirected into paying for home energy retrofit.

These redirected costs are deemed to include the saving in financial help with energy bills, such as the £0.5b per year spent on the Warm Home Discount[140]. Consumer energy bills, and hence social support costs, have fallen following the peak in 2022, but are assessed as levelling out at about double what they were in 2019 (Figure 5.7). Consequently, this financial assistance to the fuel poor can be expected to continue in one form or another for the longer term. Home energy deep retrofit would eliminate the need for most of these social support costs. Support measures such as the Energy Price Guarantee[141] financial support, being a temporary measure, is not included as a long-term cost saving that can be meaningfully redirected towards funding retrofit.

The results of these identified cost savings and how much is redirected into contributions towards home energy retrofit are in Figure G.1. These numbers have been converted from English to UK-wide numbers using the number of homes as the multiplier. The savings would ramp up progressively as mass retrofit is rolled out. The assumption is that the rollout occurs between now and 2050, providing an annual saving that linearly increases over this period, giving an overall average of 50% of the identified savings between now and 2050.

G

G.2. Added tax income of new jobs created

A mass retrofit rollout will generate new jobs, which in turn generates new additional tax revenues to contribute towards the retrofit rollout programme.

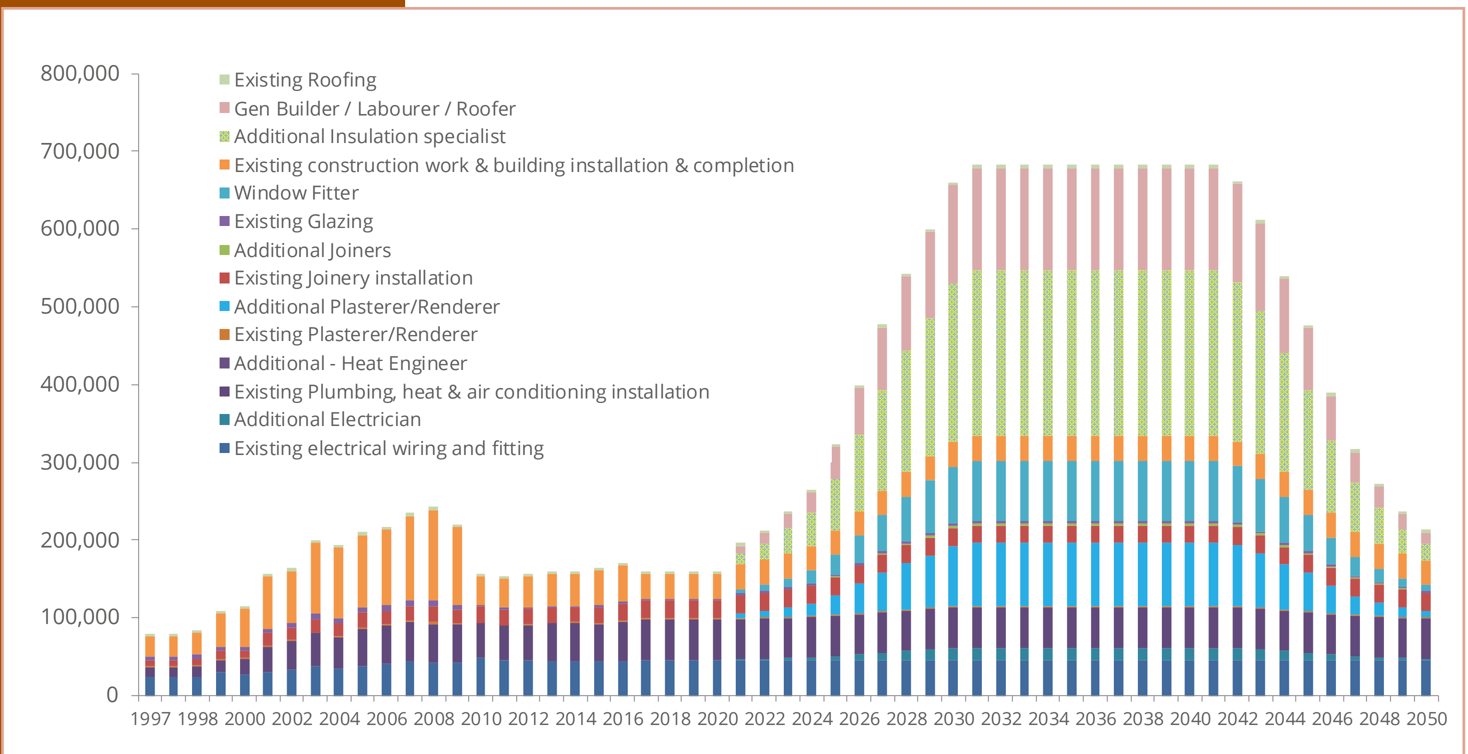
For such a retrofit rollout programme, the Construction Leadership Council (CLC) has assessed the additional employment created as part of their National Retrofit Strategy (NRS)[142], in line with the Climate Change Committee (CCC) 6th Carbon Budget. From this the added tax accrual was assessed using average salaries extracted from Office for National Statistics data. How much per person this equates to is summarised in Figure G.2.

However, **RETROFIT-AT-SCALE** proposes an higher overall halving of UK heat demand, whereas the CCC 6th Carbon Budget has only an averaged 12% energy efficiency improvement for homes (Chpt 6). This near four-fold improvement should not be reflected as an equivalent employment multiple increase, because **RETROFIT-AT-SCALE** focuses on improving the implementation productivity. Besides, the NRS already anticipates trades-people time being spend in most homes for the switchover to heat pumps or an equivalent.

RETROFIT-AT-SCALE identified a doubling of time that needs to be spend compared with the NRS assessed extra trades-people up to 2050. To this is added a doubling of site productivity, along with an associated four-fold increase in materials used. The bottom-up productivity gains analysis (Annex E) illustrates how site personnel durations can be more than halved if the process is well pre-planned and measures chosen for a quick turnaround, and then coupled with an uninterrupted workflow onto subsequent sites.

In practical terms, this doubling of extra employment is achieved by extending the duration for which the NRS extra employment is harnessed (Figure G.2) instead of increasing the number of people required. For delivering the combination of **RETROFIT-AT-SCALE** retrofit levels (Figure 0.1),

Figure G.2
Profile of skilled workforce for Retrofit-at-Scale mass rollout programme by comparison to statistic in recent years (adaptation from CLC National Retrofit Strategy figure, adapted for deeper retrofit to more homes coupled with higher productivity).



of the order of 10,000,000 person-years extra employment is needed instead of the ~5,000,000 person-years proposed by the NRS. The new jobs tax income is therefore based on doubling the NRS employment numbers. By way of comparison, this relates to an overall **RETROFIT-AT-SCALE** budget of £820bn compared with the NRS assumed budget of £250bn.

There will also be additional materials supply chain employment, albeit of a lesser level, but this has not been assessed or included here. Added VAT revenue has also not been included because it is a **RETROFIT-AT-SCALE** recommendation that VAT is not applied to retrofits warranted and verified as being to certified retrofit standards.

Once again it is assumed that this added tax income, and hence retrofit funding, ramps up (and down) across the years to 2050.

G.3 Energy bills savings contribution

Reducing consumer bills creates potential cost savings that could be put towards paying for retrofit. In practical terms a limited contribution has been assumed to come from this because of the **RETROFIT-AT-SCALE** objective of reducing home energy bills, and not keeping them perpetually high to pay back the retrofit costs (Chapter 5.12).

A cap of just 3 years of energy savings is included as an average across the stock. This has been further adjusted to avoid double accounting as the CCC funding element in Figure G.1 also assumes some energy bill saving contributions, albeit based on a lower percentage energy saving.

A proportion of Exemplar level retrofit is also assumed to be of the Energiesprong type rollout, which uses a funding cost model that harnesses up to about 30 years of capped energy bill savings to fund the retrofit works.

This energy bills saving contribution assessment is based on a long-term retail average cost of electricity of 35p/kWh, framed by the future energy cost profile illustrated in Figure G.3, with the overall retrofit funding contribution shown in Figure G.1.

Figure G.3
Salary generation and resulting tax accruals for added workforce based on NRS information

For additional jobs identified by CLC

Job	Average Salary* 2021	Tax (20%, after tax free allowance***)	National Insurance***	No. Jobs (peak)
Gen Builder / Labourer	27054	2897	2008	115000
Insulation specialist	27054	2897	2008	190000
Window fitter	23058	2098	1479	80,000
Joiner	27961	3078	2128	10000
Plasterer	26806	2847	1975	70000
Heat Engineer	36537	4793	3265	10000
Electrician	34787	4443	3033	25000
Retrofit Coordinator**	38952	5276	3585	50000
Average salary	30276	3541	2435	550000

- Source: ONS https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/bulletins/annual surveyofhoursandearnings/2021

** Equivalent job used for salary estimate 'Construction PM and Related Professionals'

*** Money Saving ExpertCalculator used to estimate https://www.moneysavingexpert.com/tax-calculator/

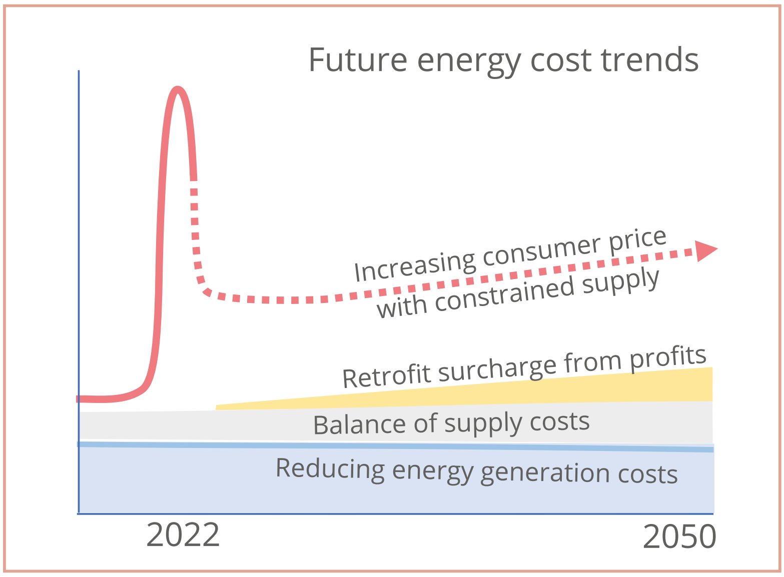


Figure G.4
In formulating their net zero carbon trajectory recommendations, the CCC assumed energy prices would fall from 2019 to 2050 as generation costs fall. In practice, after the 2022 spike, retail prices are likely to settle at about double this level and steadily rise in real terms, largely based on supply constraints, and independent of generation costs. Data sources Ofgem, CCC, Cornwall Insights, and beyond 2030 based on 1% over inflation [143] [144] [145]. Excludes EPG subsidy (see Glossary).

G.4 Able-to-pay contribution

The potential funding from those who are able to pay for the works themselves is large, even if they are likely to need some encouragement to get involved. To put this in perspective almost a third of the retrofit rollout cost is expected to be borne by the 'able-to-pay'. Put another way, the cost of a **BASIC** retrofit for an average home is just over £18k, about equivalent to the average cost of a second-hand car in the UK[146]. The importance of making retrofit appeal to this section of householders cannot be understated, and is the reason **RETROFIT-AT-SCALE** has a focus on making retrofit easier and more attractive for them.

As an indicator of the proportion of householders able to pay for the energy retrofit of their homes themselves, those that are mortgage-free has been used. In practice, there are likely to be additional householders with mortgages who are also willing to pay, given appropriate drivers and support. There is also likely to be a proportion of mortgage-free who are cash-poor and unable to fund their own retrofit. For this assessment these latter two categories are assumed to roughly similar in size and so cancel each other out.

As of 2021-22, 64% of UK households are owner occupied, with 35% of that number being mortgage-free with outright ownership[147]. For this sector the retrofit cost is in practice a small fraction of their owned property capital value. They will also directly benefit from post-retrofit lower energy bills, and any property value appreciation resulting from this investment into energy retrofit.

The aggregate contribution from this 'able-to-pay' sector is assumed to be divided as follows:

- **35% of 28 million UK homes, is 9.8 million households who are likely able to pay.**
- **75% (i.e., 7.35 million) of these households are assumed to pay for the BASIC retrofit level costing £18k per home, hence contributing £132.3bn of funding.**
- **25% of these households (i.e., 2.45 million) pay for the Best Practice retrofit level costing £55k per home, hence contributing £134.75bn of funding.**

Overall, the 'able to pay' sector could generate £267bn of funding contribution towards a mass retrofit rollout. This will nonetheless need pump priming and so the equivalent of a £5k grant or similar incentive is factored in for providing encouragement and support to the houseowners. This would amount to £49bn, so the net contribution from the 'able to pay' sector would be £218bn.

G.5 Redirected peak grid capacity investment

The energy supply industry is currently expecting to invest heavily in grid increased capacity. A key benefit of reducing peak home heating demand is that it directly reduces the capacity needed of our future electricity supply grid. This avoided grid investment provides more overall benefits, economically as well as socially, if redirected into funding home energy retrofits.

The National Grid Future Energy Scenarios (FES), updated each year, have been developing the thinking for what is needed to match the 2050 net zero carbon energy supply-side to the expected energy demand-side requirements of society, divided between transport, industry and buildings[148]. This has highlighted the major impact on peak demands of switching existing building heat demand onto the electrical grid [CEDG[134] Figure 3.2]. This becomes critical because future energy generation is less able to be switched on and off like fossil fuels. Even with a complete switch to heat pumps, thereby reducing the peak demand by a factor of about 3 for delivering the current heat demand provided by gas, the electrical grid capacity would need to more than double (Figure 5.5).

In grid system design and funding terms, having highly fluctuating demands means poor utilisation of this grid capacity, and its investment. In other words, the peak capacity is needed for relatively short durations, sitting idlily by for much of the year, so generating low system revenues but being relatively costly to provide. For private sector electrical system providers this is not a good place to put their investment. The same issue impacts generating capacity. Building excessive green energy generation capacity to cope with short lived peak demands, means it is more difficult to get a return on capital investment. For the National Grid this servicing of peak demand is a major concern, particularly given their obligation to consider the continuous balance between supply and demand on a short half-hourly basis, for keeping the lights on.

Energy storage forms part of planning to meet the grid's future peak demand challenge. To a limited degree storage addresses the general mismatch between green energy supply generation and the fluctuating energy demand. Energy storage allows periods of excess supply to become available for servicing subsequent periods of peak demand. Electrical battery storage tends to be effective at coping with relatively short duration peaks and troughs, but is relatively costly. Bio-energy with carbon capture and storage (BECCs)[149] in effect uses biomass as a chemical energy store, coupled with the capture of combustion emitted carbon to be placed in some form of long term storage (CCS)[150]. While this biomass electrical generation is relatively proven, the CCS at scale is not, and hence comes with significant future implementation risks. Direct-air-capture (DAC) of carbon dioxide from the air[151] is a way of allowing some limited gas fossil fuel generation to deal with energy demand peaks, but still requires some form of CCS. Hydrogen has also been suggested as an energy storage medium, and then harnessed during peak demand periods using gas turbine power stations[152]. The unresolved challenges remain for how the hydrogen is created and the relative inefficiency of this process[153]. Nuclear does not help cope with peaks because it is difficult to switch on and off, and so is regarded as a constantly running 'base load' supply. Nuclear has also been suggested as a means for generating hydrogen, however nuclear may not have the high process temperatures needed to best create hydrogen.

All in all, the use of large-scale supply side technologies to cope with building heat peak demands is far from mature, and expected to be relatively costly. It is also likely that these large-scale costs will be far more unpredictable, as demonstrated by nuclear power generation.

On the other hand, using the demand-side to smooth and attenuate demand peaks has been largely overlooked in the investigations of how to match supply and demand. Unlike supply-side, demand-side smoothing of peaks and attenuation of overall demand uses low tech solutions with more predictable costs, which tend to be more labour intensive, hence provide greater local employment benefits, as well as reducing householders' energy utility bills. This is the basis of the **RETROFIT-AT-SCALE** approach for a retrofit mass rollout.

Figure 5.5 shows the expected peak electrical grid capacity required once building heat demand is added, based on modelling done by UCL Energy Institute using their highRES system model[154]. This shows a peak demand increase from 61.5 GW up to 131 GW, hence more than a doubling of grid capacity for a 90% penetration of heat pumps supplying building heat. The **RETROFIT-AT-SCALE** halving of residential heat demand using retrofit reduces the peak capacity demand on the grid by about 25%.

This modelling also generated an anticipated cost for the provision of this new grid Transmission system capacity, and from this the savings due to not having to increase the grid capacity as much as necessary. These grid Transmission costs were then scaled up to include the grid Distribution system costs, based on the ratio of the operating costs extracted from National Grid information[155]. The cost saving due to not providing this extra grid peak capacity has been assessed at £91bn. This is equivalent to about 3% of the cost of each delivered GWh of wind power based on the FES[154] projected quantity of wind generated power (see Figure G.1).

It should be noted that this grid cost saving assessment does not include the cost, or a saving, due to green energy generation capacity, be it wind turbines or otherwise. This is because retaining this excess generation capacity serves a better purpose by producing excess energy as a UK export, from which a slice of the added income can be redirected into the retrofit that made it available. Besides, it should be noted that this generation capacity is expected to be largely funded independently by private investors.

G.6 Wind profit retrofit surcharge

Home energy retrofitting at scale, freeing up national green energy generation capacity for other purposes, opens up opportunities for the retrofit funding.

There is a significant price gap between the energy generation costs (including return on investment) and the retail price, as shown in principle in Figure G.3. This is applicable for most large-scale energy generation, with profit levels largely governed by world energy retail market pricing, and not directly related to production costs. This production versus retail cost difference can be expected for future green renewable energy, with producers in a free-market system able to sell to the highest bidder, often to countries that are also planning to become net zero carbon but are less well endowed with their own renewables.

The UK has a history as a major energy producer, be it during the days of King Coal, through to North Sea gas and oil, and this seems likely to continue given its yet-to-be-tapped large offshore wind potential[156]. The main constraint on this export is the limited capacity of electrical interconnectors between the UK and European electrical grids[157] Even for this, it is the private investor sector that has recognised this opportunity and is funding increased UK to Europe interconnector capacity. Indeed, there are now plans being developed for offshore connector hubs in the North Sea that mean UK produced offshore wind power can be routed to European purchasers without going via the UK land based national grid[158 159]. Reducing the domestically produced energy needed for heat, increases the amount of green energy available for such export, particularly during winter peak demand periods when energy prices and European demand are both expected to be highest. This has been assessed as being some 47 TWh/year[160], ramping up to a sum total of 611 TWh by 2050, which at a retail price of 35p/kWh equates to an accumulated £214 t by 2050, all enabled because of the reduction in homes heat demand.

Such green energy is a valuable export commodity and a means for increasing both the UK tax revenue and UK GDP. Energy production supplementary taxes are already paid by producers, and this includes the Supplementary Tax and Ring Fence Corporation Tax[161] applied to North Sea oil and gas production profits, where similarly, production costs are small compared with the international market driven consumer price. Off-shore wind has yet to be brought into this tax framework.

Given the **RETROFIT-AT-SCALE** mass rollout is enabling this additional green energy availability for other uses, a small slice of this additional Supplement Tax could be ringfenced for part funding the home retrofit rollout to the scale illustrated in Figure G.1. This equates to about 1% of the retail cost for wind power using the FES[154] projected quantity of wind generated power. Put another way, this is only 0.015% of value of green energy made available by halving UK home heat demand being used to contribute towards paying for this mass rollout.

Annex

H

CCC's 12% is not enough

Annex H: Why 12% home energy improvement is not enough

This Annex provides additional background information in support of Chapter 6, explaining why the Climate Change Committee proposed relatively little energy efficiency for our existing homes.

The Climate Change Committee (CCC) analysis for the 6th Carbon Budget[162] and net zero report both assume deep retrofit remains a niche activity. Instead, the CCC says that the UK should focus on a huge increase in net zero carbon electricity supplies (largely through off-shore wind) and a mass roll-out of heat pumps, with very modest energy efficiency improvements to most homes (Figure 6.2). However, the practicalities of the proposal to roll-out heat pumps have been questioned by politicians:

"Asking households to pay upwards of an extra £10,000, as part of the objective of net zero, to replace their existing home heating which is working perfectly adequately is a major challenge".

The LETI Climate Emergency Retrofit Guide (CERG [139]) sets out a Best Practice approach, recommending deep domestic retrofit for those willing, and able to take this path. If implemented across the whole UK housing stock, it is estimated this would yield an overall average reduction in space heating demand of about 62% (CERG – Figure 0.1) albeit this is not as far as EnerPhit, the 'gold standard' retrofit specified by Passivhaus. The results would create a national stock with energy performance significantly better than new homes built to current (2021) Building Regulations. This CERG proposition raises fundamental questions:

1. **What proportion of the existing 28 million homes should aspire to Best Practice retrofit?**
2. **What is the minimum acceptable depth of retrofit for the rest of the stock?**
3. **How is a retrofit rollout paid for.**

RETROFIT-AT-SCALE explores if and how these differing visions of the future might become better aligned.

H.1 How much did efficiency retrofit contribute to the CCC's 2019 vision of net zero?

The CCC's net zero analysis found it was technically feasible, and more cost effective, to extend offshore wind supply capacity than apply deep retrofit across the UK stock of existing homes. It reached this conclusion after relatively detailed and granular modelling of the national stock, and on the basis that the average deep retrofit including heat decarbonisation would cost some £40k (typically £29k for the energy efficiency measures and £11k for an air source heat pump). Rolled out nationally, that would entail spending some £1.12 trillion across the stock of 28 million homes.

Instead, in its recommended 'Balanced Pathway' approach, net zero can be reach by 2050 with an average spend of only £9k per home, with most of this on heat pumps, and a national total net investment cost of £256 billion to 2050. This route to net zero according to the CCC has the lowest (i.e., most favourable) average cost effectiveness, at £229/tCO_2 for the carbon saved.

Retrofit advocates may find it somewhat surprising that the overall figure for heat demand reduction across the stock in this Balanced Pathway is only 12% (37 TWh from 313 TWh/yr). From this, the current target of EPC 'C' has been derived. Admittedly, this CCC average masks significant variation across homes. Their home retrofit of cavity wall insulation, loft insulation, and floor insulation, sees heat demand savings of some 30%. But their overall figure is much lower due to many homes already having some existing energy efficiency measures, or they are currently heated to lower standards (and therefore lower capacity for further savings), or they have hard to treat lofts and cavities.

Figure H.1
Home energy efficiency individual measures considered by the CCC and their individual cost effectiveness using typical industry costs.

Measure	Cost Effectiveness (£/tCO2)	Low	Medium	High
Loft insulation, easy to treat (0-99 mm ETT) [1]	84	✓	✓	✓
Easy to treat cavity wall insulation (ETT CWI)	-70	✓	✓	✓
Hot water tank insulation	-32	✓	✓	✓
Loft insulation, hard to treat (0-99 mm HTT) [1]	-2	✓	✓	✓
Loft insulation, easy to treat (100-199 mm ETT) [1]	233	✓	✓	✓
Draught proofing (draught stripping)	294	✓	✓	✓
Hard to treat cavities wall insulation (HTT CWI)	303		✓	✓
Suspended timber floor insulation	338		✓	✓
Thin internal (solid) wall insulation	435		[2]	[2]
Loft insulation, hard to treat (100-199 mm HTT) [1]	566		✓	✓
Internal (solid) wall insulation	642		✓	✓
External (solid) wall insulation	639			✓
Solid floor insulation	702			✓
Double glazing (from single glazed)	3150			
Triple glazing (from double glazed pre 2002)	6091			[3]
Double glazing (from double glazed pre 2002)	8013			

[1] Potential savings for varying existing levels of loft insulation is based on a calibration to NEED data; a level of uncertainty is present based on this.
[2] Thin internal (solid) wall insulation replaces standard internal (solid) wall insulation in the Widespread Innovation scenario.
[3] Glazing is present as part of the deep retrofit, which replaces the standard high package, in the Widespread Innovation scenario.

In number terms, on the Balanced Pathway, 63% of all homes spend less than £1000 on retrofitting energy efficiency measures, 32% spend up to £10k and 5% spend more than £10k. A negligible number are assumed to go for deep retrofits, but all homes where the household is deemed to be in fuel poverty receive a 'high' energy efficiency package as defined in Figure H.1, to be applied to 3.2 million homes, some 11% of the stock. On average, homes receiving the high package were calculated to achieve a 35% reduction in their heat demand at a capital cost of £12k. This is a long way short of the 62% average reduction in heat demand expected by the CERG proposals.

The CCC analysed four alternative pathways to their central scenario, but only one of these included significant numbers of deep retrofit, defined as doing whatever it takes to reduce a home's space heat demand to 40 kWh/m^2/yr, a level at the deeper end of Best Practice spectrum of 40-70 kWh/m^2/yr, but significantly above the EnerPhit level of 25 kWh/m^2/yr. This was used in the Widespread Innovation pathway instead of the high efficiency package in all 3.2 million fuel poor homes (except in those instances where a fuel poor household was in a high-rise flat or listed building). The CCC's analysis estimated an average 57% heat demand saving was achieved by deep retrofit. This rose to 80% when applied in a disproportionately under-insulated home with the highest potential for savings. In contrast, most homes in the Widespread Innovation pathway (19.4 out of 28 .3 million homes) do not receive any energy efficiency measures. Therefore, the Widespread Innovation, has the lowest total deployment of energy efficiency measures amongst the exploratory scenarios, with an average cost effectiveness of £341/tCO_2 of carbon saved, over 50% higher than the Balanced Pathway.

Given the wider benefits of installing energy efficiency measures (including improved comfort, health and well-being, reduction in fuel poverty, regeneration, job creation, and improved energy security) were a key part of the CCC's assessments, additional energy efficiency was used for every model in the scenario, beyond the level found to be 'cost optimal'. In consequence, the Balanced Pathway scenario includes all practicable loft and cavity insulation (i.e., all with cost effectiveness up to £700/tCO_2e of carbon saved), in addition to solid wall insulation where part of an overall measure package with a cost effectiveness of up to £600/tCO_2 saved. Carbon criteria of £600-700/tCO_2e of carbon saved, are well above the expected value of £350/tCO_2e consistent with achieving net zero in 2050. However, the report notes there would be value in further bottom-up analysis to explicitly quantify the value of wider benefits, with a view to refining the appropriate boundary for economic potential.

It is also worth noting that more recent research on behalf of the Greater London Authority (GLA)[163], with the brief to explore what would be technically needed for London to reach net zero by 2030, concluded that an average 37% saving on heat demand should be used. The similarity of this level of saving with that achieved by the CCC's high efficiency package infers that most homes in London would have to follow something similar to the CCC's high efficiency package, although methodological differences between the two studies may make such a simplistic read across somewhat speculative.

H.2 The world has changed a lot since CCC published their net zero pathway

Given the energy security and price issues triggered by the war in Ukraine as well as the wider cost of living crisis, **RETROFIT-AT-SCALE** believes, and the CCC has recently acknowledged, that the context for the CCC 6th Carbon Budget analysis is already out of date. Another reason 'everything has changed' is the perception that the public would be more receptive to deeper retrofit than they were back in 2019-20 when the House of Commons facilitated the Citizens' Climate Assembly. This informed the CCC reduced emphasis on retrofit and increased emphasis on supply side solutions. Since then, the UK has endorsed a national policy of reaching net zero carbon by 2050, and there has been numerous local Declarations of Climate Emergencies, with an accelerating media coverage of climate change impacts, even if the politicians still baulk at disruption to homes.

However, since then energy prices have risen at unprecedented levels (Figure G.3) even as they settle after the initial peaks. The prospect today also foresees continuing increases in the following years if EU sanctions continue to tighten on imports of gas and oil from Russia.

Fundamentally, the cost to consumers of zero carbon energy is likely to rise faster than inflation, even with a readjustment down after the Ukraine war situation passes. With most countries seeking to decarbonise, and many not as well endowed with renewables as the UK, carbon free energy is likely to remain a limited supply for the next few decades. Consequently, its price for consumers is likely to continue to rise in relative terms irrespective of falling production costs.

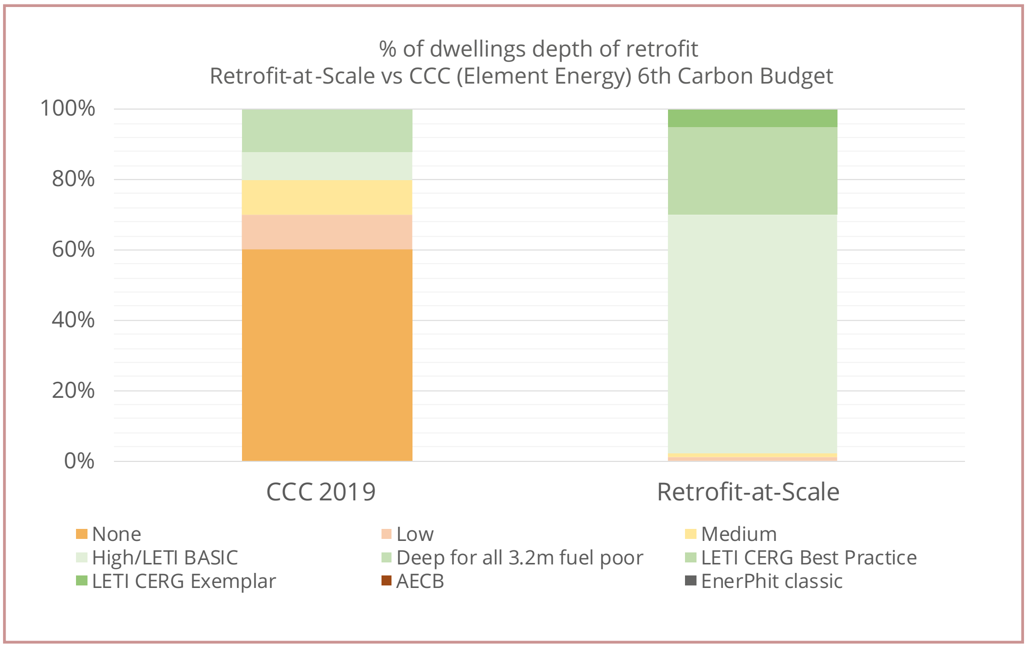


Figure H.2
Comparison between CCC:2019 assumed levels of home energy retrofit and Retrofit-at-Scale.

Only reducing heat demand offers consumer protection against energy price increases. Enabling the funding and market mechanisms to undertake retrofit on existing homes offers householders an opportunity to increase their resilience against future price increases. There is an opportunity to instigate widespread retrofit programmes, while the public are overtly aware of energy prices and climate change risks.

In short, the Overton window of acceptable political policies has shifted with mainstream organisations and commentators, not just groups like Insulate Britain, now calling for the roll-out of national insulation programmes. This gives the CCC licence to revisit their central pathway with a view to considerably extending the uptake of both the high efficiency package and deep retrofit. The aim of this **RETROFIT-AT-SCALE** document is to clearly articulate what a minimum acceptable depth of retrofit might look like as a national ambition (Figure H.2) and to make it attractive to both policymakers and homeowners.

H.3 Behavioural assumptions

The CCC 6th Carbon Budget lays considerable store on behavioural change to deliver the modest home energy efficiency improvements. Many of these appear fragile and need to be better related to practical implementation measures.

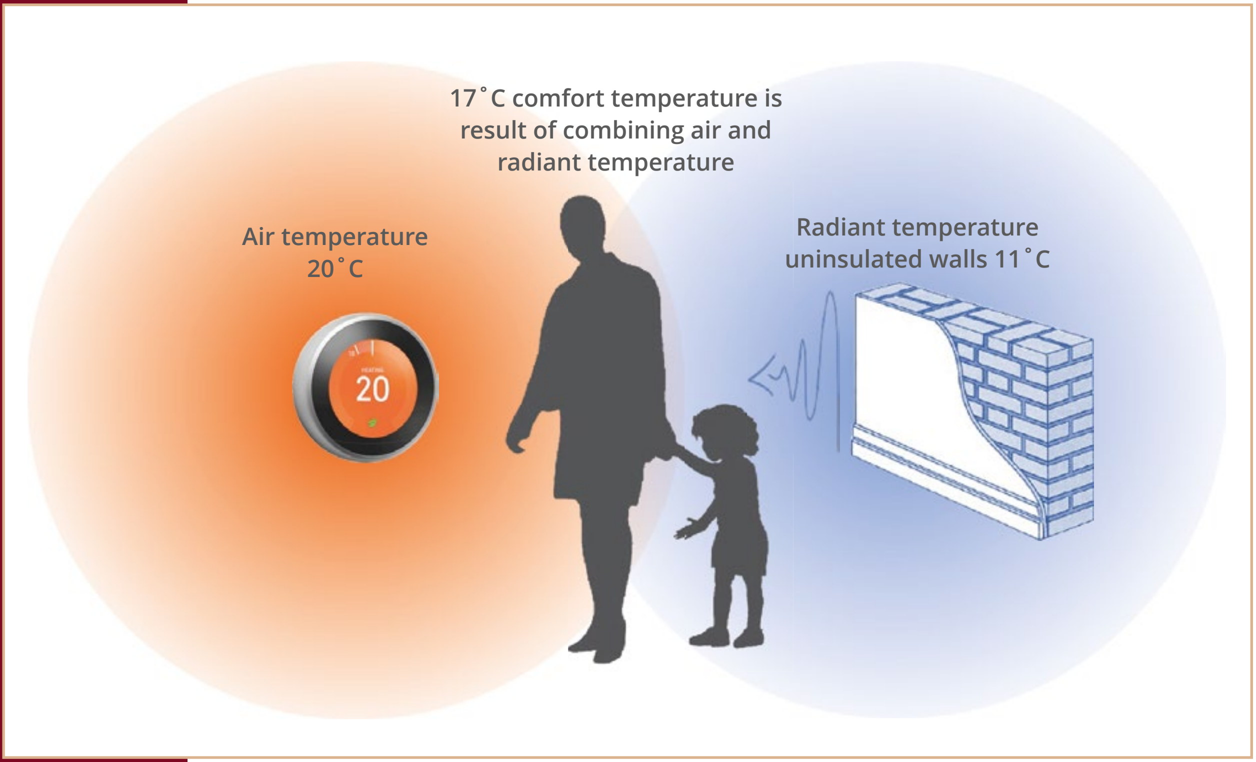


Figure H.3
CCC proposes a 1˚C room temperature reduction due to behavioural change, however this is not supported by real life evidence. In poorly insulated homes occupants tend to instead increase the heating control temperature to offset cold radiant temperatures

Behaviour change can lead to a reduction in energy demand through changes in heating behaviour and patterns, adoption of energy-efficiency measures and improved heating control. Element Energy's 'Balanced Pathway'[164] technical report informing the CCC 6th Carbon Budget assumes a 22% reduction in total energy savings through behavioural take-up, including a mix of pre-heating, heat as a service, smart metering & control, reduced water temperature and low flow shower heads. However, this depends on householder decision-making and policy incentives, and is largely theoretical and not backed by physical evidence. The incentives to enable these are not set out in the Element Energy report or the CCC reports. Behaviour change incentivisation is a challenging area, requiring tailored policy actions, and is littered with rebound effects. Previous research has found that energy demand reductions between 0-20% are possible via information from smart meters, but this varies widely per householder income group, their motivations and policy led incentives. Indeed, there is measured evidence showing a falloff in energy efficiency measured over barely a few months, as the visible meters become part of the home background 'wallpaper'. Current expectations from the energy supply industry are for a less than 1% improvement, unless there are additional fiscal incentives.

To illustrate the fragility of one example, namely the proposal that behavioural change will deliver reduced heating temperature settings and hence reduce energy use. However, the poor state of our housing stock means this is simply unlikely. The **BASIC** physics of cold radiant temperatures from uninsulated walls means that, in practice, occupants set far higher air temperature control (if they can afford it) than assumed in normal thermal modelling to maintain comfort levels (Figure H.3). There is no physical evidence that occupants will accept lower heating thermostat settings given the levels of poor insulation most UK homes. More, and deeper energy retrofit of homes is likely to be needed before expectations of mass behavioural change of this type could be considered as realistic.

H

Annex

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Annex I:
References and further information

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Glossary

ach Air change per hour within a room or space. A metric for ventilation or air infiltration.

AECB Association for Environment Conscious Building, www.aecb.net

BECCS BioEnergy with Carbon Capture and Storage

BWIC 'Builders' work in connection' is work that is necessary as a result of other works like mechanical and electrical systems. BWIC is normally priced separately as it is done by different contractors.

CCC Climate Change Committee, www.theccc.org.uk

CCS Carbon Capture and Storage

CIBSE Chartered Institute of Building Services Engineers

DAC Direct Air Capture of carbon from the atmosphere

DNO Distribution Network Operators for the neighbourhood electrical supply system

DPM Damp Proof Membrane

DSM Dynamic Simulation Modelling - advanced finite element energy modelling tool

ECO Energy Company Obligation policy for energy suppliers to reduce selected consumers energy use

EnerPHit A retrofit design and construction standard, www.passivhaustrust.org.uk

EPC Energy Performance Certificate

EPG Energy Price Guarantee policy paid for additional cap on domestic consumer prices from October 2022 to June 2023

EUI Energy Use Intensity - the amount of energy (in kWh/m^2.year) delivered to a building to provide for all its requirements - both regulated and unregulated energy.

EWL European Water Label - www.europeanwaterlabel.eu/thelabel.asp

Fabric-first The principle of applying building fabric energy efficiency measures before active mechanical and electrical systems

GHG emissions Greenhouse gas emissions

GWP Global warming potential. A metric used for defining heat pump refrigerant emissions impact.

HEM Home energy model. Proposed SAP replacement planned for 2025

H&S Health and safety measures or procedures

HLC Heat Loss Coefficient W/K or W/°C

IAQ Indoor Air Quality

Ofgem Office of Gas and Electricity Markets government regulator

MCS Microgeneration Certification Scheme, https://mcscertified.com

Passivhaus A design and construction standard, www.passivhaustrust.org.uk

PCM Phase Change Material used in a heat battery appliance to store heat

PHPP Passivhaus Planning Package - spreadsheet based method for highly insulated homes

PRS Private Rented Sector

Q-Bot Remote control installation of floor insulation, www.q-bot.co

RH Relative humidity

RdSAP Reduced Data Standard Assessment Procedure, for surveying existing homes and producing an EPC rating

SAP Standard Assessment Procedure. National model for home energy assessment

SMETERS Smart Meter Enabled Thermal Efficiency Ratings

Whole-dwelling approach All aspects of a home considered together, and the combined implications assessed. Does not mean all possible measured are implemented.

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