RETROFIT FOR THE FUTURE

Reducing energy use in existing homes
A guide to making retrofit work

Technology Strategy Board

Driving Innovation

ABOUT RETROFIT FOR THE FUTURE

Retrofit is the introduction of new materials, products and technologies into an existing building to reduce the energy needed to occupy that building. Retrofit is not the same as renovation or refurbishment, which often make good, repair or aesthetically enhance a building without aiming to reduce its energy use[1].

The Retrofit for the Future programme explored how existing homes can be improved to use less energy, cut carbon emissions and save costs. The £17m programme, funded by the Technology Strategy Board, has helped businesses discover new opportunities in the growing retrofit market. In 2009, funding of up to £20,000 was awarded to 194 project teams to develop a retrofit strategy. Up to £150,000 was then awarded to 86 of those teams to find out how their strategy would work in real homes: ambitious targets were set to reduce energy use and carbon emissions. This guide tells the story of 40 of those homes, offering useful information and guidance for any organisation considering a retrofit project.

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RETROFIT FOR THE FUTURE GUIDE

This guide examines 40 homes from the Retrofit for the Future programme. It describes innovative energy saving systems and explains how they were used in the context of lived-in homes.

The practical information in this guide will benefit all parties working towards a successful retrofit project:

- designers
- project managers
- main contractors
- energy consultants
- contractors working on Energy Companies Obligation (ECO) funded schemes (www.gov.uk/government/policies)
- clients, such as social housing providers, and their project teams.

The real-life case studies will help professionals and their businesses to improve their products and services, build competitiveness, understand and manage risks, and meet the growing demand for retrofit.

The Technology Strategy Board worked with Energy Saving Trust to develop tools to measure the actual performance of the retrofit homes so they could be compared to each other and against performance targets. The tools included:

- data on energy use
- data on water use
- environmental conditions
- spot test reports from thermography (heat losses)
- airtightness (air leakage) tests
- independent on-site technical reviews of the completed retrofit homes
- interviews with residents
- project team diaries
- final project reports.

The energy and carbon performance of many of the homes was presented in *Retrofit Revealed*[2].

This Retrofit for the Future guide asks:

- what was done well
- what could be improved
- what lessons can be learned.

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"We love our retrofit - it's saved us money and the house is much more comfortable to live in - we've had the neighbours round and we're spreading the word!"

[House 72]

SIX RETROFIT THEMES

Six retrofit themes provide a framework for ensuring all parts of the retrofit are done well.

Retrofit planning

Building fabric

Indoor air quality

Services

Working on site

Engaging residents

Each section in this report summarises the key findings and gives practical examples of what happened. Four case studies (pages 44-47) highlight the connections between themes.

The themes explained

A successful retrofit will encompass all these factors in a 'whole-house' approach. When attention to detail and clear communications are added to the mix, the results are much more likely to lead to better energy savings.

The building fabric consists of the walls, roof, floors, windows and doors. The fabric is a major area of heat loss which can be reduced by adding internal or external wall insulation, loft and floor insulation, and improvements such as new glazing.

An additional way to reduce heat loss is to improve airtightness. This is to minimise unwanted air flow in or out of the house. However, people still need fresh air to be brought in as ventilation. The balance between airtightness and ventilation can be addressed in different ways. The majority of the Retrofit for the Future homes chose MVHR (mechanical ventilation heat recovery) systems, whereby heat is recovered from warm air taken from kitchens and bathrooms before it is expelled while fresh air is brought in elsewhere.

Services (such as heating and hot water systems, lighting, renewable energy, controls) have to work with the insulation, airtightness and ventilation of a home to provide comfort and convenience. The installation of different retrofit elements can involve complex construction works and multiple suppliers, so careful planning of work both on and off the site is important.

How these six factors are brought together in one house can have a large impact on the people living there and the way they use their new energy systems. The residents' input can be invaluable and softer skills are needed to keep them engaged through the retrofit process.

House references

Numerous real-life examples are provided in this guide. Each house has a number which relates to references in the two databases[3] developed to support Retrofit for the Future.

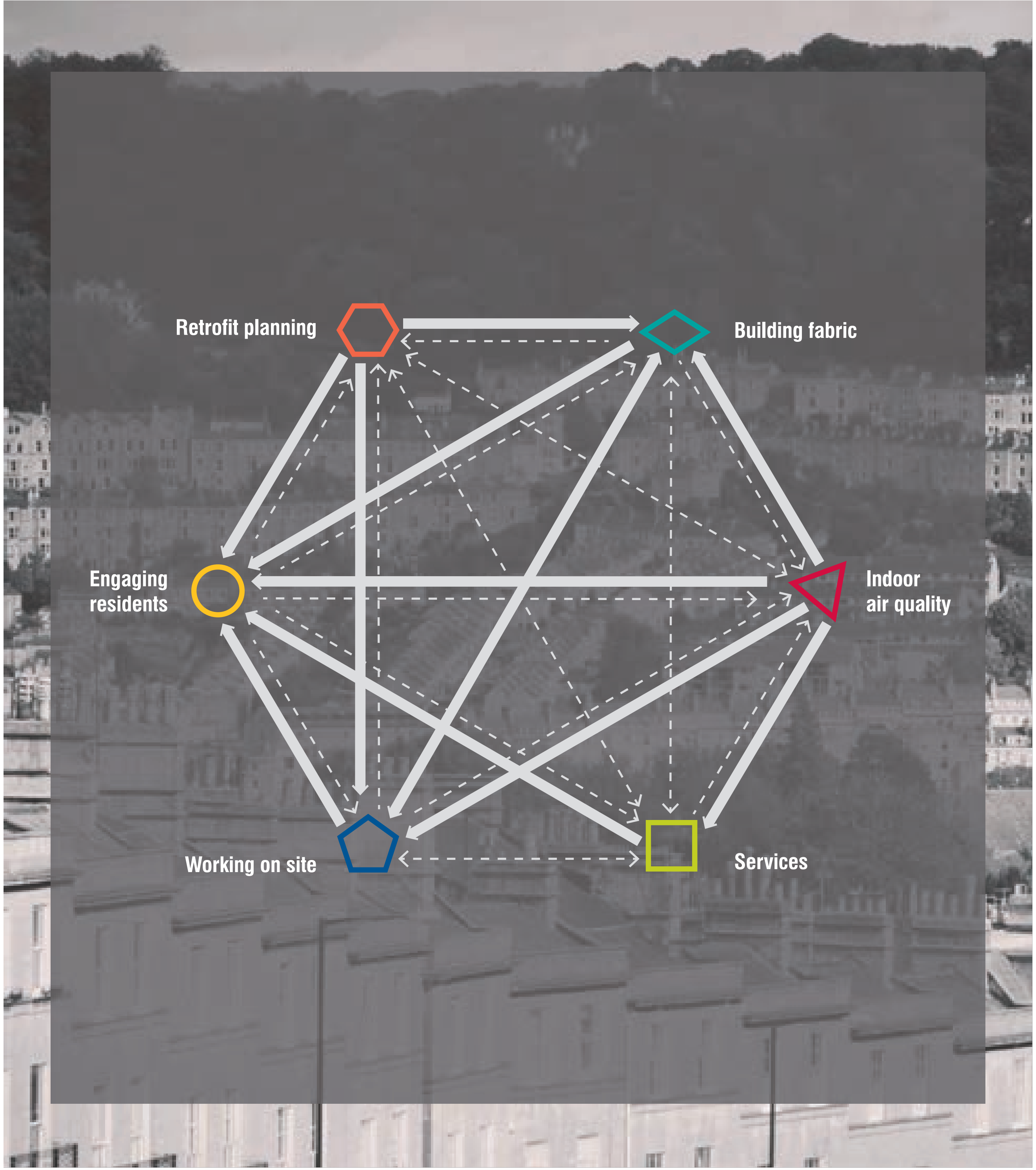
SIX CONNECTED THEMES

Six connected themes

In retrofit homes no single area stands alone. Imagine a web of connections where the web is the whole house and the themes are the anchor points. Changes in one theme will affect another.

This diagram illustrates the degree of connection found between the six themes. The arrows show the direction of the connection. The thickness of each arrow shows how often the connection occurred. For example, Services had a significant impact on Engaging residents.

Note: several themes are connected with two-way arrows.



MAKING RETROFIT WORK

Retrofit can provide huge benefits

Retrofit for the Future shows that a whole-house retrofit can provide huge financial, comfort, carbon and social benefits. A good retrofit also helps prevent health risks from damp and mould, reduces the risk of fuel poverty and generates local employment. The reductions in energy use and carbon emissions can be as much as 80%[4].

Integration gets the best results

Thinking about a house and its residents as a single energy system is complicated. Individual components can seem straightforward but getting them to work together as one system in a house is complex. There are connections between almost all components and each weak link will affect the whole. The best results come from integration, by considering all the interdependencies and getting the details between them right.

Collaborate and communicate

Decisions made at one stage can have significant impacts elsewhere, so excellent communication is critical. Well-delivered projects have clear lines of responsibility across teams who are committed to the retrofit's objectives. When all parties understand what is required and why, it leads to better results; for instance, in continuity of insulation, meeting airtightness targets, or high quality installation.

Engage with residents

The people living in the homes should be at the heart of the project and they can be involved in imaginative ways. Involving residents helps the project team to manage expectations, avoid costly misunderstandings and reduce concerns about timescales, mess and disruption. Providing people with handover support and guidance helps them to take responsibility for keeping their home comfortable while also reducing their energy use.

Tailor the retrofit strategy

The scope for 'one size fits all' solutions is limited by the variations between existing homes. The most effective retrofits have a full understanding of the house and the residents' needs before work begins. More cost-effective and replicable methods to achieve this are needed for the growing retrofit market.

Pay close attention to controls

Services (eg, heating, lighting, ventilation) typically need some control by the residents. The retrofit will deliver better results if people are empowered to make their home environment comfortable all year round.

Get obsessed with detail

Project teams should develop an obsession with detail. From engaging with residents and local planners, through to installation and commissioning, an obsession with detail reduces the need for re-work and helps to control the retrofit costs.

80%

The energy and carbon reductions in Retrofit for the Future homes were as much as 80%

RETROFIT PLANNING

Retrofit planning is about getting the project right from the beginning. Planning should cover energy and construction solutions; pre-design and project planning; performance targets; procurement; engagement of the right people at the right time; and planning the time to document, learn and share lessons.

BEST PRACTICE

WHAT WORKS WELL

- performance targets help unite project teams
- prioritising insulation and airtightness (or ‘fabric first’) was the most commonly taken approach
- retrofit must be tailored to specific, existing conditions of the house
- detailed surveys, flexibility and contingency plans are all needed
- an initial meeting at the home helps design teams understand existing conditions, the overall strategy and the installation process
- early engagement of residents helps in understanding their needs and managing their expectations
- temporary services can be installed for people who stay at home during the works
- early talks with suppliers can ensure that products and services are chosen according to the suppliers’ capabilities
- early engagement with local planners reduces the risk that proposed solutions may not be approved
- items made off site (eg, modular heating pods, pre-fabricated roofs) can be easier to install on site.

WHAT TO LOOK OUT FOR

- a poor understanding of targets can lead to poor decision-making (eg, a smaller heating system met the target but could not heat the house in winter)
- greater attention to services early on may help (eg, hire a mechanical and electrical services consultant and carefully consider how services will interact with the fabric)
- additional works should be planned for (eg, redecoration, adaptation of doors or staircases)
- installing retrofits with residents in situ requires careful management
- off-site storage may need to be found for residents’ possessions
- retrofit can be messy and disruptive; changes to the timetable need explaining to residents
- product or service changes can impact on the installation team, the residents and the results.

PLUS POINT

Prioritising insulation and airtightness (or ‘fabric first’) was the most commonly taken approach

PRACTICAL LESSONS FROM THE RETROFIT HOMES

House 69 before (top) and after (bottom) the retrofit. Note the deeper window reveals (depth of cills) as a result of adding external wall insulation.

Consider the house as one system

In developing a whole-house approach, most project teams prioritised heat retention and reduced air leakage, followed by efficient heating and ventilation systems. This is often called a 'fabric first' approach which requires careful planning.

Retrofit planning involves prioritising spending; for instance, achieving a balance between building fabric and energy services or minimising thermal bridging (unwanted heat loss). One team tested several thermal models and concluded that party walls were the most important issue to tackle [London, case study 2, House 8, page 45].

Many projects added on-site renewable energy technologies to further reduce energy use and carbon emissions.

Fabric first was not always the priority. At one house, uninsulated cavities were not filled, the ground floor was not insulated and airtightness only slightly improved. Gas-fired heating was replaced by an electric borehole-based ground source heat pump [House 60].

Use performance targets

Performance targets that are clear, well-communicated, ambitious and achievable can help unite the project team around a vision:

- a clear airtightness target led to robust, well-engineered details that ensured insulation continuity [House 19].

However, any absolute goals must not lead to poor decision-making:

- using an air source heat pump complied with the target but the house could not be warmed sufficiently on the coldest days [House 31]
- the bathroom can feel cold as a radiator was not provided for top-up heat [House 96].

A number of projects worked towards recognised retrofit standards, such as Passivhaus EnerPHit, Minergie and Active House [House 69 (pictured), House 85 and North Belfast, case study 1, House 1, page 44]. These provide a clear assessment method and a standard for design and workmanship. They can also improve decision-making as they have checks and balances built into their assessment procedure.

Engage people early on

The retrofit plan should be explained to the residents as early as possible:

- residents could visit a similar retrofit home to see the systems in action [House 60]
- residents could join site meetings and watch installations [House 96].

Some projects created an energy system based around people's needs:

- residents requested a wood-burning stove, so the team made sure they could source sustainable fuel [House 75]
- a project team changed the passive ventilation system to a mechanical system which was felt to be simpler for people to use [House 26].

Consider how to work with people in place

Understanding people's responses to living amongst building works is particularly important as retrofit scales up and the private sector market grows (where moving people out temporarily will be more challenging). For example:

- when residents stayed whilst internal wall insulation was installed, they found it dirty and disruptive [House 60]
- opportunities to improve airtightness were not taken fully as the extra works were considered too disruptive [House 75]
- work can be rushed and quality can suffer when priority is given to minimising the disruption
- temporary services may be needed when people remain at home [House 75]
- off-site storage may be required to protect belongings and to make space for the contractors [House 75]
- contingency plans should allow people the option to move out (if their home cannot be made watertight or secure).

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PLUS POINT

Items made off site (eg, modular heating pods, pre-fabricated roofs) can be easier to install on site

Problems uncovered by "systematic destruction" before the retrofit work began [North Belfast, case study 1, House 1, page 44].

Plan for unforeseen works

It is difficult to really know a building until work is under way. An early investigation, with some careful destruction, can help the project team to develop design flexibility and contingency planning:

- walls that look non-loadbearing may be structural [House 108]
- even bay window frames may be structural [West London, case study 4, House 109, page 47].

Older homes can be unpredictable and contingency should be provided for additional works:

- exposed dry-lining had previously caused damage to brickwork and joist ends and increased unforeseen costs by £25,000 [North Belfast, case study 1, House 1, page 44]
- floors thought to be suspended timber were solid [House 75].

Additional works may be needed:

- after floor insulation, appliances might not fit under worktops; units, sink, supply and waste pipework and tiling may all have to be raised [House 75]
- building control may require changes to a staircase following a raise in the ground floor level [London, case study 2, House 8, page 45]
- energy meters may have to be moved to accommodate new energy services (this led to lengthy delays) [House 76].

Carefully manage procurement

Simple contracting relationships can streamline the procurement process, provide better cost management and increase build quality. Procurement-driven changes to the specification should be checked with the project team:

- a biomass heating system hopper needed to be filled manually every day, rather than automatically as originally specified. Consequently the resident found it "completely impractical" and has reverted on occasion to using the coal fire [House 4]
- trickle vents were omitted from triple-glazed windows as they could not be readily sourced [House 25]
- procurement plans need to be realistic about lead-in times for innovative products and the availability of suppliers and installers
- complex contract structures can lead to a lack of clarity about where different costs lie.

Engage early with local planners

The local planning department should be involved early on:

- planning discussions took eight weeks; both parties made compromises which added costs [House 75]
- planners resisted external wall insulation because the property would "stand out" [House 35]
- a readily approved strategy used internal wall insulation, window styles and panes that minimised visual impact, and placed solar panels on the rear roof [House 51].

Engage early with potential suppliers

Early input from suppliers can be beneficial, particularly when using innovative products that may need new skills from installers and contractors:

- external wall insulation is an innovative product for many contractors. The supplier was involved at the design stage and drew up initial plans and a condensation risk analysis [House 106]
- innovative vacuum insulation panels were punctured on site before they had been installed. There were also challenges in installing the panels [House 44].

Consider off-site construction

Solutions that can be made off site and/or fitted to the exterior of a house can be installed faster and with less disruption:

- working with a roof frame company and wall tie supplier, an off-site timber frame roof was developed [House 69]
- rotting rafters, decaying brickwork and rotting floor joists led to a new roof constructed off site and new joist hangers for intermediate floors, enabling a continuous floor-to-roof insulation barrier [North Belfast, case study 1, House 1, page 44]
- a 'pod' housed the heating and ventilation systems (ground source heat pump and exhaust air heat recovery). It was craned in and plumbed in with minimal internal disruption [House 64]
- a pre-fabricated, insulated loft conversion unit could be refined further to reduce manufacturing costs in future [House 57].

Innovative off-site methods can also introduce new on-site challenges:

- one project reported manoeuvrability difficulties with the installation of a pre-fabricated internal wall insulation system [House 85].

Consider the lessons learned

Each project team was required to hold an 'end of project' meeting and produce a project report to review lessons learned and to consider improvements. This type of consideration can lead to better collaboration and fewer mistakes on future projects.

The original roof (top) at House 69, and its replacement timber frame (centre) which was developed off site through working with a roof frame company and wall tie supplier.

The pre-fabricated loft conversion unit (above) is lifted into place at House 57.

95%

Fabric insulation helped reduce the predicted annual space heating demand by as much as 95%
[West London, case study 4, House 109, page 47]

BUILDING FABRIC

Almost all projects significantly reduced heat loss by insulating the fabric (walls, roof, floors, windows and doors). The most comprehensive approaches considered all fabric elements with particular attention to insulation continuity (including thermal bridges and airtightness at critical junctions and openings). Improved insulation meant that heating systems could be smaller or removed in places.

BEST PRACTICE

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WHAT WORKS WELL

- insulation continuity is essential for reducing heat loss
- carefully consider party walls, gaps around services into the house, wall and roof junctions
- attention to detail during construction is absolutely critical
- replacing doors and windows at the same time as adding insulation gives them a closer fit
- external wall insulation can be continued below the damp proof course in an insulation trench
- the thinnest insulation materials can be expensive, so should be used where saving space is most beneficial (eg, narrow corridors, floors)
- blown fibre insulation can reach significant depths in lofts; overboarding helps retain usable storage space
- daylighting design can overcome any loss of natural light from thick insulation and deeper window reveals.

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WHAT TO LOOK OUT FOR

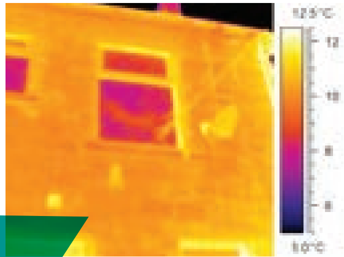
- consider the risks of thermal bridging if adjoining houses are not being insulated
- external wall insulation can be continued across boundaries
- internal wall insulation can be returned along party walls
- unaltered guttering can allow rainwater to damage external wall insulation
- the relationship between insulation, airtightness and moisture build-up is still being researched
- moisture build-up or damp occurs mainly in uninsulated areas, on windows, joist ends and at the base of external walls
- services on external walls may be repositioned to ensure insulation continuity
- floor insulation can affect door heights, stairs, kitchen units, appliances and worktops
- when insulating floors, spaces may become classed as 'unvented' so gas copper pipes may have to be replaced with a continuous flexible pipe.

PLUS POINT

It is critical to fully communicate the fabric detail designs to the site team

PRACTICAL LESSONS FROM THE PROJECTS

This thermal image of House 115 shows the effectiveness of edge insulation installed within the intermediate floor.



Fitting underfloor panels at House 85. Each panel integrates insulation and low temperature heat distribution and reduces air movement through existing exposed floorboards.

External wall insulation

Although external wall insulation can be less disruptive than internal, other factors may need to be considered:

- the team at House 75 installed apron insulation below damp proof course level creating a 'warm pocket' beneath the house
- where external wall insulation was stopped at the damp proof membrane, 150mm above the ground, thermography showed evidence of a thermal bridge. This can be even worse when outside paving allows rainwater to pool against the wall
- a new drain may need to be dug to enable external insulation to be continuous [West London, case study 4, House 109, page 47]
- external insulation with a parge coat (a low-cost alternative to repointing) and taping, combined with Passivhaus-certified triple glazing and doors, can largely eliminate cold bridging [West London, case study 4, House 109, page 47]
- thermal bridging can occur at any uninsulated party walls with neighbouring houses.

Internal wall insulation

Internal wall insulation was added to more than half the homes and many examples of good practice emerged:

- wall and roof insulation were connected and reveals, cills and soffits of openings were insulated to reduce thermal bridging [House 60]
- insulation was returned 500mm along the party walls to reduce thermal bridging at junctions with external walls [House 24].

Party walls that remain uninsulated may have a negative impact:

- it might be a cavity party wall, in which case significant heat loss may occur through it
- uninsulated internal party walls can result in noise from the neighbours becoming more disturbing than noise from outside [House 96].

Floor insulation

Raising floor levels with insulation can lead to:

- ill-fitting kitchen units, appliances and worktops
- a smaller first stair riser
- a higher front/rear door threshold
- small level differentials where solid floors meet suspended floors.

High-performance thin insulants can be useful, for example, on ground floors, at reveals, adjacent to stairways and in corridors. One home used 18mm chipboard with a Spacetherm blanket backing [Bungalow, case study 3, House 35, page 46].

Filling the floor void with blown insulation can result in it being classed as 'unvented'. As a consequence, at House 51 the copper gas main had to be changed to a continuous flexible pipe with no joints.

Thermal imaging shows the effectiveness of adding edge insulation to the intermediate floor in House 115. It is important to prevent joist ends embedded within the wall becoming cold and damp from condensation[5].

Roof insulation

The loft is a significant heat loss area:

- blown fibre is a useful loose fill that reaches all areas and settles evenly [Norfolk, case study 3, House 35, page 46]
- phenolic boards between rafters can insulate loft space with mineral/glass wool in the eaves (flexible and easy to install) [House 75]
- when boarding was not used, thermography showed that loose cellulose could become uneven resulting in heat loss [House 19]
- access and storage need to be considered when specifying roof insulation, particularly in homes where storage space is at a premium.

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PLUS POINT

Improved insulation meant that heating systems could be smaller or removed in places

35

of 40

35 of the 40 retrofit houses were fitted with mechanical ventilation with heat recovery systems

INDOOR AIR QUALITY

To be certain of good indoor air quality and low condensation, airtightness and ventilation have to work together in all seasons. Airtightness keeps warmth in the home so insulation must have no gaps (be continuous), construction joints need to be sealed, and service penetrations also carefully sealed. Good ventilation is essential for fresh air movement, health, comfort and to reduce the risk of condensation and mould.

BEST PRACTICE

WHAT WORKS WELL

- testing for airtightness midway through construction can identify unforeseen airflow paths
- a parge coat (a low-cost alternative to repointing) on external walls bonds floor and roof airtightness barriers
- most projects used mechanical ventilation with heat recovery (MVHR). Improvements in air quality were reported in some of these homes
- the MVHR unit will perform more efficiently when located inside the insulated envelope of the house.

WHAT TO LOOK OUT FOR

- on-site installation quality is vital and can involve multiple trades
- airtightness can be affected by a badly hung door or poorly sealed wall fittings
- it is important to determine the robustness of airtightness to justify the use of MVHR over other ventilation systems
- MVHR is just one option and should not be treated as the default approach. Many projects experienced challenges with MVHR
- the MVHR unit must be easy to access for changing filters, maintenance and cleaning.

The key objectives should include good airtightness, good indoor air quality and the removal of moisture at source so it does not get into the building fabric. A poorly integrated system can lead to stuffy indoor air or mechanical noise, so people may leave windows open (leading to high heating bills and carbon emissions) or worse, switch off the system altogether.

In aiming to achieve the right balance, most of the retrofit houses fitted mechanical ventilation with heat recovery (MVHR) systems. MVHR uses fans and ducts to exchange the indoor air: they extract 'wet' warm air from bathrooms, kitchens and utility rooms and use that heat to warm incoming fresh air.

PRACTICAL LESSONS FROM THE PROJECTS

Attention to detail can result in excellent airtightness [North Belfast, case study 1, House 1, page 44].

Airtightness

Factors that contribute to good airtightness are found throughout a home:

- good airtightness requires attention to detail by all sub-contractors [North Belfast, case study 1, House 1, page 44]
- testing for airtightness midway through construction can identify unforeseen airflow paths (ie, via socket back boxes, electrical oval conduits, patched plasterwork or joist ends) [House 96]
- a visual inspection may find defective windows [House 22] or a badly hung door [House 31]. Air permeability tests can identify finer points of detail
- a parge coat on external walls can bond floor and roof airtightness barriers to form an unbroken barrier [West London, case study 4, House 109, page 47]. Airtight grommets for services can maintain this barrier.

A parge coat (a low-cost alternative to repointing) on external walls can bond floor and roof airtightness barriers to form an unbroken barrier [West London, case study 4, House 109, page 47].

The importance of integration

In one project, good airtightness was achieved by taping floor-to-wall and wall-to-ceiling junctions, sealing service penetrations and adding new external doors and windows. However, the trickle vents in the new windows made the MVHR less efficient. Furthermore the resident felt the intake air was warm in summer and cold in winter. It was found that intake air came from the roofspace rather than outside as the intake vent was blocked by insulation. Closer integration of airtightness, ventilation and insulation, with good on-site quality control procedures, could have prevented these issues.

Passive ventilation

Ventilation was innovative at House 8. A ventilating lightwell and rooflight produce natural stack ventilation. Fresh air enters through panels next to new triple-glazed windows. The system automatically opens when needed and closes when it rains [London, case study 2, House 8, page 45].

In contrast, another home uses a natural ventilation system combining passive stack ventilation (PSV) and trickle vents. Temperature data suggests that the residents underheat the house, resulting in higher relative humidity. During cold weather, condensation drips into the house.

Mechanical ventilation with heat recovery (MVHR)

Many of the projects included MVHR as a low-energy ventilation solution. At the time of Retrofit for the Future there was limited experience in the UK of MVHR and 17 projects had notable challenges. When used appropriately MVHR can improve air quality. One property was located beside a busy road and under a flight path and both residents have reported improved respiratory health [West London, case study 4, House 109, page 47].

Learning points about MVHR[6]:

- the MVHR air filters and controls must be convenient to access without special tools
- the condensate pipe must be safe from freezing
- the heat exchanger unit and all ductwork should be inside the insulated envelope
- the fans should be as efficient as costs allow
- the heat exchanger should incorporate a summer by-pass option
- ducts should be smooth, rigid and as short and straight as possible
- mechanical noise must be minimal in the living spaces
- people need to understand the system and how to use the controls.

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PLUS POINT

Testing for airtightness midway through construction can identify unforeseen airflow paths

11

properties

The ability to control services was a common area for improvement, with issues identified in 11 properties

SERVICES

Services include heating and hot water systems, lighting, renewable energy systems and controls, all of which should be an integral part of the retrofit from the start. Factors such as the design, sizing, procurement, installation, positioning and interface of services have a direct impact on the comfort and satisfaction of residents. Services need to be positioned and installed with care, otherwise the service penetrations can significantly affect the airtightness of the fabric.

BEST PRACTICE

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WHAT WORKS WELL

- consider how all services interact with each other, including lighting
- heating and ventillation controls should knit together complex systems and be simple to use
- a good daylighting strategy can reduce the need for lighting and heating in the daytime
- handovers should be used to ensure people understand how to use new services and technologies.

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WHAT TO LOOK OUT FOR

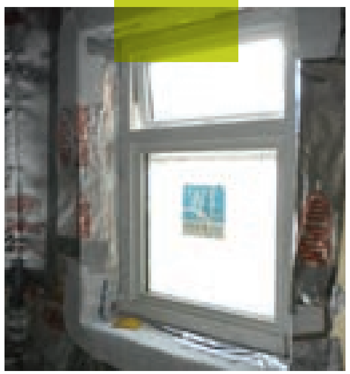
- technologies need to interact with each other and the supply chain needs to have the knowledge of how this can be successfully achieved
- support and technical guidance should be requested from manufacturers of innovative products (or for products used in innovative combinations); this can be more difficult if the manufacturers are overseas
- the ability to control services was a common area for improvement, with issues identified in 11 properties
- some residents wanted more control rather than fully automatic systems.

PLUS POINT

Services should be an integral part of the retrofit from the start

PRACTICAL LESSONS FROM THE PROJECTS

A solar hot water tank provides a thermal buffer to integrate the heat pump hot water and the water from the solar panels.



Adding internal wall insulation will deepen the window reveals (cills) and could reduce natural light levels [House 57].

Integrating into one system

Some of the homes are using new technologies in unusual combinations. This can be complex, particularly when multiple systems are integrated to provide a single service:

- hot water controls for two properties were initially set so the heat pump would heat the hot water cylinder between 6.30am and 8.00am. This ‘blocked’ input from the solar thermal system because the tank was already hot when the solar heat became available [House 60 and House 25].

Limited support for some new products can make it difficult to repair or replace components, particularly when sourced from overseas:

- a hybrid heating unit (air source heat pump combined with gas boiler) was new to the UK and spare parts were not readily available [House 61]
- controls for a ventilation system came with instructions only in German [House 85].

Designing with daylight

Several projects reported that deep window reveals created as a result of thick wall insulation had reduced levels of natural light and could lead to residents using more energy for lighting [House 96, House 22, House 57, House 56].

Enhanced daylight can reduce the use of lighting:

- one project simplified windows and introduced a sunpipe. The residents say, “The level of natural light is fine in all of the rooms. We don’t use the lights as much in the day.” [House 44]
- another team considered daylighting and airtightness and used Passivhaus-certified, inward-opening windows [North Belfast, case study 1, House 1, page 44].

Choosing systems carefully

Poorly selected or positioned heating systems can create an uncomfortably warm or cool home:

- despite improvements in building fabric, one home retained its original radiators; the residents often feel too warm and open the windows
- lighting distribution was affected by new MVHR ducts so supplementary lighting had to be installed [House 85].

Designing for residents

The team at House 1 [North Belfast, case study 1, page 44] specified energy systems that require little or no resident input. The only controls are a simple on/off switch for all services and two room thermostats. A boiler interlock prevents the boiler firing if the MVHR is not running or if windows are open.

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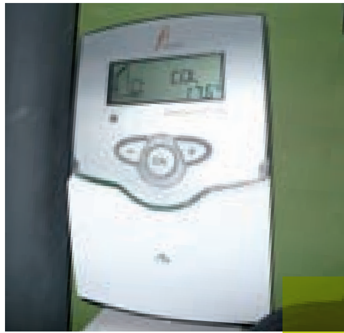
PLUS POINT

Heating and ventillation controls should knit together complex systems and be simple to use

Controls should be simple, well-positioned and provided with user-friendly instructions:

- at House 75, a potentially complex energy management system has been simplified. The resident controls the heating using a conventional heating programmer. Behind the scenes, the programmer interfaces with a 5kW wood burner with back boiler, evacuated tube solar collectors, a thermal store, MVHR and a gas boiler back-up. The control supplier can access the system remotely to check on its operation and install firmware and software upgrades. Additional controls automatically boost the MVHR when the cooker, a hot tap or shower is used
- many people did not touch the controls once they had been set. User-friendly instructions may have empowered them to achieve better comfort and to save money
- some residents would have preferred more control. In one project, residents wanted a water temperature indicator on their solar thermal tank [House 85]. In another, a faulty heat pump did not include a pressure alarm so the resident did not know that a temporary problem had arisen [House 60]
- control switches should not be positioned next to conventional light switches as this can lead to people regularly pressing the wrong buttons.



Some of the monitoring and controls equipment installed at House 60.

1

coordinator

Coordination works best when a single individual or organisation takes the lead

WORKING ON SITE

The on-site delivery of retrofit has a significant impact on people and their overall satisfaction with the process. The quality of on-site delivery also contributes to the integrity of fabric and services and to achieving effective airtightness and ventilation.

BEST PRACTICE

WHAT WORKS WELL

- effective and informed project management and coordination
- continued involvement of the design team once on site
- briefings to help teams to understand and commit to the retrofit aims
- site operatives should watch airtightness tests to see the results of their work
- whichever supply chain model is chosen, clear responsibilities and communication are critical
- a realistic timetable with a logical sequence of works, well-structured contracts and clear expectations on the supply chain can mitigate delays.

WHAT TO LOOK OUT FOR

- where residents remain in situ, they are likely to face disruption, mess and delays - this may impact on their relationship with contractors
- on-site changes to the design specification (for example, the tenant requesting a piece of technology to be moved) should be checked with the coordination and design team to prevent avoidable impacts on the overall results
- site operatives may need input and support from specialists when using innovative products or technologies for the first time
- the process of making good after a deep retrofit can be more difficult, costly and time-consuming than normal.

PLUS POINT

Contractors may need support from specialists when using innovative technologies for the first time

PRACTICAL LESSONS FROM THE PROJECTS

Lack of space on site caused difficulties on several projects including at House 69 (top). At House 85 (above) materials had to be stored on the road in front of the house.

On-site coordination

Coordination works best when a single individual or organisation takes the lead:

- the lead contractor on House 1 [case study 1, page 44] installed, supervised, commissioned and led the handover
- the housing association on House 109 [case study 4, page 47] was both the property owner and the lead contractor. Keeping work in-house simplified communication
- the client on House 61 used a single contractor who directly employed the majority of construction trades; this simplified on-site delivery. The designers and engineers also visited the site regularly to meet with the relevant trades.

Engaging the supply chain

For example:

- subcontractors on House 96 attended the airtightness tests so they could see the connection between airtightness and heat loss. It was reinforced by discussions about continuous insulation and airtightness details
- the manufacturer of the internal wall insulation used in House 52 visited the site to ensure joiners were properly trained to undertake the work
- site operatives may need support from specialists when using innovative technologies for the first time. One contractor said that procuring unfamiliar systems and products was challenging and that longer lead times would have helped [House 25].

Installation

For example:

- attention to detail is critical at installation. At one property, installers removed plaster before finding that the manufacturer recommends insulation be fixed to a smooth, flat surface. Battening was added, costing time and money and reducing internal space
- sequencing should be thought through carefully. For instance, components should not be fixed to the walls before the internal insulation is completely finished
- retrofit teams should allow for more snagging and remedial works than usual. Making good after a deep retrofit can be difficult, costly and time-consuming. For example, carpets may need to be cut back and fixed, skirting and cornices fitted, sockets repositioned and rooms redecorated.

+

PLUS POINT

A realistic timetable will include contingency for additional works discovered through the course of the retrofit

£360

One resident has estimated fuel savings of £360 a year



ENGAGING RESIDENTS

Engaging residents from the start can increase their understanding and acceptance of the works, and this can be a defining factor for success. The project teams took various approaches to working with people, to handing over the home and its new systems and to technical support.

In some cases project teams did not know who was going to live in the house. This reflects the reality of the retrofit market so keeping some flexibility and future-proofing for different types of people can be extremely beneficial.

BEST PRACTICE

WHAT WORKS WELL

- continual engagement with residents during the project
- tours of the house while work is under way
- if there are delays or additional works, give residents time to reflect and adapt to them
- a handover should cover all elements of the retrofit but with particular attention to the different systems and how to use them together as one system
- provide user-friendly controls and clear guidance
- aftercare visits to make sure people are comfortable and are using systems well
- visit again when new residents move in.

WHAT TO LOOK OUT FOR

- if the handover is too basic, it will not be effective. If it is too complex, it may alienate people who might then use the controls and systems as little as possible
- in the user instructions, use language that the residents find clear and easy to understand
- be clear about where responsibilities lie; for example, who is responsible for maintenance or who receives the feed-in tariff or renewable heat incentive.

PLUS POINT

If there are delays or additional works, give residents time to reflect and adapt to them

PRACTICAL LESSONS FROM THE PROJECTS

Engage residents throughout the process

When delays occurred at House 109 [case study 4, page 47], the housing association's resident liaison officer recommended that works be suspended for a day to allow the residents to prepare for the next stage.

At House 109 the resident was initially cynical about energy-saving behaviour, but the retrofit process encouraged him to change (eg, using appliances on sunnier days to maximise use of the solar panels). His fuel savings are estimated as £360 per year.

Do a full handover

All handovers included a tour of the house with a demonstration of the new systems and instructions. Adding a post-retrofit interview and walk-through can reveal how the house is actually being used; it can highlight quality issues and whether controls and systems are working as planned [London, case study 2, House 8, page 45].

Some projects went further:

- at House 1 [case study 1, page 44], the project team spent time living in the property to fully understand its operation. Only after this did they develop verbal and written handover materials. The residents were also visited twice in the first month
- at House 96, the M&E (mechanical and electrical) contractor explained how the MVHR and solar thermal unit had been programmed
- for House 109 [case study 4, page 47], an A1 poster was produced identifying, with drawings and photographs, the equipment and systems installed in the house.

PLUS POINT

A handover to residents should cover all elements of the retrofit but with particular attention to the different systems and how to use them together as one system

Be considerate with the level of information:

- the resident at House 52 did not understand the MVHR system and so continually left their windows open
- at another property, on the day that new residents moved in, not yet unpacked, they were given a four-hour tour of the property's energy systems
- another resident found the paperwork too complex and so left the controls on their default settings [House 24]
- in an example of innovative good practice, at House 21, the resident was asked to compile a user manual, in their own words, to help future residents. They produced a very effective document.

Consider the controls:

- if controls are complicated people may simply not use them (causing higher energy use, discomfort, or disabling the ventilation system) [House 60, House 25]
- one resident struggled to light the wood burner, so bought a portable electric heater [House 14]
- not knowing how to use the wireless thermostat, one person simply left it in a drawer [House 64].

Follow up with residents

Follow-on support for residents can affect their everyday behaviours, their energy use and the long-term performance of the retrofit. This is particularly important in retrofits that include unusual features or technologies. For example:

- follow-on support should be planned for the long term; maintenance staff may need training on how to fix new problems [House 22]
- a real time display at House 53 has made people more aware of their energy use and led them to buy an eco kettle
- the people at House 72 have spread the word about retrofit as something everyone should do for greater comfort and to save money.

+

PLUS POINT

"Watching the 'real time' display has really changed how we use heating and lighting, we've even bought an eco kettle."

[House 53]

Case Study 1

HOUSE 1

North Belfast, mid-terrace solid wall house built in 1896. Previous work in 2001 included installation of double glazing, a non-condensing gas boiler and partial dry-lining.

Retrofit for the Future included:

- phenolic internal wall insulation bonded to 18mm OSB, phenolic insulation to the solid ground floor and a combination of insulation types to attic ceiling
- Passivhaus certified windows
- solar PV panels
- MVHR
- highly insulated pre-fabricated roof.

House 1 in North Belfast looks similar to its neighbours after the retrofit.

PLANNING

From the outset, the design team worked to a solution that prioritised the resident. They sought to choose appropriate technologies with straightforward controls that would provide a comfortable and easily controlled environment.

The main contractor took on the role of retrofit coordinator, overseeing the installation of all energy measures and closely managing sub-contractors.

The residents are delighted with this retrofit.

BUILDING FABRIC

During the systematic destruction before the retrofit, the team encountered numerous structural and safety concerns that needed to be addressed. This added unforeseen time and cost.

When it was discovered that the original roof timbers were decayed, a prefabricated roof with a high level of insulation was commissioned. The old roof was removed and the new roof lifted on and made weather-tight within 24 hours.

The team considered daylighting and airtightness as part of the overall strategy and commissioned innovative Passivhaus certified, inwardly opening windows that had not been produced before.

INDOOR AIR QUALITY

Before the retrofit, airtightness was over 12 $m^3/m^2/hr$ @50Pa. Through the retrofit this was reduced to 0.25 $m^3/m^2/hr$ @50Pa. This was achieved through attention to detail, driven by the retrofit coordination team and involving all sub-contractors. The whole on-site team were present at airtightness tests.

Intermediate floor joists were cut short and slotted into a steel universal beam positioned within the thermal envelope, the rotting roof was replaced with an off-site, pre-fabricated construction, and 1.6km of sealant tape was used.

A user-friendly, hybrid ventilation system and controls were designed, combining active ventilation from the MVHR with passive ventilation via automatically opening roof windows.

SERVICES

A straightforward services strategy included an efficient gas boiler with flue gas heat recovery, PV and MVHR. The boiler has an interlock that prevents operation unless the MVHR is running and windows are closed.

The only controls were a simple on/off switch for all services and two room thermostats.

WORKING ON SITE

The main contractor took full responsibility to ensure any on-site changes kept to the overall strategy. They even returned to make sure a service penetration, created subsequently when broadband was installed, was sealed and airtight.

The project team spent time living in the property to fully understand its operating characteristics and optimise the systems.

The handover process included guided tours and instructions with follow-up visits to check the residents were happy with the controls and how the house was working.

The arrows indicate which retrofit themes had noticeable impacts on other themes during the project.

Case Study 2

HOUSE 8

London, mid-terrace two-storey house with three bedrooms built in 1992. It had masonry unfilled cavity walls, double glazing and a pitched roof with a limited amount of loft insulation.

Retrofit for the Future included:

- rigid PIR foam internal insulation to front, rigid phenolic foam external insulation to rear
- glass wool in-fill of party wall cavities
- 20mm vacuum insulation panels to ground floor
- triple-glazed solar ventilating lightwell
- hemp-flax quilt and rigid wood fibre insulation to loft
- triple glazed windows with ventilator panels
- solar PV and solar thermal
- existing boiler fitted with flue gas heat recovery.

House 8 in London showing the minimal visual impact of the new lightwell in the roof.

PLANNING

Early discussions with the residents highlighted some limitations with the existing home, such as summer overheating, the size of the bedrooms and the need for more storage space.

The loft conversion provides a ventilating lightwell and has improved the residents' quality of life by providing storage space.

The residents lived in the home throughout the retrofit. This required changes to the planned programme of works (such as starting with the ground floor rooms at the residents' request).

BUILDING FABRIC

Several strategies for whole-house insulation were developed. Analysis of thermal bridging for each strategy highlighted that party wall thermal bridges had the greatest potential for significant heat loss. The party walls were insulated with granules of glass wool fibre injected into the unfilled cavity.

The ground floor was insulated using ultra-thin high performance vacuum insulation panels with puncture protection of thin steel sheets and expanded cellular foam sheeting. These were laid on top of the existing sand-cement screed. Although this was a high-cost material choice, it was also quick to install with minimal disturbance or loss of headroom.

INDOOR AIR QUALITY

The ventilation strategy was a major area of innovation: a ventilating lightwell and rooflight open to produce a natural ventilation stack effect to remove stale air. Fresh air is admitted through insulated ventilating panels located next to the new triple glazed windows. The panels open automatically when internal conditions are hot or humid and close automatically when it rains.

MVHR was installed in the bathroom and above the kitchen cooker. The kitchen unit was subsequently removed as the residents were unhappy with the unit's impact on the kitchen space.

SERVICES

When the solar thermal system was activated, there was insufficient pressure for the taps and shower. Limescale build-up in the boiler heat exchangers was the cause. A thorough servicing of the boiler and replacement heat exchangers and pump solved the problem.

WORKING ON SITE

There was some concern that the level of detail provided in the design stage drawings was not always equalled in implementation.

Two induction tours were provided to the residents on how to use the new systems. The tour routes were coordinated with a home guide written by the project team. The occupants were encouraged to try the technology settings as they were being explained.

The arrows indicate which retrofit themes had noticeable impacts on other themes during the project.

Case Study 3

HOUSE 35

One of a four-bungalow terrace built in 1948. Before retrofit, it had little insulation, poor airtightness and was reliant on electric heating and a coal fire. It had an EPC rating of 'G'.

Retrofit for the Future included:

- aerogel laminated chipboard to ground floor
- aerogel laminated board to internal walls
- blown loft insulation
- insulated external doors and secondary glazing system
- MVHR
- air source heat pump, solar PV and solar hot water.

The bungalow (House 35) looked little different on the outside after the retrofit.

PLANNING

Early discussions with residents were particularly effective for understanding their needs. A walk-in shower was installed and the kitchen, carpet and tile finishes were specified to the residents' taste.

The local planners were keen for the property's external appearance to be retained. This prevented the use of vacuum glazed window units. Instead, traditional crittall metal frame units were used with additional secondary glazing and thermal blinds.

BUILDING FABRIC

The loft is a particularly significant heat loss area in a bungalow. Blown fibre insulation was added to a depth of 420mm. The loft entrance was built up by 500mm and a deck was created to allow ease of access to the MVHR unit and PV inverter.

The existing solid ground floor was overlaid using 18mm chipboard with aerogel blanket backing.

Internal wall insulation was installed throughout. Unfortunately, the subsequent installation of an electricity meter required the insulation to be cut away behind a kitchen cupboard, which breached the air barrier; some evidence that this may be causing a cold spot is visible in a thermal image.

INDOOR AIR QUALITY

Before the retrofit, airtightness was 5.3 $m^3/m^2/hr$ @50Pa. Through the retrofit, this was reduced to 3.44 $m^3/m^2/hr$ @50Pa.

The summer bypass, an optional extra on this MVHR product, was not installed. Monitored data shows temperature peaks of 25-26°C and relative humidity in the region of 55% during the summer months, which could be a source of discomfort. Both could be more manageable if an automatic summer bypass option had been installed.

SERVICES

Thanks to the fabric improvements, the space heating demand can be met by an air source heat pump with newly installed radiators and the MVHR. Hot water is partially met by solar thermal and a 2.1kWp PV array offsets some of the electricity needed for the house which is not on the gas grid.

WORKING ON SITE

There was a long delay in the delivery of the external doors, which had a knock-on effect on the whole project as some internal wall insulation and airtightness details could only be done when the doors were being installed. The interconnectivity between these retrofit details placed much more importance than usual on the installation schedule for the doors.

The resident, who occupied a vacant property on the same street during the works, had regular tours of the property during the retrofit. This helped in managing their expectations and ensured the installation details were completed to their satisfaction.

The arrows indicate which retrofit themes had noticeable impacts on other themes during the project.

Case Study 4

HOUSE 109

West London, 3-bedroom, semi-detached built in the 1950s. This solid wall house needed new windows, a heating upgrade, re-wiring, and a new kitchen and bathroom.

Retrofit for the Future included:

- 240mm EPS external wall insulation
- 100mm mineral wool + 300mm cellulose loft insulation
- 150mm mineral wool between ground floor joists
- triple glazed 0.8 W/m^2K windows and doors
- MVHR
- solar thermal and a new gas combination boiler.

House 109 had external wall insulation and triple glazed windows.

PLANNING

The architects specified the detail design while the housing association was both the property owner and the lead contractor. These simplified relationships and communication channels helped improve quality assurance and problem solving on site.

Clear, well-communicated performance targets led to robust, well-engineered details that were drafted early in the design process, ensuring insulation continuity and a high level of airtightness.

BUILDING FABRIC

This project adopted a fabric first approach centred on Passivhaus EnerPHit principles. By paying a lot of attention to the thermal envelope, details and airtightness, the specific space heating demand was reduced by approximately 95% (as modelled by PHPP).

External insulation was extended 1m below ground, creating a thermal apron around the perimeter of the property that helps eliminate thermal bridging at the ground floor and reduce floor heat loss. While this is considered good practice, a common issue is how to work with services that are close to the house. In this instance, the foul drain was too close to the house to accommodate the below-ground insulation and so a new drain run was dug.

INDOOR AIR QUALITY

An airtight membrane from the attic bonded into a parge coat underneath the external wall insulation, and continuous membranes and tapes fitted around window and door openings have helped improve airtightness from 7.06 $m^3/h/m^2$ down to 1.39 $m^3/h/m^2$. The only airtightness weaknesses are within the intermediate floors which couldn't be accessed with residents in situ.

As the property is on a busy road and beneath a flight path, MVHR was felt to be an appropriate solution. Since its installation, both occupants have noted a marked improvement in their existing respiratory problems and overall health.

SERVICES

With a robust fabric and ventilation strategy in place, a relatively low-tech, simple space heating and hot water strategy has been adopted consisting of a new gas combination boiler and an evacuated tube solar thermal collector both feeding into a new hot water cylinder.

WORKING ON SITE

A dispute between the tenants and their neighbours led to protracted negotiations for scaffolding access, resulting in an overall delay to the works on site.

The resident liaison officer recommended that work was suspended for a day to allow the residents to take stock of the changes and prepare for the further work. This decision to slow the works temporarily helped ensure residents' comfort and strengthen their support for the project.

Engaging residents during all stages of the works was straightforward because the project team was uncomplicated.

The arrows indicate which retrofit themes had noticeable impacts on other themes during the project.

75%

The most energy efficient home used 75% less energy than the national average, with 80% less carbon emissions

TOPICAL RETROFIT DEBATES

Retrofit for the Future informs debates about:

- **the performance gap:** is there a gap between forecast and actual energy use
- **over or under-heating:** how to achieve a comfortable living environment
- **retrofitting at scale:** the retrofit industry needs to deliver robust houses with long-term energy savings.

The performance gap

The performance gap can be defined in different ways. Retrofit for the Future used the calculated forecasts for energy use compared with the actual energy use. A significant difference is often seen between the two figures and that difference is termed the performance gap. The data is displayed in the graphs (pages 50-51).

The forecasted energy use data includes:

- regulated energy loads captured within the Building Regulations Part L and the Standard Assessment Procedure (SAP)
- unregulated energy loads not captured within the Building Regulations Part L.

Project teams who used SAP were able to capture the unregulated loads using a module developed specifically for Retrofit for the Future. Teams who used the Passive House Planning Package (PHPP) were not required to use the module.

Actual energy use

Energy meters collected data for the lived-in homes over at least 12 months. The data is in units of kilowatt hours per square metre of internal floor area per year (kWh/m^2/yr). This can easily be converted into other units of interest (eg, primary energy, energy cost or carbon emissions).

Energy reductions

In Retrofit Revealed we reported that the retrofits achieved significant energy reductions compared with their pre-retrofit state: an average of 40% less than the national average. The most energy efficient used 75% less energy than the national average, with 80% less carbon emissions.

Retrofitting at scale

The retrofit market needs to expand quickly to deliver at scale. Retrofit for the Future provides some valuable lessons:

- adjoining houses should have fabric insulation at the same time. Alternatively, insulation can be carried along the external wall or returned along an internal wall, but this will add costs
- lead times for innovative products can be significant. Rapidly increasing demand may cause manufacturing delays. Early discussions with suppliers and specialist subcontractors can reduce the risk
- many projects benefitted from on-site coordination and close communication between design and installation teams. Coordinating retrofit across a large number of properties is a significant programme management opportunity
- a range of SME contractors and subcontractors could scale up and down as needed and enable the client team to focus on management.

Technical improvements to be further researched include re-working of the survey and specification process, new fabric treatment methods including new insulations and robotic application using 3D printing technology, and low-cost reliable energy monitoring to verify that the properties perform as expected[7].

Comparison of forecasted and measured energy use

The purple bars show the forecast energy use. The grey bars show the actual energy use for the same homes.

LEARNING POINT

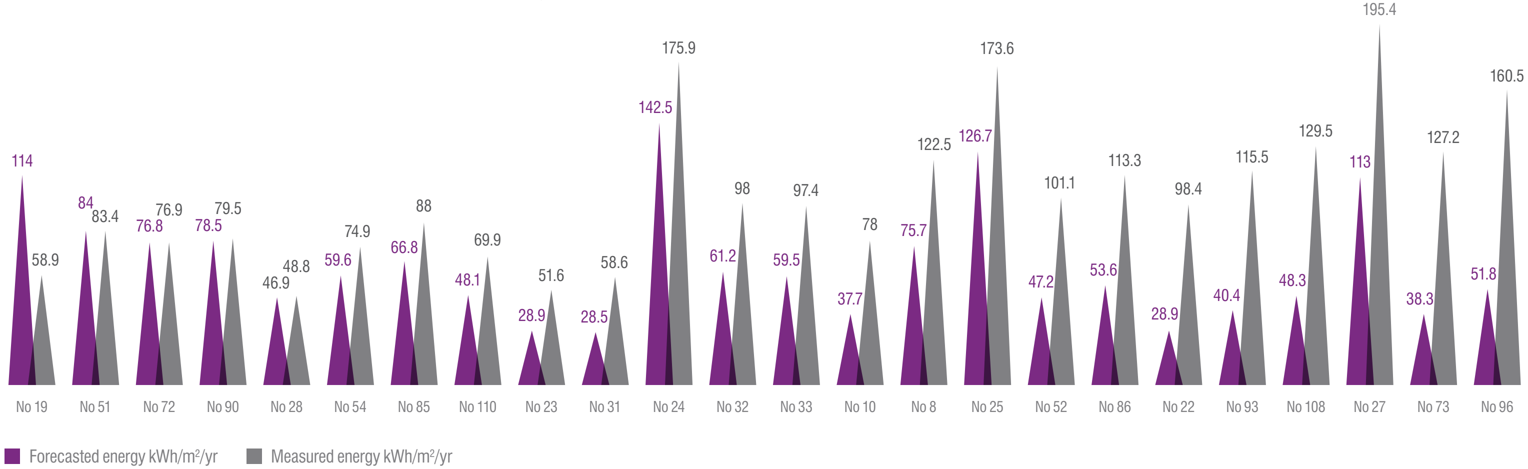
Projects that forecasted a lower energy use were likely to achieve a low energy use relative to other projects, even if not as low as the forecast.

LEARNING POINT

The retrofit industry must understand what causes the gap between forecasted and actual energy use, particularly as some of the causes are beyond the control of the industry. This is especially important where costs and payback are linked to performance, such as 'pay as you save' schemes like the Green Deal[8].

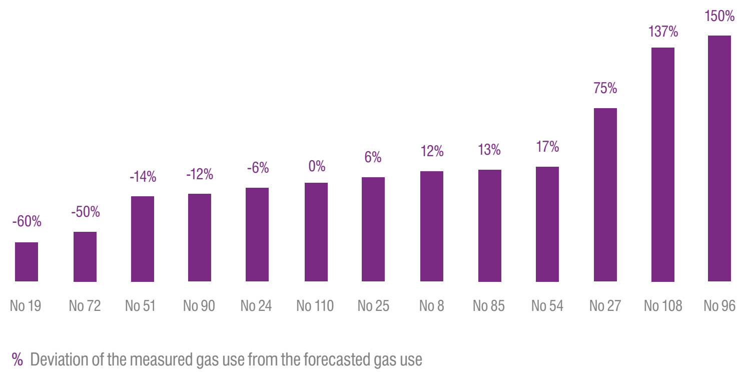
ACTUAL ENERGY USE

In one home, [House 19], the actual energy use (grey) was 50% less than forecast (purple). In four houses, [House 51, House 72, House 90 and House 28], the difference was marginal, less than 5%. In the majority of houses, actual energy use was at least 50% more than the forecast; in one home by 240% more.



PERFORMANCE GAP FOR GAS USE

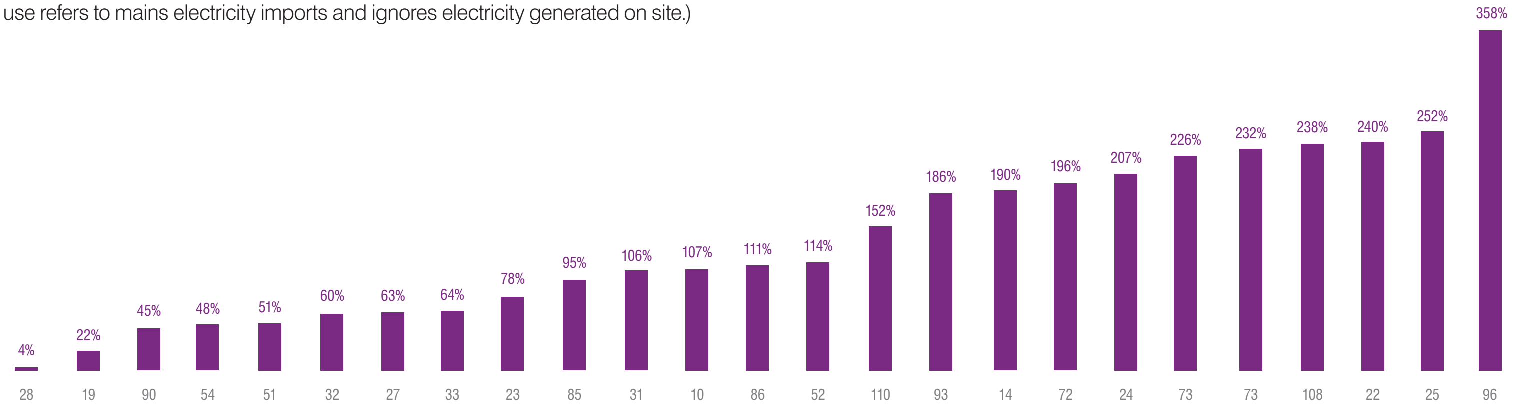
The forecasts for gas use were in most cases within ±15% of the measured gas use. There were two exceptions [House 19 and House 72] that used noticeably less than was forecasted and three [House 27, House 108 and House 96] that used noticeably more than was forecasted.



PERFORMANCE GAP FOR ELECTRICITY USE

In four homes, [House 28, House 19, House 90 and House 54] the measured electricity use was 4% to 48% greater than the forecast. In the majority of cases the measured electricity use was considerably greater than forecasted. (Note: electricity use refers to mains electricity imports and ignores electricity generated on site.)

Deeper analysis could provide further insight; for instance, by separating the regulated electrical loads (eg, lighting and heating) and the other sub-metered circuits (eg, unregulated loads and on-site power generation).



% Deviation of the measured electricity use from the forecasted electricity use

LEARNING POINTS

Electricity use, rather than gas use, was more frequently the source of the performance gap.

Homes using either MVHR or heated by electrical technologies are randomly interspersed throughout the chart on the left, which suggests that adopting MVHR or electrical-based heating may not be a major factor in the observed performance gap.

REPORTED COMFORT

There are some concerns that retrofit homes can be too warm or too cool for comfort. Factors that can influence this include: levels of insulation; effectiveness of ventilation; the nature, size and usability of the heating system; and the ability of householders to use systems and controls.

The chart illustrates how comfortable people reported their home to be. There was a significant shift from reporting poor or very poor conditions before the retrofit to reporting good and excellent conditions after the retrofit.

Overheating in homes may become more of a problem if heatwaves increase. Homes with effective ventilation and shade over glazing are less likely to overheat.

Proportion of 76 houses

LEARNING POINT

If residents cannot use their ventilation system, their homes may be more likely to overheat.

REFERENCES AND LINKS

[1] *Residential Retrofit: 20 Case Studies*, published by RIBA Publishing, November 2013. www.ribabookshops.com/item/residential-retrofit-20-case-studies/80472

[2] *Retrofit Revealed*, published by Technology Strategy Board, March 2013. Visit www.innovateuk.org.uk and search for 'Retrofit Revealed' or www.retrofitanalysis.org

[3] http://getembed.com and www.lowenergybuildings.org.uk

[4] See data at www.retrofitanalysis.org

[5] See Institute for Sustainability www.instituteforsustainability.co.uk/latestpublications.html

[6] Technology Strategy Board is undertaking a review of approximately 80 homes with MVHR ventilation. The report will be available in late 2014 at connect.innovateuk.org/web/building-performance-evaluation

[7] Technology Strategy Board is currently running a programme 'Scaling up retrofit of the nation's homes' to help businesses to radically improve their retrofit offers. Visit www.innovateuk.org/funding-competitions and search for 'Scaling up retrofit' under previous competitions.

[8] www.gov.uk/green-deal-energy-saving-measures

Background data

Two databases contain full background details to each retrofit house within this guide:

- http://getembed.com (EMBED database holds all of the Retrofit for the Future data)
- www.lowenergybuildings.org.uk (Low Energy Buildings database (LEBd) is an education tool developed by the AECB. It includes the Retrofit for the Future projects as well as new and refurbished domestic and non-domestic low energy buildings).

Guide	EMBED ref	LEBd ref
House 1	TSB001	ZA202H
House 4	TSB004	ZA237K
House 8	TSB008	ZA347W
House 14	TSB014	ZA643N
House 19	TSB019	ZA644T
House 21	TSB021	ZA644T
House 22	TSB022	ZA366J
House 24	TSB024	ZA125G
House 25	TSB025	ZA145M
House 26	TSB026	ZA146G
House 29	TSB029	ZA349C
House 31	TSB031	ZA638A
House 35	TSB035	ZA233U
House 44	TSB044	ZA628L
House 51	TSB051	ZA234Y
House 52	TSB052	ZA614G
House 53	TSB053	ZA428E
House 54	TSB054	ZA398Y
House 56	TSB056	ZA389F
House 57	TSB057	ZA577J
House 60	TSB060	ZA439S
House 61	TSB061	ZA213Y
House 62	TSB062	ZA241K
House 64	TSB064	ZA148E
House 69	TSB069	ZA246T
House 72	TSB072	ZA660T
House 73	TSB073	ZA525R
House 75	TSB075	ZA636L
House 76	TSB076	ZA538P
House 85	TSB085	ZA390M
House 96	TSB096	ZA114U
House 106	TSB106	ZA493T
House 108	TSB108	ZA521E
House 109	TSB109	ZA522P
House 115	TSB115	ZA391Y

Building Opportunities for Business: Low Carbon Domestic Retrofit Guides

The Technology Strategy Board partnered with the Institute for Sustainability to produce a set of guides based on Retrofit for the Future. The guides are particularly aimed at SMEs within the construction industry:
www.instituteforsustainability.co.uk/retrofitguides

Within this suite of guides, particular reference should be made to:

Funding and procurement for low carbon retrofit products
(Institute for Sustainability, Retrofit Guide 4)
http://bob.instituteforsustainability.org.uk/knowledgebank/retrofitguides/guide-4

Improving the building fabric
(Institute for Sustainability, Retrofit Guide 6)
http://bob.instituteforsustainability.org.uk/knowledgebank/retrofitguides/guide-6

Improving the building services
(Institute for Sustainability, Retrofit Guide 7)
http://bob.instituteforsustainability.org.uk/knowledgebank/retrofitguides/guide-7/Pages/Download.aspx

Living in a low carbon home
(Institute for Sustainability, Retrofit Guide 9)
http://bob.instituteforsustainability.org.uk/knowledgebank/retrofitguides/guide-9/Pages/9-1-Introduction.aspx

Retrofit insights: perspectives from an emerging industry

The Institute for Sustainability commissioned UCL Energy Institute to analyse a selection of Retrofit for the Future projects.
www.instituteforsustainability.co.uk/latestpublications.html

Occupant centred retrofit: engagement and communication
www.instituteforsustainability.co.uk/uploads/File/OCR_final.pdf

Controls for End Users: A guide for good design and implementation (BCIA 1/2007)
This guide concentrates on the strategy, implementation and the user interfaces of control devices for heating, cooling and ventilation
www.bsria.co.uk/information-membership/bookshop/publication/controls-for-end-users-a-guide-for-good-design-and-implementation

Domestic Ventilation Systems - a guide to measuring airflow rates (BG46/2013)
This guide covers types of ventilation systems, performance requirements, design, installation, air flow measurement, testing and commissioning.
www.bsria.co.uk/information-membership/bookshop/publication/domestic-ventilation-systems-a-guide-to-measuring-airflow-rates

Performance gap references

Green Construction Board (March 2013): The Performance Gap: Causes & Solutions can be accessed at
http://greenconstructionboard.org/index.php/resources/performance-gap

NHBC (February 2012): Low and zero carbon homes: understanding the performance challenge (NF41) can be accessed at www.nhbcfoundation.org/Researchpublications/NF41/tabid/500/Default.aspx

Zero Carbon Hub: Closing the Gap Between Design and As-Built Performance - Reports can be accessed at
www.zerocarbonhub.org/current-projects/performance-gap

Selected retrofit standards

Passivhaus: an energy performance standard promoting excellent thermal performance and airtightness with no/minimal heating or cooling systems www.passivhaus.org.uk

Passivhaus EnerPHit: a certification standard for buildings that have been refurbished using Passivhaus components
www.passivhaus.org.uk/page.jsp?id=20

Minergie: a sustainability standard based on delivering comfort to users living or working in a building www.minergie.ch/basics.html

Active House: a specification for buildings that create healthier and more comfortable lives for their residents without negative impacts on the climate www.activehouse.info

APPENDIX

Methodology

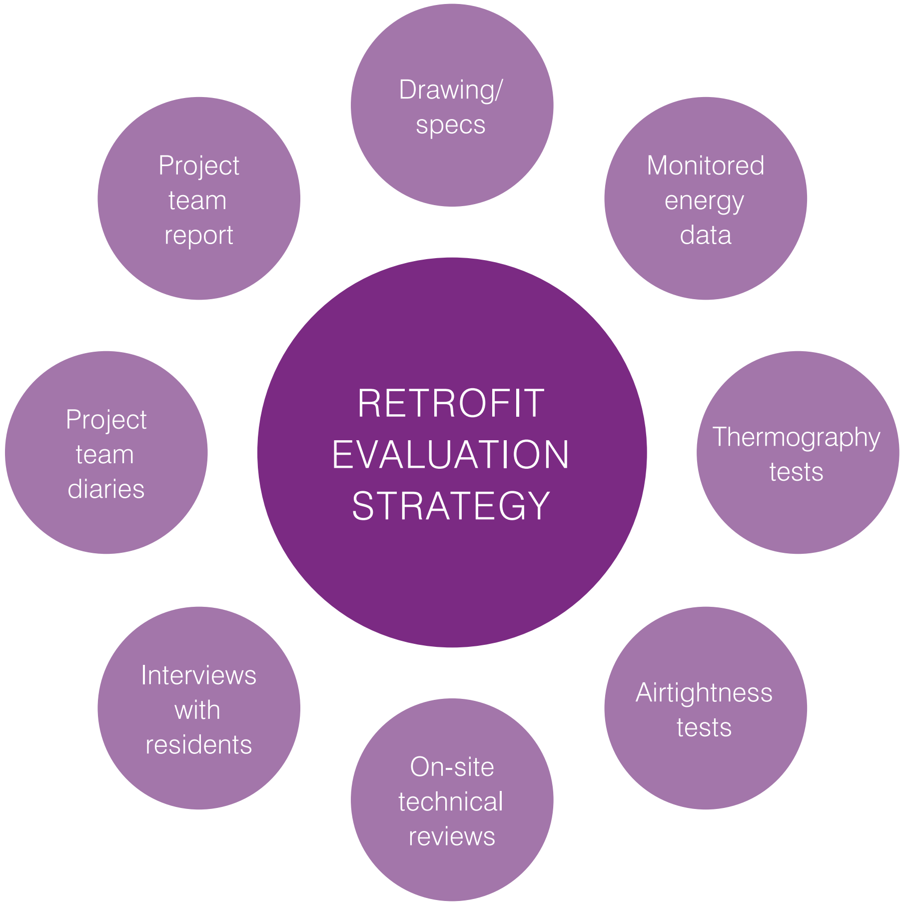
This appendix outlines how information was collected and analysed to draw the conclusions and recommendations.

Monitoring, evaluating and reporting

Energy Saving Trust and the Technology Strategy Board developed an evaluation strategy to demonstrate the effectiveness of the retrofit and indicate the particular contribution of specific measures. This strategy included remotely monitored performance data, one-off performance tests and evaluation of the project teams' and residents' perspectives on the retrofit. Projects completed further reporting to the Technology Strategy Board and some compiled retrofit diaries.

Energy Saving Trust developed a core package of evaluation measures that would be carried out to a specified frequency and accuracy. Project teams chose to monitor additional evaluation measures.

Core package	*Recommended*
Smart metering - electricity, gas and water	Co-heating tests
Monitoring of internal temperature and humidity and external temperature	MVHR performance tests
Spot tests, airtightness and thermography	Renewable energy performance monitoring
Data acquisition and transmission system	
Occupancy interviews	
Post-construction technical review	



The elements of analysis included in the evaluation of each retrofit property.

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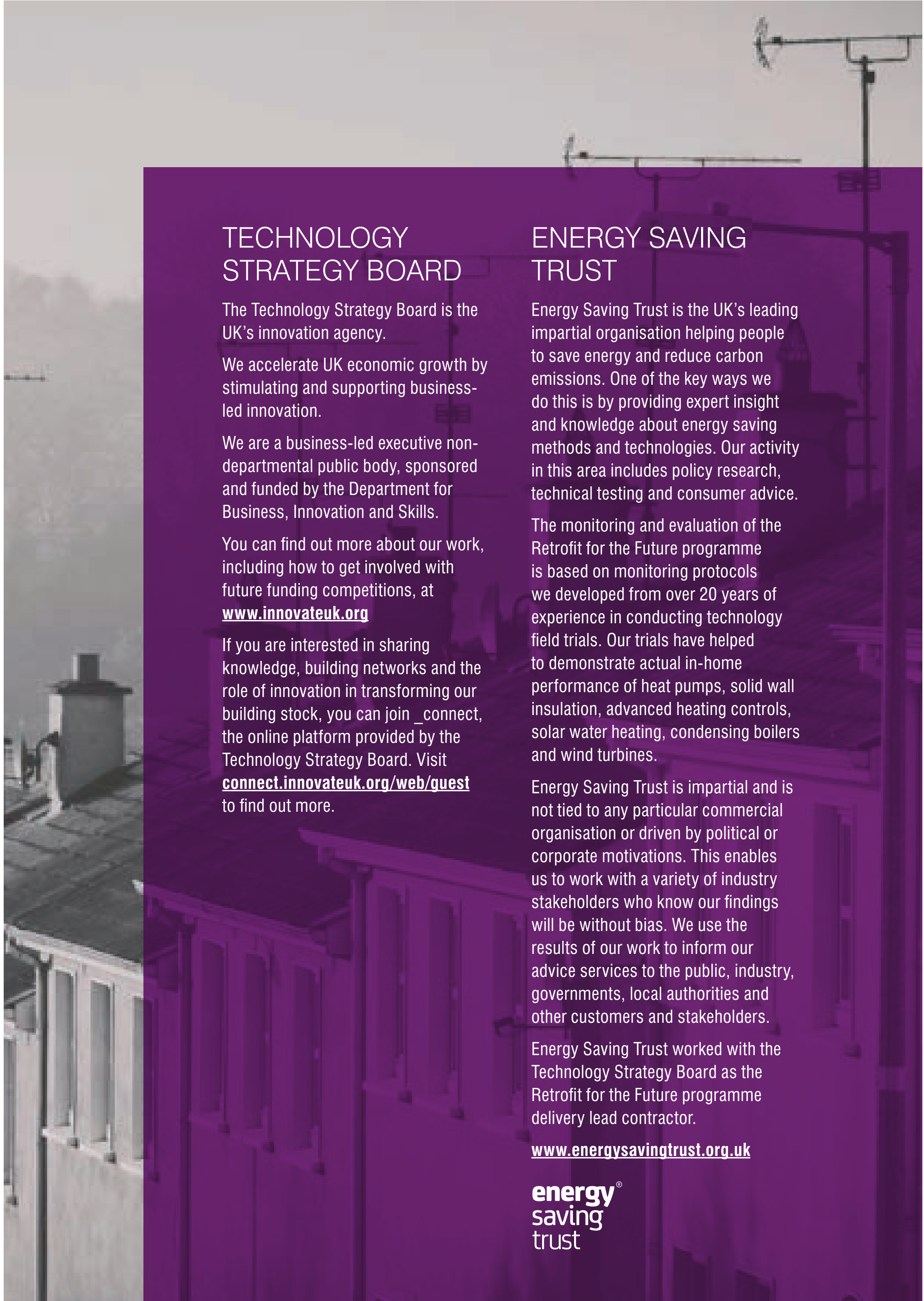

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ENERGY SAVING TRUST

Energy Saving Trust is the UK's leading impartial organisation helping people to save energy and reduce carbon emissions. One of the key ways we do this is by providing expert insight and knowledge about energy saving methods and technologies. Our activity in this area includes policy research, technical testing and consumer advice.

The monitoring and evaluation of the Retrofit for the Future programme is based on monitoring protocols we developed from over 20 years of experience in conducting technology field trials. Our trials have helped to demonstrate actual in-home performance of heat pumps, solid wall insulation, advanced heating controls, solar water heating, condensing boilers and wind turbines.

Energy Saving Trust is impartial and is not tied to any particular commercial organisation or driven by political or corporate motivations. This enables us to work with a variety of industry stakeholders who know our findings will be without bias. We use the results of our work to inform our advice services to the public, industry, governments, local authorities and other customers and stakeholders.

Energy Saving Trust worked with the Technology Strategy Board as the Retrofit for the Future programme delivery lead contractor.

www.energysavingtrust.org.uk

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