Barbrook Passivhaus Retrofit

A Retrofit for the Future project to refurbish two housing association properties to save 90% CO_2

Project managed by Energy Action Devon and North Devon Homes

Contents

The work reported here has been funded by the Technology Strategy Board under the Small Business Research Initiative (SBRI) under the Retrofit for the Future programme. This project is one of nearly 90 projects funded under the programme. Further information on the programme can be found at: www.innovateuk.org/retrofit

Introduction

The project was part of the Retrofit for the Future programme which awarded funding to innovative plans for low carbon retrofits of existing low rise social housing.
We chose a particularly difficult site and decided to aim for Passivhaus standard because it would challenge every aspect of energy reduction.

Barbrook Passivhaus Retrofit is an exciting demonstration project within Exmoor National Park. The aim of the project was to design a refurbishment solution to reduce carbon dioxide emissions from a social housing property by 80%.

The project was initiated by Energy Action Devon (EAD) who brought the team together, including North Devon Homes who own the two properties at Barbrook. In 2009 the Technology Strategy Board launched Phase 1 of the Retrofit for the Future competition to carry out feasibility modelling. In January 2010 EAD were awarded £150,000 to carry out the build in Phase 2 of the competition.

After seeking advice, we decided to use the Passivhaus standard as a means to achieve the required 80% reduction, because it offers a proven whole house approach to energy saving. The Passivhaus standard focuses on the fabric of the building rather than adding technologies; long term maintenance costs are negligible, and there are no complicated systems to operate. The house is future proofed, because even without heating it will not drop below 16°c inside, and will not overheat in the summer. This makes a Passivhaus the ideal option for reducing fuel poverty.

Energy Action Devon
INCORPORATING DARE

ndh north devon homes

The principles of Passivhaus can be applied to any building type. Barbrook is a real test of this, being situated in a shady valley location which substantially limits passive solar gain and means extra insulation and heat input is required.

Why did we do it?

- The UK government wants to cut CO_2 emissions from current housing stock by 80%, we wanted to know if this was possible in a site like this, with limited options for renewable energy.
- With the rising costs of fuel, a Passivhaus design is ideal to provide a future-proof home with low running costs and a healthy indoor environment.
- The UK construction industry is not currently skilled up to deliver low-energy homes. We wanted to work with a contractor who was willing to learn and gain new skills for the future.
- EAD is committed to working with partners and the public to reduce carbon emissions and prevent fuel poverty.

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SBRI Government challenges. Ideas from business. Innovative solutions.

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Introduction

KEY SUSTAINABILITY FEATURES

- Continuous insulation all around walls and roof with 350 mm Warmcel insulation blown into the purpose built timber frame
- Ground floor slab replaced with a new slab including 250 mm insulation beneath it.
- Insulation fitted around the edge of the slab and to sides of foundations
- Existing concrete walls retained within the thermal envelope to act as thermal mass and regulate the temperature
- New triple glazed, argon filled windows
- Air tightness levels achieved which will prevent unwanted heat loss.
- Mechanical ventilation with heat recovery installed to provide high quality air, at a controlled humidity level.
- Wood pellet boiler installed to provide low carbon heating to both properties
- Ecopassiv front door with a low U value

There will be 2 years of in-depth monitoring to test all of the measures we've installed, including thermal imaging and independent interviews with the tenants and contractors

"*We are very proud to have delivered such an innovative project with our partners. We look forward to learning how these properties will perform for our customers and how we can use this new technology on other projects*".

Martyn Gimber (Chief Executive, North Devon Homes)

View from rear windows

Energy Action Devon INCORPORATING DARE

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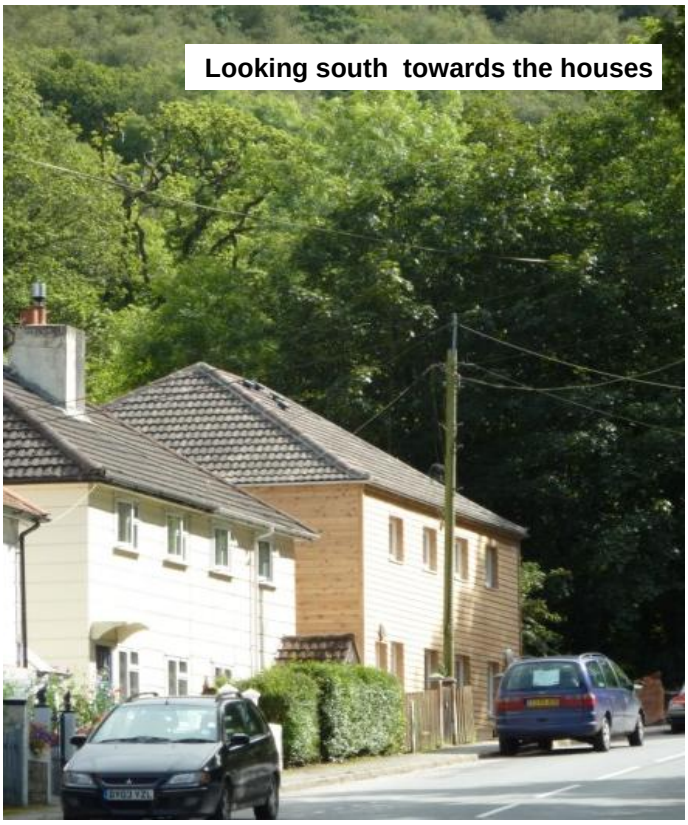

Looking south towards the houses

FUNDERS

- The project was funded by the Technology Strategy Board through the Retrofit for the Future Programme.
- Additional funding was supplied by North Devon Homes and Exmoor Sustainable Development Fund.
- Several of our suppliers have provided discounts and support.
- Excel industries supplied the Warmcel insulation free of charge.

Technology Strategy Board
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EXMOOR NATIONAL PARK
Sustainable Development Fund

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The team

This project has involved a wide range of professionals and specialists from various organisations.

The project was initiated by Energy Action Devon in 2009, when they made contact with North Devon Homes who were already considering refurbishment solutions for these properties. The core design team included an architect and Passivhaus consultant and the Building Research Establishment (BRE). Other professionals including structural engineers, an air tightness consultant and a wildlife surveyor werw also involved.

R R Richardson Ltd won the tender to manage the build contract and used local companies to undertake the works. Eco-Exmoor were used to install the biomass boiler used for heating the properties.

The tenants in one of the properties were relocated during the project to another property in the same terrace, and have been looking forward to moving into their new home.

Ivor, John and Conrad

John, Paul, Clive and Sally

Miss Richards and her family

Nick

Key personnel

- John Evans, North Devon Homes
- Sophie Phillips, Energy Action Devon
- Clive Jones, Architect
- Sally Godber, Warm: Low Enegy Building Practice
- Paul Jennings, ALDAS Ltd
- Ivor Macnamara, RR Richardson Ltd
- Ian Holloway, Southcombe Construction
- Nick Backhouse, Eco-Exmoor
- Conrad Frysol, RR Richardson Ltd
- Ron Boyd, Partners in Safety
- Tony Ley, Building Regulation Control

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Training and education

Building to Passivhaus standard is not the same as a standard build. Our contractors' knowledge was supplemented with specific Passivhaus training.
We will ensure that the residents of the properties understand how to use the systems efficiently.

We held a training day for all the contractors on our site. Having never worked on this type of project before they were all keen to learn more about Passivhaus and how to make sure the air tightness target was achieved.

The day was organised by Passivhaus Homes, and held at a Passivhaus in Totnes. The training was put together specifically for the Barbrook team. We were lucky to have four experts on hand to present and answer questions:

We started with the principles of Passivhaus to give the contractors a better understanding of the project and the importance of the details at every stage of work.

We then had opportunities to talk through specific details at Barbrook with our architect, thinking about how to ensure continuous insulation and air tightness. There were lots of samples of the specific materials that the contractors could look at, and they picked up useful tips from the team in Totnes on using the air tightness tapes and grommets in practice.

Ivor, project manager from RR Richardson

Nigel Bosanko from Warmcel

The team in discussion at the Totnes passivhaus

The central heating programmer is straightforward to use, but we plan to offer some training.

We also ran a Warmcel demo day and invited local housing providers to learn about the product, and watch it being installed.

Equally important will be helping the occupants understand the new systems and how best to control them. We will of course be supplying all the manuals and instructions for the kit, but also talking through the controllers for the heating and mechanical ventilation with heat recovery (MVHR) unit with them.

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Passivhaus

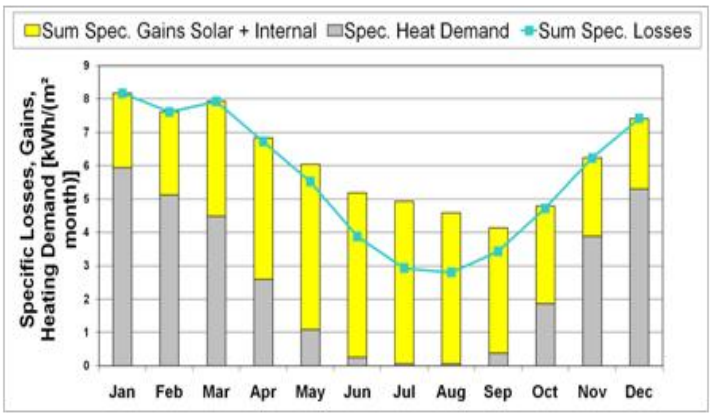
Passivhaus is an internationally recognised standard for highly energy efficient buildings.
Passivhaus is about good quality building, high levels of comfort and low energy consumption.

We chose to aim for Passivhaus standard for a number of reasons:

- It is the top standard for energy efficiency, and prioritises efficiency over generation. Our options for energy generation were limited
- Future proofing: the house will be low maintenance and equally good at keeping cool in the summer as warm in the winter
- Low running costs for low-income households
- Positive impact for fuel poor households – constant temperature
- Health benefits from good indoor air quality and warm home
- PHPP software is a highly accurate tool for modelling heat losses

Although Passivhaus is often thought of as an energy standard, it is equally a comfort standard.

- The internal temperature should not fall below 16°c even without space heating.
- The ventilation system provides excellent indoor air quality, better than just opening windows, and allows humidity control.
- All external surfaces, including windows and doors, have low u-values to maintain an interior surface temperature above 17°c. This stops convection currents forming within the room, and the lack of cold surfaces makes occupants feel warmer.



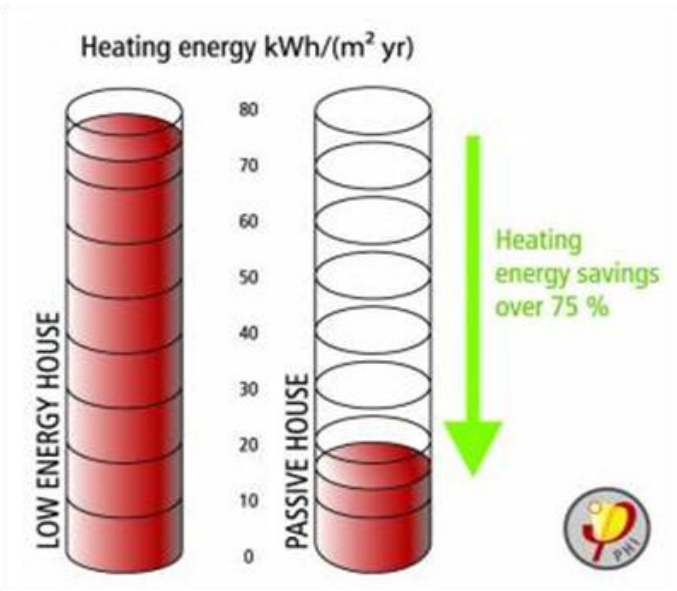


Image from :http://passipedia.passiv.de/passipedia_en/

In addition to the Passivhaus target which has in the past been aimed at new build, there is now the EnerPhit standard which is available for refurbishments.

Passivhaus standard requires:

- No more than 15 kWh/m^2.yr space heating
- 10 W/m^2 maximum heat load
- Maximum primary energy demand of 120 kWh/m^2.yr
- No more than 0.6 air changes per hour @ ± 50pa
- Whole window u-value of no more than 0.85 W/m^2.k
- Interior surface temperatures no less than 17° c
- Thermal bridges, thermal bypass, and over heating designed out.

EnerPhit standard requires all of the above but the differences are:

- No more than 25 kWh/m^2.yr space heating
- No more than 1 air changes per hour @ ± 50pa

By aiming for the Passivhaus standard we have managed to achieve an very efficient property in terms of air tightness and energy efficiency.

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The houses pre-retrofit

The two houses were built in the 1930s, and had solid concrete walls with double glazing and loft insulation.

The houses are Universal Construction, built using concrete poured in situ between asbestos shuttering, with pressed steel stanchions running vertically and horizontally. A structural survey showed that some of the stanchions were corroding and these required reinforcing works.

Heating was provided by night storage heaters and an open coal fire as there is no mains gas in the local area.

There are only known to be 1060 Universal Construction houses in the UK. We aimed to design a retrofit solution that, although bespoke, was highly applicable to other types of solid walled housing. North Devon Homes had exhausted the options for standard energy efficiency improvements and were looking for a solution to upgrade the houses.

In 1952 a flood swept down the river and washed away two identical properties to the south and there is now a memorial garden on the site. Since then flood prevention measures have been implemented and there is no longer any risk.

View of the southern aspect

Shortly after work began

Original roof timbers

Cross section of the original walls

Hydro power was considered for the site but North Devon Homes do not own a long enough stretch of river bank. There is already a larger community-owned scheme in development further downstream, from which we can purchase electricity in the future.

Site stats pre-retrofit

- Floor area is 71m^2 and has remained the same after works.
- Baseline SAP was 23, and the EI* was 26
- CO_2 emissions were 157 kg/m^2/yr
- Primary energy requirement 663 kWh/m^2.yr
- Fuel consumption was 18,830 kWh/yr electricity.

*EI—Environmental Impact rating

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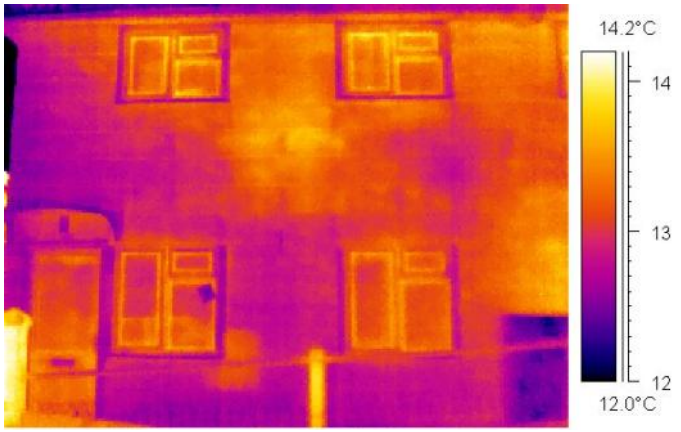
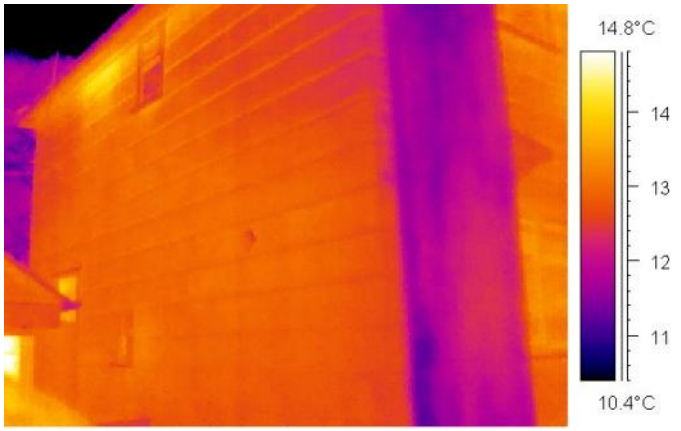
Thermal imaging before

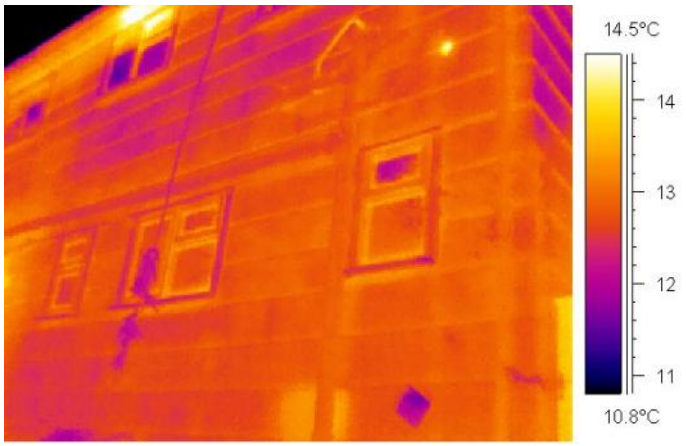
The pictures below are pre-retrofit, taken on the 25th March 2010, BSRIA will carry out independent thermography in Winter 2011. The orange/yellow areas show considerable heat losses.

External temperature: 9.4°c Internal temperatures: No.7: 19°c, No.8: 21.2°c

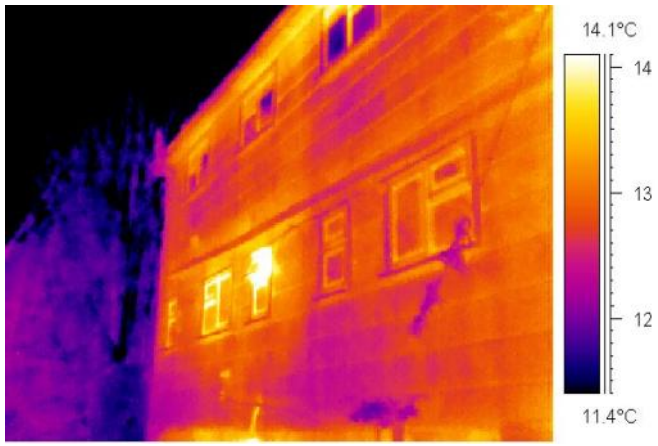
Number 7







Number 8



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Challenges at Barbrook

The site at Barbrook posed a number of challenges. From limited space, to asbestos & structural issues.
With any retrofit there will be unexpected problems, but with a good team it is possible to solve these and move forward.

The first challenge was to design a system which could potentially achieve Passivhaus standard at this site which has minimal space and heavy over shading, which limits solar gain. Due to the lack of space available materials had to be stored off site in a container and at the North Devon Homes' warehouse in Barnstaple. Access was difficult and the steep bank down to the river posed health and safety challenges.

We knew from the beginning that the first stage of the project would comprise of extensive structural reinforcement works. When we stripped back the properties, we found that some of the concrete was very poor quality and needed additional re-pairs. We also found that the existing roof was not attached to the concrete walls, and we needed a new ring beam.

Significant additional asbestos sheeting was found behind the existing wall linings, delaying works whilst it was removed.

Although we dug trial pits, there were some surprises below ground too, with extremely hard concrete and large boulders being discovered.

Limited space on site

Structural reinforcements were required, and removal of chimney stacks

Integrated chimney stacks

Previous roof-wall junction

Rear of houses drops to river

These had to be removed and underpinning works were then required to the foundations.

We also discovered that there was a load bearing partition wall which created problems laying the new slab. The chimney breasts were built across the party wall, which is very unusual, and could therefore not be fully removed to ground level

Overall it has been an exciting and demanding project, but we have all learned a lot from the experience. We also intend to replicate some of the principles on future refurbishment projects.

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Wall construction

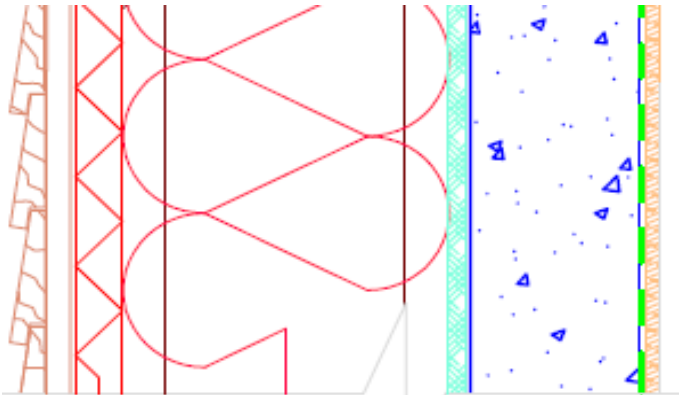
The existing concrete walls were enveloped in a specially designed timber frame to accommodate 350 mm Warmcel insulation.
The new walls were clad in Western Red Cedar sourced and processed on Exmoor.

The wall construction is a key part of the Passivhaus strategy. The new timber frame was specifically designed to fit around the existing concrete walls and accommodate the high level of insulation we required.

We wanted to retain the existing concrete walls, because they act as thermal mass to store heat and regulate the internal temperature throughout the day, making the homes more comfortable to be in. The frame is fixed to the concrete walls using a brand new Teploe Tie fixing.

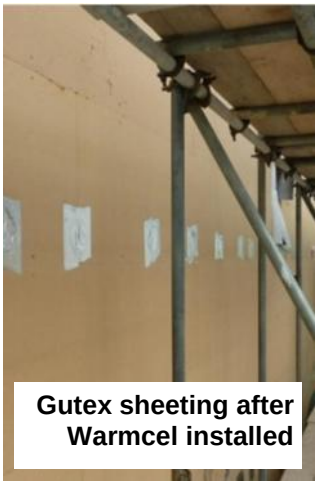
The original poured concrete contained asbestos and was made with large river pebbles, which meant it was difficult to drill into. The steel brackets supporting the base of the frame on the rear wall had to be carefully adjusted on site to accommodate the uneven concrete river wall.

We chose to clad the properties in cedar because it is a local wood, and we felt it was in keeping with the woodland surroundings at Barbrook.



Left to right:

- Timber cladding
- 25 mm vertical timber battens
- 50 mm gutex sheet
- Vertical I-beams with 350 mm Warmcel
- 18 mm OSB
- Existing poured concrete
- Pro clima Intello vapour barrier
- 13 mm Fermacell



Gutex sheeting after Warmcel installed

Original concrete walls

- The final wall depth is 580 mm
- The walls have a u-value of 0.1 W/m^2.k
- The cladding was supplied by the Local Wood Shop in Minehead and was sourced from the Crown Estate in Dunster.
- The asbestos shuttering on the houses formed horizontal channels all around, so these have been be filled in to prevent air circulation.
- The timber frame was designed by Frame UK, from Redruth, Cornwall.

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Roof construction

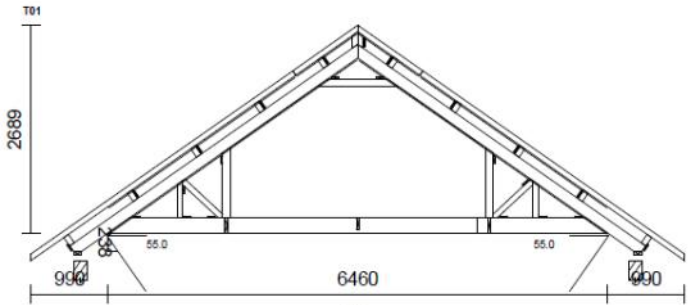
The properties have a new roof, designed specifically to accommodate the depth of insulation required.
The roof had to be extended to cover the new deeper walls.

There were a number of reasons why we chose to build a completely new roof. The deeper walls would have required the roof to be extended anyway, and the original roof was not in a particularly good condition.

From the outset we had planned to design a bespoke timber frame which would fit around the existing concrete walls and up over the roof to accommodate 350 mm Warmcel insulation. The final roof u-value is 0.101 W/m^2.k

Being asked to design a roof to a specific depth was a first for Perran Trusses, so they had to create a new method using a double truss.
A new concrete ring beam was required to which the roof is fixed. The raised tie and open loft space were non-standard requirements which means the trusses have to work harder

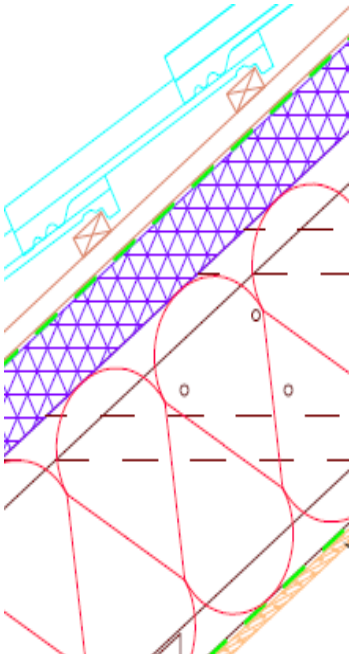
We retained the original roof tiles, which were replaced on the front of the roof. Additional roof tiles were still required due to the increased size.




The roof before


The new roof


The new roof



From outer face:
- Roof tiles
- 25 mm timber battens
- 25 mm timber counter battens
- 22 Isolair breather membrane
- 80 mm Gutex ul-tratherm
- Twin rafter system
- 350 mm Warmcel blown insulation
- Intello vapour barrier
- 13 mm Fermacell

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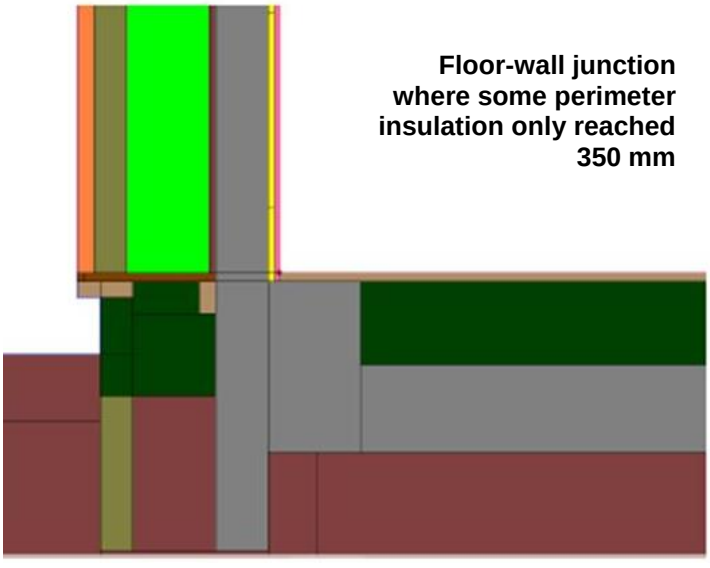
Ground floor construction

A huge challenge of retrofitting to this standard was how to deal with the floor. We had to add insulation, and without the luxury of high ceilings this meant excavating and laying a new slab.
Insulation was also required below ground around the edge of the slab.

Adding floor insulation was not optional, there would be no chance of achieving near to Passivhaus standard without floor insulation. We dug several trial pits across the site, both inside and out before commencement. This showed that the ground beneath the properties varied hugely across the small site. The existing slab was dug out and replaced with a new insulated slab.

A crucial detail is the junction between the ground floor slab and the external walls. In a new build the whole slab can be laid on a raft of insulation; however in a retrofit the original external walls have solid footings extending into the ground and acting as a thermal bridge. Our best option was to try to add perimeter insulation to a 600 mm depth all around the edge of the slab.

However this posed a challenge because a breaking out a section of very hard concrete in the SE corner may have caused structural damage to the foundations had an attempt been made to remove it.



Floor-wall junction where some perimeter insulation only reached 350 mm

Homatherm insulation on the floor

Digging out

Perimeter insulation was installed with no gaps

The perimeter insulation was specifically chosen as it had to be suitable for use below ground.

It was vital that the perimeter insulation was fitted well with no gaps larger than 3 mm. Gaps around insulation lead to thermal bypass effect, where uncontrolled air movement draws heat past the insulation. There should be no gaps larger than 3 mm.

The slab build up is now:

- 22 mm tongue & groove chipboard flooring
- polythene vapour barrier and separating membrane [and additional air tight layer]
- Yelofon X2i 255 mm thick
- 150 mm reinforced concrete slab
- 1200g damp proof membrane
- 150 mm sand blinded hard core

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Windows and doors

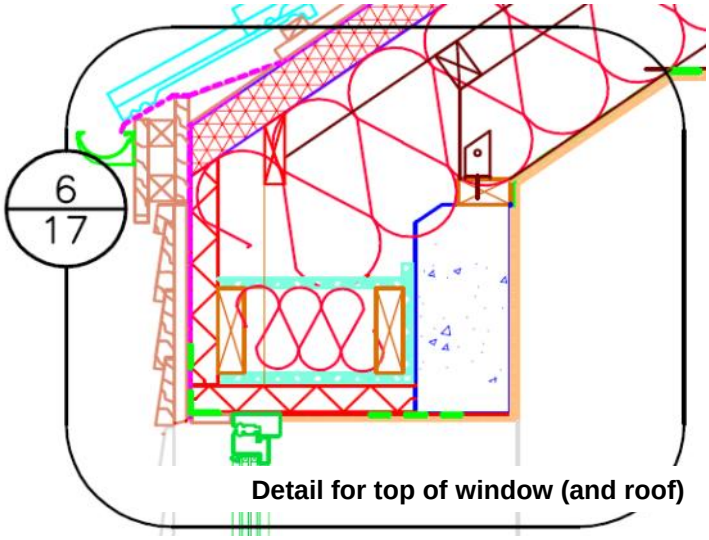
The original uPVC double glazed units were replaced with timber-framed triple glazed windows and doors.

The new triple glazed, argon filled, windows will retain more heat than the previous double glazed units.

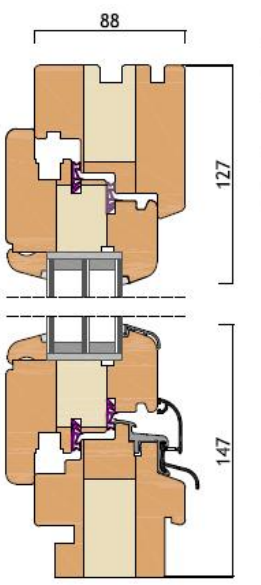
As is common on the continent, the windows are inward opening, which will be a change for the tenants. We decided on inward opening windows because it enables the wall insulation to be wrapped around the frame on the outside. This reduces thermal bridging around the edge of the window boxes.

Because the existing concrete walls were not perfectly straight, there was a slight difference in the depths of the window boxes required. Each box was made separately, after measuring up the window, and then had to be fitted in place and trimmed in line with the timber frame.

The option to increase the window size was restricted due to the horizontal and vertical reinforcement in the walls. We were concerned that the deeper window reveals would make the homes darker, but in fact it has made very little difference.



Detail for top of window (and roof)



Window reveal from inside

Window and sill from outside

- The windows are Ecopassiv, supplied by the Green Building Store.
- The timber frames are FSC certified
- The glazing u-value is 0.55 W/m^2.k
- The whole window u-value is 0.75 W/m^2.k, but each window has been calculated separately for passivhaus to take into account the ratio of frame to glazing.
- The solar fraction is 53%
- The Ecopassiv glazed doors have a u-value of 0.92 W/m^2.k
- The Ecopassiv windows are certified for use in Passivhaus projects, and for Levels 5 & 6 of the Code for Sustainable Homes.

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Air tightness

If air can leave a building this will take some of the warmed air out of the house and lead to cooling. High levels of air tightness are very important for a Passivhaus to prevent uncontrolled air leakage and therefore requires a holistic ventilation strategy.

Air tightness was one of the most difficult challenges to achieve in this project as the targets for Passivhaus are very stringent.

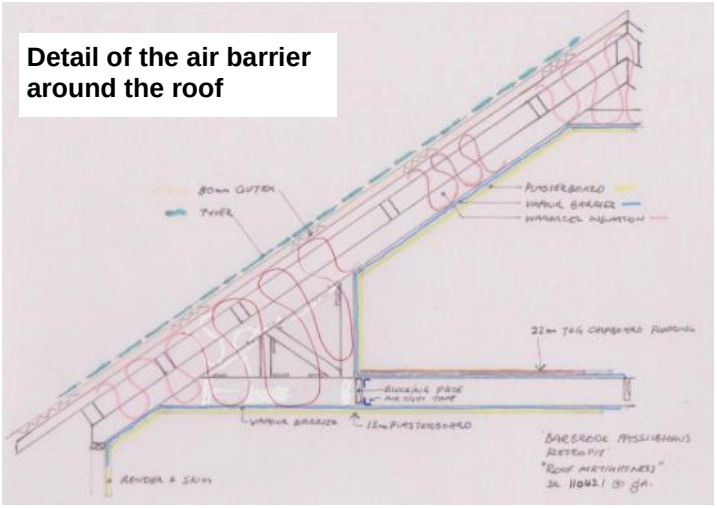
Air loss from a house is measured in two ways :
- Air changes per hour
- Air loss measured as a cubic capacity per square meter of floor area.

The target for Barbrook was to achieve less than $1m^3/h/m^2$ and the final results were :

- **Both houses achieved 1.1 air changes per hour**
- **House nr 7 achieved 0.95 $m^3/h/m^2$**
- **House nr 8 achieved 0.93 $m^3/h/m^2$**

The UK measures are in cubic meters of air leaking per hour, per square metre of floor area at a pressure of 50pa. Passivhaus standard uses cubic metres of air leaking per hour, per cubic metre of building volume.

A Passivhaus training day was organised for the contractors, part of which was dedicated to air tightness which helped the team achieve such low levels of air tightness at Barbrook.



Detail of the air barrier around the roof

Pipes sealed with Orcon

Wet plaster as air barrier

WALLS
- Skim on hardwall plaster on concrete walls
- 18 mm OSB screwed and glued with Gripfix in grid pattern to external surfaces of concrete walls, all joints taped
- Warmcel insulation [see also their contribution to the air tightness]
- 52 mm T & G Steico Universal boards
- Tyvek breather membrane

PARTY WALL
- Skim on 50mm insulation backed plasterboard
- Existing concrete party wall
- Skim on 50mm insulation backed plasterboard

PARTITIONS
- Skim on 13 mm plasterboard both sides of 38x89 studs with sound deadening insulation in between

FIRST FLOOR CEILING
- Skim on plasterboard on an Intello membrane

2ND FLOOR
- 18 mm chipboard on an Intello membrane

ROOF
- Skim on plasterboard
- Intello membrane
- Warmcel
- 80 mm Gutex
- Tyvek breather roofing felt

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Space and water heating

The two properties are heated using one wood pellet boiler, on a communal heating scheme.
The pellet boiler provides low cost, low carbon space and water heating.

Typically a passivhaus should not require additional space heating, but due to the lack of solar gain on this site we needed to install a heating system. We chose an Okofen pellet boiler because it is efficient, controllable and reliable.

The pellets are stored in an adjacent store and fed automatically into the boiler as required. Due to the limited space available on site we could only build a small store, so pellets have to be delivered bagged rather than blown.

The boiler has its own electricity supply which will be billed to North Devon Homes. The tenants will then be billed accurately for pellets and electricity based on their exact consumption of heat. The properties will have heat meters monitoring space and water heating as part of the Retrofit for the Future requirements. We hope that this will also encourage them to use the system efficiently.

The tenants are able to fully control the heating pattern in their own home. An easy to use programmer allows time and temperature settings for three on-periods for each individual day of the week.

Energy Action Devon
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ndh
north devon homes

The boiler house

- The boiler is a modulating 2-8 kW Okofen Pellematic.
- The boiler is 90.5% efficient.
- Installed by Eco Exmoor, based in Parracombe
- The cylinder is an 500 litre Akvaterm
- The boiler should use around 800 kg pellets per year
- The fuel store can hold 450 kg of pellets
- First delivery of pellets was supplied by Eco-Exmoor
- The pellets are imported from Austria. We chose this option because these particular pellets are tried and tested in the Okofen boiler. Once the boiler is well established we will aim to source pellets more locally. Even from Austria their carbon footprint is far lower than any fossil fuel.
- The flue was supplied by Stoves Online and is painted slate grey as per planning conditions.
- Carbon emissions from the heating system will be 150 kg/yr

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Mechanical ventilation with heat recovery

An MVHR system is essential in a Passivhaus, or any building with a high level of air tightness.
MVHR ensures an adequate flow of fresh air, pre-warmed with heat recovered from the exhaust air.

Each property has an MVHR unit fitted in the loft space. Waste air is extracted from the bath-rooms and kitchens, and pre warmed, fresh air is blown into the bedrooms and living rooms. The ducting needs to be designed into the build from the outset to ensure space for ducts and to avoid unnecessary drilling through air barriers after they have been fixed.

It will take a little while to get used to living in a house with MVHR. In the summer the MVHR system may be switched off and open windows used for ventilation. In the winter the MVHR system will make the house feel fresh enough for the occupants to not want to open the windows.

The MVHR unit also allows the humidity to be controlled which is ideal in a damp spot like Barbrook. It also provides high quality indoor air where germs and viruses are less likely to develop.

The Paul unit we've installed

The controller which has now been set to English!

The ducting design is crucial: To ensure most efficient delivery of air it should be straight, rigid, well insulated and as short as possible.

Both units are individually controllable using a touch screen programmer.

- The units are Paul Focus 200, supplied by the Green Building Store.
- Heat recovery rate is 91%
- Electrical efficiency is 0.31 W/m^3
- The ducting is Lindab
- The units are certified by the Passivhaus Institut which means that the efficiency has been independently tested. If we used a non-certified unit we would have to reduce the manufacturer's efficiency by 12% in the PHPP software.
- The filters in the units will need to be changed, probably every six months. This will be done by a maintenance person from North Devon Homes.
- The units will undergo an independent spot test from BSRIA later in the year.

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Thermal bridges

In a retrofit project thermal bridges can be a real problem, conducting heat past and through insulation layers. At Barbrook we had to tackle three key thermal bridges.

In a low energy building the insulation layer should completely envelop the building. If this insulation layer is broken it is called a thermal bridge.

When insulating existing buildings there are many thermal bridges that are very tricky to eliminate. These are generally found

- at the junctions of walls and roof
- at lintels that bridge a cavity to support the wall above an opening.

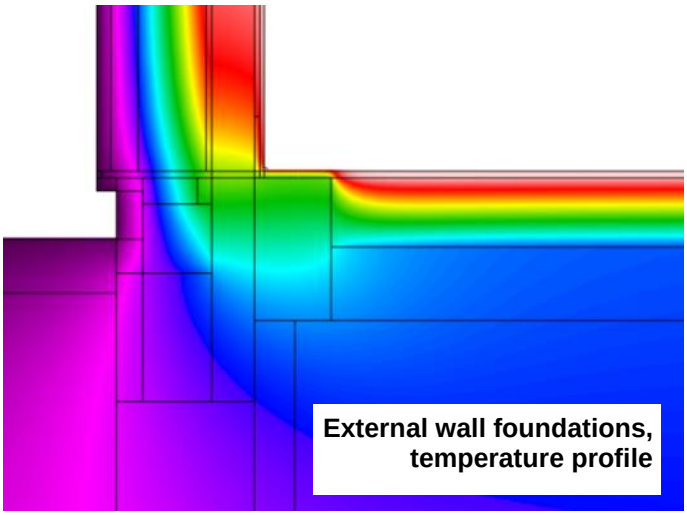
For this reason the external wall insulation using Warmcel was an ideal solution because it wraps the whole of the outside in a continuous layer.

We intended to remove the chimneys to eliminate the thermal bridge created through the roof & floor. This had the added benefit of simplifying the roof structure and also increasing the internal floor area. However, we discovered that the chimneys were an integral part of the party wall. The poor condition of the concrete meant that we could not remove the chimneys down to ground level. As a result there is increased heat loss where the chimneys meet the floor, but we did eliminate the bridge through the roof.

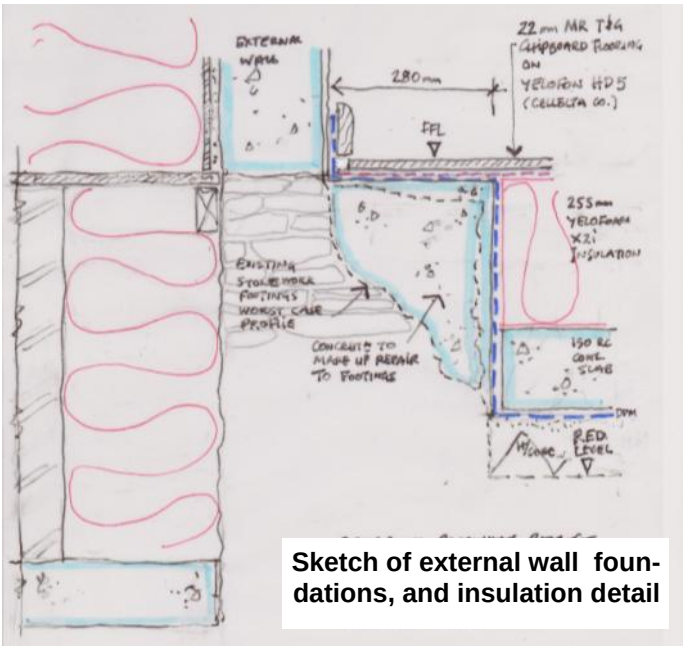
The second significant thermal bridge was the junction between the external walls and the floor slab. As it is not possible to insulate beneath the foundation of an existing building we had to wrap as much insulation around them as possible. However we were not able to dig down as deep as we hoped on the south side so there is less insulation there.

This bridge has contributed 4 kWh/m^2.yr to our space heating target.

The third thermal bridge was beneath the party wall. The existing loose stone foundation prevented us from insulating this fully.



External wall foundations, temperature profile



Sketch of external wall foundations, and insulation detail

Removal of chimneys in progress

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Monitoring

One of the aims of the Retrofit for the Future programme was to test methods of reducing CO_2 in existing housing.
The houses at Barbrook will be closely monitored for two years to assess how they perform in real life.

The properties will be fitted with a number of monitors and meters which will feed data wirelessly to a central hub. The hub will then transmit the data to a national database managed by the Energy Saving Trust where results will be collated alongside the data from the other 86 Retrofit for the Future projects.

We will be monitoring the internal and external temperatures as the context for the performance of the equipment. Heat meters will tell us how much heat each property is using for space and water heating, and enable us to bill them based on consumption. This will be linked to an electricity meter and meter on the pellet feed to see what goes into the boiler compared to the heat produced. We will also be monitoring electricity and water consumption in each property.

The Technology Strategy Board has received a high level of interest in the results of the Retrofit for the Future programme and results from our project and the others are being disseminated to policy makers, academics and industry. We hope that the results will be publicly available on www.retrofitforthefuture.org

Heat meters, not yet connected

The monitoring equipment installed comprises:

- One external temperature sensor
- 3 internal temperature sensors in each property
- 3 internal humidity sensors in each property
- Internal CO_2 sensor, as a proxy for air quality
- Heat meters on the space heating flow pipes to each property
- Heat meters on the hot water flow pipes to both properties
- Electricity meter to each MVHR unit
- Electricity meter to the boiler input
- Pulse output reader on the pellet feed system
- Water meters in both properties

Other independent tests which will be carried out are:

- Air tests in each property
- Spot test on each MVHR unit
- Thermography before and after
- Walk through surveys
- Interviews with tenants
- Interviews with design and construction teams

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Further information

THE TEAM

- **North Devon Homes** www.ndh-ltd.co.uk
- **Energy Action Devon** www.energyactiondevon.org.uk
- **R R Richardson Ltd** were the main contractor www.richardsonltd.co.uk
- **Clive Jones** was our architect throughout the build clivejones@waitrose.com
- **Warm: Low Energy Building Practice** who provided the passivhaus modelling and consultancy www.peterwarm.co.uk
- **Paul Jennings** provided advice on air tightness doorfanman@hotmail.com
- **Low Energy Buildings Database** to see details of Barbrook and other projects www.retrofitforthefuture.org
- The **Barbrook Passivhaus blog** can be found at: http://barbrookpassivhaus.wordpress.com

SUPPLIERS

- **BSRIA** supplied most of the monitoring equipment and carried out the independent testing www.bsria.co.uk
- The **Green Building Store** supplied the Ecopassiv windows and doors, and the Paul MVHR unit www.greenbuildingstore.co.uk
- **Ty Mawr** supplied the wood fibreboard products www.lime.org.uk
- **Burdens Environmental** supplied the Steico boarding www.burdensenvironmental.com
- **Eco-Exmoor** supplied and commissioned the Okofen boiler www.eco-exmoor.co.uk
- **Local Wood Shop** supplied the Exmoor timber cladding greenpope@btinternet.com
- **Excel Industries** supplied the Warmcel insulation www.warmcel.co.uk
- **Eco-fill Insulation** installed the Warmcel www.ecofillinsulation.co.uk
- **Passivhaus Homes** provided the training www.passivhaushomes.co.uk
- **Perran Trusses** designed and supplied the timber frame for the roof www.perrantrusses.co.uk

FUNDERS

- **Exmoor Sustainable Development Fund** www.exmoor-nationalpark.gov.uk
- **Technology Strategy Board** www.innovateuk.org

FURTHER INFORMATION CAN BE FOUND AT

- http://www.passivhaustrust.org.uk/
- Passipedia http://passipedia.passiv.de/passipedia_en/start

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