Technology Strategy Board
Driving Innovation

Retrofit for the Future

Project final report

Cover note

This report was prepared by the collaborative project team for this Retrofit for the Future project, to provide fuller context on their experiences and the particulars of their retrofit's specification, construction and occupation.

The authors were encouraged to include honest, transparent and constructive comment, garnered from multiple perspectives across their team. All views are taken to be an accurate account from the time.

There may have been further modifications to the property after this report was produced. It is therefore possible that a small minority of statements will no longer be valid.

Although minor modifications have been made to this report by the Technology Strategy Board, these were only to ensure the privacy of individuals, including the residents, and compliance with the Data Protection Act.

This report may contain links to other websites, such as for project partners or the retrofit project. The Technology Strategy Board is not responsible for the content of those websites.

This report has already proven to be a valuable source of information for the technical and cost analysis reports published by the Technology Strategy Board which are available at: www.retrofitanalysis.org

Retrofit for the Future Project Final Report

Project number: ZA148E
Property number: TSB064

Author: Penwith Housing Association

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SBRI
Government challenges.
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Final Report

Project information

- **ZA reference number:** ZA148E
- **Location of property:** Penzance, TR18
- **Lead participant details:** Penwith Housing Association Ltd.
  67 Morrab Road
  Penzance
  Cornwall TR18 2QJ
- **Date report issued:** 14 June 2012

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1. Project details & directory

Project reference: ZA148E

Role	Organisation	Contact Details
Property Owner		
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Design Team		
Architectural Technologist (construction design & passive measures)	Penwith Housing Association Ltd.	Address: 67 Morrab Road Penzance Cornwall TR18 2QJ Tel: 01736 334953 Website: http://www.penwithha.org.uk/
Design of Ground / Air / Solar Source Heat Pump and advanced energy modelling:	Earth Energy Engineering Ltd.	Address: EarthEnergy Engineering Ltd, Lower Treluswell Farm, Penryn, Cornwall, TR10 9AT Tel: 01326 377329
Prototype ground / air / solar source heat pump and ground loop design	Mimer Energy Ltd (formerly EarthEnergy Ltd.)	Address: Mimer Energy Ltd, Falmouth Business Park, Bickland Water Road, Falmouth, Cornwall, TR11 4SZ. Tel: 01326 211070
Monitoring system and installation	Woodmead Energy Services	Address: 2 Laverock Close, Kimberley Nottingham NG16 2QX Tel: 01159384967 Website: www.woodmeadenergyservices.co.uk
QS	Penwith Housing Association Ltd.	Address: 67 Morrab Road Penzance Cornwall TR18 2QJ Tel: 01736 334950 Website: http://www.penwithha.org.uk/
CDM Coordinator	JNC Safety Services	Address: JNC Safety Services Ltd., Woodbine Farm Business Centre, Truro Business Park, Truro, Cornwall, TR3 6BW. Tel: 01872 262261 Website: http://www.jncsafetyservices.co.uk/
Contractor		
Main contractor	Mears Ltd	Address: Mears Ltd. Jelbert Way, Eastern Green, Penzance, Cornwall, TR18 3AS

		Tel: 01736 874444 Website: http://www.mearsgroup.co.uk/
Sub-contractor - heating	M V Clatworthy Ltd.	Address: M V Clatworthy Ltd., Unit 6E, Guildford Road Industrial Estate, Hayle, Cornwall, TR27 4QZ Tel: 01736 759600 Website: http://mvclatworthy.co.uk/
Sub-contractor - Conservatory	Causeway Trading Group Ltd.	Address: Causeway Trading Group Ltd. Hayle Industrial Park, Marsh Lane, Hayle, Cornwall TR27 5JR Tel: 01736 754825 Website: http://www.ctg-windows.co.uk
Sub-contractor – External wall insulation		Address: Trewarren Farm, Newmills, Ladock, Truro, TR24 4QJ Tel: 01726 882263
Sub-contractor – Pellet stove	Stove Shop	Address: Stove Shop, 7 Pike Street, Liskeard, Cornwall, PL14 3JE Tel: 01579 345018 Website: www.stoveshop.co.uk
PV installer	Plug Into The Sun	Address: Plug Into The Sun, Unit 15, Long Rock Industrial Estate, Penzance, TR20 8HX Tel: 0800 496 1494 Website: http://www.plugintothesun.co.uk
Supplier - windows	JELD-WEN	Address: JELD-WEN UK Ltd., Snow Hill, Melton Mowbray, Leicester, LE13 1PD. Tel: 01664 484 500 Website: www.jeld-wen.co.uk
Supplier – external doors	Homesafe	Address: Homesafe Doors, Newent Business Park, Newent, Gloucestershire, GL18 1DZ. Tel: 0845 2198301 Website: http://www.homesafedoors.co.uk/
Supplier – ground source heat pump	Calorex Ltd.	Address: Calorex Heat Pumps Ltd., The Causeway, Maldon, Essex, CM9 4XD Tel: 01621 856611 Website: http://www.calorex.com/
Supplier – Ventilation & heat recovery unit	NIBE	Address: NIBE Energy Systems Limited Unit 3C Broom Business Park, Bridge Way Chesterfield S41 9QG Tel: 0845 095 1200 Website: http://www.nibe.co.uk/
Supplier – external wall insulation	Knauf Marmorit	UK Head Office and Glass Mineral Wool Plant, P.O. Box 10, Stafford Road, St Helens WA10 3NS

		Phone: 01744 766600 Web: http://www.knaufinsulation.co.uk
Supplier – white goods	Currys	Address: Currys, Unit 2B, Heliport Retail Park, Long Rock, Penzance, TR18 3 AR Website: http://www.currys.co.uk

2. Introduction

Two years before the launch of Retrofit for the Future, Penwith HA and Earth Energy Engineering were discussing how to reduce the carbon emissions of existing homes to a minimum. This led to a funding bid under the Housing Corporation's Innovation and Good Practice Programme to carry out a demonstration project. This proposed *'to explore the technical options for refurbishing existing social housing to the highest possible level of CO_2 reduction and sustainability'* and to *'carry the results of the above items forward into a practical project where one or more dwellings will be refurbished to the highest possible environmental standard.'* The bid was unsuccessful, but the idea proved prophetic. It matched very closely the aims of Retrofit for the Future and became the basis for the Penwith HA 'HeatPod' project.

Penwith Housing Association has been involved in developing best practice in energy efficiency since its inception in 1994. It was the first social housing provider in the UK to use ground source heat pumps in both new build homes and retrofit. It had also been a very early user of external wall insulation and used the previous generation of whole house energy efficient refurbishment techniques on much of its stock. The Association's bid for Retrofit for the Future drew on this practical experience to develop retrofit techniques designed to achieve the highest possible carbon reductions in a typical housing association home. It also built on pioneering work with ground source heat pumps by developing an innovation in that technology: the Ground / Air / Solar Source Heat Pump, created in partnership with Mimer Energy Ltd (formerly EarthEnergy Ltd) who are acknowledged experts in the UK heat pump field.

There are two key components to the project. The first of these provides a package of super-insulating but practical measures to the house to reduce energy losses to a minimum. The second is the 'HeatPod' – which is based on a prefabricated multi-purpose glazed conservatory. It provides extra living space, with room for green features such as cycle storage and under cover drying. It also contains most of the equipment required for reducing the carbon emissions of the dwelling. This avoids the need for much disruptive work inside the home. The HeatPod project aims to provide a highly replicable model for the low carbon retrofits of the future.

3. Occupants

The project house has been lived in by two adult tenants for many years. They have remained in occupation throughout the project and are expected to continue living there for the foreseeable future.

4. Dates

Project start date (when was the first proposal discussed or agreed)	June 2009
Planning application submitted (if appropriate)	16th March 2010
Planning permission granted (if appropriate)	12th May 2010
Building Regulations application submitted (if appropriate)	11th August 2010
Building Regulations approval granted (if appropriate)	16th August 2010
Contract for work let / signed	1st March 2011
Occupants moved out (state if they remained or property was empty)	Not applicable – remained in residence
Start on site	14th March 2011 *
Completion of retrofit	30th July 2011
Occupants moved in	Not applicable
Monitoring system commissioned and operating properly	August 2011
Building defects corrected	August 2011
Building services and controls operating correctly	July 2011
Installation of pre-retrofit monitoring equipment	May 2010

* Note: The construction company ROK was originally appointed as main contractor for the project on 5th July 2010 and they began work on site on 1st November 2010. Unfortunately the company unexpectedly entered administration only a week later, which caused a five month delay to the project. A new contract for the project was negotiated with Mears Ltd under an existing Framework Agreement for Decent Homes contracts. The contract dates included above refer to the contract with Mears.

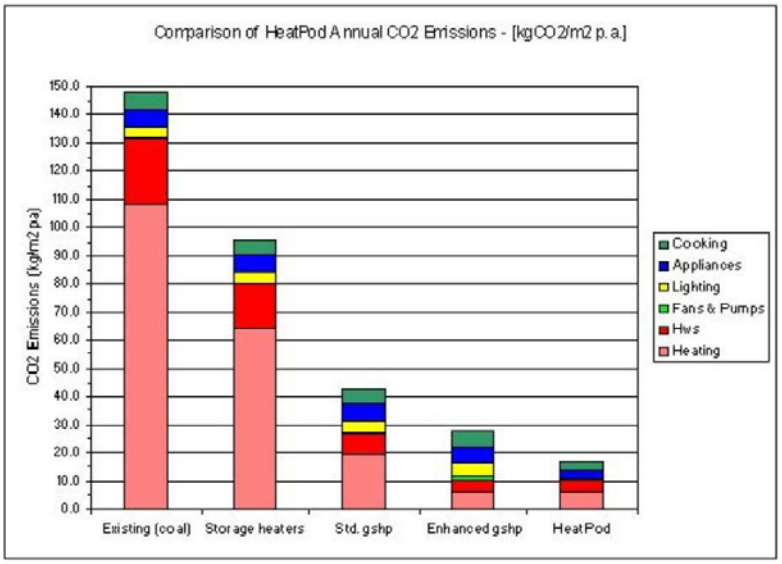
5. Pre-retrofit property

The property is located in a village in Cornwall, a few miles from Lands End, the most westerly point in the UK. The house formed part of a local authority development built in the 1950s and was typical of the kind of traditionally constructed homes that were built in large numbers at this time. Penwith HA has copies of the original working drawings for the house type in its archives. The house is an end of terrace two bedroom unit. Its original construction details were as follows:

a. Ground floor: solid insitu concrete slab (uninsulated)
b. External walls: cavity walls - 2 leaves of 100mm thick concrete blockwork with 50mm cavity, roughcast rendered and painted externally, rendered and plastered internally. The walls were cavity filled by Penwith HA. At eaves level, the external walls were fitted with precast concrete 'Finlock' gutters which combine the functions of providing rainwater gutters, closing the cavity and forming a base for the roof wallplate. These were widely used in the 1950s.
c. Roof: traditional timber pitched roof with concrete plain tile finish. The roof was insulated with 150mm mineral wool above plasterboard ceilings and fitted with tile ventilators to the roof void.
d. Windows: The house was fitted with upvc double glazed windows installed by Penwith HA.
e. External doors: Softwood single glazed 2XG pattern doors.
f. Heating: wet radiator system heated by a multi-fuel closed room heater / back boiler unit which also delivered domestic hot water. This system was installed in recent years and was programmable and thermostatically controlled.

During the feasibility study phase, a number of properties in the Penwith HA stock were considered for the project. These were generally dwellings in off gas areas, reliant on solid fuel heating (and thus having potentially high carbon emissions) and typical of traditionally constructed social housing (to deliver highly replicable solutions). NHER / SAP assessments of some of the properties were carried out based on data from the Association's archive of property plans and stock condition survey data. The assessment of the dwelling delivered a SAP Rating of 53, a primary energy demand of 43566 kWh/year and a total CO_2 of 10,109 kg/year. These figures confirmed that the property was a good candidate for the retrofit project.

Further extensive energy modelling was carried out by project partner Earth Energy Engineering to support both the feasibility study and the stage two submission, which demonstrated the relative inefficiency of the property in its pre-retrofit stage and the potential for improvement. The outcome of the calculation process in terms of potential to reduce carbon emissions is shown graphically in the histogram below.



As noted above, a comprehensive monitoring system was installed in the house in May 2010. Owing to the delay in work starting on the house following the original contractor entering administration, the pre-retrofit monitoring period extended until March 2011. This resulting data is available for evaluation and a copy of the data files have been supplied to the Technology Strategy Board.

6. Design

The original proposal for the retrofit comprised of the following measures:

(1) Fabric measures:

a) 100mm phenolic board external wall insulation.
b) Triple glazed windows
c) Replacement high performance external doors
d) Improved air tightness
e) Installation of a conservatory (the 'HeatPod')

(2) Renewable Energy systems:

a) Installation of a prototype Ground / Air / Solar Source Heat Pump (incorporating mechanical ventilation with heat recovery).
b) Installation of a PV system.
c) Installation of a wood pellet stove.

This is essentially the design that was realised in the project with no major changes, although a good deal of detailed design was added during the construction phase process which provided some very useful learning points.

The rationale of the design follows some key principles resulting from the past experience of the design team:

- Wherever possible, retrofit works should not require the residents to move out of the property during the work. This is an expensive and disruptive process, and in terms of the 'big picture' (i.e. retrofitting the entire UK housing stock) something that is probably almost impossible to achieve in either the social housing or the owner-occupier sector.
- In support of the first point, as much work as possible should be carried out to the outside of the property, but doing so without radically changing its external appearance. The work should be contained as far as possible within planning permitted development rights to avoid planning issues.
- The retrofit process should be practical, achievable by the current UK construction industry and widely replicable.
- That there is an alternative to the Passivhaus approach, which instead of aiming at almost zero energy loss combines high (but not excessive) levels of fabric insulation with the intelligent use of active renewable energy technology.

It is important to note here that the Passivhaus concept has been promoted by many in recent times as a plausible approach to retrofit and that the design team for this project has strong reservations about its practicality. A very important point here concerns insulation thickness, where it has been noted that some Passivhaus retrofits involve solid wall insulation 200mm or even 300mm thick. From Penwith HA's extensive experience in installing external insulation, it is known that such extreme thicknesses of insulation are

almost impossible to achieve inside space-restricted social housing homes and usually require major alteration to eaves, verges and openings when fitted externally. It also presents severe problems where the insulation encroaches on adjoining, possibly privately owned properties. That is the key reason for this project to pick an optimum thickness of 100mm phenolic external wall insulation. It is accepted that new technologies such as vacuum insulated panels and aerogels might change this consideration in future, but they are not currently available for large scale use in this application.

Another key issue concerns heating, where true Passivhaus can often have no other 'heating' than MVHR. This strategy, whilst laudable in suitable contexts, can have serious disadvantages in homes occupied by the elderly or others who need a warmer than average home. The project addresses this by providing an active (or dynamic) solution for heating and hot water. Penwith HA's past experience with ground source heat pumps has already shown that it is an excellent technology for low carbon heating. The Ground / Air / Solar Source Heat Pump (GASHP) is designed to enhance the performance of standard GSHP technology by combining it with other sources of energy. The key features of the system are:

(1) A standard Calorex 3.5 kW ground source heat pump served by a 60m deep single U tube ground loop installed in a vertical borehole drilled in the back garden of the house. The heat pump is fitted within the HeatPod together with a matched mains pressure hot water cylinder. The heating flow & return pipes pass through the external wall of the house from the HeatPod and feed a radiator system inside the house (mainly using the radiators previously used by the solid fuel system). All of this part of the system is very similar to Penwith HA's original retrofit GSHP systems.

(2) The HeatPod also contains a NIBE extract ventilation & heat recovery unit which ventilates the whole house. A passive air supply system draws air through the HeatPod before it enters the house and distributes it to the habitable rooms. Whenever the HeatPod is attracting solar gain, the incoming air will be warmed before being drawn into the house (this is the solar element of the system). The HeatPod floor is constructed as a passive heat sink to enhance this effect, giving off warmth when the building cools. The NIBE unit extracts air from the kitchen and bathroom and transfers the reclaimed energy to the GSHP ground loop system. When the heat pump is running, this will be of immediate benefit to the system. When the heat pump is not running, the energy is transferred to the ground and stored for later use.

(3) The effect of combining the ground source heat pump with the ventilation system is to create a co-ordinated flow of energy within and around the house. Even the warmth generated by the pellet stove can be recycled by the GASHP. It is accepted that a system such as this requires electricity to run it, but much care has been taken to use low energy pumps, fans and valves wherever possible. The inclusion of a PV system is in fact primarily intended to compensate for the parasitic losses of this equipment used to run the system. The proof of the effectiveness of this system will need to be derived from monitored data and this is the reason for including a very carefully designed monitoring system in the project. Data from the monitoring system

is already being used at the time of writing (September 2011) to fine tune the GASHP and track its performance.

Although the concept of the HeatPod has been realised in the final project, some compromises were made in the detailed design. The HeatPod proper (i.e. the conservatory and its built-in technology) is envisaged as an item that could be factory built and literally dropped into place on site and “plugged in” to the dwelling. This would necessitate some product development with a prefabricated building supplier. The version realised in the project has, of necessity, been constructed using available technology. Ideally the PV system would have been an integral part of the structure but this proved very difficult to achieve using standard PV components, so the PV system fitted was installed to the main house roof. Another area of detail that proved complex was creating a watertight joint between the HeatPod / conservatory and the house that minimised interference with the external wall insulation. A satisfactory means of achieving this was achieved but would ideally be simplified for a commercial version. Other than these points, the finished house is very much as originally planned.

7. Construction

Procurement
The project was negotiated with a framework partner. Both ROK (whose involvement in the project finished when the company entered administration in November 2010) and Mears (who carried out the contract) are / were framework partners with Penwith HA for Decent Homes projects. In both cases, the retrofit project was fully costed and agreed prior to arranging the contract.

Contract Type
JCT Minor Works contract.

Contract Structure
Mears Ltd undertook management of the work as main contractor. Several elements of the work were carried out by domestic sub-contractors employed by Mears but previously arranged by Penwith HA. These were:

- **External wall insulation**: Keith Towsey
- **Supply & fix of conservatory**: Causeway Trading Group.

Specialist installers:
The renewable energy systems were procured by Penwith HA obtaining quotations from the suppliers and placing direct orders with them for the work with the requirement that their work would be co-ordinated by the main contractor. These were as follows:

- **Ground source heat pump**: Mimer Energy Ltd (formerly EarthEnergy Ltd).
- **PV system:** Plug Into The Sun
- **Wood pellet stove:** The Stove Shop

Finally, the M & E installations were fitted by M V Clatworthy Ltd under their Measured Term Heating Contract with PHA, again with a requirement to work in co-ordination with the main contractor.

It would normally be regarded as better practice for all subcontractors to be under the control of the main contractor, but the arrangement used here proved very fortuitous as it enabled much of the pre-contract preparation for the project to be carried forward when ROK ceased trading. All of the subcontractors involved in the project were chosen because of their known expertise and reliability, which was an important factor in ensuring the success of the project.

Specialist equipment suppliers

- **Ground source heat pump:** Calorex Ltd.

- **Ventilation and heat recovery unit**: NIBE Ltd.
  Note: during the Phase 2 stage for Retrofit for the Future, applicants were encouraged to identify additional funding for projects including no-cost measures

from manufacturers. In this project, both of the above items were donated to the project by their respective manufacturers.

- **Triple glazed windows**: JELD-WEN – procured by quotation to Penwith HA and ordered by the main contractor.

- **High performance external doors**: Homesafe Doors: ordered by the main contractor under the terms of a supply contract negotiated by the Advantage South West procurement consortium.

- **Monitoring equipment and system:** T-Mac Technologies: Procured by quotation to Woodmead Energy Services and Penwith HA. T-Mac systems had previously been used very successfully by members of the project design team and were regarded as the best option for meeting the monitoring requirements of the project.

- **Low energy white goods and appliances:** Currys – reduced prices negotiated for the project by Penwith HA.

Site supervision

The greater part of the site supervision was carried out by the project manager who visited the site frequently and arranged visits by other members of the design team when their expertise was required. The Project Manager is a Chartered Architectural Technologist with many years of experience of site supervision of construction work in addition to specialist knowledge of low carbon retrofit. This arrangement also enabled a careful photographic record of the work being kept which focused on critical details. The work of necessity involved a degree of supporting the contractor's workforce in developing their understanding of low carbon construction. Relevant points include detailing to minimise cold bridging and to achieve airtight seals at joints. There is no better way to address these issues than to work with the real components and the contractors on site identifying the potential problems and solving them as they occur. The contractors for this project responded extremely well to this and will be able to apply the knowledge gained from this project to future work.

Role of the Architect and design team

The construction design was carried out by the project manager who was able to combine architectural and construction decisions with a detailed knowledge of the energy and technology aspects of the project. As project manager, he was able to direct work on site, co-ordinate the input from design team members and respond quickly to any issues that arose during the construction work. For this project, the key areas of contribution of design team members were in the energy modelling and design and assembly of the Ground / Air /Solar source heat pump and installation of the monitoring system.

Lessons learned on site

This project was designed from the outset to build on the practical experience of the design team, and much of the work was known to be achievable in practice. The finished project is remarkably close to the original design concept and there were no significant failures or insurmountable problems encountered during the construction process. However, it did provide some useful learning experiences:

1) The work on site took about 8 weeks longer than originally expected. There were two reasons for this:
    a) The contractor went about the work very carefully and cautiously, which was appropriate when undertaking a type of work that is different to industry standard processes. With more experience of the work involved, future work would be accomplished more quickly.
    b) The work required the services of numerous specialist sub-contractors who were chosen for their reliability and expertise, which was essential for a project of this nature. However, the downside of this is that fitting a small job into their busy schedules meant that they were often not available at the ideal time, and some time was lost waiting for sub-contractors to carry out their work. A solution to this problem would be to procure retrofit works in much larger quantities, thereby securing the full attention of specialist subcontractors.

2) The project involved construction of a prototype energy system. A particular focus of this was installing the equipment for the Ground / Air / Solar Source Heat Pump in the HeatPod. In addition to this, what would have been normal plumbing issues were made more complex by the addition of numerous items of monitoring equipment, especially flow meters which must be appropriately located to function correctly. Installing all of this equipment required the co-operation of the main contractor, the M&E contractor, the GSHP contractor and the monitoring specialist. The work was in fact accomplished successfully in a spirit of good humoured co-operation, but in retrospect the task could have been made easier by a higher level of pre-contract design. Although the locations of the key items of the system were specified in advance, the fine detail of the location of every item was not. In this area, the project encountered the boundary between traditional construction and product design and manufacture. The work on site in this instance would have been significantly easier if the unit had been designed and prefabricated off site prior to installation in the HeatPod.

3) Modifications to the existing space heating distribution system also proved more difficult than expected. The need to save costs caused the design team to attempt to reuse the existing radiators rather than fit a completely new system specifically designed to match the different requirements of both the low output temperature and special thermal capacity requirements of a heat pump. In the interests of reducing pumping energy, it was also intended to rejig the existing pipework into a ‘reverse return’ loop. All this proved to be confusing to the plumbers and the end result turned out to be a compromise, although one which does, fortunately, appear to work satisfactorily!

4) The HeatPod was conceived as a potentially free-standing ‘bolt-on’ addition to a house, which remains as a plausible concept, but one that would require further technological development. In practice, joining the conservatory to the house in conjunction with a 100mm layer of external wall insulation required some very careful traditional detailing to achieve a watertight and visually satisfactory connection. This

is another area of overlap between construction and manufacturing – introducing new ideas into construction work calls for smart product development.

5) The strategy of carrying out as much work as possible to the outside of the property worked very well in practice. Although external insulation is not suitable for all homes there is a strong argument that it should be the wall insulation of choice wherever it can be fitted.

6) The combination of installing external insulation at the same time as fitting new triple glazing and external doors allowed details providing substantial reduction of cold bridging - usually much more difficult to avoid.

7) Consideration was given during the project to strengthening and / or modifying the roof structure to retain some storage space after adding greatly increased insulation. A simpler (and cheaper!) solution was arrived at - to supply a small garden shed adjacent to the house.

8. Monitoring requirements and installation

The property was selected for refurbishment using improved insulation and triple glazing combined with renewable energy equipment. This equipment includes a ground/air/solar heat pump interfaced with a MVHR unit, specially designed by Earth Energy Engineering Ltd with prototype testing undertaken by Mimer Energy Ltd. Also, there is a 1.15kW PV array on the roof at the rear of the property installed by Plug into the Sun, Penzance.

For this project, the TSB specification required that remote monitoring is used and the data is available in a web portal with CSV formatted files logged at 5 minute intervals. The requirements have been met and provide analytical information comparing building performance with plant operation.

To match the TSB specification to the property and renewable energy equipment to be installed, it was evident that the substantial number of metering and sensors points needed would require more configurable inputs than the 22 available within one Maxi t-mac GSM/GPRS monitoring unit. Therefore, the design included two t-mac units and the design team agreed that the property should be monitored prior to the commencement of the building improvement work to provide valuable data in respect of improved building performance post retrofit. The first phase of monitoring (table of inputs below) was commissioned in May 2010 with temperature and humidity sensors installed in three locations within the house and a further temperature/humidity sensor outside. Additionally, the first t-mac included a CO_2 sensor in the lounge and contact temperature sensors on the cold water supply and draw off pipe of the DHW cylinder; these sensors are now relocated in the phase 2 t-mac. Two “Mod-bus” RS485 electricity meters were installed for phase 1 to replicate the house tariff meter and identify immersion heater usage

Multiple parameters	degC	RH	degC	RH	degC	RH	degC	RH	Archived data do not use		ppm
Electricity Meters	Lounge	Lounge	Hall	Hall	Bed 1	Bed 1	External	External	Spare	Spare	Lounge CO2
Modbus	1	2	3	4	5	6	7	8	9	10	11
	kWhe	kWhe	kWhp	kWhe							
t-mac phase 1	Monitoring kWh (pulse)	Stove kWh (pulse)	PV Export Meter	Photovoltaic (pulse?)	Spare	Spare	Spare	Spare	Spare	Spare	Spare
	12	13	14	15	16	17	18	19	20	21	22

Phase 2 of the monitoring project was installed during August 2011 and includes additional electricity kWhe pulsed output metering in the first t-mac for import/export of the photovoltaic equipment and the pellet stove in the lounge plus a meter to identify the cost of running the monitoring equipment.

The technology is all installed in a purpose built cupboard in the “HeatPod” at the rear of the house and the heat pump electricity meter (mod-bus RS485), heat meter and system flow meters and sensors are wired to the second t-mac (table of inputs below), adjacent to the phase 1 t-mac in the utility room. The table highlights that in addition to satisfying the TSB requirement for ground temperature data (inputs 1 and 3), a ground loop flow meter (input 2) is included to allow calculation of ground source energy. The heat pump space heating flow/return temperatures and flow rate are also monitored (inputs 4, 5 and 6) and will be

used to calculate thermal output. Heat pump operating mode may be easily identified by interrogation of inputs 7/8 and the condenser leaving and entering water temperature (higher than space heating temperature) is monitored at inputs 10 and 22. Finally, temperature/humidity monitoring in the heat pod and ventilation system and data relating to the domestic cold and hot water usage is available for analysis.

Multiple parameters	degC	litres/sec + litres	degC	degC	litres/sec + litres	degC	Off/On	Off/On	degC	litres	degC
Electricity Meters	HP Evap EWT	Ground loop flow rate + total (pulse)	HP Evap LWT	HP Space Heating Flow Temperature	HP output flow rate + total (pulse)	HP Space Heating Return Temperature	GSHP CH Demand mode (relay contact)	GSHP HWS Demand Mode (relay contact)	Ground loop EWT	HWS total (pulse)	Condenser LWT
Modbus	1	2	3	4	5	6	7	8	9	10	11
	degC	RH	degC	RH	kWhth	litres	degC	degC	degC	degC	degC
t-mac phase 2	POD sensor	POD sensor	Exhaust Coil EAT	Exhaust Coil ERH	Heat Meter (pulse)	Total house cw	Exhaust Coil LAT	HWS cyl (top) contact sensor	HWS (draw off)* pocket sensor	HWS (Cold feed)* pocket sensor	Condenser EWT
	12	13	14	15	16	17	18	19	20	21	22

The requirement for installation of the ground/air/solar heat pump and monitoring equipment added significantly to the complexity of the installation and some compromises were necessary with the positioning of the water flow and heat meters. There was also some concern over the likely accuracy of the heat meters recording such small thermal increments in such a low output system recording at 5 minute intervals. Water flow meters were therefore added to measure flow rates in both the condenser and evaporator of the heat pump. At present, it has only been possible to fit one heat meter (fitted into the space heating pipework) but the remainder of the system was completed and commissioned during August 2011 and functionality checks are substantially completed.

On the positive side, this type of monitoring system has been used on previous projects and, as well as providing good quality analytical data to establish efficiency of performance, it is invaluable as a diagnostic tool prior to site maintenance visits.

9. Commissioning and occupancy

One advantage of the residents remaining in occupation of the home throughout the retrofit is that it was possible to explain and discuss each stage of the work with them as it happened. So rather than there being an intensive ‘user-training’ session at an occupation stage, there was a constant flow of information between the project team and the residents throughout the work, including involvement with design decisions wherever possible.

The main focus of commissioning activities for the project was on the central heating and monitoring systems. There were issues related to the reverse return loop modifications and the removal of 2 port valves inserted unilaterally by the plumbers ‘because you always have these on an ‘S Plan’ (which the system is not, it has twin pumps). Once these were resolved, commissioning of the heating and hot water systems went well. The main programmer and wireless room stat fitted were not actually the ones specified (being more suitable for a gas fired boiler than a heat pump) but worked adequately. The first heat pump fitted exhibited some anomalous behaviour from the outset so was replaced with another which was fine.

The commissioning of the monitoring equipment took much more time than expected with some sensors having to be repositioned and some test values delivering unexpected results. Particular problems were found with the humidity sensors (probably relatively unimportant) and electricity current transformers (definitely very important and which will be reported on at a later date).

There were few issues with occupancy since the residents had remained in occupation throughout (although it must be recognised that they showed considerable forbearance when their storage cupboards, wardrobes, and first floor floorboards were all out of use at the same time for about a week in July 2011!) They were instructed on the use of the system as it was being installed and were also involved in the commissioning process. They also have copies of the manufacturers’ manuals for individual pieces of equipment.

10. Costs

The first main contractor for the project, ROK, went into administration shortly after starting work on site. Following ROK's cessation of trading it was necessary to completely reappraise the position of the project.

Under the Association's contract for the project with the Technology Strategy Board, it was expected that the retrofit works would be carried out during 2010. Whilst in practical terms the insolvency of ROK was beyond the Association's control, it was necessary to swiftly make alternative arrangements to resurrect the project to avoid any impact on the residents. In order to avoid the loss of much preparation that had taken place with ROK, it was considered pragmatic to retain the existing subcontractors and suppliers in place and to identify an alternative principle contractor. To minimise further delay to the project it was considered appropriate to approach the Association's other framework contractor, Mears, using the existing agreement for Decent Homes work in a comparable way to the approach used with ROK.

Following a meeting with Mears in December 2011, detailed costings for the builders work were submitted by Mears and a contract sum of £62,329. (incl. VAT) with a contract period of 12 weeks was agreed. This was less than the sum previously agreed with ROK as, by this stage, in order to save time, the supply of some of the renewable energy technology had been ordered directly with specialist suppliers. At this stage, the project costs were still within the original budget. The similarity between the pricing of the work by Mears and ROK illustrated that the work had been priced accurately. A pre-contract meeting was held on 11th February 2011 and work started on site on 14th March 2011.

Following physical completion of the works, the final account for the contact for building works has been negotiated with Mears and a final account sum of £74,660 (incl. VAT) has been agreed. However, for the purposes of the grant funding of the project the construction costs to be claimed will be as set out in the original project bid. The additional costs of construction detailed above have been met by Penwith Housing Association.

Item Stage>	Design stage		Post-construction		Comments
	Materials	Labour	Material	Labour	
Management and administration					
Design					Design & project management contributed by PHA at no cost to the project.
Construction overall					
- Prelims		14,352		14,715	
- Fabric measures	14,104	21,156	20,023	30,035	
- Building services (conventional)	800	1,200	5,092	7,638	
- Low /zero carbon technologies	10,289	15,433	7,957	11,935	
- Other: Low energy appliances	4,123		5,030		
- Consequential costs	n/a	n/a	n/a	n/a	
Occupant temporary housing	n/a	n/a	n/a	n/a	Tenants remained in occupation throughout the project.
Monitoring equipment	8,431	12,647	8,431	12,714	
Monitoring and reporting service	5,280	7,920	5,289	7,934	
R&D costs: design of ground/air/solar source heat pump & energy modelling.		11,500		11,569	

11. Doing it again

Definitely do again: The retrofit was designed to be very replicable and the finished work suggests that the package of measures chosen would be well worth repeating on other properties. In construction terms, there were no experimental items that turned out to be bad ideas. This is not, however, to say that the design could not be improved. The HeatPod and the Ground / Air / Solar Source Heat Pump are prototypes for potential products and would benefit greatly from further development. The ventilation ductwork installation also requires work to provide a more replicable solution. But the fabric measures used are all mature products already in the market place and have served their purpose on this site very well.

Definitely not do again:
The project demonstrated that an item as complex as the GASHP would benefit from more detailed design before installation rather than being assembled experimentally by trial and error on site.

A contract management arrangement which places all subcontractors under the management of the main contractor would be preferable to the approach used here, although the retrofit market needs to mature to make this more feasible.

Reduction of costs:
In the planning stages of the project, there was some debate about the cost effectiveness of replacing existing double glazing with triple glazing, and it was included in the finished scheme in order to meet the RF4F carbon target. It is worth noting that replacing the windows enabled great improvement in terms of removing cold bridges from the building envelope.

The value of fitting of external insulation below ground, again carried out here to meet the carbon target, is of debateable value. In the case of this project, it was easily accomplished owing to relatively easy digging conditions around the perimeter of the property, but if the house had been surrounded by concrete paths the task would have been much more labour intensive and expensive. In the latter case, the small reduction in heat loss would not be worth the extra cost.

The wood pellet stove room heater was included in this project to continue the presence of a focal point room heater in the home previously provided by a multi-fuel burner. However, the main heating system is entirely capable of fully heating the house and the pellet stove is not strictly necessary. It does however provide the reassurance of emergency backup heating in the event of the heat pump system being out of action.

The PV system is another item that was necessary to help meet the carbon reduction target. There is certainly considerable benefit to be derived from the zero carbon electricity it provides and the potential for FIT income. There is, however, a good case to be argued that a well thought-out package of fabric measures combined with a well designed ground source heat pump system is a very effective carbon reducing retrofit on its own.

A production stage retrofit would not include the extensive monitoring system that has been used here. For this project, monitoring is not only essential to meet the Technology Strategy Board requirements, it also forms a very important part of the research and development of the GASHP heat pump system. However, its inclusion involved additional complications in designing for the inclusion of the larger items of equipment and its power consumption (and increased hydraulic resistance) has a bearing on the energy consumption and carbon emissions of the house.

Improvement of the design process:

The design process for a Retrofit for the Future project was, at least in the project team's experience, unique insofar as such a high level of carbon reduction had not previously been applied to retrofitting dwellings. It was also influenced strongly by the various TSB requirements for energy modelling and cost effectiveness and the encouragement to innovate. The last point is perhaps the most significant: the construction industry is usually conservative in its approach and prefers tried and tested solutions over the completely new in order to eliminate the risks of innovation. The terrain of 20th century construction is littered with the remains of good ideas gone wrong and the scars of the ensuing litigation. One of the outcomes to be hoped for as a result of RF4F is that there will be a recognised roadmap developed for the domestic retrofit market. Unfortunately, at least at the time of writing, it appears that the plans for the 'Green Deal' are set to fall far short of the level of energy efficiency and carbon reduction embodied in RF4F. There is every chance, therefore, that key lessons learned from this programme could be lost until such time as maximum reductions in carbon emissions become mandatory for building retrofits.

Improvement of the construction process:

Familiarity with the work involved would lead to much time saving and better planning of retrofit work.

12. Business benefits

Housing Association perspective:
The experience of being involved in RF4F has been invaluable in providing an opportunity to take retrofitting to an entirely new level. On the basis of this experience, it would be much easier than it would otherwise have been to set up a retrofit programme involving many properties. However, whilst the government that sponsored RF4F had plans for a major retrofit programme in the social housing sector, its successor is far less clear about its intentions in this area. And at a time of radical financial cutbacks the scope for large scale retrofits aiming for standards anything like RF4F seems greatly diminished. The programme has clearly shown that the majority of dwellings require a well thought-out and comprehensive package of measures to achieve greatly reduced carbon emissions. Even with the benefits of smart bulk procurement, by present standards, the cost of such works is going to be in the order £20 – 40k per unit rather than below £10k. The model of financing retrofit purely on energy cost savings as embodied in the Green Deal cannot approach this level of funding, at least until increases in energy costs are severe enough to radically change the equation. In the meantime, the Penwith HA retrofit property provides a very valuable exemplar of the direction in which ideally all of the Association's existing stock should follow when funds allow, or when retrofit becomes a mandatory requirement.

Data Monitoring and Analysis:
The opportunity to monitor multiple parameters of data relating to the installed technology has provided analytical material which adds greatly to existing databases already archived. Additionally, the advantage of this project over the usual commercial packages is the breadth of information we have been able to collect because of the hybrid nature of the equipment. Such information will be a great asset in the future development and evolution of renewable energy technologies!

Building Services consultant perspective:
The infant heat pump market is struggling to move away from being a cottage industry for eco-enthusiasts and largely dependent on subsidies. The genuine need to understand the why's and how's of low temperature heating system design in highly insulated dwellings will however be an essential requirement if annual household fuel costs are not to spiral out of control as fossil fuels become more difficult to obtain. Detailed technical knowledge about the design and installation of such systems is very rare in the UK and the housing market seems to be unwilling to pay to acquire it. It is also true that the practical aspects of installation are outside the experience of the majority of domestic plumbers or central heating specialists who would normally be expected to carry out such work. The development of the 'HeatPod' package which could incorporate all the necessary knowledge and skills in one 'box', factory built off site and capable of being installed by semi-skilled labour, could be a real breakthrough in both reducing fuel poverty and decarbonising the existing housing stock in the UK at an affordable cost. This RF4F project has proved it is possible to do, the next year's monitoring will hopefully prove that it works.