ACT Energy Case Studies

Author / Contact :

Fuad Al-Tawil

Fuad@ActionClimateTeignbridge.org

01626 87 2721

Contents

Section 1. Introduction

This is a collection of Case Studies from ACT members. They are intended to help those planning to reduce their Energy consumption with experiences from others. ACT has included some additional information and signposting to further materials where appropriate.

The case studies cover all areas of the Energy Hierarchy from cutting out waste to sequestration and offsetting. They are grouped under the following headings with each case study taking up less than one A4 page of text (2 pages including pictures):

- My motivation
- Cutting out unnecessary energy consumption (in the home, at work, travelling, food, purchasing goods and services)
- Replacing and improving appliances and devices in the home/work
- Retrofitting my home/work place
- Changing my transport habits and vehicle
- Getting my own low-carbon energy sources
- Helping others to reduce their energy use
- Reducing emissions elsewhere through offsetting and investment decisions

Section 2. My motivation

2.1 It started in 1998

My wife and I were lucky enough to afford a very old stone-built barn that was converted in around 1990. The building is set in the Deer Park of an ancient Devon estate, it was quarried on site and constructed many 100s of years ago. When we moved in 1998, we knew we needed all our skills honed from the improvements done to a circa 1900 terraced house in London. That project took nearly 20 years as we'd done most of the work ourselves, practically gutting the building while living in it.

Deer Park Farm was very habitable, having been recently converted by the previous owner. The mortgage survey looked good, especially as the surveyor asked for remedial damp proofing works to be undertaken. The property had radiators throughout, it was heated by a medium-sized multi-fuel Villager fireplace with back-boiler.

We very soon realised the limitations of this, both in terms of sourcing the 'dry' wood and the ability of the fireplace to provide our water and space heating needs. Like everyone would do, we asked how do people out in the 'sticks' with no mains gas keep warm? The answer was oil or LPG, we chose oil because a majority of those we asked used it, it was cheap at 8.5 p/L. Filling the first 2,500 L cost us £223.13 incl. VAT, we made sure we used much of that over the first winter of 1998/99.

The house was reasonably warm, but we couldn't look out of the windows, they were constantly misted up and dripping water everywhere. Removing the wet curtains was the answer to that. We put up with misted windows since they were 6-inch square single panes set in 100's of Georgian bars so didn't give much of a view anyway.

Next autumn, time to refill the tank, we were quoted 14.50 p/L . The advice was, buy when no one else is buying, so we waited a month for it to drop to 13 p/L and felt smug. Then we got a knock on the door from a nice solar thermal salesperson who told us this was the way to beat soaring energy prices, renewables were all the rage. We had a large roof that could supply 'much' of our heating demand and pay back in just 5 years. And by the way, it was made by Daimler Benz in Germany, so the best technology money can buy.

We learnt from our London days never to accept that 'special price' just for us, there was no statutory cooling off period in those days. So off we went and did our research, what we worked out is that the system would be great in the summer for hot water, but at £4,500 incl. VAT it would take at least 15 years to pay back even when using the sales numbers to heat two water tanks. In our research, we also came across the 'green revolution' and references to Climate Change. Climate Change turns out to be a bit more specific than a general concern about the 'environment'.

A penny dropped, we are lucky to afford these 'green' technologies and actions so why would we not do them. We got our first Solar Thermal system installed in 1999. We had 3,000 trees planted, registered with Good Energy for our 100% green electricity and replaced our many Georgian windowpanes with 132 larger double-glazed glazing units. We were quoted £25,000 to put in 'modern' UPVC units, but simply couldn't bring ourselves to throw away all those frames and openings, they were just 10 years old. It was also too expensive for us. We did the work ourselves with the help of a glazier for £1,500 spent on materials and his labour. We felt smug again!

By around 2005 we'd internalised that tackling Climate Change was about reducing our greenhouse gas emissions. It was early days for calculating emissions, but data was around. All this encouraged us to join the new Transition movement. The experience from those first few years is why we've turned that approach on

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its head. If our motivation is to reduce emissions, we need to know what these are first before deciding on what action is best for our circumstances.

2.1 Oure new 2005 home

We are a second time round couple that moved to Devon in 2005. Our new home was a new build, built to the standards of the day, that included cavity wall insulation and double glazing throughout. At the time we were certainly aware of Climate Change but not really very engaged in tackling it apart from recycling and growing much of our own veg.

My job involved extensive international travel. Probably 5 long haul flights and 10 short haul a year, two of which would have been holidays. Zoom, or similar, were unknown to me then. I had a big 2.5L V6 petrol car, plus we had a smaller run around car and oil-fired central heating, but I was increasing aware that things needed to change.

We installed a significant amount of secondary glazing thus making those windows triple glazed but in truth the driver was noise reduction more than energy saving. The big car was next after a fatal diagnosis and was replaced by a smaller family diesel car, in line with advice at the time. Shortly after we installed a 3.9 kW PV system on the roof, which faced directly south. At the time there were high FIT payment inducements and 12 years later this system has earnt in excess of £25K plus generating on average 3.8MWh of electricity a year.

While we were increasingly aware of Climate Change and our impact on it, we were slow to amend our lifestyle until I retired. We then resolved not to fly, if possible. We added a battery and solar diverter. The latter heating the water instead of exporting excess PV power to the grid. This worked really well when run on a two-tariff system (ie off-peak) and for the 4-5 months with longer day length we were close to being "off grid".

The next change significantly reduced our carbon footprint but also upped our electricity consumption. We sold both cars, even the three-year-old diesel and went down to just one electric car, with a home charger. Driving our two ICE cars some 25,000 emitted an average of 6,767kgCO2e a year.

It took a while to learn how to operate with just one car, but it is now (5 years later) very rarely an issue. While significantly cheaper than public charging, home charging an electric car that does about 10,000 miles a year has a cost and impact on electricity consumption, which is nevertheless cheaper than running an Internal Combustion Engine (**ICE**) car the same distance. So, the Electric Vehicle (**EV**) emits 747kgCO2e a year when charged from grid electricity. In addition, EVs currently attract no road tax and generally require less servicing compared to ICE equivalents.

That left us with the biggest question, what to do about our oil central heating. After significant research I opted to go for a high temperature ASHP. While more expensive than a standard heat pump, there is no need to instal under floor heating or increase radiator size because this type of heat pump can, if required to, heat water to the same temperature as an oil or gas boiler. Before installing the pump, we increased loft insulation and replaced three external doors we knew were draughty. So the oil storage tank, boiler and hot water tank were removed and the pump installed with almost no disruption over 2 days. The pump has two heat exchange units, one outside and a second inside (where the old boiler was). The outside unit looks like a large aircon unit and when running makes about the same amount of noise as a gas or oil boiler. A new hot water storage tank is also required but slots in the same place as the old one.

The ASHP has now been in place for two years. It clearly increases electricity consumption, up from 11MWh to 18.5MWh p.a. The old oil heating used about 1,500L and emitted 4,602kgCO2e p.a., while the ASHP, emits

1,765kgCO2e p.a. Although we get about 3.8MWh p.a. from our PV system, this is mainly used to charge the EV, and feed the house electricity needs, avoiding 994 kgCO2e of emissions if we were to import that from the grid.

We no longer directly purchase any fossil fuels for transport or heating; our combined transport, heating and domestic electricity costs in 2022 at 12 p/kWh were £2200 p.a.

To facilitate holidays, and keep us off planes, we do now have a diesel motorhome that does approximately 5,000 miles a year. That is 2,397kgCO2e when averaging 30mpg, while a short haul flight the same distance would create 2,696kgCO2e for the two of us.

All told, we have reduced our annual emissions. But there is more to be achieved especially as the emissions associated with all this new technology will also need to be compensated for.

We need now to look at further reducing energy consumption. One way will be to use more public transport. We have already succeeded in visiting our latest grandchild in Germany, by train. Now we need to use the bus more locally and see if more insulation can be cost effective.

A recent “energy” survey showed we were doing the right things, but further insulation could help. So, our next projects will be increasing the depth of the loft insulation and filling the gap that remains in the cavity with polystyrene beads.

Interestingly over this period the way I grow our vegetables has also changed. I no longer use granulated fertilizer, which is made from fossil fuels. Instead, I use animal manure and homemade compost, produced from vegetable food waste, and composted weeds, grass etc. Crops are protected by nets/mesh now rather than sprayed with pesticides (made using fossil fuels, but at least the nets can be recycled). All rather ironic as I spent my entire career in Agricultural R&D testing and developing new pesticides.

2.2 Retrofitting a very old family home

I was brought up while rationing was an active memory and have always been concerned to reduce waste and to save energy. My career as a plumber and then a building company owner (since 1980) consolidated my interest in older buildings and led to a substantial and life changing contract to restore a 100 room medieval manor house Wytham Abbey on the West of Oxford.

Towards the end of the Wytham contract I registered and was fortunate to complete the part time, 3 year Diploma in Conservation and Restoration Course at Bristol University that covered a variety of aspects of working on old and Listed Buildings in the UK plus the legislation that applies. My dissertation "A Practical Guide for Builders and Householders working on Listed Buildings" is available on my company website www.redlandbuilders.com on the Advice page.

To distil my 12,000 word dissertation into two words, they are Breathability and Lime. Old buildings are usually single wall construction i.e. the composition of the walls are a range of materials, stone, earth, mortar etc formed at various widths adequate to support floor joists, internal walls, ceiling and roofs. The moisture content of these walls varies ,on surrounding soils, heights of ground, internally in relation to external ground, water surrounding the buildings e.g. rain, ground water, humidity etc. and coverings e.g. cement render that prevents the passage of water (unbreathable) Lime render that allows the passage of water (breathable) and impervious materials e.g. slate covering to walls in Cornwall, slate or plastic damp proof courses to arrest rising damp. N.B. I do not include injected silicone DPC which in rubble walls is completely ineffective despite being often specified by mortgage lenders.

Modern buildings, post 1910 are often formed of two leaves of blockwork/stonework/timber construction walls with a gap between the two. The gap prevents water passing between the two layers unless compromised by incorrect cavity fill installation or inadequate or incorrectly fitted damp proof courses, wall ties etc. Cement renders enhance the external water prevention, however internally applied, they can increase water condensation in cold spots.

To summarise, all conditions, building fabric etc must be assessed and considered before applying materials in order to achieve the desired breathability and finished surface.

We moved to Little Clampitt in 2018 and started the retrofit project to convert a perpetually cold, damp cottage into a warm family home that after alteration, does not cost the earth in financial and carbon terms.

The cottage is Grade II listed and is in Dartmoor National Park with all of the nature and environmental considerations. Planning and Listed Building approval took over a year to prepare before submitting the over 50 page application which took several months to approve.

The cottage is built into the hillside with all of the inherent water issues. The new section at the rear is of modern construction techniques and includes underpinning, drainage and land drainage with damp proof membranes as required.

The flat roofed extension built in 1960, re-roofed in 1980 and 11 years past its use by date, which we wanted to change to a gabled roof at the rear to reflect the cottage gabled roof and to hide the eight PV panels in the centre. The old cottage roof was structurally unsound, now supported with cranked steel beams internally fitted in the West section of the roof. The roof and wall insulation exceed the current building regulation by at least 20% and we have been very careful to achieve air tightness around timbers, windows etc. by taping all these.

The old cob/stone walls had been rendered with cement, this was removed and lime rendered internally. The old floors were concrete on soil now 200mm of Geocell beading with 100mm of limecrete containing underfloor heating coils and covered with unsealed clay tiles to allow breathability in the old cottage.

The cottage had been heated with an oil combination boiler that we have now changed to an 18kW air source heat pump.

The work is not yet complete but the house is already warm, light and comfortable. I plan to gather data to show the impact.

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2.3 Thinking and designing a PassivHaus

"What are we trying to achieve" was the question we set ourselves as we embarked on our self-build project. You cannot build what you want until you are clear about what you want.

We decided:

1. That we wanted to minimise our daily carbon footprint in the finished house by building an energy efficient house. A house that would be powered solely by electricity with zero emissions at the point of consumption and a house that could generate more electricity than it would consume each year.
2. We wanted a high level of environmental comfort in the house that included a stable internal temperature, low and stable humidity, a quiet environment and plentiful natural light.
3. We wanted to use sustainable and local materials where possible in constructing the building and wanted to avoid the use of chemicals that would emit toxic gasses.

We took these objectives to a local architect and discussed the various design and energy performance standards. We settled on the PassivHaus standard.

Passive House Institute

The PassivHaus standard requires that space heating / cooling energy demand does not exceed 15 kWh per square meter of treated floor area per annum. The average UK home is estimated to require around 140 kWh per square meter per annum.

Total energy consumption including all heating and cooling as well as cooking, hot water and all domestic energy consumption must not exceed 60 kWh per square meter of treated floor area per annum.

A PassivHaus is required to meet an air tightness standard of less than 0.6 air changes per hour at 50 pascals of pressure (N50) to ensure there are no uncontrolled draughts and air leaks but with ventilation, should achieve an air change rate of 0.37 air changes per hour (all air is changed every 3 hours, keeping the air fresh and removing any pollutants).

There are PassivHaus standards for thermal insulation, window performance, ventilation and heat recovery, absence of thermal bridges and thermal comfort.

With vital design decisions made and standards adopted some aspects of architectural design were inevitable. For example, large windows on the east and south sides of the building to maximise thermal gain from sunlight during the winter, overhangs and other shading strategies to keep the high summer sun off the windows. All water kept to one small area of the house to minimise pipe runs and heat loss from piped but unused hot water. Small bore hot water pipes with individual supply pipes to each tap from the tank to provide fast delivery of hot water with minimal heat loss. Minimal windows on the cold north side of the house to minimise cooling and small windows on the west to avoid summer overheating. Right angles where possible on the building exterior – because all other angles are less easy to insulate.

Once the architectural designs, thermal designs and energy designs were agreed, planning permission granted and detailed drawings prepared we were ready for ground works.

Section 3. Cutting out unnecessary energy consumption

3.1 Using 'My Electricity' for a community building

Although I missed the free facilitated session offered by ACT and Teignbridge District Council, I was already familiar with the assessment approach available to TECs members. So it was relatively easy for me spot that the community centre I was asked to look at was using an unusually large amount of electricity (over 18,000kWh p.a.

My challenge came when I tried to identify where all this consumption was being used. The baseload, i.e. consumption when no one was using the building, was about 1.3 kW. That is equivalent to 11,388 kWh p.a. or over 60% of their total electricity usage. A lot of energy and a lot of money which needed to be justified or reduced.

The centre is a 4-year-old 'eco' building, but most appliances were wired in so difficult to measure using the monitoring plugs. I decided to approach this systematically, as my ACT friends keep reminding me. I took monthly readings from all the meters available in the centre, this included solar PV and battery systems. Once I saw the baseload, it was clear that I needed to find out what. It was also clear that I needed to call ACT for help.

The ACT Energy group quickly mobilised an inspection team bringing with them some monitoring plugs from their 'My Electricity' programme. We walked round the building to identify the most likely culprits using the list of electrical items and their typical consumption in the My Electricity tool. We managed to identify a few, computer screens, a large photocopier, several instant hot-water elements and a noisy fan, all left on when no one was in the building.

It became clear that we needed more detailed consumption readings which only a smart meter per fuse circuit could provide. As this is a public building, ACT put me in contact with a new company focused on low-carbon energy solutions. The building owner agreed to pay for this analysis in the expectation that the savings were likely to exceed the modest price of fitting a large number of monitoring points and analysing the results.

What a surprise when Sunny Patch shared their findings. There were indeed several opportunities to significantly reduce our baseload and therefore our overall consumption, probably by more that least 50%. They provided me with the very detailed raw data for further analysis as well as the summarised results using the 'My Electricity' tool.

The main culprit turned out to something labelled "trace heating". It turned out to be coils around all hot water taps running continuously, all year round. It looks like this solution was considered best to deal with legionella, but had been set to run continuously. A simple change of setting to 'eco' would reduce consumption by 70% and still deliver well beyond the required legionella regulation. That's saving of total annual electricity use of ~7,800 kWh or an amazing 2,144 kg of ghg emissions avoided each year. Not many renewable generation schemes can achieve this level of ghg reduction at comparable cost/effort per tonne.

I'll be looking to find a further 1,200 worth of savings.

I'm already considering where else to use this assessment approach and tools in my area. If these are the easy savings from an 'eco' business building, there must be at least as much potential in older ones. I'm told the facilitated sessions offered by ACT/TDC have already identified savings for households who've taken up this free offer.

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3.2 How much is reasonable energy consumption?

This is a question we all ask ourselves, I certainly did. On the face of it, it seems quite reasonable to say: do what you can, every little helps. There are two risks associated with this as a way forward. Our actions may not have the impact we think and we rightly believe we are doing our best, certainly compared to those others who are so much more wasteful.

The other risk is to take this approach to its limit, where we obsess about doing every possible action we hear about. We keep cutting back on most things and accept that means a less enjoyable life. I'm sure we all know people who've taken these two approaches. The answer is of course a middle way, but how do we know where this is?

In the early days of Transition, we used to use averages, national and international, as a guide. Taking the average UK household and comparing our electricity consumption to that, same for heating, food, etc. This approach is still widely used, but am I really an average consumer? I don't believe anyone thinks that, unless maybe if they know they are a high energy consumer but don't want to face having this confirmed.

One of the first things we did when we understood the connection between our energy use and Climate Change, back in 2005, is to ignore these comparisons. Instead, we used our measured energy consumption, which we'd made to do a comparison, and asked what is our energy being used for? Is any of it unnecessary? In other words, would our lifestyle be diminished if we stopped some of that use.

The messaging at the time was all about electrical items on stand-by, low-energy light bulbs and settings for your heating system. Getting a diesel car was also the talk of the town as was going vegetarian and taking the train instead of flying. Many of these required spending money, but no one ever mentioned carbon emissions or payback on the money/carbon of the new thing/action other than in terms of average numbers.

Using some simple techniques of taking meter readings once a month and using a £5 plug-in monitor quickly identified where we were using our ~400kWh p.m. electricity. We were running our home on ~250 Watts continuously (that's over 2 MWh p.a. when we're not doing anything). We cooked with electricity, so our annual consumption of ~4,500 kWh compared reasonably with the UK average of 3,500 kWh. Or so we persuaded ourselves to maintain the reputation of doing our best.

Telephone 0345 650 650
for any customer service enquiry.
Lines are open: 8.00 am to 8.00 pm Monday to Friday
8.30 am to 2.00 pm Saturday
Please quote: Customer account number [redacted]

SWEB
Customer Service
Osprey Road, Exeter EX2 7JZ

[redacted]

For electricity supplied to
[redacted]

Quarter	Charges for period to	Issue date/Tax Point
1/99	4 January 99	06 January 99

This is not a tax invoice

A bonus from the Home Team. For all normal quarterly bills produced for periods ending in January, February and March 1999 only, the standing charge will be reduced by at least 10%.

Tariff description	Present Meter Reading	Previous Meter Reading	Units used
Economy 7 (normal)	33564	32365	1199
Economy 7 (low)	59371	59004	367

If the present reading is estimated please see the back of this bill

How we work out your bill		VAT Rate%	VAT £	£
1199 units at 7.54 p				90.40
Quarterly charge				9.71
367 units at 2.67 p				9.79
Total electricity charges subject to VAT				109.90
Electricity charges	109.90	5.00	5.50	
Total VAT charged				5.50
Total amount now due				£ 115.40

paid by cheque [redacted] sent 11.1.99

24 Hour Emergency Service: Telephone 0345 651 651
South Western Electricity plc
P.O. Box 352, Exeter, EX2 7YF
S 02 030 030
22[redacted]

It took about a year to systematically go through our electricity consumption, first turning things off, only heating the water that we needed and replacing those cool looking halogen spotlights that were all the rage a few years back. That and replacing some inefficient appliances, after doing the pay-back calculation, cut our baseload from 250W to 100W and reduced our monthly consumption from 400 kWh to 250 kWh.

It took a few more years to cut the average monthly electricity consumption down to ~150 kWh. This was done when certain appliances broke and were either replaced with a new one or not at all. We also made better use of the oven.

We continue to take monthly reading, just to check everything is as we expect it to be. If we spot a significant change, we always try to get to the bottom of it. For example, we'd forgotten to switch off a Compact fluorescent light in a store which is only occasionally used, this was 20W more than our usual baseload, so was easy to spot, but took several days to hunt down.

Section 4. Replacing and improving appliances and devices

4.1 Is it time for that fridge to go?

We live in a world where new is good, progress is essential and "only dead fish swim with the stream". Our decisions are strongly influenced by all these, sometimes conflicting, societal norms.

It's very reasonable to argue that the money I have is there to be spent on things that make me happy. This is particularly true if I've worked hard for this. So why should I not treat myself to a new appliance, fridge or dishwasher, especially if that has a higher efficiency rating?

That's what we did when we moved into our new home, we got A rated white goods and those all important halogen spot lights. It was a celebration of having made it and a reward for our efforts.

Several years later, some of the appliances looked a bit old and tatty, time to get a more efficient upgrade. We'd learnt a thing or two about energy and associated emissions, thanks in particular to a couple of books:

- Energy and Carbon Emissions- Nicola Terry
- How bad are Bananas- Mike Berners-Lee

Instead of relying on our gut feeling, which is so readily influenced by what others say and what we'd ideally like to do, we decided to calculate. The well-known concept of payback was recommended by the first of these books. We could use it to make an informed decision on both financial and carbon payback time.

Payback time is essentially working out if this is longer or shorter than the expected life of an item we want to replace. This needs us to know how much it costs to run the old item compared to the new item, the cost of the new item and its expected lifespan.

We did this every time we felt we needed to replace something, the fridge, car, light bulb, etc. Basically, anything that uses energy, that's practically everything. So here is the equation we used to see if it was time to replace our A rated fridge/freezer:

Money payback time in years = cost of new thing / (annual costs of old thing – annual cost of new thing)

Carbon payback time in years = emissions of making new thing / (annual emissions of old thing – annual emissions of new thing)

Getting the money numbers was easy enough, measure the energy used and multiply by what we pay for this energy. At the time 1kWh cost us 9p, so

Money payback period = £450 / (365 x 1.2kWh x £0.09 – 365 x 0.6kWh x £0.09) = 23 years

Carbon payback period = 200 kgCO2e / (365x1.2kWh x 0.52 kg – 365x0.6kWh x £0.52kg) = 1.8 years

Ok, financially it made no sense, but we'd make an appreciable dent into our Carbon Footprint after less than 2 years. Since then, electricity prices have increased and we worked out that by setting the fridge to 6^{o}C and defrosting the freezer every 6 months or so, we consume 0.4 kWh per day instead of the 0.6 kWh stated by the manufacturer for that A+++ model and subsequently measure to be that.

Getting a 'quality' product pays off in several ways, that new fridge is still going strong after 14 years and we still feel good about owning it.

Postscript: three years on we inherited a newer auto-defrost fridge/freezer. We measured this at the same temperature setting, unsurprisingly it used 0.2 kWh per day more energy. That's 73 kWh more consumption per year. The benefit of not having to defrost manually every 3 months, a much newer device and the ability to pass our old fridge on to replace a very inefficient one, made the decision relatively easy.

4.2 Improving my Heat Pump

Our air-source heat pump (**HP**) was installed in 2011, when our near PassivHause home was built. Over the years I have evolved a heating schedule to meet our needs and be efficient. The main means of control has been via thermostats, and hot water controlled via a simple timer. I knew that with very little data to monitor, I may not be achieving the best efficiency. i.e. coefficient of performance (**COP**).

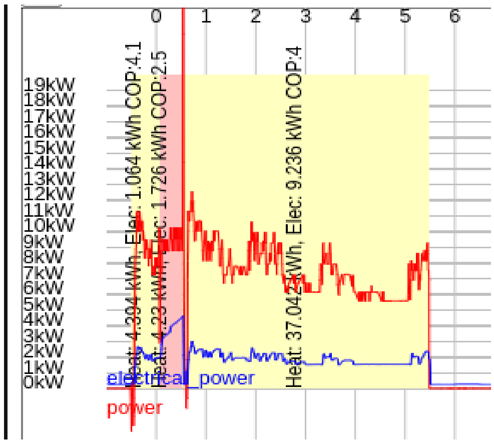
It was becoming obvious that newer installations have a lot more information available to control/tune the system. Towards the end of 2024 we had our system serviced. I discussed fitting a heat meter with our installer, and concluded that for not much more cost the control unit could be completely replaced. This would give much more information about the system and therefore allow for much more control and tuning.

As a software developer, I have over the years developed my own home automation system and wanted to integrate the HP control with that, rather than using a separate cloud based phone app.

I now have daily graphics to see how the HP is performing, this has included electricity consumption since the early January. The red line shows the metered heat output and the blue the metered electricity input.

What have I discovered so far?

- Controlling the HP using room thermostats leads to cycling, which reduces heat output and still uses a similar amount of electricity (lower efficiency).
- Heating difficult to heat rooms outside the main schedule is pointless, unless there is a need to heat these.
- The most efficient heating periods are long and unbroken.
- As a bonus, the HP also gives enough data to calculate heat loss rate and degree days.



What makes an efficient heating schedule?

- Here the daily heating cycle ran continuously between 23:30 and 05:30 (set to take advantage of the lower electricity tariff).
- At an external ambient temperature between 6 and 8 ^{O}C, and flow temperature between 32.5C and 36C, the COP was about 4. Over 41kWh of heat energy was produced from just over 10kWh of electricity.
- Hot water heating follows on directly from other heating so there is no initial temperature drop and a reasonable COP of 2.5 is achieved.
- As the flow temperature gets towards 40C the heat pump heats too aggressively, resulting in cycling, as shown in the next example.

What makes a less efficient heating schedule?

- Here the HP ran continuously overnight and again in the evening to maintain internal temperatures. The later heating cycle was triggered by unused colder areas dropping below their room thermostat settings, these result in much worse HP performance.
- At an external ambient temperature between 0 an ~5 ^{O}C. The flow temperature was higher, between 38.5 and 40.5 ^{O}C. The COP was about 2.6 based on 58kWh of heat energy generated from 22kWh of electricity.
- It appears that when the flow temperature gets close to the upper set point it causes the HP to shut down for a short period before starting again. Possibly an inappropriate ‘hunting’ or ‘cycling’ occurs due to the ‘hysteresis’ setting, see diagram below.

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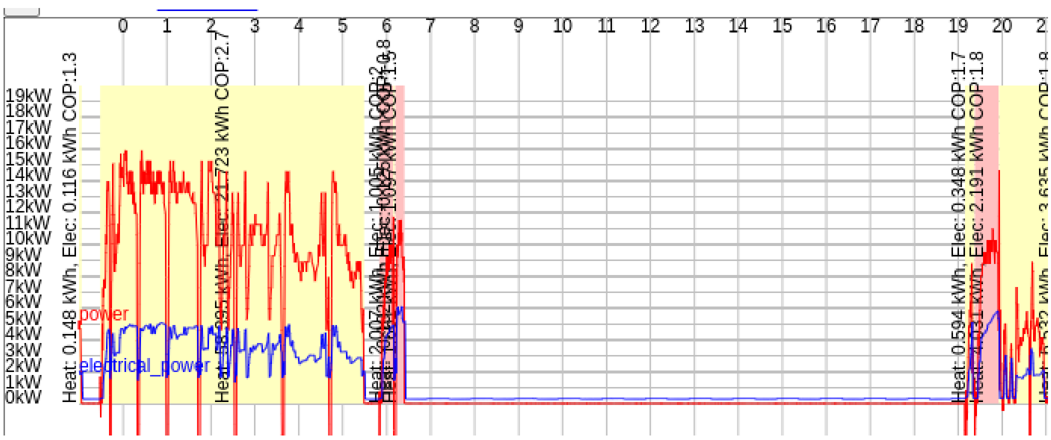
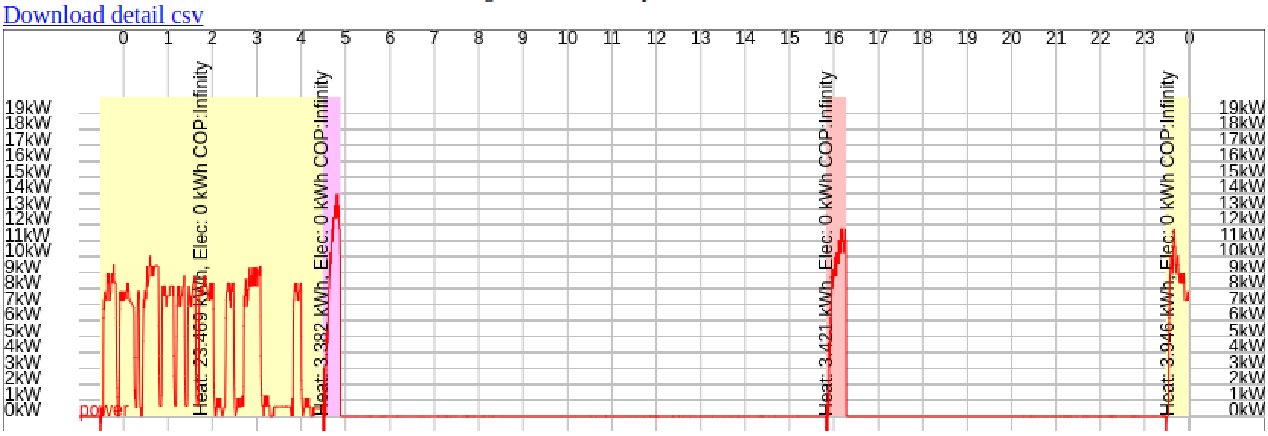


- The same hunting/cycling of the HP was observed on the 5th December before electricity consumption readings were available. This was at an external ambient temperature of 12 °C and a flow temperature of 29°C, about 27kWh of heat energy was produced. See diagram below.

Download detail csv



What's Next?

I am now in a position to tune the system to perform better. I want to get better electricity readings using an in-line meter rather than CT-clamps. I also want to use weather forecasts with heat loss data from the heat pump to calculate target flow temperature and optimal length of heating period.

For further information Upgrading to FTC6

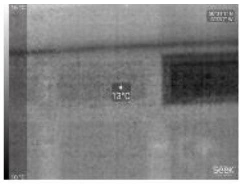
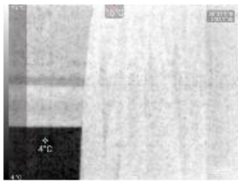
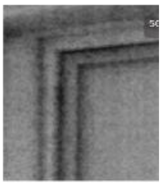
Section 5. Retrofitting my home/workplace

5.1 The 20-year window story

Having to replace all 21 windows with plastic framed double glazing was beyond our budget and the existing wooden frames seemed in pretty good condition. We decided to do the work ourselves replacing the glass and Georgian bars with double glazed units, it cost us £1,500.

We were very happy with the improved windows, until we started looking at our Carbon Footprint in a more serious way. This started in around 2010 when we replaced our oil boiler. The 'fabric first' penny only dropped fully in 2016, this coincided with us being involved in a local Community Energy initiative which eventually developed a self-assessment programme to help homeowners reduce their greenhouse gas emissions. We did the programme and discovered that our double-glazing windows were responsible for nearly 40% of our heat loss, the next largest was the roof which we significantly improved. Despite our split-log boiler heating system which is close to zero emissions as we self-supply the wood, we decided to 'splash out' on improving our home in terms of comfort and look. By then the windows were showing their 25 years of service, so they were next in line.

Given that I'm a hobby furniture maker and have my own sawmill and access to wood, it seemed obvious to make my own window replacements, which I did. We wanted the best quality solution that our limited budget allowed, but I was surprised at the price of the 'best' double glazing units I could buy in the UK. The labour involved in making the frames and the unpredictable nature of some of the timber I had access to were pretty significant. I was encouraged by my partner to seek help, so I started asking friends and looking at what was on the market as affordable products with good value for money. There were many choices, mostly 2 or even 3 times the cost of me making my own windows. Given that we had access to not only seeing examples of quality windows, but also the ability to measure their performance using the tools and methods provided by the self-assessment pack, we were able to refine our criteria to help us make a more informed choice for our circumstances.


Having decided to get triple glazing in wooden frames, I started contacting various supplies/distributors of the short list of window manufacturers we'd made. Normally all windows for a project would be ordered in one go, unfortunately our budget would not allow this. Worse still, I'd discovered that not all windows did what they claimed, even some well-known manufacturers fell short. This meant that I wanted to try one window before buying 21 to make sure the product was of the quality we wanted, and I could get it supplied and installed in stages. We have access restrictions to the property, and I was doing my own installation of some pretty heavy windows.

Our chosen supplier was happy with me ordering just one 'trial' window, they listened and responded promptly to all my numerous questions and were very friendly. Everything went to plan with a slight hiccup on the size of the delivery vehicle, but the driver was patient enough to wait and help with the final leg of the trip. Installation was straight forward once I recruited enough helpers to lift the unit into place.

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The first window was duly measured and tested over a winter season, remarkably it conformed to the U-Value for the glazing and was a revelation in what an affordable high-quality window should be. I could now look out onto the garden while washing up without window frames obscuring my view and no condensation problems. We've since ordered and installed another 20 windows. The finish, internal and external, is unscathed after 4 years of quite harsh conditions.

Using the self-assessment pack, I'd also measured the cold bridging at the frame to wall junction. This was addressed by wrapping an insulation layer in the inner/outer window reveal as these are set in a 700 mm solid stone wall.

5.2 What's the problem with Internal Wall Insulation (IWI)?

In short, it's not easy for older buildings. There are lots of risks and disruption when doing IWI, not least condensation within the building fabric, referred to as interstitial condensation. In our case External Wall Insulation (EWI) was not an option.

The particular space, 4.5m x 5m and 4m high, was very difficult to heat. Three sides are 700mm external solid limestone and brachia walls constructed some 350 years ago, that's a lot of thermal mass to heat. The two large radiators would need to work at full blast for 3-4 hrs to make this lounge feel comfortable for someone watching TV.

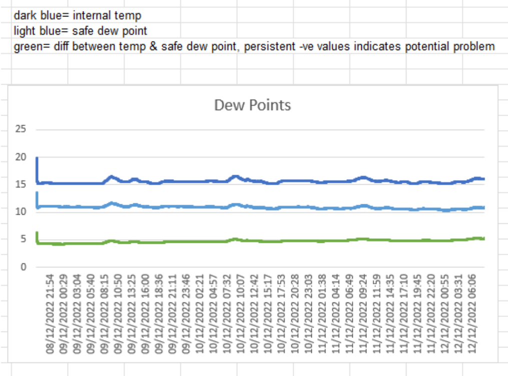
In around 2010 we decided to replace the radiators with underfloor heating. We considered other heating options, but as we'd converted our heating to a split-log boiler, a wet underfloor system was the obvious choice. This doubled up to insulate the floor.

The roof had already been insulated a U-value of ~0.1 $W/m^2/^OK$. I'd also replaced the 3 windows with triple glazing units which made a significant difference, as reported by our guests. It was clear from the temperature and heat meters, that the space was still difficult to heat and not too comfortable to spend an evening in.

Lockdown was a good time to take on the walls. I knew enough about the risks of interstitial condensation to realise that the existing layer of plaster and emulsion paint were not going to allow moisture to 'breath' out through the walls. Replacing ~50m^2 of non-breathable plaster with a breathable flat surface was going to be expensive. We'd considered the usual stud/batten and foam IWI system until an installer suggested using dehumidifiers to remove excess moisture from within the cavity.

Luckily, I'd been using Mike Wye (the southwest's mecca for all things to with lime) to source my cork for the wall insulation around the new triple glazed windows. They suggested using lime as a breathable internal wall finish on top of cork or wood-fibre boards, but they also recommended replacing the existing plaster/paint layers. So I did some more measurements and asked a PassivHaus architect what he thought.

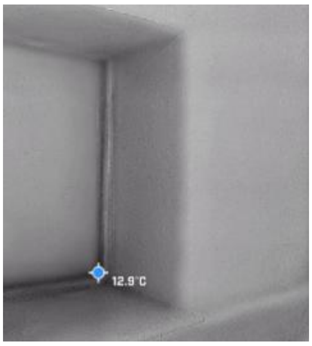
The question we needed to answer is what the worst dewpoint would be if we used IWI. The solid wall's internal surface would be much colder as it no longer gets heated by the warm air in the room. Any moisture reaching this surface, which would now be trapped between the insulation and the wall would condense, potentially causing damage and mould growth. The thicker/better the insulation, the colder the wall surface and the worse the interstitial condensation. This moisture could only escape back into the room.

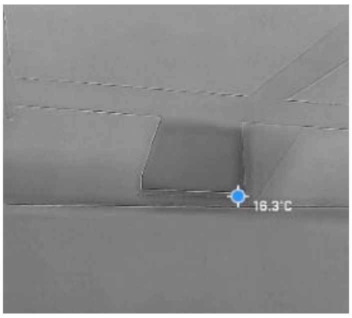


I needed to know the coldest temperature the internal wall surface could reach, so the north facing wall. This was easy to measure using an Infra-Red (**IR**) thermometer during a very cold spell (<5^{O}C) and not heating the space for several days. Because the walls are thick, this didn't drop below ~12^{O}C. I also had to know the highest likely internal humidity and temperature to work out how close 12^{O}C is to the dewpoint for the worst case. It was too close for 100mm of natural insulation, in fact I needed to go down to 60mm of insulation. This can be calculated with the help of the TECs E-Pack or there are some on-line tools to do that calculation.

We decided to go for wood-fibre boards rather than cork, mainly because the manufacturer we chose published certified embedded carbon data for their product. Unfortunately, when we eventually managed to find an installer, we were quoted £13,500 for the work. That's without a finishing lime layer or the two layers of breathable paint. So in March 2022, I did it myself! With help from my wife and friends, it is within the capabilities of a regular DIYer. I tried to get a traditional plasterer and pay for them to train to use lime, but even they are a scarce resource these days.

Early measurements during a cold spell, indicate the results are excellent, the measured wall's U-value is now ~0.35 W/m^2/^{O}K. We'll continue to measure performance using the E-Pack methodology and tools over a year before confirming results.





Since then BEIS has published excellent advice on IWI retrofit. The Bristol Guide to solid wall insulation includes details for good and poor practice with some excellent details.

The Mike Wye natural insulation system we used can be found here. A useful trade body to find practitioners is the AECB. For those in Teignbridge who cannot do their own assessment under the TECs E-Pack, there are two services being launched in Devon, Retrofit Devon for organisations and ECOE's Retrofit Advice for home owners.

5.3 Replacing a mains gas boiler with a Heat Pump

Our 1980's Home has had lots of extensions and refurbishments over the years. Our extended family numbers 5 people, we have different jobs and different routines.

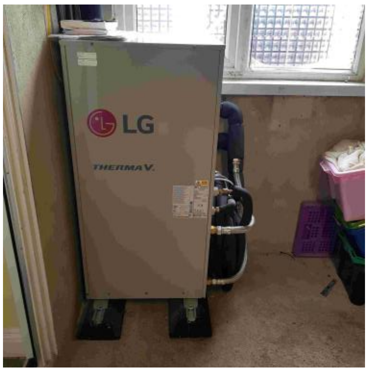
The mains gas heating system itself was extended into the various extensions, and consisted of a 30kwatt gas boiler with a separate 24kwatt gas boiler which powered two central heating loops but on a common gas and water supply. There are thermostatic Radiator Valves on 16 of the 20 radiators. There was no hot water tank with hot water direct from the gas boilers feeding 2 of the 4 showers and 2 kitchens. The other 2 showers were direct electric. Each central heating (c/h) circuit was on a master thermostat the temperature being set at about 18C in each case.

The 24kwatt boiler was 14 years old and the 30kwatt boiler was 10 years old.

Being aware of our contribution to Climate Change, I've been looking at a number of things I could do to reduce my greenhouse gas emissions. Having done the obvious ones like installing a 6.25kW PV system with a 13.5Kilowatt Battery and replacing the petrol and diesel cars with battery electric Vehicles (EV), I decided it was time to get rid of the gas boiler since this was burning fossil fuels and the 14 year old one needed replacement. I opted for a high power LG Therma V split unit rated at 16kwatts so I could use the same radiators and replace both boilers with 1 heat pump. I also had a 290 litre water tank installed which could also be heated by a solar diverter and an internal boost immersion as well as from the heat pump.

I'd been taking regular readings for a full year, our annual water and space heating consumption was 26,558.6 kWh based on bills and meter readings. This was for 2020/21, the period is relevant as I wanted to compare like for like; that is adjusting the heating consumption used to that of the outside temperatures, measured in degree-days. I did this using the TECs E-Pack and comparing the two years, one heating with gas, the other with the HP. Internal temperatures and heating system controls were kept the same in both cases so I knew I had a good set of data to compare.

Isolating the electricity consumption for the HP's first year of operation was made easier because the data was provided by the LG Therma V unit, it recorded 9,827.1 kWh for 2022, this included 167 kWh for hot water diverted from surplus PV generation. Normalising this for the two years suggests a seasonal performance factor (SPF) of ~2.4 . There are several factors that I've not yet checked which would affect this efficiency, e.g. the number of days people were away and how family members may have changed how they adjusted the heating controls. However an SPF of 2.4 is within the range reported for RHI registered system that have been monitored.



My running costs remain very similar in comparison with the previous gas system. This is mainly because of the off-peak electricity tariff between 0030 and 0430 hrs which enables both the battery to be charged as well as the heat pump during those hours. There is a wider differential between gas and electricity unit prices (about 1:3) compared to the heat pump's seasonal coefficient of efficiency (currently 1:2.4) during the peak rate period. However, this difference is at least partially compensated for during off-peak periods when gas and electricity unit prices are comparable. Some surplus PV contributes further to reducing running costs, but this is minimal.

My ongoing carbon emissions have, however, reduced significantly. From 4,953 kg CO_2e using gas to 2,527 kg CO_2e using the heat pump, removing almost 2.5 t CO_2e from our household's annual carbon footprint.

After learning more about heating and heat loss from TECs and an getting specific advice from an independent local heating engineer, I'm now planning to make a number of adjustments to how we use the HP. These include reducing the master thermostat by 0.5 ^{O}C, to 17.5 adjusting some of the TRVs and fitting better insulated and higher capacity flow pipes 28 mm rather than 22 mm between the HP and water tank and central Heating buffer tank. Also varying the ASHP target temperature depending on the season. The works to the HP piping have just been completed. As it is summer the hot water has been turned down from 55 to 45 C.

Heating is down from 55 to 40 ^{O}C. I will manually adjust the heat pump temperatures depending on the average outside temperature with a winter setting of 52 C for the heating and 50 C for the hot water.

I'll continue to take monthly measurements to see what improvements to the ASHP's efficiency can be achieved without triggering complaints from others in the household!

5.4 Constructing and living in a PassivHaus

A well-insulated building begins below ground level with insulation preventing heat escaping from the building into the ground below. This was our first challenge. The slab on which the house would sit is very heavy and requires dense, structurally strong insulation to hold its weight. The only good solution was Polystyrene insulation. Polystyrene is a plastic derived from hydrocarbons. Ouch! The good news is that it should bear the weight of the slab and perform its insulating function for the expected life of the building.

Although the house, by design, will need very little space heating, we decided to integrate underfloor heating into about 85% of the ground floor slab area with heating in the two bathrooms only upstairs.

The house is built of pre-assembled insulated and airtight panels with more insulation between the exterior of the panels and the final exterior cladding layer. The insulation is wood fibre, which is sustainable and together with the slab, provides a high thermal mass meaning the house will retain temperature, slow to heat and slow to cool. It also locks in carbon.

The first internal fit out included the ventilation system and duct work that draws "stale" or moist air out of the kitchen, utility room and bathrooms and supplies fresh air to living rooms and bedrooms. There is an air source heat pump for space heating. The house includes some simple systems to optimise use of our PV generated electricity to heat the water tank and charge an electric car. These were installed early in the fit-out task.

Once these systems were installed the fit out was much the same as any other house aside from the fact that there cannot be any unplanned penetrations (holes) in the airtight membrane of the house. This means the electrical and water services come into the house through ducts incorporated into the slab. There are no air bricks or trickle vents and no stand-alone extractor fans. When decorating we selected a clay paint for its lower emissions than standard paint.

The finished building from the southwest.

We consume around 12 kWh per day of electricity to heat the house during the period from 1 November to between late February and mid-March each year. The heat pump is shut down for the remaining months of the year. This keeps the living areas between 20C and 22C all winter and between 21C and 24C (cooler if we open the windows) all summer and 2 degrees cooler in the bedrooms.

Our solar array generates more electricity than we consume in each year, providing daytime power to the house and heating the water tank for much of the year as well as charging the car when convenient in the summer months.

The house has an almost constant humidity level of 42% which is comfortable but dry. We dry a washing machine load of clothes in the utility room in around 6 hours, irrespective of outdoor conditions, without causing any damp problems in the house.

There are no cold or hot spots in the house, no draughts, no humid rooms (shower steam clears in minutes), the inside of the house is remarkably still and quiet and there is little dust because the ventilation system filters incoming air.

5.5 How much loft/roof insulation do we need?

<include cold/warm lofts & ventilation/condensation>

5.6 My floor coverings

<include solid/suspended/vented differences>

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Section 6. Changing my transport habits and vehicle

6.1 I’ve stopped flying!

<explain the journey and why it is so personal>

6.2 What transport for what journey

<cover the decisions to use modal shifts and the appropriate (to us) transport for each journey, EV, train, bus, bike e-bike, walk>

Section 7. Getting my own low-carbon energy sources

7.1 Solar PV

By 2009 the need for renewable generation had become topical, even the government was planning various subsidies to stimulate the market. I remember being on holiday in Wales and overhearing a conversation in a pub about the Feed in Tariff (**FiT**) scheme, there was a lot of confusion about it. Although the intention was to make us more aware of our energy use and to shift to low-carbon on-site generation, it inevitably ended up being seen as a financial opportunity. At the time I'd talked to one of the people involved in devising the scheme, who agreed that it could have been better structured, to incentivise a more careful use of electricity.

Like FiT, Renewable Heat Incentive (RHI) and other government incentives to stimulate or nudge market/consumer behaviour, they tend not to last. Rightly so, because they invariably benefit those who have the ability to extract as much of the financial incentive as possible.

As our main motivation is to reduce our greenhouse gas emissions, we evaluated renewables on their ability to do so. As long as the cost of avoiding emissions (£ per tonne/kg of CO2e) was low compared to other options available to us and the payback period was short enough (see 4.1 Is it time for that fridge to go?), we would go for it. This was not always the case, it took us 5 years of mistakes before we fully grasped the importance of this approach.

The world looks very different today, the government incentives have long gone and we have an Energy pricing crisis. We also still have a Climate Emergency!

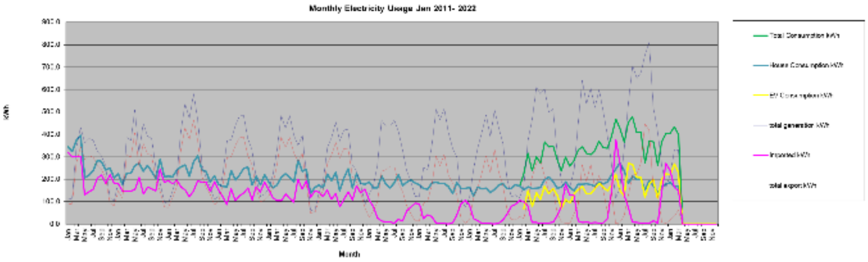
PV today, especially where the majority of the generation can be used on site, is almost a 'no-brainer'. You still need to make some basic assessment as set out in TECs' advice on PV systems.

We installed our first system in 2010, having first tried to install a community owned system. The latter was rejected because one or two residents were sceptical, so we ended up with a 'buying club' to reduce what were quite high capital costs at the time, £11,000 for a 3.8 kWp ground-mounted PV. It only made financial sense with the highest level of FiT. It's a small goldmine now, paying for other initiatives.

The PV system was one of those pivotal moments which made us look much more closely at our use of energy, not just electricity. Exactly what those who devised the FiT scheme had intended, but maybe only because we didn't do it for the money.

Despite modifying our behaviour in terms of when we would use the PV generated electricity, we struggled to get over 40% on-site consumption. The rest would be exported, not a bad thing because our neighbours would benefit from low carbon electricity, albeit without the financial benefit. Reducing our overall consumption reduced this to 25%, the average for people who are not at home during the day is ~20% on-site PV consumption. The obvious answer was a battery.

After a quick assessment of having a battery along the lines of TECs' advice on Residential Battery systems, we made a decision. Although the financial payback would be ~20 years, 10 years longer than the battery's expected life, we still went ahead. The reason was that it reduced our emissions, paying back in 2 years and we needed something to deal with our unstable grid connection.



We've since installed two additional PV systems, one off-grid to supply the barn and sawmill and the other to extend generation to cover the additional Electric Vehicle (**EV**) consumption. We worked out that we could put these plug-and-play PV systems together ourselves, we just needed a qualified electrician to ensure system safety and grid connection were all proper and legal. This demonstrated that the market price is a function of 'conventional' government subsidy or level of market demand, rather than cost of material and labour.

7.2 Solar Thermal

7.3 Biomass heating

7.4 Hydro power, really!

You only realise how much sun there is in the summer and how little in the winter when you've lived with a solar PV system for at least a year. It seems obvious, but not the extent of the difference. Namely that while 80% of generation is in the summer, only 20% is in the winter. Winter is of course when the highest energy demand happens for a building, mainly heating but also other appliances because people spend more time indoors.

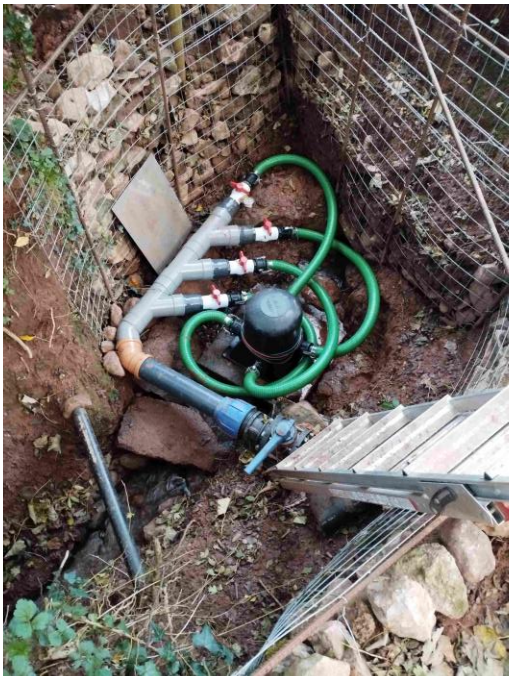
The solution is to find another residential scale low-carbon (renewable) energy source that works in the winter. Energy for heating (typically 10,000 – 15,000 kWh heat energy) will be difficult to come by. A well oriented PV system will generate 4,000 kWh, in winter that's 800 kWh, nowhere near heating requirements, even when this is supplied by a typical heat-pump.

We're lucky enough to be able to consider wind and hydro as a potential renewable source. Both have their challenges in terms of having a suitable site/resources and the effort/cost in setting them up. At the micro-scale (< 1 kW peak power generation) residential systems would struggle to pay back given the maintenance/durability associated with turbines (especially bearings).

It was therefore important to carefully consider the objectives of such a scheme. In my case it would be Carbon payback and use as a demonstrator of what is/isn't feasible. While costs so far have been kept to under £4,000 , this was only possible because of the help received from others. Their time/labour/machinery would probably have doubled my costs, so clearly not financially viable for wind/hydro if the power output was low.

From basic measurements of water/wind resources, wind could provide much higher power for shorter bursts while water would be the opposite, lower power but consistent for longer periods. Given that our PV/battery system struggled to deliver enough electrical energy for the house and EV during most days of Oct-Feb inclusive, I concluded that supplying a constant 100W would cover nearly all our baseload (360 kWh in that period). So the decision to try hydro was made. This also fitted neatly with my other objective, giving first-hand advice to the many enquiries to extract energy from the streams running through people's properties in the area. This included a challenge a neighbour set who was against solar and wind.

After 10 years of consideration, calculation and prevarication (as well as lots of groundworks), I installed a micro-hydro from PowerSpout. With excellent support from Hugh Piggott at Scoraig Wind in Scotland. We all knew it was a marginal set up at 3m head and 11L/s flow, even with a well-designed low-head Turgo generator.



Theoretical maximum without any losses,
Power (W) = liquid density x head x flow rate x gravity
= 998 kg/m^3 x 3 m x 0.011 m^3/s x 9.81 m/s^2
= 323 W

At a typical system efficiency of ~50% for the turbine, pipes and electrical equipment,
expected power (W) = 160 W

That should do it even if I initially didn't have the full head, I should be able to get my target 100W. Unfortunately, I'd not done my pipe resistance calculations (K values), relying instead on observing the obvious guidelines. As big a feed pipe diameter as possible, as few bends/valves/couplings as possible. If there are bends make them as wide as possible, a radius to diameter ratio of more than 3.

While accepting a steady 40W power feed-in to the house, given the lower 2.6m head and 9L/s flow restriction to optimise the 4 jets of the turbine, I needed to work out where the additional losses were. With mentoring from Hugh and a bit of belated research, I realised I'd made a mess of the intake pipe's profile. This was protruding into the water reservoir, the worst possible option (with a K value of 0.78, I was losing nearly 1m of an already low head). Even the very expensive and beautifully shaped butterfly valve was losing me about 0.25m of head, so that will have to go, relying on the 4 ball valves to shut off water flow.

Head loss = K $v^2/2g$ (for my set up $v^2/2g$ is **1.188** for both the 100mm and 50mm pipes)
based on v = 1.27 x 9L/s / D (flow rate is reduced to 1/4 in the four 50mm hoses)

Intake pipe K = 0.78 >> reduce to 0.04 with R/D > 0.15
Butterfly valve K = 0.24 >> reduce to 0.04 with a straight coupling
2*45° elbow K = 0.2 (R/D = 3)
16m pipe K = 0.1
4 ball valves K = 0.08
flexible hoses K = 0.2 (180° R/D >10)
all couplings K = 0.3

Total head loss =0.96 x 1.188 = 1.14m

Assuming 60% efficiency of turbine and electrics, I should achieve my 100W target.

The Carbon payback was made even more difficult by the 190 kg CO2e airfreight contribution I'd not considered as I'd assumed the turbine would come by container ship. At today's grid carbon intensity (0.275 kg CO2e/kWh), the turbine would need to run for ~750 days to pay back it's embodied emissions. That's about 5-7 years or a carbon intensity of 0.7 kg CO2e/kWh if I generated 720kWh over the 2 year product warranty period, three times the grid's carbon intensity.

I have to admit that my Carbon payback objective will be hard to achieve, although not impossible if I look after the turbine's bearings for at least 5 years or manage to squeeze more energy out (power and running time). On the other hand, I learned a lot about very small-scale (pico) hydro generation which I'm sharing. It's also been a very enjoyable experience shared with others including my very supportive partner.

<<<<< My first kWh, planning for many more!

Section 8. Helping others to reduce their energy use

Section 9. Reducing emissions elsewhere through offsetting and investment decisions