DIY GSHP

RobL, Jan 2022

Disclaimer disclaimer disclaimer! This is a record of what I have built, and not an endorsement to copy it, there are several dangerous activities needed!

I have long wished to stop burning things to minimise our impact on the planet; car, gas boiler, gas stove. One by one, it has been possible – an electric car, an induction hob, and now, the last to completely replace, is the gas boiler. This article discusses making and installing a small diy heatpump, so small it is only really suitable for well insulated properties. As it is diy, and heating is important for a correctly functioning marriage, I choose to leave the existing gas boiler in place for some time, so that either heating source can readily be used. Eventually I hope the gas boiler will be decommissioned, and the gas connection removed from our property.

Contents

Existing heating system

As with the majority of UK homes, we have an oversized gas boiler. In our case it is a Worcester Bosch greenstar 18Ri regular boiler, Honeywell bimetallic thermostat in the hallway, 220litre DHW tank with thermostat, Grunfoss Alpha water pump, Honeywell timer unit, and 2 off Siemens 1-way valves in a “S plan” system. The DHW tank has 2 coils, the lower one is used for solar thermal, and it also has an immersion which is controlled via a timer. The house was originally plumbed with a 1-pipe system to some rooms, and while this is retained several other radiators have also been added, so almost every room has at least one, the newer ones being plumbed in the now preferred 2-pipe style.

Heat Requirement

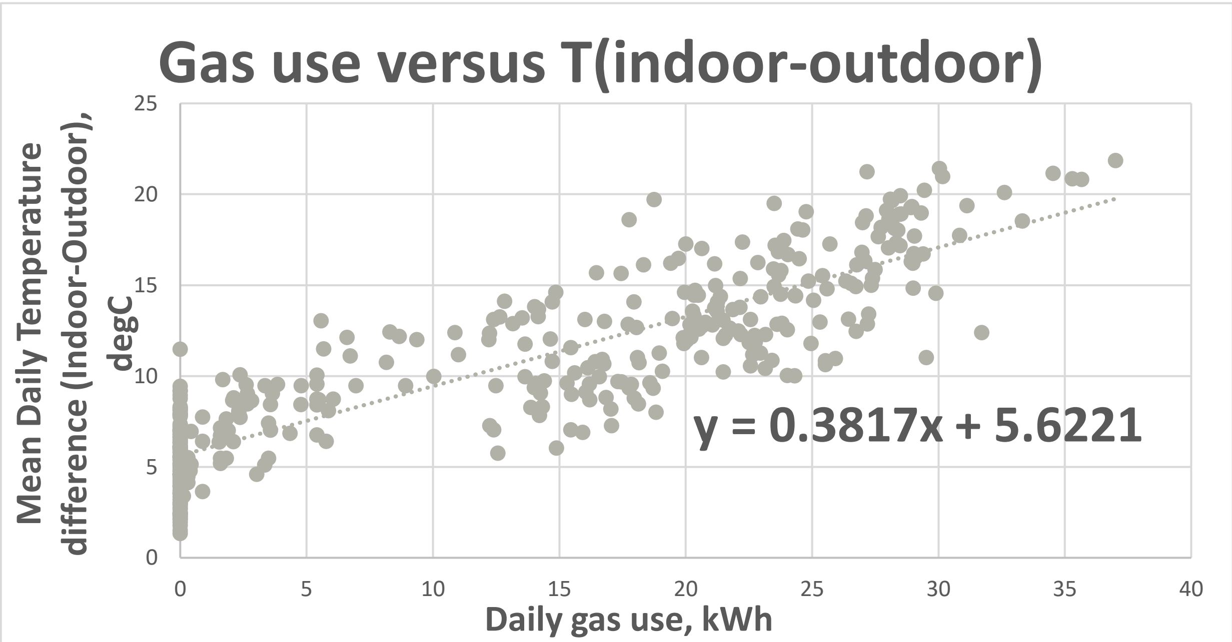
Our house is a 4 bedroom, 1963 property with significant insulation upgrades, CWI+150mmEWI walls, windows with a mix of new 2G and 3G glass, uninsulated solid floor but with perimeter insulation down to the foundations, and the loft has many layers of insulation added over the years. The annual gas used was 4.4MWh last year to achieve 20.5°C, so I anticipate a heatpump needing <1.5MWh to achieve the same result, and at this point heating would be a small part of our annual 3MWh electricity. For comparison, when we first got the house (U=2.7 DG, no CWI, minimal loft insulation, etc), we used 18MWh/year of gas to achieve what even I thought was slightly chilly in winter. The table shows the calculated losses – the total matches actual perfectly as I know the "answer" from measurements, and massaged the U value data slightly to give an overall fit. It is sadly likely that running the heatpump will cost marginally more than using the gas boiler until we turn off gas to save the standing charges, but it will immediately be a worthwhile CO_2 reduction, as the CO_2 intensity of electricity is now similar to that of gas.

	Area	U	Loss/degC
	m^2	W/m^2/deg	W/degC
walls	150	0.18	27
windows	22	1.1	24.2
floor	65	0.3	19.5
loft	65	0.2	13
garage	18	0.5	9
MVHR			5
Total			97.7

We have a smart meter and uniquely heat with a gas boiler, so knowing the heat requirement is simple. Our energy supplier, Ovo, logs our gas use daily on their website, this is copied into excel, and plotted versus the temperature difference indoors to outdoors for the last year. I already had a logger that continuously records temperatures, but it's just a nice-to-have, not actually needed to size the heatpump.

The graph gives the insulation performance of the house – you can see a few interesting features: the slope of the best fit line represents $98W_{heat}/°C$ (assuming a gas boiler efficiency of 0.9) – good, but could always be better! There are places where insulation could be improved, so hopefully slight improvements will be made over time – but it's unlikely that we ever achieve zero heating, assuming a static 21°C internal requirement.

From the graph below, the peak daily use was 37kWh – this was on the coldest day in 2020, at a mean of -1°C outside. If the heatpump was run on that day for 16hours straight, this corresponds to a power requirement of 37/16 = 2.3kW. The size is actually a compromise between efficiency (smaller) and capability (larger). The smaller heatpump will be able to run at lower temperatures with available radiators, which will improve the system COP. A small heatpump in our thermally heavyweight brick house will struggle though to change the temperature of the structure. It would take a day to increase temperature by a degree, and considerably more time in cold weather due to the steady state losses. However using a small heatpump allows simplicity – it avoids the need for an inverter drive, and a buffer tank, and the original radiator emitter circuit can be used to efficiently couple to air, giving good COP values.



Radiator Calculations – What temperature will they run at?

For efficient heatpump operation, it is important to ensure that the outlet temperature is low. This typically requires underfloor heating, or larger radiators to be fitted. In our case, we have pre-insulated the house so that there is a lower heat requirement, so that cooler radiator temperatures can be used. To estimate the run temperature, a simple experiment was run using our gas boiler: the boiler was set to run continuously for 2 hours by setting the hallway thermostat high, the system on continuous, and all radiator TRVs on high. The boiler itself has a flow temperature setting – this must be high enough that the boiler can run continuously without powering down. After the system has reached steady state operation -the house may be slowly warming, but this is so slow as to be ignored- all that is needed is the air temperature, water flow temperature, and boiler power. The boiler power is tricky as our unit modulates; luckily we have a smart meter, which accurately measures this. I had to adjust things a fair bit to prevent hunting between modulation schemes, but eventually got stable results.

In our case the boiler took 10kW with 70.9°C outlet temperature at 22°C air temperature. Arguably I should have tried to get lower temperature data than this, closer to the intended heatpump operating point – I found it difficult to stop the boiler changing modulation though, which renders the experiment useless. Simplistically those figures give 4.8°C/kW temperature rise of the radiators over ambient. For the intended heatpump of 2.3kW, the radiators are then anticipated to run at 21°C + 4.8°C/kW * 2.3kW = 32°C. In order to keep good low temperature operation, it is important to ensure the radiators are actually on – I intend to remove all of the communal area ground floor TRVs, to ensure a certain minimum radiator-air coupling, but allow bedroom TRVs to have control. If TRV's were permitted to cut the system water-air coupling down, then that 5degC/kW could rise, the operating temperature would rise, and efficiency would fall.

HeatPump-A2A A2W W2W ?

There are so many types of heatpumps now, at such a variety of prices. In general the price is associated with supply and demand rather than with complexity – A2A units are actually the most complex but cheapest – probably as they are most suitable at cooling which is what most of the world wishes, while the more expensive W2W are the simplest units. A2W units either require planning permission, or professional installation. As I enjoy diy, I wanted to be more involved, and searched for available W2W units; there are very few small units available, they generally use F-gasses which have a high GWP, and generally are actually quite simple devices with on/off operation rather than the more efficient inverter drives which can be slowed down. Units that I found also came with warranties that were dependent on a pro install, which put me off. As W2W units are by far the simplest, they seem within grasp of diy so long as F-gasses are avoided; they do not need complex 4 way valves or clever strategies to minimise icing up, nor do they need modulating down which air handling units do to prevent noise being a significant issue - high power fans, and on/off cycling both caused a noise nuisance with older fan units.

What Fluid?

The operating fluid in a heatpump changes state from gas-liquid then liquid-gas, the transitions occurring at different pressures hence different temperatures. The pressure increase is by using a compressor, which is generally designed for a specific hvac gas - so it's best to pick the gas up-front rather than after you have a compressor that may not be suitable. The compressor will have oil in it that is gas-specific, and it will be optimised for certain pressures in and out – again, best to use the intended gas.

Most suitable gasses are F-gasses – they are Fluorinated greenhouse gasses, and training is mandatory for anybody using them – it is illegal to release these gasses into the atmosphere, and they were not considered for this project.

CO_2 (R744) and Ammonia (R717) need significantly higher pressures so finding heat exchangers might be problematic. R717 is both toxic and explosive, but R744 might be worth consideration.

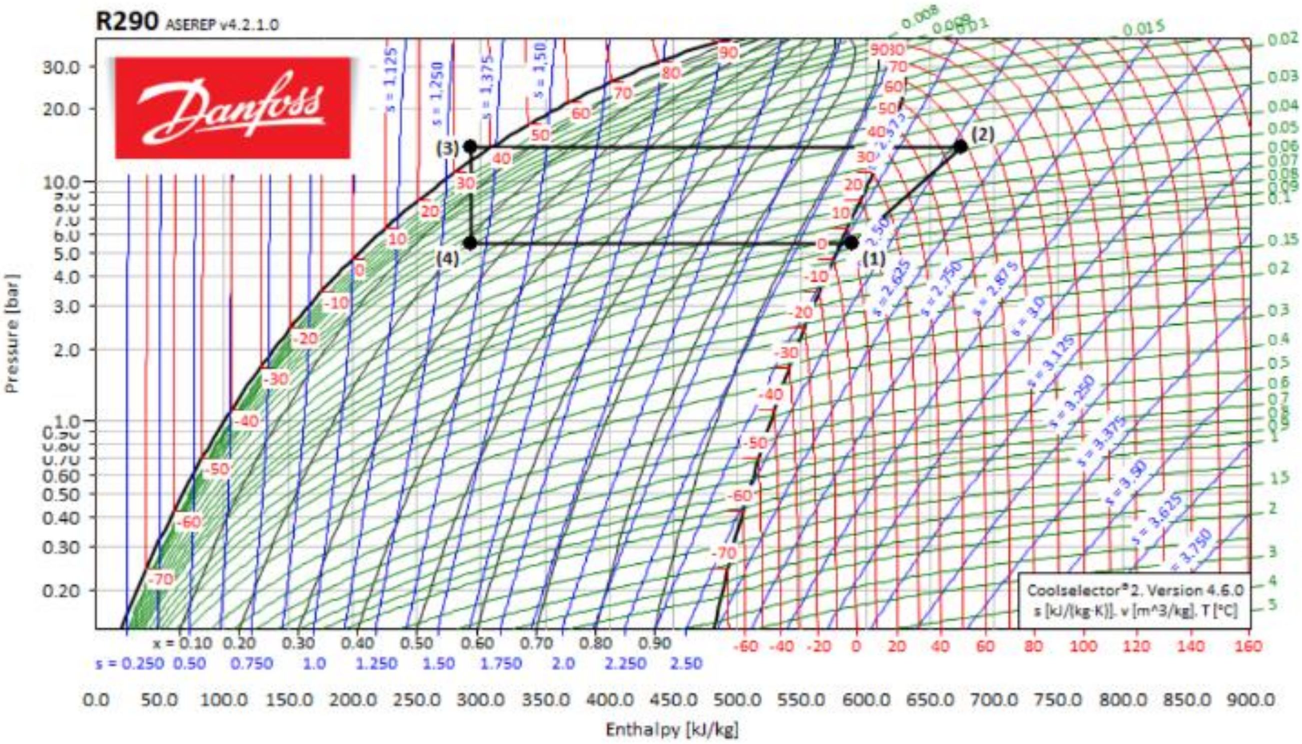
Propane (R290) is an excellent fluid to use, however it is explosive, so precautions must be taken. It is not an F-gas, but indoor use is restricted by amount, and clearly safety is important here.

Propane (R290) is used in this project, and to mitigate the risks only a small mass of it is used, outdoors, and with no electrical switching near the unit.

Outdoors does seem a difficult environment for a heatpump; but in my case I am insulating the house, and so while the heatpump is outside the original brick envelope, it is thermally connected to it, and housed in insulation. The insulation has a removeable door which is far from airtight, so that a propane leak would quickly and safely dissipate out of the insulated box, which has no ignition sources in it, and there are none nearby.

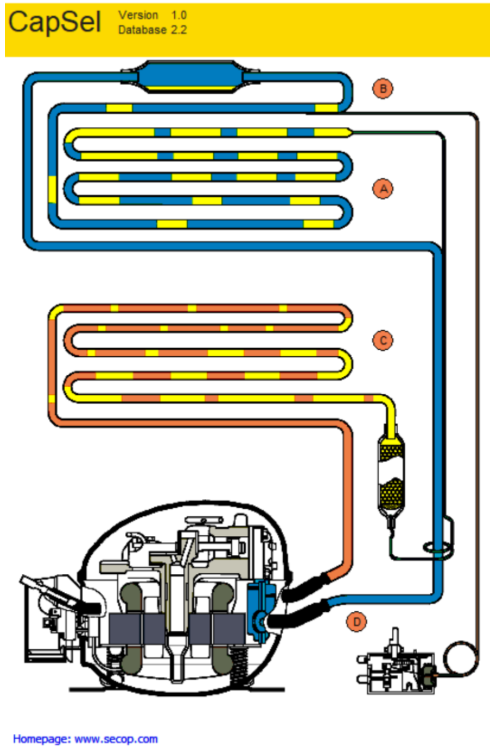
Compressor choice

The two likely compressor types are reciprocating (fridge style), or scroll. Reciprocating ones are the simplest and cheapest, but often not suitable for inverter drive, as they cannot be slowed down while operating correctly – but need to "resonate" during operation at ~50Hz, so may not operate at all at 10Hz. Scroll compressors need accurate machining to make so tend to be more expensive, and they also tend to be higher power. For this project the reciprocating compressor style is used as there are many examples available. To find a unit, first "Danfoss Coolselector2" was downloaded, which is free software helping choose various Danfoss HVAC components. The power requirement and operating temperatures (5C and 40C) were filled in, and then a few appropriate compressors were chosen by Coolselector – from which type NLE12.6MN was picked as there were a few examples of on ebay. I bought 2 of these at £40 each – one was 2nd hand, the other technically 2nd hand but never fitted. A spare might be useful, and it can be used as a vacuum pump which is a requirement for the project. Both units arrived fully charged with oil, and sealed so the oil would not be contaminated with water. The Pressure-Enthalpy diagram below shows the operating principal chosen:

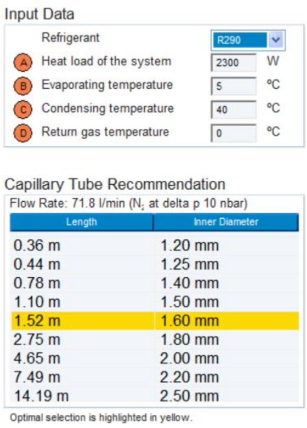


It takes a lot of getting your head around! Enthalpy is the state energy of the fluid – hotter or lower pressure fluids have more of this energy. In the weird pressure-enthalpy graph there are three regions; at the top left the propane is a liquid, at the right is a gas, and centrally is a mix of gas and liquid – think boiling kettle. It is this central phase change region that most of the useful work of a heatpump is to be had. The black geometric box labelled 1->2->3->4->… shows the intended fluid process, 1->2 being the compressor, 3->4 being the expansion capillary tube. The other two sections represent the two heat exchangers – in each case they can pass a significant enthalpy = energy, but at almost constant temperature due to the phase change, and crucially at very different temperatures to each other due to the pressure difference.

Expansion Valve calculation



While the compressor is the heart of a heatpump system, the expansion valve is crucially important too for good operation. The role of it is to decrease the liquid line pressure after the hot heat exchanger, so the working fluid will evaporate at a much lower temperature, and can absorb energy from the cold side. There are many types of expansion valves; the simplest has been used for this project, a capillary tube. There are mechanical feedback types, and also ones with electrical feedback. I used "Capsel" software from Secop to calculate the best thin tube for my compressor design, and it gave me a target tube length and inner diameter. I couldn't find 1.6mm tube, so went with 1.1m of 1.5mm inner diameter copper tube. Capsel also gives a handy picture of the process flow, and the picture of the compressor even looks like the one I picked! The upper pipe from the compressor(right), in orange, is the hot compressed gas output going to C the hot heatexchanger, the result of which is hot liquid going through a desiccant to the capillary tube which drops the pressure and temperature, so that the liquid is cold entering the ground loop heatexchanger A where it picks up energy and vaporises. There is a gas-vapour separator in the suction line, going back to the heatpump, to ensure only gas gets back to it.


Input Data

Refrigerant	R290	
(A) Heat load of the system	2300	W
(B) Evaporating temperature	5	°C
(C) Condensing temperature	40	°C
(D) Return gas temperature	0	°C

Capillary Tube Recommendation

Flow Rate: 71.8 l/min (N_2 at delta p 10 nbar)

Length	Inner Diameter
0.36 m	1.20 mm
0.44 m	1.25 mm
0.78 m	1.40 mm
1.10 m	1.50 mm
1.52 m	1.60 mm
2.75 m	1.80 mm
4.65 m	2.00 mm
7.49 m	2.20 mm
14.19 m	2.50 mm

Optimal selection is highlighted in yellow.

Practical Design considerations

-The compressor oil is damaged with water making it acidic, which will cause winding insulation failure; there should be some way to remove any water in the system, a desiccant is generally used in the liquid line.
-The compressor will be chronically damaged by any liquid entering it, as it doesn't compress much. To avoid this, use a liquid/gas separator in the suction line, and do not overcharge the system.
-Ensure the cold side does not freeze – if it did there may be ice damage to a heat exchanger, or liquid may enter the compressor.
-Ensure the hot side does not get too hot; the system pressure would be much higher, and there is a limit to how high this should go to keep within spec of the compressor and heat exchangers.
-The capillary tube is soldered to the suction line giving a simple heat exchanger; this will tend to equalise the subcooling and superheat for a simple capillary metered system. But I'm really not sure!
-Brazed Plate Heat Exchangers will generally work in any orientation – except when there is a phase change. Both heat exchangers used by the heatpump must be used hot (gas) end uppermost for best efficiency so that the density difference between gas and liquid works with rather than against you. Brazed plate Heat exchangers tend to have an even number of plates and odd number of fluid flows, so using the terminology Water=W and Propane=P, then the fluids in a 4 plate heatexchanger should be arranged W:P:W:P:W, so that the working fluid is fully encompassed by the system water. I used 24 plate units – larger than "required", but this will improve efficiency by keeping the temperature drop low.
-The BPHE units must be rated for sufficient working pressure – many are only rated for gas boiler use, and so are inappropriate, with presumably thinner stainless steel sheets. Ebay or Alibaba are likely sources for them, "wort chiller" is a useful search term, these beer chillers are sometimes used with heatpump systems hence at higher pressures.
-Braze all pipework, especially anything connected to the compressor. Brazing is soldering at a higher temperature, using an alloy that melts at over 450C, and it makes mechanically stronger joints that resist vibration better than soldered joints. Braze with a passivating gas in the system, eg CO_2 or N_2 – this will avoid copper oxides forming inside pipes being brazed, which could flake off and block the system up later. I used a mapp gas torch to braze with, using a rothenburg torch shield – the shield reduces heat loss, and I found brazing without it almost impossible. The brazing rod used was Harris stay-silv 15 Phos-Copper.
-Have several bends in the pipework from the compressor – the pipework should not be mechanically strong in any direction, or vibrational motion of the compressor will produce high forces in the pipework and it will be more prone to fatigue failure. The soldered capillary tube should be twisted like a spring as it leaves the vibrating suction line, for the same reason.
-I added a bodgy bit of blue tack to my design, which is still working fine 3 weeks in: I found that a significant high frequency noise source was the capillary tube entering the heat exchanger, I assume as there is a liquid-gas transition here, and the moving bubbles give a white noise effect. I coated the last 10cm of capillary tube in blue-tack as a sound-deadener, and it does seem to work so far. I had considered soldering on extra mass to the capillary tube to achieve the same goal – but decided against this as for safety the system would have to be bled out, pumped down, soldered, refilled – no naked flames near a R290 system!

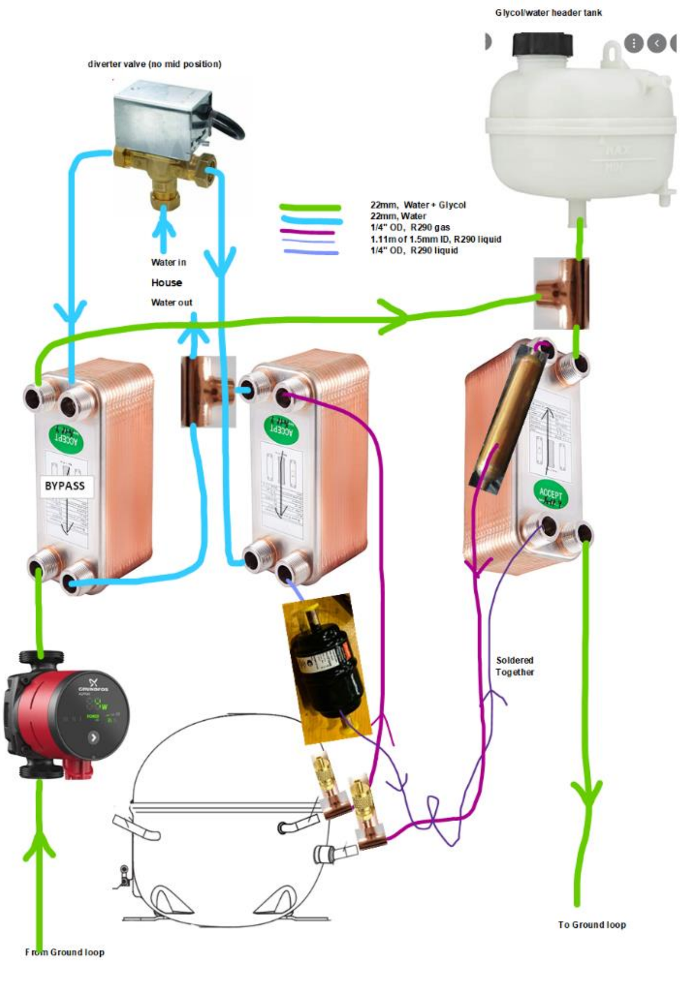
Passive Cooling option

As the ground is likely to be cooler than indoors in summer, it could be used for a small amount of passive cooling – that is operating indoor and outdoor pumps, via a heatexchanger, but without the compressor running. The scheme intended uses a diverter valve – unpowered this valve could send water to the passive cooling bypass heatexchanger. When powered, and the compressor is also powered, then the heatpump would work as normal. I anticipate around 7C per kW total thermal impedance in cooling mode, so at 22C indoors and 15C groundloop temperature 1kW could be pulled out of the house with radiators at 17C. There is a significant risk of unwanted condensation due to this – the pump speed could be dropped to reduce the effect, and a humidity sensor could be added as an additional control input. The control of this is a little more complicated, as our heating system was not built for cooling operation – the simplest I can think of involves a relay to invert the active state of the thermostat, and a manual 3way switch to select heating versus cooling operation. This switch will also disable DHW – as we have solar thermal panels we won't need DHW heating while in a heatwave! This is in line with many heating/cooling systems, requiring the operator to manually choose in order to avoid the possibility of inappropriate heating and cooling choices.

Mechanical Layout

Here is the intended layout of various parts of the heat pump. The conventional heat-pump circuit is shown in purple. The screw fit flare connections were moved away from the vibration of the heatpump, but it is very close to what was actually built below. The main heatpump loop is shown in purple: compressor->hot heatexchanger->liquid line dessicant-> capillary tube->cold heat exchanger->liquid/gas separator->suction line of compressor. Also shown is a header tank, which allows easy top up, and checking for any losses. All the parts are shown more or less where intend to be – compressor at the bottom for stability and good mechanical coupling to a base, and other items above it. The compressor was considered placed at the top – some heatpumps (typically ASHP) have trouble in cold weather due to the compressor being low down and collecting liquid in them, and to avoid this causing failures due to startup stresses they constantly heat the compressor continuously – a horrible waste of energy. The compressor in this application will likely not get so cold as it has good coupling to a high thermal mass, and no such heater is included.

Not shown is a strainer added at the last minute to the ground-loop circuit, before the heat exchanger. Around a teaspoon of black plastic bits was caught in the strainer presumably trapped inside the pipe from manufacture. I'm glad I added this – if not for it, those bits of plastic would be clogging up the thin channels in the heatexchanger.



The compressor circuit was mounted to a portable structure, and the ground loop pump etc in a more fixed way. The heatpump water connections are made with rubber washer compression fittings, for ease of removing the central heatpump for any maintenance in future.

Brazed Heatpump

The bare heatpump after brazing is shown below. There is surprisingly little to it, I think largely as the power is so low, the components are small and simple, and I have so far left off the bypass circuit. The heat exchangers are held in place with some U shaped aluminium, firmly bolted to the wood.

I have brazed all connections to the heatpump and all copper parts, but for now left the BPHE units with nitrile rubber washers and compression fittings, to allow for future modifications. Brazing is quite difficult I found, needing lots of heat – ideally I think an oxy-acetylene torch would be used. I used a mapp gas torch that I had, which could only just get hot enough. Crucially important is the removal of oxygen prior to brazing with a trickle of inert gas, and obviously strict protocols to ensure propane is nowhere near any brazing! There are many you-tube videos on the subject, but if in doubt get somebody knowledgeable here – propane must not be contaminated especially by air/oxygen, and a naked flame should never be used on a system with propane in. Thus the brazing process needs an inert gas when brazing, pressurizing up with an inert gas to leak test, vacuuming down again to leak test and in preparation to filling with propane. If it is found leaky, it must be purged, vacuumed, and flushed again with inert gas prior to brazing. No short cuts with Propane, under no circumstances may a naked flame be used on a system that may have some Propane still in it, and the system must never have any chance of air/oxygen in it prior to filling!
The system was filled from the low pressure side, while the compressor was on, and continuously checked the high and low pressures, stopping filling when they matched the values given by Danfoss “coolselector2” of 5bar and 13bar at low and high pressure sides, when the operating temperatures were reached.

The heatpump is constructed on two pieces of exterior plywood, firmly held at a 90degree angle to each other with a couple of 90degree “mending plates”, and a larger bracket as well for stiffness. The compressor is bolted to the base, which has rubber door stops as feet, all bolts held firmly in place with “Tee nuts” and generally stainless M6 bolts. The heat exchangers are firmly held to the top wood – I realise now I should have put insulation around and behind them, especially the cold one as condensation can form there – future upgrade! It would also be better to use a material that cannot burn, and cannot rot – there is sometimes condensation dripping in various places- more by luck than judgement no drips are near any electrical connections - but it will be detrimental to the plywood eventually – another upgrade needed!

The leftmost unused heat exchanger will be used for pass through passive cooling in the future, all being well.

Brazing

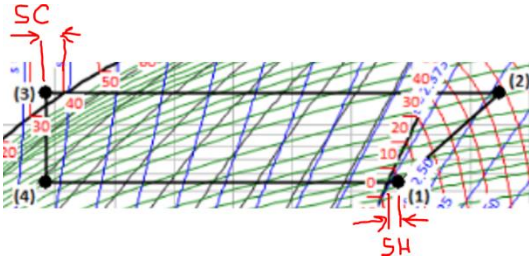
It's tricky to get a leak free circuit – I had a few trial runs with cut up bits of copper pipe that were enlarged (swaged) on one end (pic of tool to right) so they fitted back together again without needing an extra joining piece. These were cleaned up with wire wool, then brazed back together while bleeding CO_2 through from an old discarded fire extinguisher. In retrospect CO_2 from a fire extinguisher has a lot of water in it, so isn't really a good idea as on heating it still forms oxides inside the copper pipe. Then I bought a CO_2 tank from screwfix – I think pro's use N_2 although I couldn't find any, however CO_2 is ok, albeit a controversial choice. Somewhat annoyingly, every gas

tank needed a different regulator valve. My first attempt was clearly rubbish – I needed a lot more heat than expected – I bought a Rothenburger heat shield (right), which traps the Mapp gas exhaust gasses near the pipe being brazed, and allows hotter temperatures to be achieved. The copper tube must be heated to cherry red colour, then braze rod applied – once it's this hot the rod melts in very easily, and a good joint is obtained. No flux is needed for this process – nor should any contaminants like these be used - the braze rod used has phosphor in it and this acts as a flux, readily cleaning all but the most stubborn joints. It's well worth watching a few youtubes on this, and practicing. An oxy-acetylene torch would undoubtably be far quicker at this, but there is a risk of heating beyond cherry red and melting copper pipes away.

The 2nd hand compressor intended to be a vacuum pump had its ends crushed and brazed shut for transport – these I sawed off, carefully pulling out any swarf with a drill bit afterwards. I brazed two pre-made (ebay, right pic) copper access flare valves onto the spare compressor, one on the discharge and one on the suction lines, while blowing CO_2 slowly in one and out of the other flare valves– it must be slow, else the gas will quickly steal available heat preventing a good joint. Too slow, or off, and air will creep in, risking oxide formation internally. The flare valves are the same fitting as the manifold gauge set also bought (yellow tube to CO_2 tank, conventionally blue to low pressure side, red to high) – note that the clever little sealing valves inside them must be removed using the cap before brazing to prevent rubber seal failure. These same valves can be pushed open by an adjustable fitting in the pipe with the manifold set – minimising unwanted air entering the system, or gasses exiting. Then I tested the joints by blowing CO_2 into the compressor, and checking for leaks using liquid kitchen soap on all the joints. Yet again, I hadn't got it hot enough, bubbles showed that both leaked. Repeat, with far more heat, and success!
I wound the chosen 1.11m long capillary tube around the suction line, then soldered the capillary tube to it, and dry fitted all parts together in the correct places. The manifold set can then be connected to the access flare valve so that an inert gas can be again pushed through the system, and brazing begin.
All connections suffering vibration from the compressor have been brazed, while the hygroscopic filter is soldered, as it may be damaged by excessive heat. The heat exchanger connections are still only compression, as they are probably too large for the mapp gas torch to braze – future problem!

System Leaks / Filling

Once the system is fully brazed, it can be pressurized with inert gas, and leak tested. Caution was needed here – pressurised gasses could leak out, and cause a "cold burn" as they chill down due to the pressure drop, so it's wise to wear gloves, and protect eyes with goggles. The entire assembly of the heatpump was done outdoors, as the space allowed for safer use of the mapp gas torch, good light, and dissipation of any soldering fumes or vented gas.
Only after leak tests are deemed a success, the new vacuum pump should be connected to the yellow manifold gauge connection tube, and system high and low access ports to red and blue connections, and the system vacuumed down as low as the manifold gauge set reads, which takes maybe 20minutes. To be sure, it was left longer again – gasses do dissolve in the compressor oil, so this can be a slow process. An electrical power meter is a useful tool, the compressor power decreases markedly as a vacuum is reached, and no more work can be done. Lock off the manifold set holding in the vacuum for a while, confirming airtight again.
To fill with the wanted gas – first weigh the R290 bottle, and write this number down, don't lose it (like I did!) – then the yellow manifold pipe is connected to the R290 bottle only and some gas trickled out of the bottle to purge this pipe, connecting it to the manifold set while trickling – thus all plausible air is purged. Some sort of thermal load should be connected to both heat exchangers, to allow for 10 minutes of operation – I used a hose pipe pushing water through the cold side, and a pump on the hot side to a bucket of water. Both low and high side manifold valves are opened, and the compressor turned on, and R290 will be introduced – we want the pressures to match those chosen by Danfoss when the heat exchangers are at the target temperatures – once this all matches, it's likely to be optimised without any further work (it was for me). Remove the R290 bottle, weigh it again, and the difference is the system charge used. For a small system as described here it's likely 200g or so of propane is used.



Once at the target temperatures, the “subcooling” (labelled SC in the diagram to the right) and “superheat” (SH) could be used to indicate if too much or too little mass of R290 is in the system. The most important is Superheat – this must be positive, or some liquid propane will enter the compressor, slowly damaging it due to its incompressibility – this would occur if too great a charge were used with the system. If too little gas charge is used, the superheat will be very high and system efficiency will suffer. Superheat can be calculated from the lowside pressure and temperature at the suction inlet of the compressor (after the cap tube has warmed it slightly), and using the appropriate gas chart - there’s even an iphone app for it! It’s hard to measure the temperature accurately – the best I found was a thermocouple cable taped to the pipe firmly by the suction inlet, then insulated.

I tried increasing and decreasing the charge subtly, using temperature probes to verify heat transfer, to also confirm the operating point. This was quite time consuming, both over and under charge resulting in reduced COP, and in retrospect the Danfoss predictions were perfect - it is also far simpler to do now the system is running – during initial tests there were significant static losses from the hot water bucket, wind related losses, etc, not present with the insulated box, whereas now I have a COP output display which simply needs to be maximised, and could give a new reading every minute or so.

If/when R290 were to slowly bleed out of the system, the system heat produced will drop from ~2400W at 32C. No damage should occur, but the COP will be adversely affected, and should be easily spotted by the system monitoring – this alone making some sort of monitoring worthwhile. Monitoring the input-output DT would achieve this minimum. Currently I left the manifold gauge set fitted – I must remove it, as it is likely the largest source of possible leaks itself!

Connections

A din-rail mount was used for various electrical wiring, which you can see in the attached photo – as yet it is not in a box, which it must be for safety. Any mains electrical work is inherently dangerous, and must not be undertaken if in doubt about competence. No circuitry should ever be altered while live, everything must be assumed live until proved dead, and work should not be conducted by lone individuals. Initial tests with the unit were done with system powered from a 13A fused mains plug with an earth leakage trip, and as confidence grew it was transferred to take over the boiler cabling as is to be described.

The whole heatpump now operates from the original boiler cable harness, which uses 5 core 0.75mm^2 copper wire, and originally had a 3A fuse prior to it, which is replaced with a 5A part. While the heatpump running current is just below 3A, the startup is briefly 15A, which caused a 3A fuse to fail. The 5A replacement seems to be ok, and is below the cable rating (6A), and significantly below the LRA (Locked Rotor Amps) of the heatpump should it catastrophically fail. This 5A fuse has always been fed by our consumer unit from a 32A MCB – I am considering having this changed to a 32A RCBO, which will include added earth leakage fault detection as an additional safety feature. The existing gas boiler in our outhouse, and controls, have in-line local 3A fuses fitted, to limit them as their manuals demand.

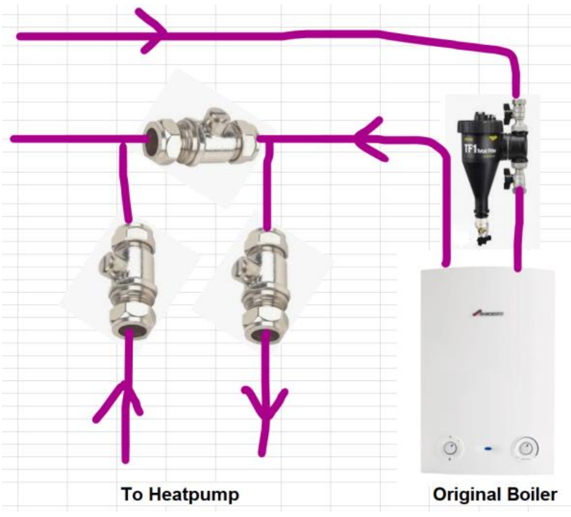
The 5 cores are used for Earth, Neutral, Live, Call4Heat, Pump, and originally connected the Honeywell controller to the gas boiler via a 3 way isolation switch. The Honeywell controls heating from the system by connecting Live to the Call4Heat cable to the gas boiler, which responds by connecting Live to the Pump cable, then after a few safety checks starts up. Now, these 5 connections still pass via the 3way isolator switch, which cuts Live/Neutral/Call4Heat, but the electrical connection to the boiler has been removed, and these 5 wires now connect to a 3 position 3 way changeover switch (Earth and Neutral bypass this switch). This switch has two sets of outputs; one set goes to the heatpump, the other set goes to the original boiler – so the switch can be set to HeatPump / Off / Gas Boiler.

In this way, if the boiler is selected, it will run as it always used to, if things go badly wrong!

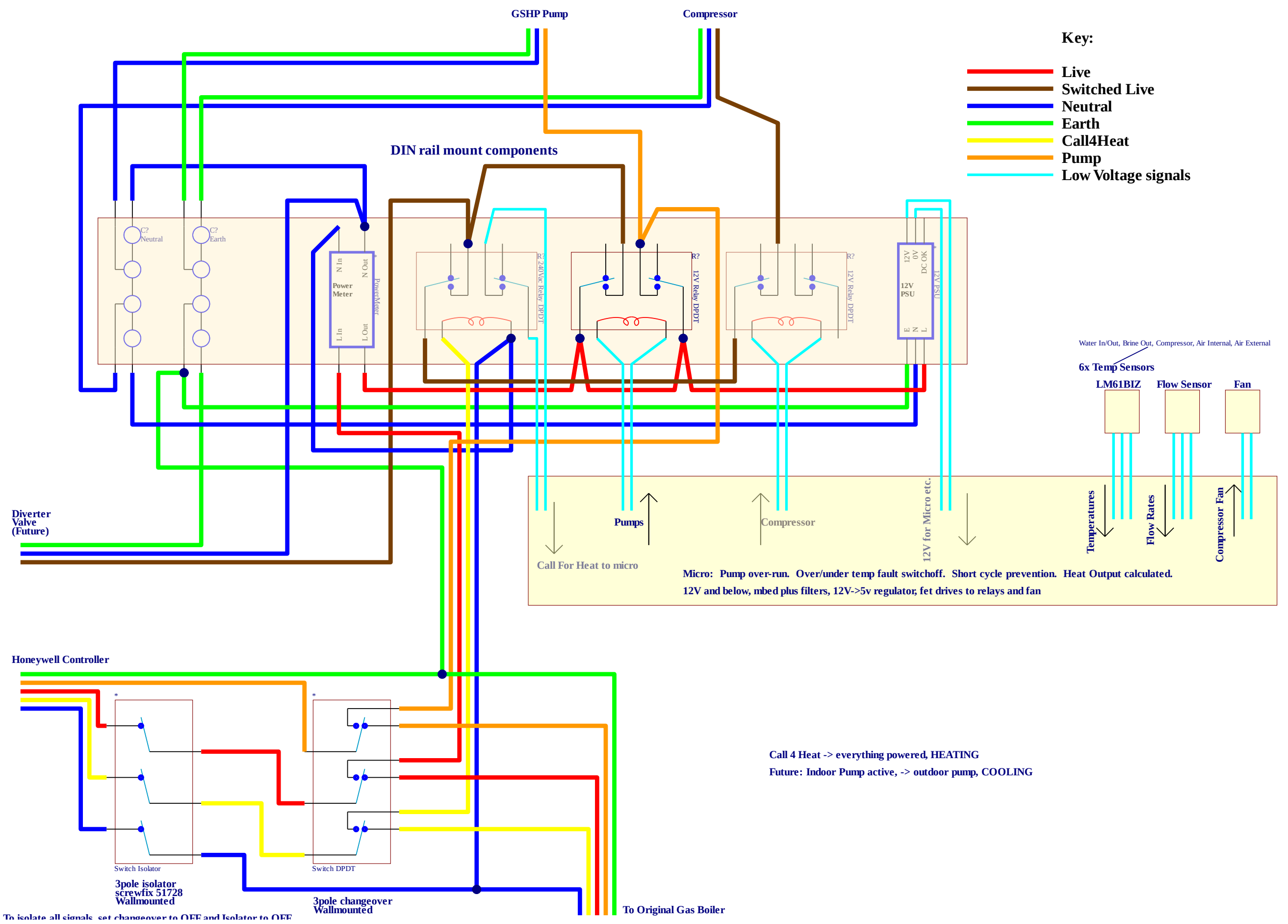
The din rail circuitry is shown below – all power is routed through a power meter, so excessive indoor pump power would result in a low COP figure. There is a 240V ac relay, used to detect the Call4Heat signal, and two 12V relays, used to turn on pumps and the compressor. The wiring is arranged such that Call4Heat must be on AND Pumps must be on for the compressor to be on. It also allows the Pumps to be run prior and post compressor run – prior allows the software to confirm the pumps are working, post improves efficiency and allows pressures to stabilise after use. A few minutes for each, so the minimum OFF of the compressor is at least 5minutes.

In the photo below, from left to right, you can see the water pipes to the heatpump, heatpump power controls (din rail) amd mbed controls, 3 way rotary switch, and original gas boiler.

Drawing below shows the boiler & heatpump water connections. It's all via a magnetic filter to keep it all clean, and there are a few valves so that the heatpump can be fully removed from the system if I need to fully revert back to the gas boiler or remove the heatpump for modifications.



Below shows the schematic of the mains supplies to the heatpump, including the isolation switch and 3 way rotary switch. The relays are carefully arranged so that Call4Heat must be Live to activate the mains relay, and the mbed must activate the pumps prior to the compressor being on – it seems a small detail, but it's very easy to write software that makes a mistake which could turn on and destroy the compressor due to the pumps being off. The way it is arranged, a software fault alone cannot destroy the compressor. The three relays used each have an led embedded, driven by their coil connections, as it is very useful to be absolutely certain of each state.



Electronic Monitoring Circuitry

This revolves around an “mbed” microprocessor which monitors 6 different temperatures, two flow rates, and the call4heat signal via a mains relay… I accept that it is over the top – I could have avoided the use of a micro entirely, and just used relay-logic. While the lure of monitoring was too much for me, I expect that power monitoring may have off-the shelf solutions available. The bare minimum I think needed are cold and hot side thermostats, which I would expect only to operate in a fault situation (broken pump, frozen pipe, etc). I think these should ideally be manual reset, to ensure the compressor does not quickly keep retrying in a fault scenario. I have not done that with my software solution – but there are startup and shutdown time delays built in, so the compressor would cycle on and off with a 10minute cycle time worst case, repeatedly attempting to work in the worst case fault at present, and it would be simple to slow this down this further.

The mbed uses the call4heat signal to start the compressor via a relay that provides isolation. Generally approximately 1hour or greater cycle times have been seen, as the hallway thermostat kicks in and out – I think a higher power heatpump would likely have a much faster cycle time, so perhaps need a buffer tank or deliberate slowing with software.

The mbed can also calculate the heat output, monitor the electrical power, and hence calculate the coefficient of performance.

The simple software loop has several potentially slow measurements – the flow meters and the electricity meter both change digital state when an amount of water, or quantity of energy has passed. Both measurements then need timeouts – for this reason the water flows cannot be measured below 0.2lpm, or a 1s timeout would occur. Likewise, low electricity use is problematic – the timeout is adjusted depending on the expected power draw, so a maximum timeout of 1 hour is chosen in standby giving a 1W minimum measurement, and 2 minutes the rest of the time giving 30W minimum measurement. In addition to a timeout, the slow electrical measurement loop should be aborted if a change in Call4Heat is noticed, so that the system startup is quick. Possibly interrupts could be useful here, however I like the deterministic approach chosen.

On the pcb, as shown in the schematic below are the following features:

The mbed can drive several 12V relays or fans, each driven by a small sot23 n-channel mosfet.

Small battery backup, allowing an RTC in the mbed, and non volatile memory of electrical and thermal energy.

12V-5V psu

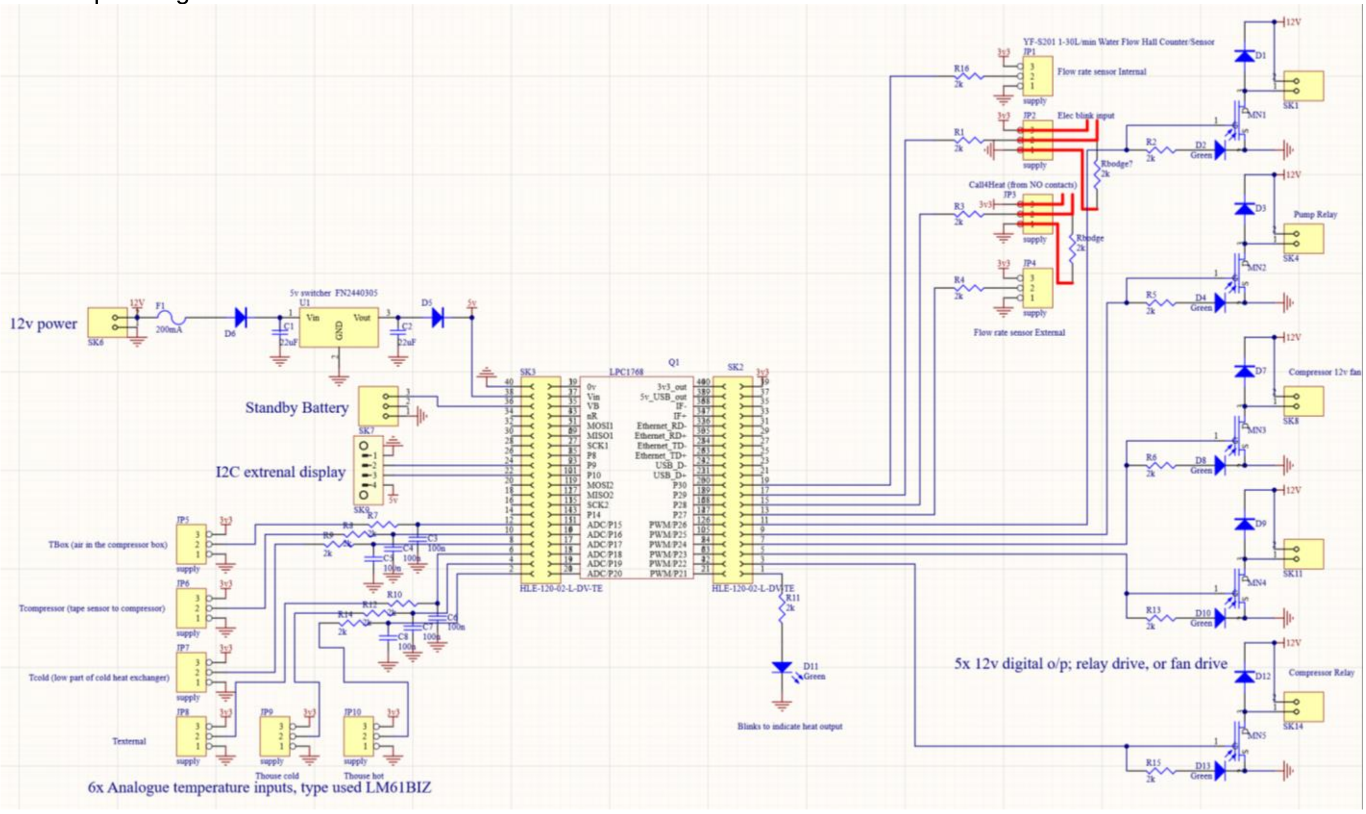
Several inputs, for the following measurements taken:

Temperature of the cold heat exchanger, taken at the lowest(coldest) point, using an LM61BIZ analogue sensor(pic), cabled, sprayed with varnish, then inside some heatshrink. Initially it was attached to the exit pipe to get the actual exit water temperature– but this fails if the flow stops when frozen, is difficult to fit, and the BPHE is actually slightly colder.

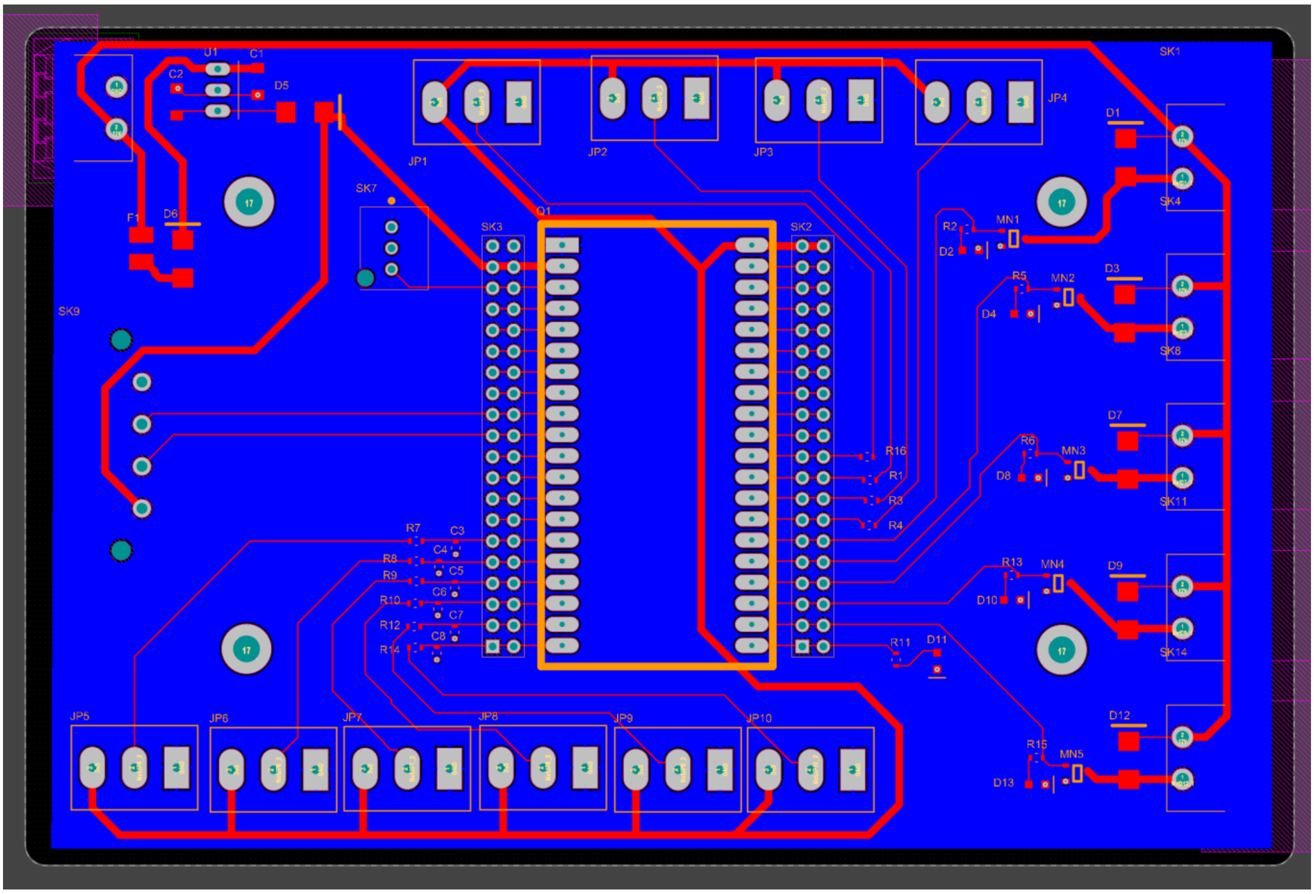
Also it must be thermally well connected to the groundwater, and this cannot be done to the flexible compression fitting hoses used, as these use a rubber pipe inside a metal braid and give a poor thermal contact.
Temperature of the inlet house water flow
Temperature of the outlet house water flow
Temperature outdoors
Temperature of the compressor casing
Temperature of the air inside the insulated box
Flow rate of the house water
Flow rate of the ground loop water/glycol
Electrical power from the din-rail power meter opto-isolated transistor

At present, the measurements and reasons why the mbed could abort the compressor include:
Indoor flow <3lpm (faulty pump/switched off)
External flow <10lpm (freezing / electrical fault)
Cold heat exchanger <0degC(freezing)
Indoor hot water temp > 42degC (not really a fault, I will in any case increase this for better DHW use eventually)
Also possible is aborting if the total electrical power in is outside expected limits, perhaps 600W+/-200W after a few seconds of startup, as this would indicate incorrect propane charge or some other major fault.
Also considered is aborting if the heat output is below expected, or maybe if the COP has changed. For now a COP display is a useful addition, using a filtered PWM output from the mbed straight to volt meter.

The datasheet of the compressor mentions using a fan, presumably to keep the compressor temperature lower than it might otherwise rise. A temperature sensor is therefore fixed to the compressor, and used via the mbed to control the fan, so to keep the compressor casing at a relatively stable temperature as I expect this improves reliability by keeping stable operating conditions.



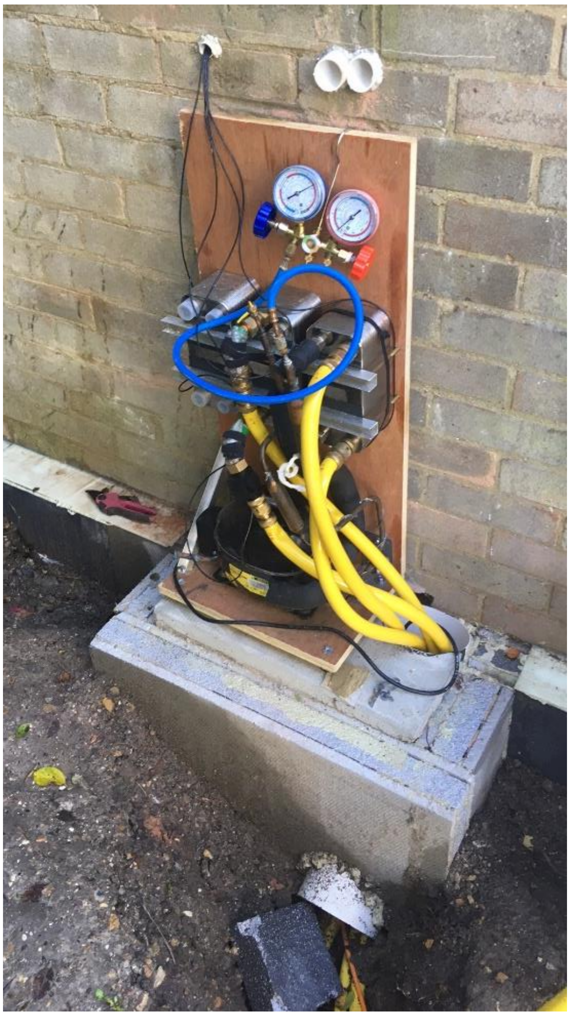
The layout of the mbed circuitry is shown below. It is a simple 2 layer board with 0v on the back as a groundplane. It could be done on a veroboard (stripboard) if needed, however pcb manufacture is actually quite inexpensive now, and the groundplane will likely improve measurement accuracy. There are no high voltages on the pcb, these are all constrained to the din-rail objects. Great care must be taken with mains voltages – always turn the unit off with both isolator and 3 way changeover before modifications, confirming power was present and then has been removed due to the power meter switching off and mbed deactivating, and all relay leds off.



Heatpump location

The heatpump is to be thermally connected to our outhouse at the back of our garage, to give it a stable operating temperature away from freezing conditions, but actually outdoors due to the indoor risk from propane. After digging down 2 feet a concrete foundation was found to be there already – perhaps somehow part of an old coal bunker that used to be there. An insulating box was made out of offcuts of insulation, 100mm thick, glued together, and keyed into the perimeter wall insulation fitted at the same time. An old bit of 150mm mvhr plastic pipe was placed in to allow GSHP water pipes in and out. This 150mm pipe had a few V shaped cuts into it, and was then bent and taped to hold it, to allow pipes to enter and exit the new foundations at a convenient angle. It was filled with sand, unwanted stones, and some old bags of basecoat from EWI, finishing with a bit of mesh to make a stable strong surface. The picture shows the basic heatpump, with a “manifold gauge” set attached, and some test hose pipes attached. You can also see pipes fitted through the wall, to carry wires (inside a plastic pipe sleeve) and in/out water intended to be in 22mm copper plumbing on the right in 40mm plastic pipe. Another photo shows the outhouse, with the insulated box, part way through the EWI process.

There is a waste pipe going to a concrete open gully close to the heatpump – I discovered that this had no water trap, but simply had a rest-bend + grate + gully, then was attached to the sewer. It is very important that no propane could enter the sewer system as a matter of safety - so I excavated it, and replaced the rest bend etc with a P-trap+grate+original gully.



Groundloop

There are many ways to bury a pipe - considered were HDPE slinkies, direct heat exchanger with copper pipes, boreholes with HDPE pipes and electro-fusion welded 180degree bends. All of them are difficult, and time consuming, and effort is the enemy! In the end a trencher was used to dig eight straight channels 1m apart, giving fully 4 loops of 25mm PE-100 pipe, each approximately 40m long. These loops are used in parallel to give good flow characteristics, so that a regular circulating pump could be used, as excessive pump power will affect the system COP. The trencher dug a channel 0.9m deep by 100mm wide – it couldn't make any useful bends in the trench, so 90degree corners were made by crossing the trenches. This involves lots of earth falling into the original trench, so there's a lot of laborious digging afterwards to clear out the unwanted spill – the best tool found for this was a narrow digging hoe. After buying a 100mm digging hoe, 10mm was removed from the edge with an angle grinder – turns out a perfect fit into a 100mm trench is actually a terrible idea as it kept jamming originally.

Undoubtably, digging this set of trenches was the hardest work of the project. While the trencher dug the basic holes in 2 easy days of intermittent use, there were many many days of digging out overspill, and fettling corners perfectly. Old osb3 boards were placed over exiting trenches while doing the end trenches at the top and bottom, to reduce spill down the holes, but even so, a lot fell down. My family really came to the rescue here, it was such a lot of manual work! The approach used was probably a good one for diy – I found the trencher very simple to operate – although I had never used one before, the learning curve was pretty quick. I've used a digger in the past – they require more skill. There is a lot of manual work afterwards to do with the trencher approach, probably more so than with a digger and slinkies - so I think digger+slinkies would be quickest=cheapest if professionally installed with a competent digger operator (ie. not me!).

The hdpe pipe is very stiff, and difficult to bend around tight corners, and even to straighten! We pre-straightened our coiled pipes by wrapping them around a table indoors for a few days, forcing the 1m dia coil to widen to a 2m dia coil, which probably helped the install. A 25mm "cold pipe bender" intended for underfloor heating pipe, and a hot air gun, were used to persuade the pipe into tight bends without kinking, then cold water afterwards to set the pipe before removing the bender entirely, so it can be used again. Installing the pipes was surprisingly straightforward, hooking them into the manhole opening and unrolling them into the trenches, the curve holding them they stayed in place nicely. I bought a 50m and two 100m lengths of pipe, and managed to complete the project without any underground joints, even fitting a "spare" pipe in just in case.

We have 4 loops, every pipe end being in order of the trench it is in, and labelled **1**-2,3-**4**,**5**-6,7-**8**. They are staggered into the manifold, the coldest water straight out of the heatpump being indicated by bold text in the list above. It is a small detail, but I think more efficient to avoid routing in and out pipes near each other and cross conducting where possible (this does admittedly happen in many places, but avoid if free).

Filling in the trenches is not to be underestimated – this was surprisingly hard too, moving lots of earth about by hand is hard work! We had around 200m of trenches, 0.1m wide by 0.9m deep, making around 18m^3 of spill. Most of the spill was right next to where it had to go back, but many loads had to be shifted around the garden by wheelbarrow so that it was out of the way. We filled in halfway, then either placed an identifying tape in the hole: "Caution Geothermal Pipe", and / or some drainage pipe – with a view to making a linear soakaway for the back of the house sometime as I understand that wet pipe conducts better than a dry GSHP collector. The black pipe that can be seen in the photo above is actually some of the slotted drainage pipe used, the 25mm hdpe pipe is already buried deeper. The leftmost run is partly fully filled in.

Connecting the pipes to the GSHP unit itself would be very difficult directly, as the pipes are so stiff. In the end they were translated from 25mm PE-100 to ½" BSP male, then from there to a simple tap to hose fitting, which connects to a high quality PVC see-through braided hose pipe with a clip on it. It's helpful to see bubbles chasing through the see through pipe, and possibly diagnose issues later. These hose pipes then are able to bend into the GSHP box without kinking, and connect up to the GSHP manifold made using 15mm copper pipe and 15mm full bore screwdriver operated valves. The photo shows a manhole that constructed just for this purpose, after it was found that the pipes couldn't bend to fit directly. There's a steel lintel in and out of the manhole, made of whatever I had lying around.

Above is a picture of the connecting trench to the manhole, done mainly by hand, as the main sewer is situated around this area. Over the years many buried things have been “discovered”, and I had no wish to “discover” the sewer pipe with the trencher! Prior to trenching, “linesearch before u dig” were contacted, who will give a free check for homeowners to see what is there. Our back garden is happily free of any high voltages or phone lines or water or gas.
The gshp insulated box can be seen, with and without its insulated door on, and the new manhole just below it. The outhouse is partway insulated now, leaving the roof to do, and some detail around the original gas boiler flue to consider. There are several objects fitted to the outside – a hose pipe reel, tap, mains outlet, all fixed in place with some compactfoam. There is also a cable poking out through the wall, connected to a 30V 3A dual power supply inside – it’s been very useful for insulation hot wire cutting, especially as I am a diy-er, so time on projects is short, and bring in and out power supplies cuts into useful work.

Also shown is a photo of the heatpump box, with a 5x15mm pipe in + 5x15mm pipe out copper manifold, and hose-pipes connected though the base to the manhole and to the hdpe pipes. The 5 way manifolds are made to measure out of 22-15mm Tee pieces and 15mm wide bore valves and allow for 4 loops plus a spare pair that are just used to fill the system with around 50litres of tap water, and 100ml of Fernox F7 biocide. If found necessary, some sort of non toxic gycol will be mixed in. The insulated box is made from inside to out: basecoat+mesh, 50mm rockwool, basecoat+mesh, 50mm eps, and is intended to have another basecoat+mesh+render on the outside eventually. The construction intention is to have rockwool on the inside of the box, as it cannot burn; EPS is stronger and so was initially used to construct the box, the rockwool being added afterwards. Since this photo, the manhole lid has been insulated on the inside, to protect the pipes from frost while they are off.

Costs:

Compressors	2*£50	Ebay, 2nd hand (£350 new)
Heat Exchangers	3*£40	Alibaba
Copper pipes, fittings	£200	Screwfix
Tools	£100	Amazon etc
Pump	£60	Ebay
Electronic controls	£200	Ebay, Farnell, Amazon, jlcpcb.com
HDPE pipes & fittings	£250	BES
Trencher hire	£750	includes transport of trencher, insurance, 2 day hire
Glycol	£120*	
Diverter Valve	£120*	
Labour	0**	Me + anybody else I could rope in

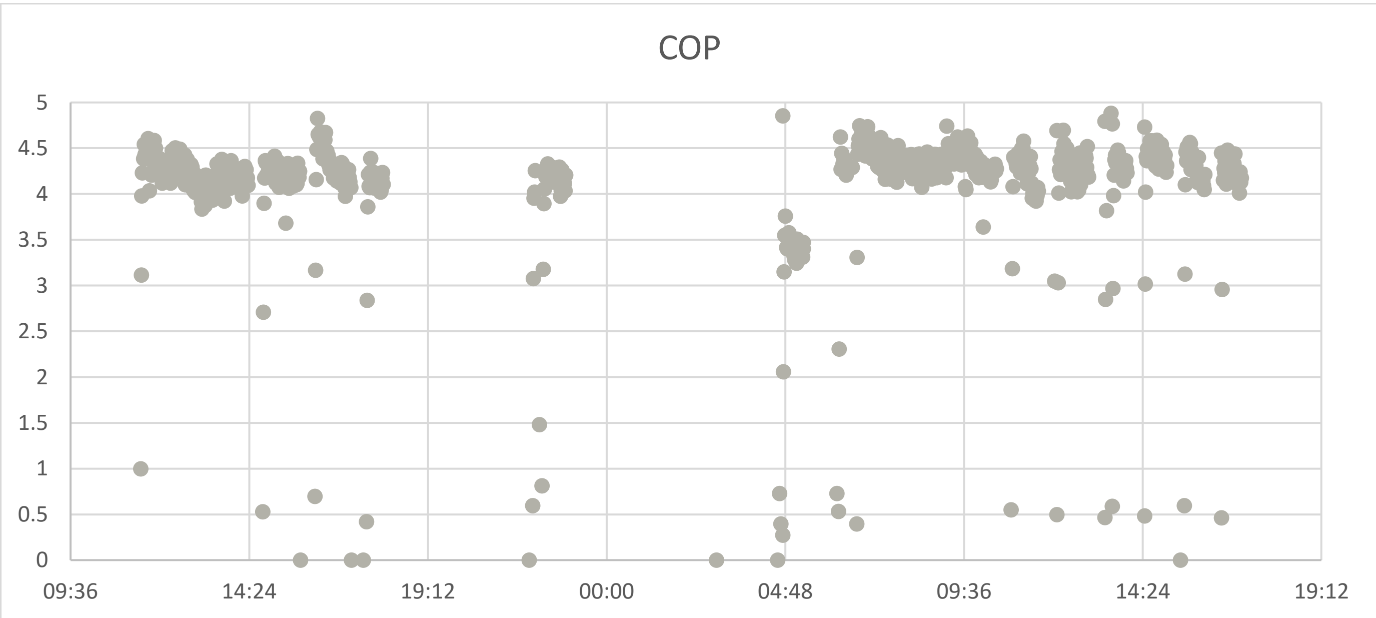
*not added yet
**Or £10000, depending on how my time is costed!

Results

We have been living with it for 3 weeks in December as I write this, data being recorded onto the mbed, and for convenience onto a laptop I have left next to it. The heatpump has been solely used, the gas boiler is off, we have used no other heating. There have been a few cold days, but largely it has been mild, February will be the true test!

Radiators run at about 32C, barely even lukewarm, but it does heat the house – the measurements indicate that 2.5kW is dissipated while the house is at 21C, hence around 5degC/kW as found with the gas boiler. There may well be subtle differences –the test run used the internal pump on high speed with the gas boiler –now the internal pump is on lower power and silent, with perhaps a slight reduction in radiator-air coupling.

The measurements indicate an output of around 2.5kW, with ~600W electrical in, including the internal and external pumps and internal relay and mbed controls. The COP can then be calculated to be ~4 including all of those elements, or 10% higher if excluding the 60W of pumps. The accuracy of the 2 temperature sensors used to measure the COP is crucial, and it is a major source of possible error, but even so it is very useful to identify that the system behaviour is unchanged. An worthwhile upgrade would be to improve the accuracy of these 2 temperature sensors. An auto-calibration routine was tried, but it proved unreliable – the result of the calibration was +/-0.6C depending on the last few hours use, while leaving it for a day gave <0.1C difference at ~15C. While this suggests the sensors are well matched below 20C, the error at the operating temperature of ~30C is still unknown.

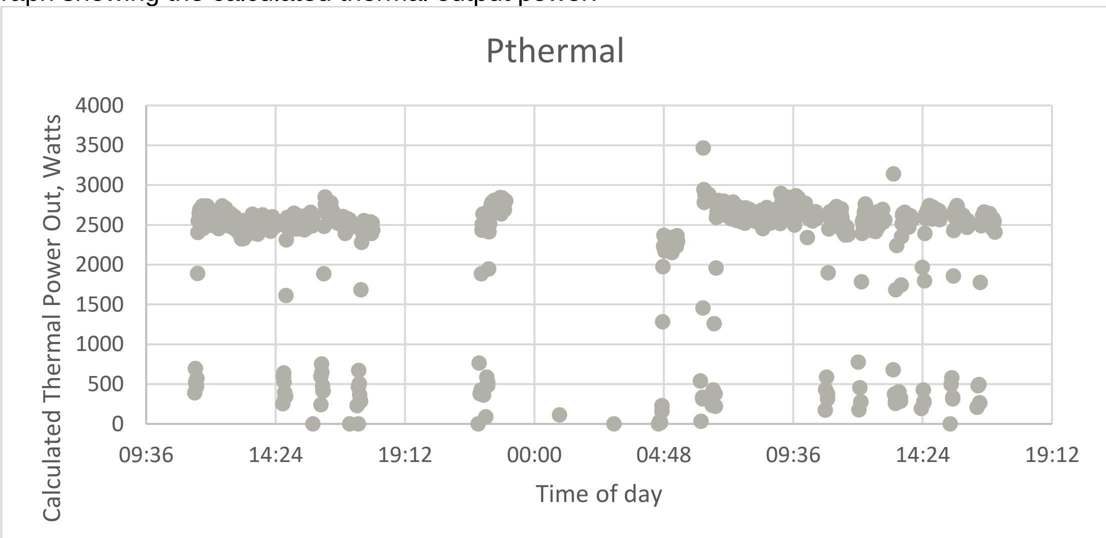


A typical day or so run is shown in the few graphs here. You can see early in the day, after turn on the unit runs continuously, then quickly settles into an on/off pattern, with roughly a 1hour period due to the hysteresis of the Honeywell air thermostat we have. I've heard on/off cycling should be below 6x per hour to keep fatigue failures low, so I am happy with this, and do not think additional software controls are necessary – it's best to keep it simple unless absolutely needed.

The electrical draw follows a pattern; first thing every morning is higher – perhaps a result of higher flow temperatures due to longer run times and also DHW use. The peak DHW temperature capability is software limited, and will be increased slowly as confidence grows.
An example of results taken from a PC terminal window ("terraterm") of the mbed stored data is given below. Every line shows a minute of data, roughly in order of: date & time, box temperature, compressor temperature, cold heatexchanger temperature, outdoor temp, House cold and hot temps, water flows in and out in litres/min, various deltaT(for reference), on state (2=fully on), elec power, thermal power, cumulative energy (electrical then thermal).

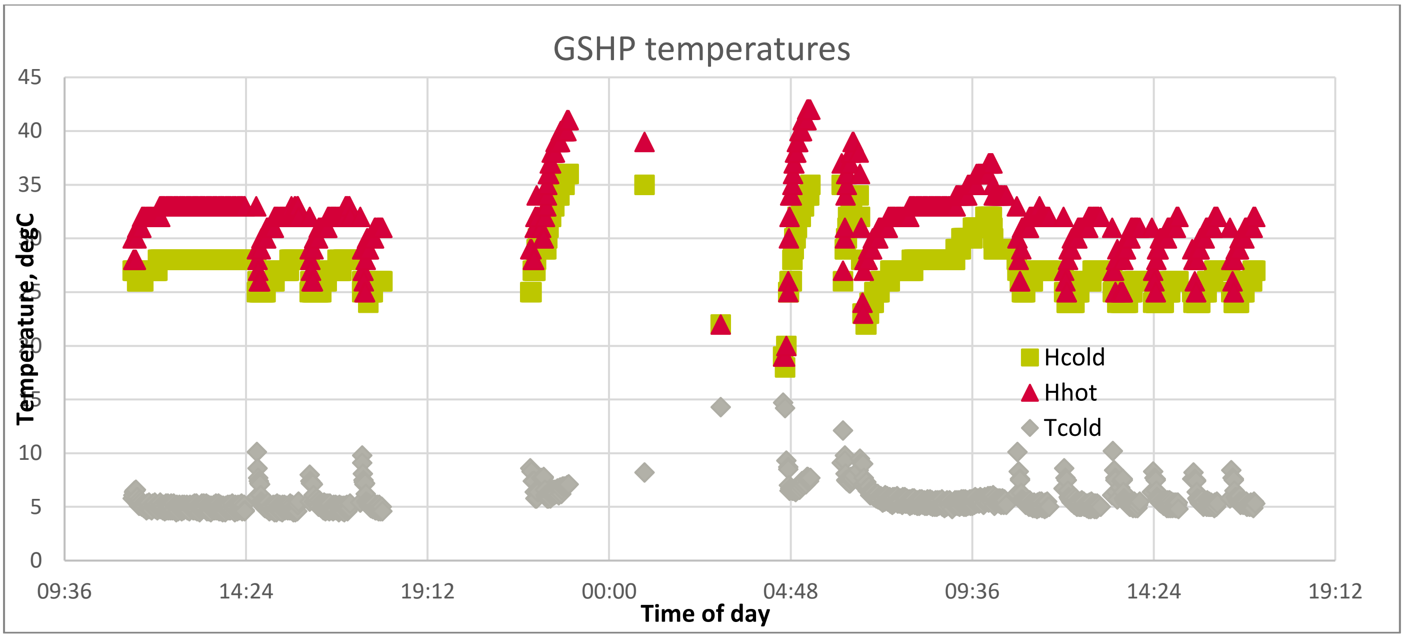
```
16 21:09, Box 20, Comp 39, Cold(degC) 7, Ext 8, HCold, 24, HHot 25, FlI(lpm) 1.79, FlE 2.79, DT 0.816, DT0 0.816, DTc 0.000, on 1, Pe 30W, Pt 102W, Ee 24.272kWh, Eh 90.418kWh
16 21:10, Box 20, Comp 39, Cold(degC) 7, Ext 8, HCold, 24, HHot 24, FlI(lpm) 8.34, FlE 19.17, DT 0.579, DT0 0.579, DTc 0.000, on 1, Pe 30W, Pt 338W, Ee 24.272kWh, Eh 90.424kWh
16 21:11, Box 20, Comp 38, Cold(degC) 7, Ext 8, HCold, 23, HHot 24, FlI(lpm) 8.18, FlE 18.57, DT 0.627, DT0 0.627, DTc 0.000, on 1, Pe 30W, Pt 359W, Ee 24.273kWh, Eh 90.430kWh
16 21:12, Box 20, Comp 38, Cold(degC) 7, Ext 8, HCold, 23, HHot 23, FlI(lpm) 8.17, FlE 19.24, DT 0.482, DT0 0.482, DTc 0.000, on 1, Pe 30W, Pt 276W, Ee 24.273kWh, Eh 90.435kWh
16 21:13, Box 19, Comp 38, Cold(degC) 7, Ext 8, HCold, 23, HHot 23, FlI(lpm) 8.01, FlE 18.95, DT 0.438, DT0 0.438, DTc 0.000, on 1, Pe 30W, Pt 246W, Ee 24.274kWh, Eh 90.439kWh
16 21:14, Box 19, Comp 38, Cold(degC) 7, Ext 8, HCold, 22, HHot 23, FlI(lpm) 8.34, FlE 19.25, DT 0.429, DT0 0.441, DTc -0.012, on 2, Pe 551W, Pt 250W, Ee 24.283kWh, Eh 90.443kWh
16 21:15, Box 20, Comp 38, Cold(degC) 6, Ext 8, HCold, 22, HHot 26, FlI(lpm) 8.40, FlE 19.02, DT 3.179, DT0 0.441, DTc 2.738, on 2, Pe 576W, Pt 1869W, Ee 24.294kWh, Eh 90.476kWh
16 21:16, Box 20, Comp 38, Cold(degC) 6, Ext 8, HCold, 22, HHot 27, FlI(lpm) 8.09, FlE 19.65, DT 4.171, DT0 0.441, DTc 3.730, on 2, Pe 574W, Pt 2361W, Ee 24.304kWh, Eh 90.518kWh
16 21:17, Box 20, Comp 38, Cold(degC) 5, Ext 9, HCold, 22, HHot 27, FlI(lpm) 8.46, FlE 20.81, DT 4.402, DT0 0.441, DTc 3.962, on 2, Pe 581W, Pt 2608W, Ee 24.314kWh, Eh 90.563kWh
16 21:18, Box 20, Comp 39, Cold(degC) 5, Ext 8, HCold, 23, HHot 27, FlI(lpm) 8.36, FlE 19.23, DT 4.481, DT0 0.441, DTc 4.040, on 2, Pe 587W, Pt 2621W, Ee 24.324kWh, Eh 90.608kWh
16 21:19, Box 21, Comp 39, Cold(degC) 5, Ext 9, HCold, 23, HHot 28, FlI(lpm) 8.43, FlE 18.15, DT 4.499, DT0 0.441, DTc 4.058, on 2, Pe 584W, Pt 2655W, Ee 24.334kWh, Eh 90.655kWh
16 21:20, Box 21, Comp 40, Cold(degC) 5, Ext 9, HCold, 23, HHot 28, FlI(lpm) 8.21, FlE 18.33, DT 4.479, DT0 0.441, DTc 4.038, on 2, Pe 587W, Pt 2576W, Ee 24.344kWh, Eh 90.699kWh
16 21:22, Box 21, Comp 40, Cold(degC) 5, Ext 9, HCold, 24, HHot 28, FlI(lpm) 8.69, FlE 18.73, DT 4.483, DT0 0.441, DTc 4.042, on 2, Pe 588W, Pt 2728W, Ee 24.354kWh, Eh 90.746kWh
16 21:23, Box 20, Comp 36, Cold(degC) 6, Ext 9, HCold, 24, HHot 28, FlI(lpm) 8.72, FlE 18.97, DT 4.480, DT0 0.441, DTc 4.040, on 2, Pe 592W, Pt 2735W, Ee 24.364kWh, Eh 90.793kWh
16 21:24, Box 20, Comp 36, Cold(degC) 5, Ext 9, HCold, 24, HHot 28, FlI(lpm) 8.33, FlE 19.31, DT 4.482, DT0 0.441, DTc 4.041, on 2, Pe 588W, Pt 2612W, Ee 24.375kWh, Eh 90.838kWh
16 21:25, Box 20, Comp 38, Cold(degC) 5, Ext 9, HCold, 24, HHot 29, FlI(lpm) 8.56, FlE 18.15, DT 4.498, DT0 0.441, DTc 4.057, on 2, Pe 588W, Pt 2696W, Ee 24.385kWh, Eh 90.884kWh
16 21:26, Box 21, Comp 39, Cold(degC) 5, Ext 9, HCold, 24, HHot 29, FlI(lpm) 8.48, FlE 19.38, DT 4.504, DT0 0.441, DTc 4.063, on 2, Pe 588W, Pt 2674W, Ee 24.395kWh, Eh 90.930kWh
16 21:27, Box 21, Comp 40, Cold(degC) 5, Ext 9, HCold, 25, HHot 29, FlI(lpm) 8.56, FlE 20.28, DT 4.456, DT0 0.441, DTc 4.016, on 2, Pe 595W, Pt 2670W, Ee 24.405kWh, Eh 90.975kWh
```

It is very quiet, internally and externally it is quieter than the gas boiler it replaces. It is slightly louder inside due to sound creeping through the holes drilled - they should be blocked fully – blue tack perhaps! If the external insulating "door" is removed then it sounds similar in volume and tone to a regular fridge – not disturbingly loud still - but with the door on nobody will notice it. The door must be left on generally, as there is a significant risk of damage due to frost otherwise - the external groundloop could freeze, and disastrously the internal heating water circuit loop could freeze up and rupture a pipe!
Below is a graph showing the calculated thermal output power:

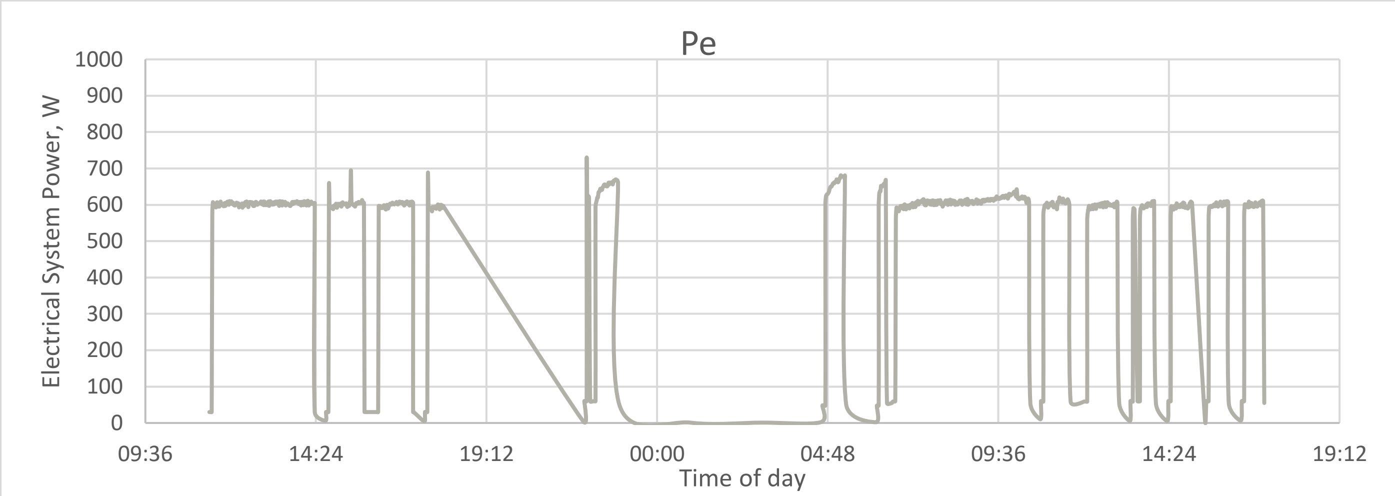


Below shows GSHP in and out water temps in red and green, with the cold heat exchanger in grey. Twice the heatpump reached 42C, this is when DHW has been called for – the heatload is small so the temperature must increase, however at 42C the mbed software stopped the heatpump at a cautiously low temperature, preventing high pressures reached in the heatpump. This will be increased in due course – the compressor spec suggests 55C is allowable, although this might not be practical without lagging the long pipes to the tank. The DHW heatup is not a straight line even though the power is constant – this curve suggests high pipe losses to the surroundings, hence the system struggling at elevated temperatures, inefficiently taking a long time at high temperature and lower COP. I have since found a plumbing detail I didn't realise – somehow our bathroom radiator is hot whether heating or DHW is active, sapping the limited DHW power and limiting the maximum temperature achievable. With our high power gas boiler this really didn't matter, but now it does. My first thought was to replumb it, but that seems like hard work; then I found an electronic TRV (terrier i30) that I trialled years ago – the bathroom radiator is now programmed to 22C generally, and 5C overnight while the DHW is operating – a simpler way to prevent that rad from sapping DHW power.

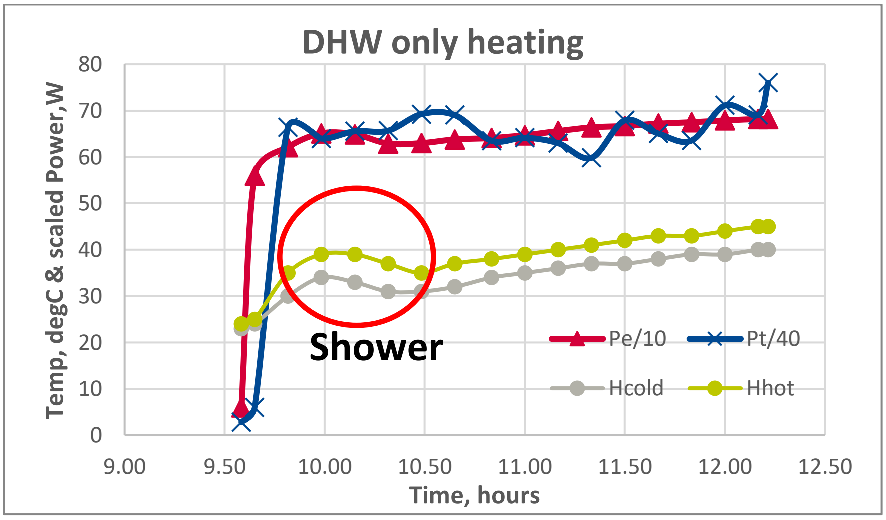
Our immersion is on a timer, so once a week boosts up to 60C to sterilise it anyway – a feature important with a low power heatpump, allowing generally a lower temperature water store to be used safely.
The rest of the time the GSHP unit is heating the house, and naturally self limits at around 32C, where radiator losses equal the heatpump capability. The cold heat exchanger temperature seems to start at maybe 10C, and quickly fall to 5C every time it is used. Will it stay above zero? Will I need glycol?



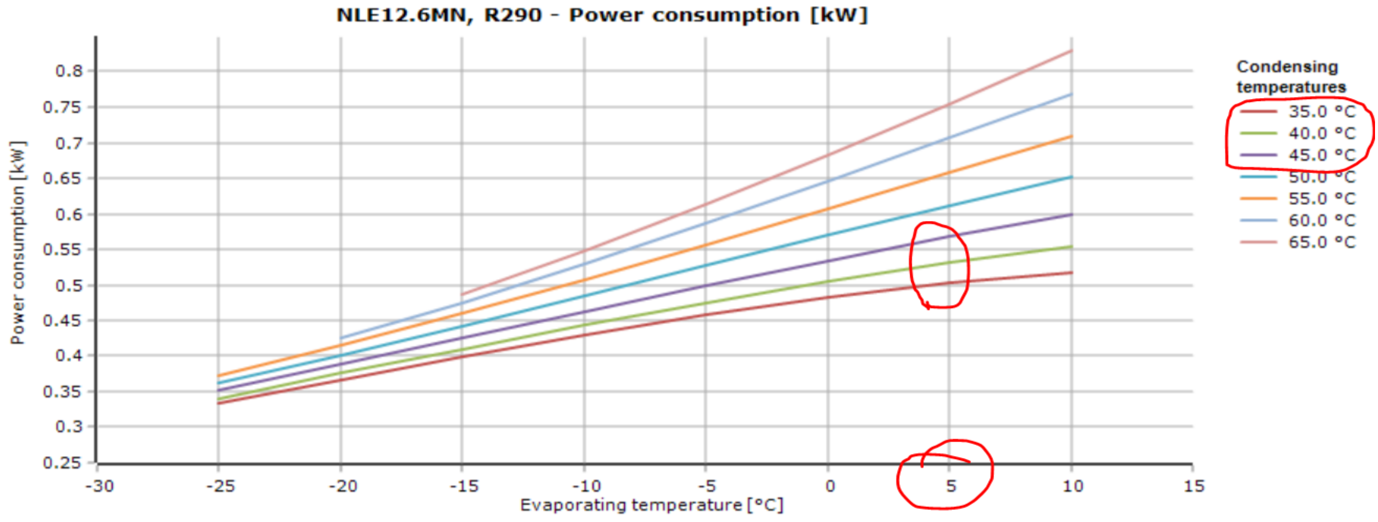
The plot below shows electrical power taken by the heatpump. Generally it operates at 600W, including pumps and control logic, rising slightly above that when DHW is heated due to the slightly elevated temperature.



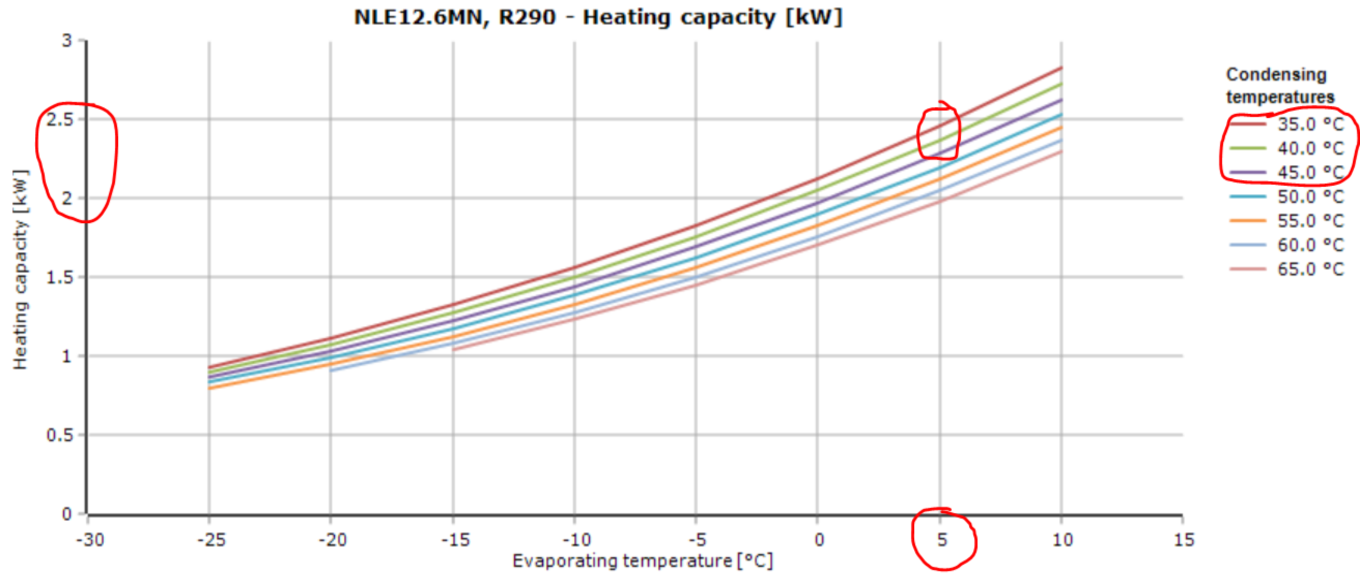
For the below DHW heating graph the bathroom radiator is off, DHW is now permitted to run to 45C, and is showing recovery after a long shower. The COP (graph shows scaled elec and thermal power, see legend) seems oddly stable and at 4 between 25C and 45C output, I had expected it to fall – maybe measurement inaccuracy?



Increased power draw is expected at higher output temperatures – the graph below from Danfoss shows expected power increasing from 500W to 570W for the temperature range seen, to which another 60W of pump power must be added, matching results taken fairly well. There may well be discrepancies though away from the chosen operating point, as a simple capillary tube rather than a PRV(Pressure Regulating Valve) or ERV(Electronic Regulating Valve) has been used, either of which can better set the “metering” pressure drop required under differing conditions.



Another plot from Danfoss, showing anticipated heating capability, which matches the ~2.5kW measured at the operating point chosen.



Groundloop Temperature

The bottom of the cold heat exchanger settles at around 5C, and the ground loop water is likely 2-3C above this. This point was chosen to monitor as it will be an early freeze indicator as the system is straight tapwater so far. The heat exchanger was frozen up completely in early experiments using a water butt as the cold source, and it survived – I remember noticing the cold water flow had stopped, then I turned off the compressor and had to wait for it to defrost, while watching the manifold gauge set to see if the propane pressure fell which would indicate a terminal leak in the heat exchanger. Luckily all was well, no pressure was lost, the heat exchanger survived intact – phew! Now the cold temperature and ground water flow are being monitored, and it's expected that the software would spot it prior to being completely iced up, minimising the risk of damage.

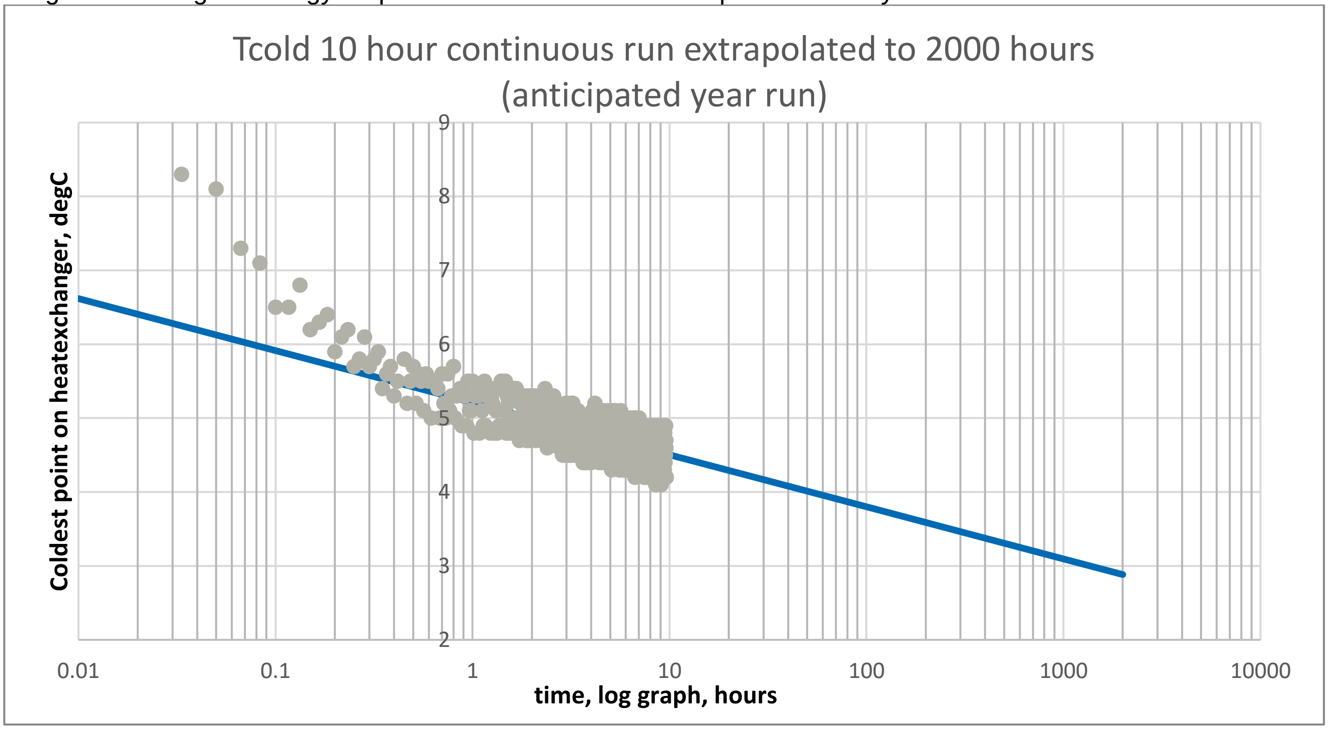
Pipe Outer Diameter	25	mm
Power Extracted	1500	W
circumference	0.0785	m
Active Length	160	m
Pipe Area	12.56	m^2
Pipe Thickness	2.5	m
Pipe internal Volume	50.24	litres
HDPE Lambda	0.5	W/m/degC
Pipe Thermal Conductivity	2512	W/degC
DeltaT through Pipe	0.597133758	degC
Water Flow Rate	20	lpm
Water mass flow	333.3333333	g/s
Water SHC	4.2	J/g/degC
Water Power Capacity	1400	W/degC
Water DeltaT	1.071428571	degC

Below shows the temperature of the bottom of the cold heat exchanger, during a 10hour continuous run. During this run, the temperature can be seen to fall – there is an initial fast fall for 5mins or so – this corresponds to heat being quickly taken out of the 50litres held by pipes, which then couple poorly via the 2.5mm thick plastic pipe interface. Calculations to the left indicate there should be a 0.6C drop through the HDPE pipe, and a 1.1C drop due to the flow through the cold heat exchanger. The cold temperature sensor will drop below the water during operation though, so the calculations will not match reality perfectly.

After this the rate slows down, then thermal diffusion with a constant power draw produces a curve that fits a log(time) expression found by excel of:

*ColdTemp = 5.21-0.306*ln(time in hours)*

Extrapolating this to a runtime of 2000 hours, which is the expected total year runtime is the blue line on the graph, dropping to just under 3C, depleting the earth of heat. In reality the heatpump will kick in and out – and when off there is significant “recovery” so this extrapolation is pessimistic – but the ground around the pipe is not infinite, also the air temperature should be dropping – so it is hard to know whether this is overall pessimistic or optimistic. Certainly, this temperature must be monitored carefully. If it drops to 0C, or the flow drops (an indication of internal heat exchanger ice formation), then glycol must be added to the system to avoid the heat exchanger icing up and possible damage. It is best to avoid glycol if possible – there’s a cost, and it would subtly reduce the efficiency both due to the external flow dropping due to higher viscosity, and the reduction in thermal heat capacity. Total runtime to date is 230hours, but we haven’t had a long continuous run for a while now as the weather is mild - the ground is actually recovering now and is warmer than the graph below “predicts” (as the graph extrapolation is only for a continuous constant power draw). Interestingly, while the thermal energy expected to be taken from the 100m2 of land used by the groundloop is 3MWh, the unshaded yearly energy provided by the sun is a huge 100MWh, covering it in PV panels could provide 20MWh, but growing and burning an energy crop such as Miscanthus would provide merely 0.6MWh.



Making good

The pic below is of the garden 40days after the trencher hire. Most of the grass that can be seen is new “winter” seed, as the original grass is now buried under 5-10cm of excavation soil. The tracks that can be seen are where the ground has repeatedly sunk and has been filled in with a mixture of compost and the original sticky clay soil. The seeds were treated like beansprouts (dunked in water for 1 day, then left moist for 2 days) to hurry them along, as it’s winter here (pic taken 2Jan2022) but it has been a mild 2 weeks, and the grass has been growing. I’m pleased with the results – the bare clay was very “claggy” and terrible to walk over, so anything growing is an improvement.

Conclusions

Possible to diy a small GSHP if the garden area is sufficient, although it's a lot of work!
A trencher is great for diy as it's very easy to use, but for an expert using a digger and slinkies is probably quicker as there is likely to be less manual work afterwards.
Heating DHW very hot may not be possible without lagging the pipe runs to it, and ensuring no radiators are driven via the DHW circuit. Losses are in the house, so extended inefficient DHW heating may be acceptable in winter but less so in the summer.

Future improvements:

Box up & label electronics, label heatpump as R290
Add passive cooling option
Insulate heat exchangers – hot HX all over + cold HX interface with woodwork
Oil woodwork, to give longer life against condensation drips

If necessary, changes that could be done:
Replace temp measurement parts on water pipes for more accurate ones to improve COP accuracy (eg TSIC 503)
Add humidity sensor, calculate dew point and minimum radiator temperature in cooling mode
Braze up the HX connections
Swap out wooden frame for longer life metal one
Improved COP compressor, ERV, weather compensation, Wifi link to elec pricing & on/off decisions

Links:

https://www.danfoss.com/en/service-and-support/downloads/dcs/coolselector-2/#tab-overview - Danfoss software
https://www.secop.com/updates/news/news-show/secop-capillary-tube-selection-software - Secop Capsel software
https://www.youtube.com/results?search_query=r290+propane - Youtubes associated with R290, watch them all!
https://ecorenovator.org/forum/ - many heatpump projects are here
https://www.gshp.org.uk/pdf/MIS_3005_Ground_loop_sizing_tables.pdf - UK specific groundloop sizing tables
https://lsbud.co.uk/ – free check it's safe before digging
Ebay, Amazon, Bes, Waterirrigation, Alibaba, Screwfix, Toolstation etc for parts
http://www.ammonia21.com/files/pdf_672.pdf Discussion about CO2 use as a heatpump gas