Zero Carbon House

Making an ordinary suburban Edwardian house Zero Carbon with reasonable measures, and without busting a gut.

The business of saving the planet from catastrophic global warming relies on ending the burning of fossil fuels. Currently around a quarter of the UK's energy goes to heating homes. And most of this is with boilers burning natural gas – a fossil fuel.

Going zero carbon is in theory very simple: switch from gas to electricity, which is increasingly generated without burning fossil fuels. The problem for us consumers is that electricity costs much more than gas. Prices vary wildly(!) between suppliers, but currently the average prices across the UK are: electricity 14.4p/kWh, and gas 3.8p/kWh – a factor of nearly four.

So, how do we reduce domestic energy demand, and how do we bring the cost of electricity down to the same as gas, or less? We can't knock down all our existing houses and build spanking-new totally-and-utterly zero energy high-tech houses. We have to deal with our existing housing stock: millions of leaky old houses of all ages, shapes and sizes, *using reasonable measures*.

In 2018 we moved into a leaky old Edwardian detached house in Orpington. We have now adapted it to use Zero Carbon, using readily available and affordable measures.

What we've done is…

1. Replace the gas boiler with an electric heat pump (air-to-water)
2. Increase insulation as much as possible (where reasonable)
3. Double-glaze all windows
4. Have an all-electric cooker (with fast-acting induction hob)
5. Install solar PV panels (which often power the heat pump for free)
6. Get a little electric car (8 year old Citroen C-Zero)
7. Use an electricity tariff with low night-time rate

Heat pumps use electricity, not to heat directly, but to *move* heat from outside to inside. You've already got one – it's called a fridge. Typically a heat pump will use 1kW of electricity to move between 3 and 4kW into the house. This works even if it's freezing outdoors and you want a cosy 20 degrees C indoors. The efficiency factor, between 3 and 4, is called Seasonal Coefficient of Performance (SCOP). We've installed a NIBE 16kW Air-to-Water heat pump, with an average SCOP of 3.29. Here it is, humming quietly at the side of the house.

In practice the SCOP will vary a lot according to the outside air temperature and the water temperature going into the radiators. With outside air at 10degC and radiators at 40degC, our heat pump will achieve a SCOP of up to 4.5. But with outside air at minus 15degC (rare in Orpington!) and radiators at 55degC (maximum output temperature) the SCOP would drop to around 2.0.

This is the reason people say that heat pumps work best with under-floor heating, which works at lower temperatures than radiators. But under-floor heating is difficult and expensive to install in old houses with timber floors. Fortunately heat pumps work perfectly well with radiators, provided they're reasonably sized, and combined with good insulation. We've added a couple of extra radiators for luck, and the system is working very well.

When choosing radiators, bear in mind that the rated output in the catalogue is usually based on hot water from a central heating boiler, at around 65degC. With a heat pump chucking out water at 35-45degC, you need to roughly halve this. So a radiator quoted as 2kW will produce more like 1kW of heat. To put this in context, our big Edwardian house, with increased insulation (see below) needs around 10kW to keep it at 20degC when it's freezing outside.

The other reason you need to increase insulation is down to the way a heat pump is programmed. A gas CH system has a simple programmer, typically with four ON/OFF periods each day. It tends to be set to turn off at night, and come on just before you come down for breakfast. It *assumes* the house will cool down at night, because of poor insulation, and then need to be heated up quickly with very hot water pumped through the radiators.

A heat pump is controlled with a more sophisticated box of tricks. It never actually turns off, but modulates according to outside air temperature, which it constantly monitors. The house is warm all the time (though it can be set cooler at night) so it is more important than ever not to waste heat to outside.

This brings us to insulation.

Our Detached Residence in Leafy Orpington was built around 1906. It was (fairly) well built, but with no consideration for namby-pamby things like insulation. You lit a fire in one of the open fireplaces, and pulled up a chair. And at night you put on several pairs of pyjamas and/or froze.

When we moved here in 2018 it had…

Solid walls of 9" (225mm) brickwork, with no insulation

Pitched roof with negligible insulation: 2" (50mm) of fibreglass quilt, probably 1960s vintage

Timber ground floor, over a well ventilated therefore cold air space, with no insulation

Windows partly replaced with aluminium framed double-glazing, probably 1990s.

Insulating solid brickwork walls is possible but expensive. You either change the external appearance (in our case rather nice Edwardian red brickwork) or destroy the internal features such as cornices, skirtings etc, not to mention making the rooms a bit smaller.

So we *haven't bothered.*

But we have…

Insulated the loft space with 12” (300mm) of fibreglass quilt, or with 6” (150mm) of foam insulation board where less space was available. As foam board is twice as effective as quilt, these are equivalent, and both give a U value of less than 0.15W/m^{2}K. This is better than the standard for new built housing.

Super insulated the flat roof of the large rear extension, adding 4” (100mm) of foam board to the existing 6” (150mm) of quilt. This gives a U value of 0.12W/m^{2}K.

Insulated the ground floor, by lifting the floor boards and putting down 4” (100mm) thick foam boards, which span over the under-floor void. This gives a U value of 0.22W/m^{2}K (while retaining the ventilation underneath, from airbricks.)

Replaced all remaining single-glazed windows with new Class A uPVC windows with high performance double-glazing, 20mm argon filled spacing and low-emissivity glass. In the converted loft we’ve put in *treble-glazed* Velux rooflights.

As mentioned above, the solid brick walls remain uninsulated, with a U value of around 2.0W/m^{2}K. As it’s a detached house, there’s a lot of outside wall, and this is where most of our heat energy is lost – probably around 7kW of the total of 10kW for the house as a whole, when it’s zero outside and 20degC inside.

Solar panels

In March 2019 we put up 15 solar photo-voltaic panels. At 300W nominal capacity each, these make up a 4.5kWp (kilowatt peak) array. They don't all face in the same direction: seven panels are on the main side roof of the house, high up, facing a bit south of west; the other eight are mounted on the flat roof of the rear extension, facing a bit east of south. Clearly the sun can't shine straight down on all of them at the same time, so they never produce 4.5kW in practice. But they have achieved an impressive 3.2kW, on sunny days in the afternoon.

The installation cost £7,969.50. In the two years since then it has generated 7,962kWh of free electricity. We just got in on the last knockings of the government's Feed-In Tariff scheme, and are being paid FIT at 6.5p per kWh generated. This is based on an *assumption* (unmetered) that we use 50% of what's generated, and the other 50% goes out to the grid. For the 12 months of 2020 we were paid £265.

Assuming we used half the electricity generated, this will also have saved us buying 1,875kWh per year, at 14.4 pence per kWh = £270 per year. So the total benefit comes to £265 + £270 = £535 per year, a rate of return of 6.7% on the investment in the panels.

We decided not to invest in a big (and expensive) domestic storage battery, which would have stored the free electricity generated during the day, to use later, such as to cook our dinner in the evening. This was probably the right decision, because the solar panels work very well in conjunction with the heat pump. This spring has seen lots of cold but sunny days. For six or seven hours on each of these days, the free electricity from the sun has powered the heat pump, thus providing free electricity, times the SCOP of 3.29! Of course this won't apply in the summer, when the heat pump isn't needed to heat the house, nor on gloomy winter days when there's no sun. But in the spring and autumn it's a great combination.

Electric car

In August 2019 we bought this little Citroen C-Zero electric car. 2012 vintage, cost just £6,100. It has a battery of 'just' 14.5kWh, which limits its range to around 70 miles on a good day. This is perfect for shopping trips and chauffeuring grand-daughters round SE London. We try to do longer journeys mainly by train where possible.

On sunny days, the solar panels produce a maximum of just over 3kW, so we charge the car from an ordinary 13amp domestic socket in the porch, at a rate of 2.4kW. We haven't invested in a high-speed charger (7kW) as this would exceed the output from the panels, and draw electricity from the grid. On those days when the sun forgets to shine, we charge the car at night at 5p/kWh, available between 12.30 and 4.30am on Octopus Energy's Go Tariff. So the car costs either 0p per mile (when the sun shines) or around 1p per mile (when it doesn't). VASTLY cheaper than petrol.

The heat pump hasn't affected the electric car directly - it charges with electricity rather than hot water. But the future for electric cars is likely to involve Vehicle-to-Grid (V2G) technology. New EVs have Enormous Batteries, which, using two-way inverters, can be used to power the house while your car is sitting in your front drive. This will allow you to charge the car battery when the sun is shining, or on off-peak tariffs, and use it later to power things INCLUDING HEAT PUMPS.

So, having helped save the planet, how much has all this cost, to install and to run?

Capital costs

The heat pump installation, with its clever controller and the electrical connexions, cost £10,165.05. We kept the nice big 250 litre highly-insulated hot water cylinder, installed in 2018, despite the fact that its heating coil is designed to work with a boiler rather than a heat pump. It seems to be fine.

The cost of the extra insulation and new double glazing is difficult to quantify, as we've been installing it gradually over the last three years, and would have done so anyway.

Capital subsidy.

We managed to get a Green Homes Grant (GHG) from the government, just before they scrapped the scheme at the end of March 2021. We were granted a voucher for £5,000 which went to the installer, reducing the installation cost to us to £5,165.05. The GHG was widely criticised as a shambles, with obscure and late payments etc, but our application went through fairly smoothly. BUT, having granted us £5,000 up-front, the government will DEDUCT the £5,000 from the Renewable Heat Incentive payments (see below). So, although the GHG scheme has come to an end, you can still get exactly the same government subsidy to install heat pumps – you just have to wait for it to be paid in instalments (over seven years) as RHI, instead of getting some of it up-front.

Running costs

This is where it gets a bit speculative. We used 34,454kWh in gas, for heating and hot water in the 12 months of 2020. Using the heat pump, theoretically the annual electricity input requirement should be 34,454 ÷ SCOP of 3.29 = 10,472kWh. Our electricity (from Octopus Energy) costs 14.4p/kWh during the day. But for four hours at night (12.30 – 4.30am) it drops to 5.0p/kWh. We set the heat pump to heat the hot water during those four hours, and also to charge the electric car. So our electricity bills are likely to be £1,500 to £1,600 per year, or £125 to £135 per month.

Running cost subsidy

As electricity costs around four times more than gas, per kWh, the government has the Domestic Renewable Heat Incentive scheme (RHI). This dishes out subsidy over the first 7 years of a scheme such as installing a heat pump. We have been granted the maximum, based on a ceiling of 20,000kWh per year. They apply the SCOP of 3.29 (which they refer to as *Seasonal Performance factor*) in a peculiar formula, and come up with a figure for subsidy of 13,921kWh per year. The tariff for Air Source Heat Pumps such as ours is 10.92p/kWh, which as it happens pretty closely reflects the difference in cost between electricity and gas. So the subsidy (for seven years) will work out as 13,921 x £0.1092 = £1,520 per year. But they will DEDUCT the £5,000 we've received as GHG, over seven years, at £714 per year. So we'll get an annual subsidy of £1,520 - £714 = £806. (Four quarterly payments of £201.50).

So, a nutshell…

Old cost for gas: £1,125 per year (£94 per month).
New cost for electricity: £1,600, less £806 RHI, so net cost around £800 per year (£67 per month).
Annual saving of around £325 (£27 per month) or nearly 30% on our fuel bills.

References

Heat pump: NIBE F2040, 16kW model (largest of four sizes): www.nibe.eu
Heat pump controller: NIBE SMO 20 (we've learnt to understand it - mostly!)
(other good heat pump makes include: Panasonic, Mitsubishi, Hitachi, Daikin, Vaillant, LG)
Installer: Bushby, of Biggin Hill, Kent: www.bushbygas.co.uk
Domestic Renewable Heat Incentive (RHI): www.ofgem.gov.uk

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