Eco Heating by Exhaust Air Heat Pump

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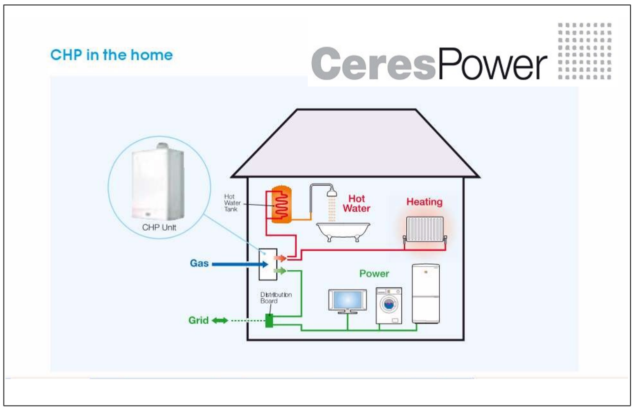
INTRODUCTION

This is my house with its Solar PV panels.

This also my electric bicycle which is also rather 'eco'. Everyone over 50 should have one. But neither the bike nor the PV panels are part of this story.

The house was built in 1957 and I set myself a budget of £100,000 to extend and modernise it. I allowed £10,000 to update the heating system. Other things like double glasing I counted as part of modernising it. The cavity walls had already been filled by my mother when she lived in it.

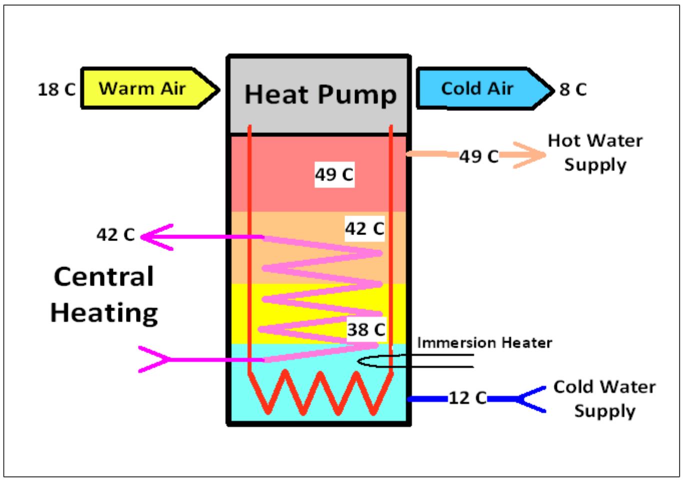
I wanted to heat it in future proof way and as economically as possible. I already knew I should save up to 25% heating energy by heating from below. That is because much of the heat from normal radiators rises to the ceiling. Heat from below and the average room temperature can be less. Underfloor heating seemed obvious, but it would have been too costly to install throughout, so fan assisted radiators (EcoVectors) were used in about half the rooms. This makes it future-proof as the heat to heat the water can come from any source now or in the future.



Most people expect an all-electric future from 'renewables'. But I expect we will generate our own electricity and heat from gas, probably 'renewable' hydrogen. There are already (in 2012) tens of thousands of fuel cells in Japanese homes. This picture from Ceres Power shows a fuel cell both heating water and generating electricity, and even exporting some to the grid. When the heat and electric power are added together about 85% of the energy in the gas can be used. Compare that with a power station. Much of the energy goes up the cooling towers. Only about 40% reaches us. So a fuel cell should cut the fuel consumption by about 50%.

But in 2009 in Europe such fuel cells were not yet generally available. It looked like I'd have to install a gas boiler. Then I realised that underfloor heating is ideal for use with a heat pump, and so are EcoVectors. If I were to install a heat pump now I would still be 'future-proof' as one day I could run it with my own electricity from a fuel cell. Then 100 kWh gas should produce 45 kWh electricty plus 40 kWh heat. A heat pump using that 45 kWh could deliver 135 kWh more heat to add to the 40 kWh from the fuel cell. I could get 175 kWh heat from 100 kWh gas! Compare that with the 40 kWh or so I'd get when a power station consumes 100kWh gas, or even the 90 kWh heat I'd get from a 90% efficient condensing boiler.

So what kind of heat pump was it to be? A ground source heat pump looked expensive, especially boring or digging holes in the garden. An air source heat pump sounded better, but I was concerned their performance drops off just when most needed – in the coldest weather. Then I discovered Exhaust Air Heat Pumps (EAHPs) normally used to heat water.



In a Chinese restaurant kitchen there will be plenty of heat where where rice and stir fry are being cooked. At the other end of the kitchen salad may be in preparation and that should be cold. An EAHP can suck in the hot steamy air, take heat out of it to put into hot water for washing up and blow the cooled air into the salad preparation area. An ideal solution!

The 'EcoCent' I bought included a 'coil' in the lower half of the hot tank for additional heating by solar thermal panels. I asked the supplier 'Earth Save products' if I could instead take heat out of this coil for underfloor heating. They agreed that in principle I could do this. In this way I could draw hot water from the top of the tank and warm central heating water from the bottom, as shown in the diagram.

So I planned to suck air from the kitchen / utility areas and blow the cold air out through the roof. This would put the house under a negative pressure collecting heat that normally leaks out through the bathroom window, loft hatch, etc. I'd be catching some lost heat, raising its temperature in the EAHP and re-using it in my underfloor heating.

Next I obtained estimates of how much heat I would need in cold -5 C weather. I'd need about 7 kW, but the EAHP would provide only about 3 kW. I could turn ON its immersion heater and get 3 kW more, but that heat would be costly. Then I realised I might not have to turn it ON if I installed a gas fire. The heat from the gas fire would be sucked up into the EAHP to help heat the water. Of course I could have used a wood stove, or outside Heat Pump, etc.

My next discovery was a 2 kW 'flueless' gas fire in B&Q. Instead of a flue, it has a catalytic converter to ensure no carbon monoxide is produced. It is 100% efficient, even better than a gas boiler.

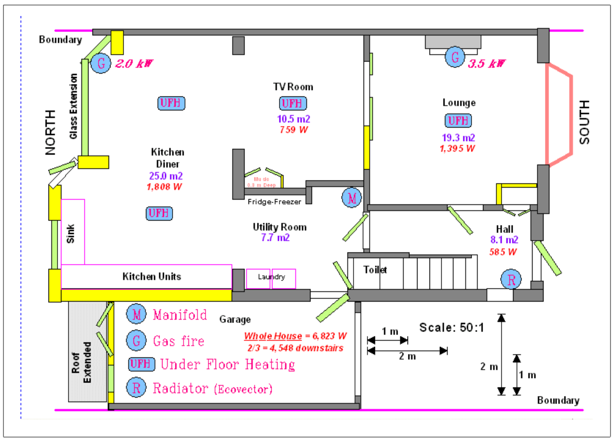
It was easy to install in the Kitchen-Diner. So when I need some top-up heat I use that. Visitors regularly comment on how homely its real flames look. If I need more heat I can turn ON the immersion heater as well.

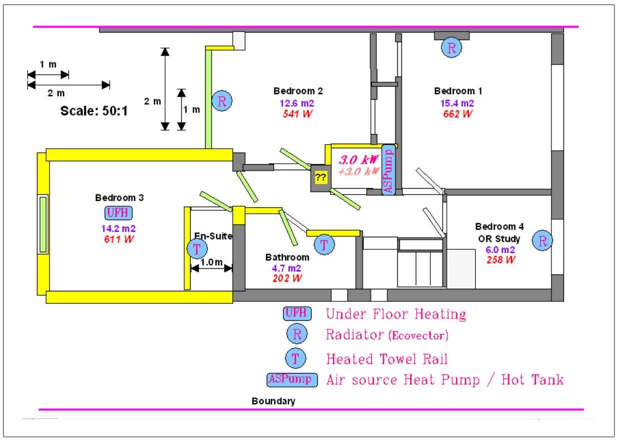
We also updated the ancient gas fire in the lounge. It too looks nice, but we've found we don't need to use it.

That describes in outline our heating system which I believe is somewhat more efficient than a boiler. The house remains comfortable and the air is never stale. I hope one day to add a fuel cell. The system is ready to take one.

HEAT REQUIREMENTS

Here are the plans for the modernised house. The new construction is shown in yellow. It shows the area of each room (m^2), its heat requirement (W) and how it is heated: Underfloor (UFH), Ecovector, Gas fire (G) or heated towel rail (T). Total living area is 135 square metres.





The total heat requirement was calculated from a modified Mitsubishi spreadsheet that can be found at www.fairshares.co.uk/heating/Heat Loss Calculator.xls

SUMMARY FOR 1957 SEMI at 53 Bury Road					
FABRIC LOSSES	104.0	sq m			
- Window Area in walls	20.8	sq m	1,684.8	Watts	
- Wall Area remaining	83.2	sq m	1,010.9	Watts	
Roof Area	66.0	sq m	1,247.4	Watts	
Floor Area	66.0	sq m	712.8	Watts	
TOTAL FABRIC LOSS			*4,655.9*	*Watts*	*68%*
VENTILATION LOSS					
Volume	330.0	cu m	*2,227.5*	*Watts*	*32%*
HOT WATER			*0.0*	*Watts*	*0%*
TOTAL HEAT REQUIREMENT (At -5 deg C)			*6,883.4*	*Watts*	*100%*
i.e. per square meter			*52.1*	*W/m2*	
or per cubic meter			*20.9*	*W/m3*	

This predicts 68% heat loss through the fabric and 32% through ventilation with 6.8 kW needed in all. The ground floor was allocated more heat per square metre than the first floor.

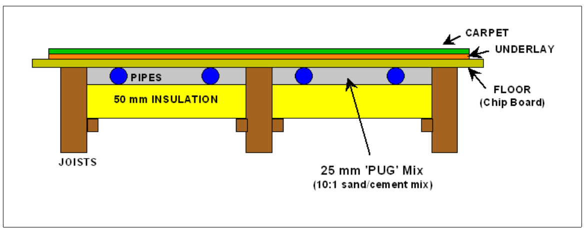
The heat sources available are the EAHP (3 kW), the Flueless Gas fire (2 kW), the Lounge Gas Fire (3.5 kW) and the Immersion Heater (3 kW) totalling well over 6.8 kW. The EAHP is the primary heat source with the others available for top up as described below.

A gas engineer would take a different approach. He'd install a boiler 20% or so more than 6.8 kW to heat hot water also, but this is not necessary with an EAHP as described below.

HEAT CIRCULATION

Water is heated as it passes through the coil in the tank of the EAHP, then pumped to the UFH and radiators to deliver heat around the house. A programmable wireless thermostat in the hall controls this pump, turning heating OFF when the hall temperature is sufficient.

The original house had suspended wood floors. I was advised not only to keep these, but to use them in the extension also. This keeps the wood ventilated.



After looking at many options we installed UFH pipes between the joists as shown. We used a dilute 10:1 dry sand / cement 'pug' mix 25 mm thick to spread the heat in preference to heat spreader plates.

I investigated heat flow through floor materials and learned that plastic foam underlay should be avoided. But other floor coverings transfer heat well enough, even carpet with a dense rubber underlay which we have in the lounge. In the kitchen-diner we have a laminate floor.

The UFH piping, room thermostats and manifold were not expensive, but the labour and disruption installing the UFH was substantial. It did however insulate the floors as well.

We could not face the cost of extending UFH to the hall and existing bedrooms. EcoVector radiators were used instead. They are far easier to install.

These operate like a car heater. A two speed thermostatically controlled fan blows warm air downward over the floor. The temperature 'span' between ON and OFF for this thermostat is very small allowing close room temperature control. It is very easy to set as you can feel the fan circulate the air.

It also has another thermostat intended to prevent the fan coming ON if the water temperature is too low. I found the temperature at the main circulating pump had to be over 43 C before the fan would come ON, but once ON the water temperature could fall to 35 C before it cut the fan OFF. I found this a nuisance. Sometimes the EcoVector fans would not come ON even though the water temperature was quite hot enough to give useful heating. I therefore opened the EcoVector and bypassed this second thermostat. Yes, it is now possible to leave the fan running when the heating is OFF, but it is obvious when the fan is running.

Although the fan was OFF in our spare bedroom, I noticed that the EcoVector was still acting as a 'normal' but poor radiator and therefore using heat. In order to cut it OFF completely I had stop taps fitted to the water inlet of each EcoVector. The EcoVectors are now work well with UFH.

Overall control is achieved by the hall thermostat and fine control in each area by the UFH room and EcoVector fan thermostats.

CONTROL AND PROGRAMMING

Heat circulation is controlled by a wireless thermostat in the hall. This is generally the coldest place in the house, and most affected by outside temperature.

It is programmed to the following times and temperatures: - 10.0 C from 5.20 a.m.; 18 .0 C from 7.10 a.m.; 10.0 C from 12.30 p.m.; 18.5 C from 2.20 p.m.; and 16.0 C from 11.40 p.m.

The span between ON and OFF is only 0.5 C. This means that from 2.30 p.m. the heating turns OFF at 18.75 C, but turns ON again at 18.25 C.

In summer the hall temperature is always high enough to keep the heating OFF. This does not mean that the EAHP stops. It goes on heating the water in the tank until it reaches 49 C right down to the bottom. It then stops. The hall temperature never drops as low as 10 C set for two periods of the day. During these periods the heating is therefore shut OFF. The tank therefore heats up fully, ensuring domestic hot water is available in the kitchen and bathroom in winter too.

Hot water is drawn from the top of the tank, and which refills with cold from the bottom. It is remarkable that these hardly mix even over many hours. For the same reason space heating taken from the coil in the bottom of the EAHP tank has little effect on our hot water at the top.

The EAHP itself is set to run all the time, but stops when the tank reaches 49 C at the bottom. It starts up again when the this temperature falls to 43 C. Every week the immersion heater comes ON automatically and takes the water to a higher temperature to 'sanitise' the water.

Programming might be differ for different lifestyles. In my case the 5.20 a.m. setting ensures hot water in the bathroom for a morning shower. We rise around 8.00 a.m. So in winter the heated towel rail will have taken the chill off the towel from 7.10 a.m. Since we may have used some hot water during the morning we recharge the hot water again from 12.30 p.m. Heating comes on a little higher for the afternoon and evening from 2.20 p.m. The 16 C overnight setting from 11.40 p.m. is ensure that the house does not get too cold overnight.

All this is automatic once the wireless thermostat is programmed. On rare occasions there can be so much cooking going on that the heat from the kitchen reaches the hall and turns the heating OFF. Then the kitchen is hot, but my study (bedroom 4) goes cold! The solution is to over-ride the programmed temperature. It returns to the programmed value for the next period.

There is also individual control in each room. The hall radiator need only be ON in cold weather. Bedrooms 1 and 2 radiators are also normally OFF. Their EcoVectors respond quickly when needed. Bedroom 3 is where we sleep, and is set to about 17 C.

I use Bedroom 4 as a study. I find I'm surprisingly comfortable at 17.5 C . This is because the EcoVector delivers its heat downward so my legs stay warm (until 11.40 p.m.!) It is the coldest room in the house. Turning up gas fires downstairs is too indirect to help much. So, in very cold weather I do sometimes turn ON the immersion heater in the EAHP until the water temperature reaches about 43 C.

The Lounge and TV rooms remain comfortable with UFH heating from the EAHP. So does the kitchen-diner for much of the time, but the 3 kW heat from the EAHP is insufficient when the weather gets colder. That starts roughly from the time the winter duvet goes on. We then light the pilot light in the flueless gas fire. The pilot light itself (160 W) makes a difference to the kitchen-diner, as does cooking, etc. We turn its heat up (2 kW) and down (1 kW) as needed during the day. The pilot is generally left ON overnight. We have found the EAHP copes better if we turn OFF the UFH in the kitchen-diner during periods that we run the flueless gas fire.

We find the kitchen-diner is about 18.5 C at breakfast and rises gradually until it is about 21.5 C at night. The TV room and Lounge are much the same temperature.

For holidays we normally leave the EAHP running, but shut OFF the circulating pump. Returning from a winter holiday the house may be only 11 C or so. We then turn ON everything! Both gas fires plus the immersion heater. The house is comfortable again in two or three hours.

PERFORMANCE AND COSTS

I have an energy meter attached to the EAHP and read it and my household use of gas and electricity each week. This enables me to separate the EAHP consumption from other household appliances.

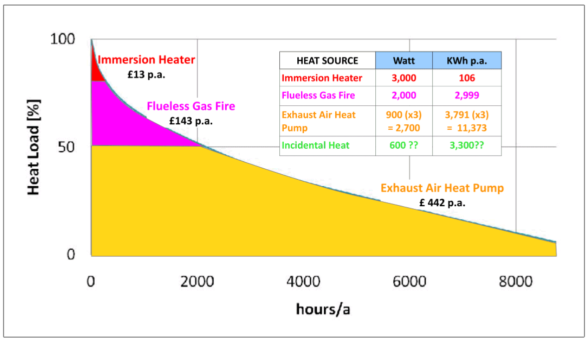
It has enabled me to compare performance with an 'average English home' and with other Cambridge Carbon Footprint 'EcoHomes' open in May 2012. See these links for the full comparison:-

www.fairshares.co.uk/heating/EcoHomes 5-2012.pdf
www.fairshares.co.uk/heating/Comparison of 2012 EcoHomes.pdf

An average English home is has 91 m2 living area, consumes 16,500 kWh gas and 3,300 kWh electricity giving it a total carbon footprint of 51,458 g CO2/m2 of which I estimate about 37,000 is for space and water heating. My home is 135 m2 area, and for 12 months from March 2011 required 2,999 kWh gas, and 6,897 kWh electricity of which 3,897 was to the EAHP achieving a carbon footprint of 18,200 g CO2/m2 for space and water heating i.e. about half that of an average home. I estimate that my new solar panels will reduce this to 15,048 g CO2/m2.

The left of the following diagram shows where heat comes from for the coldest hour of the year and the right shows the warmest hour. When coldest I needed the EAHP, flueless gas fire and a bit of top-up from the immersion heater. At warmer times the EAHP was sufficient. The areas of each zone show the amounts of energy from each source. The costs shown assume electricity at 12 p/kWh and gas at 4.8 p/kWh.

The table inset in the diagram shows the heat delivered by the EAHP is about 11,373 kWh assuming it has a 'coefficient of performance' (COP) of three. I also estimate that there is typically 600 W incidental heat from appliances, solar gain and body heat. This incidental heat is harvested by clever architects, but it makes even a normal house comfortable inside when it is about 15.5 C outside.



The system cost about £10,000. The EAHP cost about £2,000 which is similar to a boiler plus hot tank. The EcoVectors and UFH pipes, etc. plus other hardware cost about £2,500. The balance was the cost of installing it.

If EcoVectors had been used throughout the hardware costs would have been similar, but the installation cost much the same as for a conventional boiler system. Conventional radiators are now very in low cost and this is the main reason an EcoVector based system costs a bit more. However conventional radiators are not suitable for use with heat pumps whereas EcoVectors are and are also more controllable and require less heat. I guess an all EcoVector solution would have cost about £6,000, and a conventional system about £4,500. A flueless gas fire costs about £350.

THE 'ECOCENT' EXHAUST AIR HEAT PUMP

The EAHP deserves a longer discussion. It could be used in other perhaps better ways, and it is interesting to compare it with other heat pumps. (See Ref: 1)

Here are simply a few notes on the EcoCent from Earth Save Products. It should be set to run all the time so its clock and timer settings are trivial. I set Parameter '0' to shut it it OFF when the temperature of the whole tank reaches 49 C. I set Parameter '1' to bring it back ON again when the temperature at the bottom of the tank falls by 6 C, i.e. falls to 43 C.

Parameters '2' and '3' are to bring ON the immersion heater for a set time if the temperature of the domestic hot water at the top of the tank falls too much. I make no use of these Parameters as I use the immersion heater so little. Nor do I bother with Parameters '4' and '5' which set the conditions for the weekly sanitisation cycle.

Condensation can form in the EAHP and just like a condensing boiler. It has a waste pipe to take this away. This should be routed to a place where it cannot freeze.

There is are criss-cross of wires where the air ducts connect. I've cut out a piece from filter material intended for a cooker hood and fitted it to the side that sucks. This should catch dust that might otherwise lodge in the heat pump reducing its efficiency.

I had a 3 kW instead of the normal 1.5 kW immersion heater installed. This was probably not necessary. It lasted hardly a year before cracking up due to hard water deposits. This is Cambridge! This might have been aggravated by frequent use of the immersion heater in its first winter before I'd discovered how best to balance heat from the flueless gas fire and EAHP. We've now installed a water softener! There is also a 'sacrificial anode' of magnesium which should be checked annually. Its purpose is to corrode away instead of other components of the system. See Ref 1 for other ideas for avoiding these sources of water damage.

The duct through that expels cold air through my roof is short. The warm duct is split and sucks some air from the utility room where there is a large fridge-freezer, washing machine and tumble dryer. That is not vented outside, simply into the utility room where this warm moist air is sucked up into the EAHP. It sucks other air from above the the kitchen cupboards. This is a long run of duct in the loft and I found 5 C temperature drop to the EAHP. I reduced this greatly by massive extra insulation over the warm ducts, and for good measure installed an in-line extractor fan. I opened the EAHP and connected this across the heat pump motor so that it goes OFF whenever the EAHP goes OFF.

Of course some air has to leak into the house. It does so in various ways. We keep the trickle vents open in all downstair windows, the door between the garage and utility room is not well sealed, and there could be some leakage through floor boards in the hall and utility room.

The EcoCent from Earth Save products is not the only EAHP available. The best known is the Swedish NIBE. This is has separate tanks for hot water and for space heating. I believe it's heat pump is also more efficient, but it is about twice the price, and users have found it expensive to run when its immersion heater is used for winter top-up. I've found the EcoCent plus some other form of top-up a very effective solution.

Servicing consists of checking the dust filter and sacrificial anode. The gas fires should also be checked. These checks should cost much less than a boiler service contract.

CONCLUSIONS

You can cut your energy use by heating from below, by either fan assisted radiators or underfloor heating. Underfloor heating also insulates the floor but is more disruptive than fan assisted radiators.

An Exhaust Air Heat Pump can further reduce carbon footprint. But since it delivers only about 3 kW heat it needs some form of top up. The simplest is a gas fire, but wood stove, or external ground or air source heat pump could be used.

Use of EcoVectors, Exhaust Air Heat Pump and a flueless gas fire with good controls could cost as little as £2,000 more than the normal radiator plus condensing boiler solution.

Solar panels further reduce the carbon footprint.

The addition of micro-generation (e.g. a fuel cell) in the future will make a further great saving in fuel consumption and carbon footprint.

SUPPLIERS

Installation was by a small local builder who called in local plumbers and electricians. They were a typical team of 'white van men'.

EcoCent (EAHP) with 300 litre tank came Earth Save Products draws about 900W. (They and NIBE are at the time of writing the only MCS approved suppliers of EAHPs.) www.esavep.com
[Energy My Way are now franchised installers of the EcoCent. www.energymyway.co.uk]
Wundafloor provided the UHF hardware and layout plans to fit it. www.wundafloorheating.com
EcoVector LL1200 came from www.smiths-env.com
[There are several on-line suppliers. There are also alternative brands of fan assisted radiators]
Focalpoint flueless gas fire came from B&Q.
Wireless programmable thermostat (Horstmann HRFS1) came from Screwfix.

REFERENCES

1: 'Understanding Exhaust Air Heat Pumps' to be written (Watch this space!)
2: This file may be downloaded at www.fairshares.co.uk/heating/My EcoHouse 5-2012.pdf