Micro-generation

Power Your Own House!

Price 50p

Background

The notion that energy should be supplied to a dwelling from 'outside' through pipes and wires is relatively new. The first gas main was laid only in 1812 and mains still reach only 70% of homes. The widespread availability of electricity is barely 100 years old. For most of our history our ancestors collected wood for warmth and cooking and used candles for light. Many in the third world still do so today.

The gas and electricity utilities came to dominate supplies because they were more convenient as well as being reliable, cheap and relatively clean. Now the age of abundant cheap fossil fuel is drawing to a close. Fossil fuel must be used more frugally and alternatives found. Electricity generation at large remote power stations has received particular criticism because the steam turbine technology used ends up with large quantities of 'low grade' heat which have to be wastefully discarded to river, sea or air. Energy is also lost transmitting power to users and, though this occurs with wind farms and other distant renewable sources as well, there is increasing interest in 'local' or 'micro' generation of electricity in or near individual homes.

Currently there is a ferment of ideas and, in economic terms, the market is 'chaotic', that is to say the best way forward is still not clear. Micro-generation is only one of many technologies being pursued.

This note draws on the expertise of Arup, the international consulting engineers, to point a way forward. At its heart the strategy the country is looking for is to use less energy and much less fossil fuel.

The available technologies can be split into 3 groups: micro-generation of both electricity and heat, the use of heat pumps, and greater efficiency of use.

Micro-generation

Solar hot water panels: The simplest and best proven technology is the simple solar hot water panel mounted (ideally) on a south facing sloping roof. Direct and indirect sunlight heats water (or another fluid) in the panel and the heated water is circulated through a heating coil in the house hot water tank. A 4 person household would need about 4 square metres (m^2) of panel and a hot water tank of some 250 litres capacity. The pump is controlled by thermostats which switch it off when the temperature in the panel is lower than in the tank, and also when the tank temperature reaches an upper limit. The system may be drained in winter or anti freeze added but other maintenance should be limited to an annual check. Cost, including installation, will be between £1500-£3000 and this will typically provide 40-50% of annual hot water and almost all that is needed in the summer months. It will not provide central heating. About one third of the heat required in a house is used for hot water so a solar hot water panel would save about 15% of the heating bill. Payback would take at least 10 years with a gas fired boiler but would be very much better where heat is provided by electricity. Technically there is no reason on earth why hot water panels should not be installed on most new houses, particularly in the south of England. Worldwide this simple technology currently produces more renewable energy than wind.

An elegant, quiet 6 kW wind turbine suitable for an apartment block

Because the panels can not meet all demand the house hot water tank requires 2 heating coils (or a supplementary electric element). This means that in existing houses the hot water tank has to be replaced, adding a few hundred pounds to the cost.

Small wind turbines: These are usually mounted on a pole fixed to a wall taking them above roof level. There are 1 kW (max) Windsave and 1.5 kW Swift turbines on the market. The first is 1.75 metres in diameter and the second 2 metres. They are visible, but not massively so. The Windsave generates about 45dB noise, the level of a normal human voice, though this will usually be hidden by the prevailing wind. The Windsave produces 100 W (a conventional light bulb) in winds of 6 mph with output rising rapidly with wind speed to 1 kW. The electricity produced is fed into a black box which synchronises the power with the mains and is then simply plugged into a 13 amp socket. Thus, when the wind is blowing and the householder is using electricity, the power comes from the wind rather than the mains.

Savings of 30% on electricity bills are claimed but 15% seems more likely. The power has to be used instantaneously (there are no batteries) and the system does

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Material for this briefing note draws heavily on information presented by Chris Trott of international consulting engineers Arup at an ALDES fringe meeting at Harrogate in Spring 2006. If you have comments please send them to the ALDES secretary, Richard Balmer at 79, Links Drive, Solihull, B91 2DJ, or richard_balmer@blueyonder.co.uk

not export to the mains, so quite a lot of the available power is unused. The Windsave is on sale for £1000 plus 5% VAT and 2 hours installation. Grants are available and, because the black box includes a meter, householders can claim a refund under the renewables obligation certificate (ROC) scheme. Payback is certainly less than 10 years. A great advantage of these small wind turbines is that they can be retro fitted to existing properties at little extra cost.

Though imaginative, small wall mounted turbines may not prove the best solution in the long term. There is an inevitable mismatch in a single household between demand and supply. The greater the number of houses however the more the demand for electricity evens out. It is possible that 50 kW wind turbines, supplying say 30-50 house estates or large apartment blocks, would have lower unit costs and greater utilisation and prove better value for money. Whether a single large tower would prove more or less intrusive and noisy than 50 house mounted turbines has still to be decided.

Solar photovoltaic (PV) panels: PV panels suffer in comparison to wind. They are more expensive and, in the UK's northern latitudes, less efficient. Average utilisation is barely 10% of the installed capacity. Another problem is that the panels give a direct current (DC), usually 12 volts, which has to be transformed to the 230 volt AC mains supply via an 'inverter'. Furthermore performance tends to tail off with age. Currently one doesn't expect more than 25 years use. Thus if PV panels are used to replace roof tiles in new housing to save money the owner either has to replace the roof (or part of it) every 25 years or forgo the solar electricity for most of the building's life. This is less of a problem with commercial buildings which tend to have shorter lives.

Two main types of panel are commercially available. The so called amorphous silicon panel is cheaper and uses less energy in its manufacture, but is less efficient than the crystalline type. A 2 kW panel, installed, would cost about £6000 and be 31 m^2 in area. The crystalline alternative would cost about £8,000 and cover 14 m^2. On the south coast one might achieve an annual output equivalent to 900 hours use. Assuming a cost of £7000 and a unit price for electricity of 7p/kWh, the panels would generate 1800 units worth £126 a year. This is a return on capital of only 1.8%, not enough to cover the capital cost even spread over 25 years. The economics are worse as one moves north and if one doesn't have a south facing roof or the optimum tilt. 1.4% return is perhaps a better average. Further south, around the Mediterranean for example, the economics are very much better and it seems likely the market will thrive there first.

Micro-CHP: Whereas wind turbines and solar panels can only supply energy when the wind blows or sun shines, a true micro-generator is like one's own small power station. Even so one must not be carried away. The only advantage of generating electricity locally is so that one can make use of the otherwise wasted low grade heat. Small may be beautiful but is invariably more expensive and less efficient. Here we are considering the provision of combined heat and power (CHP), not power alone.

Basically micro-CHP replaces the conventional hot water/ central heating boiler with a unit not much larger than a standard washing machine. It uses a 2 stage process. First the hottest gas from combustion is used to generate electricity and only then is the remaining heat used for hot water and central heating. Micro-CHP can use 'biomass' fuels such as wood pellets or chippings as easily as gas or solid fuels, though energy is saved even using gas.

Small machines cost more per unit of output than large ones so capital costs are high, around £4200/kW of electric output. The main disadvantage with micro-CHP however is that although there is an *overlap* in the demands for electricity and heat, the match is far from perfect. The need for heat goes up and down with outside temperature whereas the need for electricity varies by the hours of darkness and daytime household activities. Furthermore the efficiency of generating electricity is relatively low, barely half that achieved in big power stations. It is usual to run micro-CHP according to the heat demand and accept the electricity as a bonus. Though some electricity can be exported to the grid, the need for the national grid remains.

Even so electricity bills will be reduced. Also, where biomass can be employed instead of gas, CO_2 emissions will be reduced from around 0.2 kg/kWh to an eighth of this. Biomass from forestry sources will cost about half that for gas and waste biomass even less, although there will be costs and complications in purchasing and storing fuel. Alternatively biomass can be grown in one's garden, though the garden needs to be large enough for about 4 times the area of the building to be planted.

The economics for micro-CHP are similar to that with wind. One will achieve lower costs and greater average utilisation with larger units supplying heat and power to apartment blocks or even new estates than with smaller units in individual houses.

Fuel cells: Fuel cells produce electricity directly by burning hydrogen over a catalyst in air. There is currently massive interest in using fuel cells to power vehicles, but they are expensive and the holy grail of producing the fuel, hydrogen, renewably and relatively cheaply is still being sought. Fuel cells for individual households would be an ideal solution because they could provide the 'back up' electricity currently needed from the national grid. Currently commercial exploitation is 'over the horizon'.

Heat Pumps:

Heat pumps to air: Refrigerators and simple air conditioning units utilise 'heat pumps'. Refrigerators are devices which move heat from inside an insulated 'cupboard' to the outside at the back. If one feels behind a refrigerator it will be warm. Heat pumps use the physical property that liquids need heat, not just to reach boiling point, but to boil it off as a gas - and vice versa (eg water to steam). A heat pump comprises a pump and evaporator. The pump converts the gas to its liquid form generating heat and the evaporator reverses the process. In a fridge the first half of the cycle takes place outside and the second half inside the 'cupboard'. The discharged heat dissipates into the surrounding air. The box type air conditioning units one commonly sees in warmer countries operate on the same principle. Such units can be reversed in cold weather to extract warmth from the outside air.

All heat pumps use electricity but it is commonly claimed the energy gained is 3-4 times the energy employed. Such pumps could be employed more in the UK. The only drawbacks are the need for several pumps to provide heat in all rooms around the house and the use of electricity to power the pumps.

Heat pumps to ground: Heat pumps to air have obvious disadvantages where houses are close together and, because electricity is about 3 times as expensive as gas, the economics are not particularly attractive when gas heating is available. Furthermore the outside air temperature can vary over a large range making efficient operation difficult. More recently the idea of drawing (and discharging) heat to the ground has come to prominence. A borehole is drilled and a plastic pipe circuit installed. This is taken into the house to a heat exchanger which uses the mechanism described above. Heat from a water/anti-freeze mixture in the pipes is abstracted for the house before the mixture returns cooled to the ground, where it is warmed back to its original temperature. The borehole needs to be deep: 15 to 120 metres have been used. The depth depends on the ground conditions and in particular whether one can rely on the movement of water in the ground to continuously bring heat to the borehole. Costs amount to £800-1200/kW of heat, so a typical 6 kW system would cost around £6000. The temperature achieved with these systems struggles to exceed 40^o C so they are most suitable for under floor heating systems (which require hot air at 30-35^o C). They can pre-heat but not fully heat hot water, nor feed central heating radiators which need water at 60-80^o C. Electricity is also needed to power the pumps. There is a large saving if the house is heated by electricity but little if heated by gas. The circuit can be reversed to provide cooling in hot summers at no extra cost.

Although boreholes are preferred, because ground becomes warmer with depth, the lengths of pipe can be laid out in relatively shallow trenches if land is available.

This market is in its infancy but the technology is relatively basic and the deep borehole system in particular now needs to be tested and refined by encouraging installations.

Greater efficiency:

Appliance efficiency: Appliances are consistently being improved. The energy labelling scheme has taken off and is clearly influencing consumers. Under European Directive 92/75/EEC the cost of A rated machines attract subsidy so minimising the cost disadvantages. Washing machines, tumble driers, dishwashers and so on tend to have working lives of less than 10 years so, unlike housing stock, the efficiency improvements can be captured quite quickly. An ‘A’ rated washing machine for example uses 40% less energy than an ‘F’ rated one and, though the average saving only amounts to about 100 units of electricity or £7 a year, one could shave 0.5 % off UK electricity use within 10 years through improvements in this appliance alone and similar amounts with refrigerators, freezers and so on.

Unfortunately the number of appliances increases yearly. 50 years ago a typical home had a wireless and Hoover. Refrigerators, washing machines, televisions, dishwashers, freezers, microwave ovens, food mixers, waste disposal units, videos and CD recorders, computers and printers, security lights and so on have all increased our demand for power. Many homes have several TV sets and computers and the availability of the internet and computer games lead to many hours of use. In the future air conditioning is likely to become standard, if only in one room.

Efficient lighting is widely available (though appropriate lampshades are often difficult to find) but lighting is now much more creative and many more bulbs are used. Whereas cooking was predominantly on gas, now it is electricity which is perceived to be cleaner though using 3 times the energy. In short, despite the efficiency improvements, the use of electricity in the home continues to rise.

Better insulation: Insulation standards have been improved steadily since they were first included in the building regulations in the 1970s. The 2006 regulations should reduce heat loss by another 20% over previous standards. There are 2 problems however. First, though one can add insulation in the loft, double glaze windows, fill cavity walls with foam and reduce drafts, it is virtually impossible to add insulation under floors or do more in existing homes. Second, as the heat lost through the fabric decreases, the energy required to warm cold air coming through the doors becomes more significant. It is obvious that a minimum of air must be allowed into the home so, if this need for heat is to be reduced, the warm ‘fuggy’ air going out needs to exit via a heat exchanger to warm the fresh air entering. The necessary ducting to enable this can be incorporated in new buildings but not in existing ones.

Summary:

New homes: It is technically possible to design a ‘carbon neutral’ house. This is not the same as a house ’self sufficient’ in energy. It is one with a zero *net* energy demand. It is possible for a house to be self sufficient in heat. The problems lies with the electricity. A national grid connection is still required to provide back up when the micro sources are inadequate and a dump when micro-generation exceeds local demand.

A carbon neutral house will require more technology than people are used to and more maintenance. More items will go wrong. There will be consumer resistance until the technology is tried and tested. Table 1 shows the technology that would be needed and estimated *additional* costs for a 3 storey 150 m^2 town house costing £360,000 (£1200/m^2 for building, £1200/m^2 for land). This is a

Technology	Extra cost
Mechanical ventilation via heat exchanger	£1,800
Low energy light fittings throughout	300
All white goods class A rated	-
Visible displays of current power + water use	-
Water efficient toilets	300
Spray taps in hand basins	300
Low carbon CHP with biomass + gas backup	1,800
Insulation to U = 0.11W/m^2 (c.300 mm thick) for walls, roof, ground floor	4,200
Triple glazed, Argon gas filled windows	900
Solar PV panels over 20% of roof	5,250
1.5 kW wind turbine	3450
Total	£18,300

Table 1 Extra cost of energy reduction technologies for 150m^2 3 storey town house

relatively favourable example because the extra costs will not reduce much with smaller, cheaper houses. On the other hand, the additional amount, 5% (or even 10%), is remarkably small. In part this is because, even though more expensive materials are being used, the labour costs remain much the same.

It should be noted that some of the technologies described above are mutually exclusive. For example there is no advantage is installing solar hot water panels if one is heating hot water with a biomass fired CHP unit. There are 2 other cautionary notes. The maximum amount of installed wind capacity that can be deployed in the UK is probably only 10,000 MW (providing about 7% of UK electricity). Only 1353 MW had been installed by end 2005 so there is ample opportunity for more. However if house mounted wind turbines are erected in their millions, that capacity will eventually be at the expense of large wind farms which currently produce electricity at least 2 or 3 times more cheaply. A similar reservation applies to the use of biomass in micro-CHP. The UK can not be self sufficient in biomass. There is insufficient spare land. We can either use that land for bio-fuels or biomass power stations or micro-CHP, but not all of them. For true sustainability the country actually needs fewer people.

Existing houses: Not all the technologies listed in Table 1 can be introduced into existing dwellings at any kind of sensible cost. On the other hand much, besides simple good housekeeping, can be done. The optimum order of priority would seem to be:

1. Whenever an appliance can not be repaired, replace it with a Class A alternative. Similarly steadily replace conventional lights with low energy ones.
2. Invest in insulation up to 300 mm in the roof, foam in the wall, double glazing in windows and draft excluders, where these are not already in place.
3. When the central heating boiler reaches the end of its life, investigate solar hot water panels or micro-CHP, or even ground source heat pumps. The first should save 15% of one's heating bill and the second 15% of one's electricity (and some gas if wood chippings, pellets or other biomass are used).
4. Install a 1 or 1 1/2 kW wind turbine if the neighbours will not be upset.

Conclusions

Micro or local generation of power can only make a small (though steady) contribution to CO_2 reduction because the potential gains are constrained by the slow turnover of the country's current energy inefficient housing stock. If it is assumed that buildings use 50% of all energy and that they last on average 100 years; that carbon neutral buildings arrive as early as 2016; but that gains in efficiency in existing buildings are offset by the increased numbers of buildings and equipment used within them; then CO_2 emissions from buildings will only reduce by 2% by 2020 and 17% by 2050.

Two linked initiatives are essential if even this progress is to be made. The first is to focus more attention on the rather dry sounding, but absolutely critical, 'building regulations'. Section L of these regulations determines minimum standards for insulation and energy use. The Building Regulations 2006, in force on 6th April 2006, should reduce CO_2 emissions by an average of 20% from the standards introduced in 2002 which themselves aimed to reduce emissions by 20% from Building Regulations 2000 (mainly by setting much higher standards for the efficiency of central heating boilers). The 2006 regulations provide, for the first time, for a pressure test of the property (to check for drafts and leaks through poor design or construction) and allow architects the welcome opportunity to achieve the set TER (Target Energy Rating) in various ways to encourage innovation, rather than by prescription. The standards however remain far short of those achievable in Table 1 and are not due for revision until 2010 and 2015.

The second, linked, initiative is to get as many of the emerging technologies as possible into houses (or apartment blocks or estates where the economics may be better) as soon as possible and in as large a number as possible, and tried, tested and 'tuned' so that by 2010 or at least 2015, architects, builders, house buyers and legislators can have the confidence (and the supporting evidence) to introduce them in all new properties.

This country is full of innovative people and innovative ideas. What we lack is a government prepared to take risks and work through far sighted councils and others, to initiate and support '100,000 micro-CHP' and '100,000 household wind turbine' type programmes, as the Germans and Japanese governments have done with solar panels. These are *planned* programmes with *timetables* and *reviews*, not random grant-aided efforts. They are needed to test the technology so that it can either be rejected or, hopefully, cross the bridge to commercial market *as quickly as possible*. 100,000 micro-CHP units in new houses, for example, would cost around £200M. If there was a 50% subsidy and the programme covered 5 years, the cost to government would be a mere £20M/year, a trivial sum to accelerate energy saving and CO_2 reduction.

PROFESSIONAL ADVICE

As noted on the first page, the majority of the material for this briefing note has been drawn from a presentation given by Chris Trott, of consulting engineers Arup, at Harrogate in March 2006. Further, detailed advice can be obtained from Chris at:

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A further source of useful information is the Energy Savings Trust