Proceedings European Geothermal Congress 2007
Unterhaching, Germany, 30 May-1 June 2007

Geothermal heat pumps – their role in global cooling.

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Keywords: ground source heat pumps, carbon emissions, global warming.

ABSTRACT

It may not be intuitive – that geothermal heat has a role in reducing global warming. Geothermal heat pumps are the fastest growing sector of the geothermal energy market. What is not often understood is the significant role they can play in reducing the emission of carbon dioxide. The heating and cooling of buildings is one of the largest contributors to carbon emissions due to the predominant use of fossil fuel in this sector. The IEA recognises that heat pumps are one of the most significant, single technologies for reducing carbon pollution. This paper explores how geothermal heat pumps are delivering growing, ongoing, carbon reductions, as well as offering advantages in terms of reduced heating costs, security of supply, energy efficiency and delivery of renewable energy.

1. INTRODUCTION

The years 2006 and 2007 will most probably go down in history as when the seriousness of man's impact on the planet due to the uncontrolled and accelerating growth in Carbon emissions was finally accepted by the majority of decision makers. The recent release of three parts of the Intergovernmental Panel on Climate Changes (IPCC) most recent series of reports comes down firmly in blaming man made carbon emissions as the primary cause of global warming that will occur this century. The Stern report in 2006 (Stern) had already foreshadowed this and perhaps received more attention because it was written by an economist, and as a result read by economists and governments. For the first time an attempt was made to assign costs to the result of inaction on carbon emission, and to the possible lower costs of ameliorating it. The message is that the sooner we reduce man made carbon emissions, the lower the costs and impacts of global warming. For any readers who are not already immersed in this discussion, there are numerous publications appearing in the English language press – eg "Six Degrees" by Mark Lynas, (Lynas) "Heat" by George Monbiot (Monbiot). The widespread distribution of Al Gore's film "An Inconvenient Truth" has helped to raise awareness. For those who have followed his development of Gaia theory, geothermalists can take some comfort from the un-common praise that James Lovelock heaps on geothermal energy in his recent book "The Revenge of Gaia." (Lovelock)

For anyone that works in the field of renewable or alternative energy, any of these publications have thought provoking facts and figures. Lynas quotes the work by Dukes at the University of Utah, where he points out that "an average US gallon of gasoline required approximately 90 tonnes of pre-cursor plant material in the process of its formation in ancient oceans......Calculated globally, human society consumes the equivalent of 400 years worth of ancient solar energy.....each year...through our use of fossil fuels"....Indeed, we probably use a million year's worth of fossil fuels every year – in terms of the time it took for them to form at current rates of use"

While geothermalists have historically concerned themselves with utilising heat from the earth to deliver electricity and heat as economically as possible compared to conventional fuels, they can now promote the benefits that geothermal energy offers in terms of carbon reduction. This will arise more and more as the "price" of carbon – whether real or virtual becomes the dominant feature in considering the implementation of energy sources.

It has long been understood that conventional geothermal energy, as used to deliver either heat or electricity, has a very low carbon content. This generally arises from the release of CO_2 from geothermal fluids as they are brought to service. Modern geothermal power plants will sometimes capture and sequester this small amount of CO_2 and return it to the ground to ensure that CO_2 emissions are kept as low as possible. Thus existing and future geothermal power stations will be of significant benefit in avoiding carbon emissions from energy delivery, in those countries and locations that are blessed with high and medium temperature resources. Only when HDR, or EGS, becomes available on a significant scale will it be possible for this low carbon technology to be utilised on a wider scale.

A significant development over the last five years has been the recognition, at least in Europe, of the size of the space heating and domestic hot water requirements. This, at last, is leading to calls for policies that will lead to the adoption of technologies in the renewable heating (and cooling) market. See for example the EREC call for a European Directive on Renewable Heating and Cooling (EREC). Other similar documents are being released and promoted in several European countries both by governments and NGO's. Amongst the so called "micro-generation" technologies that are receiving attention in these documents are geothermal heat pumps - GSHPs

GSHPS AND CO_2

The focus on carbon emissions is now leading to novel analysis of how, where and why man made CO_2 emissions arise. Figure 1 for example shows an analysis for the UK, of the relationship between the end user and the carbon emissions that their activities lead to. Note that this type of analysis is highly country specific – and depends critically on the fuel sources that deliver electricity, heat and transport. The depressing news for the UK public is that Recreation and Leisure tops the bill, followed by space heating and hot water, followed by food and catering. (Note that this analysis does not include for the contentious issue of air travel). Given that the hardest sacrifice will probably be the recreation, leisure and eating, we are left with trying to deal with space heating and hot water – the energy that GSHPs specifically deliver.

In this paper we address the potential carbon reduction offered by ground source or "geothermal" heat pumps. While practitioners in countries where this technology is widespread will be aware of the carbon benefits of GSHPs, it is worth newcomers to the technology understanding how, and whether significant carbon benefits can accrue in their own particular countries / locations.

Thus the initial interest in adopting GSHP technology may arise from issues such as local fuel costs, electricity demand reduction, security of supply, renewable energy delivery and so on. However, with the focus now turning to currently available technologies that can offer significant reductions in CO_2 emissions, it is important to understand the contribution that GSHPs may be able to make.

It is relatively straightforward to understand the contribution that renewable energy makes to the final amount of delivered heat from a heat pump. Figure 2 shows the simple representation of an electrically driven heat pump with a COP of 4, where 75% of the final heat arises from the renewable energy extracted from the shallow subsurface (anywhere from 1 to 250m- say). However, this simplistic figure has to be modified to take account of the way that the electricity is generated. The easiest, extreme case, is where the electricity is derived from other renewable sources, viz hydroelectric, wind, wave, PV etc. In this case the entire heat delivery arises from renewable sources and is fact one of the most efficient ways of using other expensive renewable sources to deliver heat. (The use of renewable electricity to drive direct electric resistance heaters is a sorry use of hard won renewable electricity). At the other end of the range, electricity that is derived from low efficiency fossil fuelled thermal plant, will lead to significant reductions in the overall contribution of the renewable energy from the ground. Figure 3 illustrates the net amount of "additional" energy that is delivered depending on the average COP of the heat pump (SPF or Seasonal Performance Factor) and the efficiency with which the electricity is generated. Thus any energy in excess of 100% can genuinely be considered as a net gain – derived through the extraction of renewable energy from the ground by the GSHP.

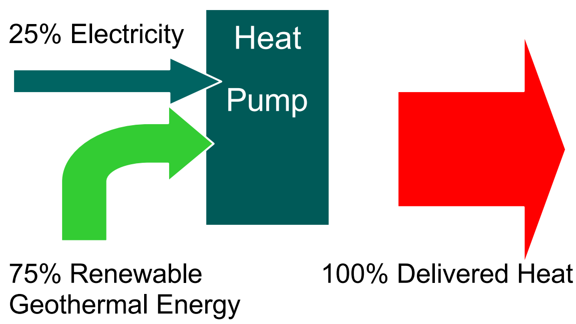

Figure 2: On-site renewable energy delivered by a heat pump with a COP of 4.

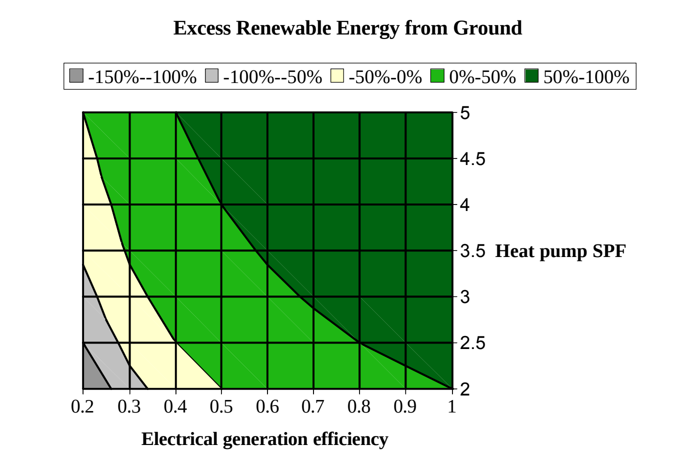

Figure 3: Excess energy delivered by heat pumps.

For other micro-generation technologies, such as micro-wind, PV, solar thermal and micro-hydro – it is self evident that any heat or electricity that they deliver is carbon free (leaving out issues related to embodied energy). For electrically driven heat pumps it is not as straightforward. Again the issue arises of how the electricity that drives the heat pump compressors is generated. If it is derived from carbon free, or at least carbon neutral, sources, ie /eg hydro, wind, wave, biomass, then the carbon emissions arising from heat supplied from a heat pump are also carbon free (or neutral). In practice, the electricity is generally derived from a mix of different fuel sources, eg oil/gas/coal/ nuclear/ renewable. Early work by the Energy Technology Support Unit in the UK (ETSU), established a methodology for calculating the carbon content of the electricity grid. To establish whether any carbon is being saved by the GSHP, it is necessary to compare the overall carbon emission arising from electrical operation of the heat pump, against the carbon emissions arising from the heating system that would have been used instead.

An important consequence of this is that electrically driven GSHPs, connected to appropriately mixed electricity supplies, can offer a significant carbon benefit compared to fossil fuelled heating. If we are to take global warming seriously, it will become increasingly important to "clean up" our electricity grids in terms of the carbon emissions. Older, carbon rich, inefficient power stations will be phased out in favour of cleaner, lower carbon, and more efficient plant. As this happens, the overall carbon emissions arising from the heat pumps will also decrease – without any alteration of the installations. (Conversely – it should be noted that if grid carbon increases, - for example by adding more coal to the power station mix, then the heat pump carbon emissions will increase).

While this information is generally understood in countries that have large scale GSHP installations, some of the ramifications may not be appreciated in countries that are embarking on the technology. For example, it is not uncommon to find bona-fide heat pumps that are manufactured in some European countries to include significant elements of direct electrical resistance heating – both for supplementary purposes and/or to raise hot water temperatures. In countries where electricity is a lower cost fuel than fossil fuels, and where most if not all of the electricity is derived from zero or very low carbon sources, this practice is of little consequence – either in terms of running cost or carbon emission. In countries with high electricity costs, low natural gas prices, and a grid with significant carbon content, there will be serious impacts on both the customer's running costs, and on carbon emissions if significant amounts of direct electric resistance heating is used. In the UK, where utilities are beginning to subsidise GSHP installations based on potential CO_2 reductions, these savings may not be realised if heat pumps with significant direct electrical heating are used. The attraction to installers is that they can offer lower cost installations due to reduced ground loop requirements. Figure 4 demonstrates the effects of grid carbon content on the carbon saving potential of heat pumps with a range of COPs. Figure 5 shows the carbon savings, against natural gas boilers, of GSHPs of varying SPFs, using increasing amounts of direct electrical resistance heating. In both cases it should be observed that it is possible to end up with negative savings – ie net increases in carbon emissions. It is therefore imperative that this is carefully considered before widespread GSHP installation occurs – if carbon saving is the main objective.

On the positive side, properly sized and installed GSHPs, will show significant CO_2 reductions compared to conventional fossil fuel boilers. In the UK context, with the current power station mix, the delivery of 1kWh of electricity emits 0.43kg of CO_2. At an SPF of 3.8 this can lead to overall CO_2 reductions in excess of 40% compared to a "natural" gas boiler. For consumers who are not on the gas grid, the CO_2 savings against oil, LPG, coal or direct electric heating, the CO_2 emission savings are even higher.

In the context of the Stern review, it is now interesting to "cost" carbon savings. Table I, extracted from a UK government report, tabulates the relative costs and outputs of 5 different micro-generation technologies. Given that the new objective must be to achieve the maximum CO_{2r} reductions for a given expenditure, the final column of the table makes interesting reading for GSHPs. Of course the table has to be evaluated for each country/region to be relevant.

In the UK context, this type of analysis, ie £'s spent per tonne of CO_2 saved forms the basis for the delivery of carbon saving measures. A very successful formula has been established through the electricity and gas utilities to deliver significant CO_2 savings based on widespread promotion and subsidy of technologies that yield the highest savings per unit of expenditure. It may be surprising to discover that GSHPs get close to the CO_2 savings that can be delivered by cavity wall insulation, and low energy light bulbs. This arises from the long lifetimes of GSHPs and the very significant long term CO_2 savings that each heat pump can deliver. The result of this type of analysis is that at least three UK/EU utilities (EON, RWE, British Gas) already have GSHP promotion programmes, and others are expected to follow.

As an example of how this approach to GSHP evaluation in terms of carbon saving and running cost benefit has developed in the UK, Figure 5 shows the retrofit installation of small (3.5kW) specially designed heat pumps in a cluster of social housing in Cornwall. The objective here was to satisfy two regulatory requirements - the need for "Affordable Warmth", and the meeting of the "Decent Homes Standard". Translated into English, this means "provide a warm home and hot water, at an affordable running cost". At the same time there is a strong drive to achieve this with a significant reduction in CO_2 emission. These houses were fitted with open grate coal fires, direct electric immersion heaters for hot water – and are in an area off the gas grid. Table II shoes the relative fuel costs of the different technologies, as well as the CO_2 savings. In this particular location the annual saving of 5 tonnes of CO_2 per dwelling, with all heating and (all) of the hot water supplied by the heat pump, at an affordable cost, is a very satisfactory outcome. The scheme was subsidised by one of the utilities (PowerGen/EON) – out of their CO_2 reduction programme (or Energy Efficiency Commitment, EEC). Next year (2008) these CO_2 reduction programmes as undertaken by the UK utilities on behalf of the government will have a step increase in available funds (derived from all domestic consumers). It is anticipated that there will be a significant requirement to deliver an order of magnitude more GSHPs under this programme. An interesting side note to this particular installation was the comment from the EU Energy Commissioner, Pielbags, who was astonished to see GSHPs fitted in this class of housing. He had previously only encountered them on houses occupied by the European "well to do" !

In recent years attempts have been made to collate information on the total number of GSPHs installations worldwide and to assign both energy and carbon savings to them. In one of the latest articles (Rybach 2006) he summarises data collected for the 2005 World Geothermal Conference in Antalya and other sources (Lund et al and Lund, Freeston, Boyd). For 2005 he suggests that there is 15,384 MW thermal of ground source heat pump capacity installed, delivering 87.503 TJ/year. Based on alternatives using oil, he computes that these GSHPs prevent the emission of 17.2 million tonnes of CO_2 annually. Allowance needs to be made for those installations that use renewable electricity (eg Sweden) , but on the other side, for those that displace coal or other high carbon content fuels.

For some time the IEA has been promoting the fact that worldwide, heat pumps (ie all heat pumps) offer the potential for eliminating 6% of worldwide CO_2 emissions. While this may seem small, it is one of the largest figures for a single technology – and could form a contribution to at least two of the Socolow Wedges (Pacala and Socolow) – ie energy efficiency and alternative generation.

CONCLUSION

The immediate challenge to the geothermal community is to deliver the rapid growth in GSHP installation rates that will be required to deliver substantial total carbon savings. In the (small) handful of countries where GSHP is an established, significant, technology eg Sweden, Switzerland, Germany, Austria and some parts of the US and Canada – this growth is well under way. In several EU countries with significant populations, eg the UK, France, Holland, the management of the growth of the industry will need significant investment and careful handling. In the UK it is expected that between 150,000 and 200,000 new homes will need to be constructed over the next 20 years. The government is currently asking the micro-generation industry to increase installation rates by two orders of magnitude in under five years. GSHPs are not the easiest of the micro-generation technologies to deliver. While the heat pump manufacturers will be able to ramp up the production of suitable ground source heat pumps – the constraints will arise elsewhere. There will be significant demands for training, and a rapid expansion in drilling capacity and capability. Immense care will be required to ensure that appropriate GSHP systems for different countries are applied, based on the local electricity supply mixes. If this can be achieved, then GSHPs will be able to play a significant role in the immense challenge to limit manmade carbon emissions – and hence to contribute to global cooling.

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Figure 1: UK CO_2 emissions arising from end-user activity.

(from "The carbon emissions generated in all that we consume, The Carbon Trust, January 2006 – www.thecarbontrust.co.uk)

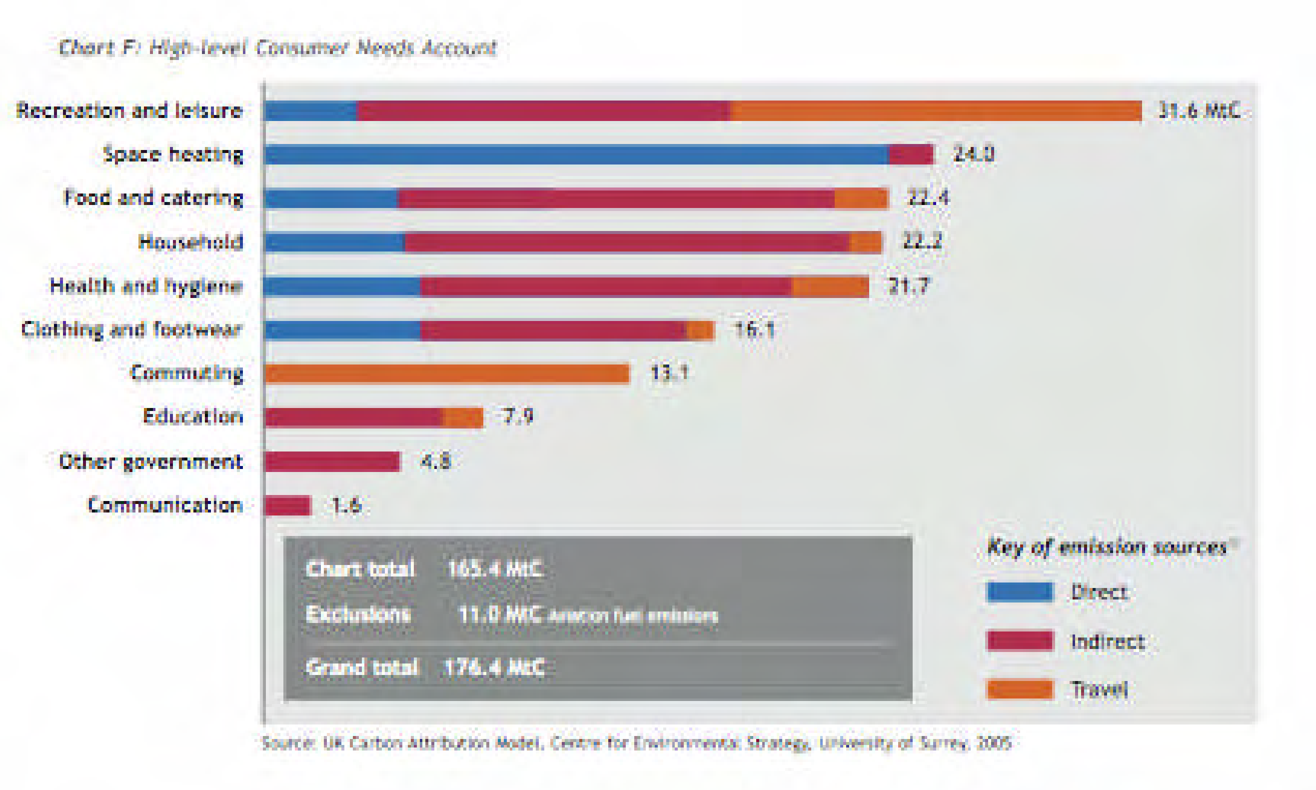

Figure 4: CO_2 savings – heat pumps vs gas boilers for a range of electricity supplies with different carbon content.

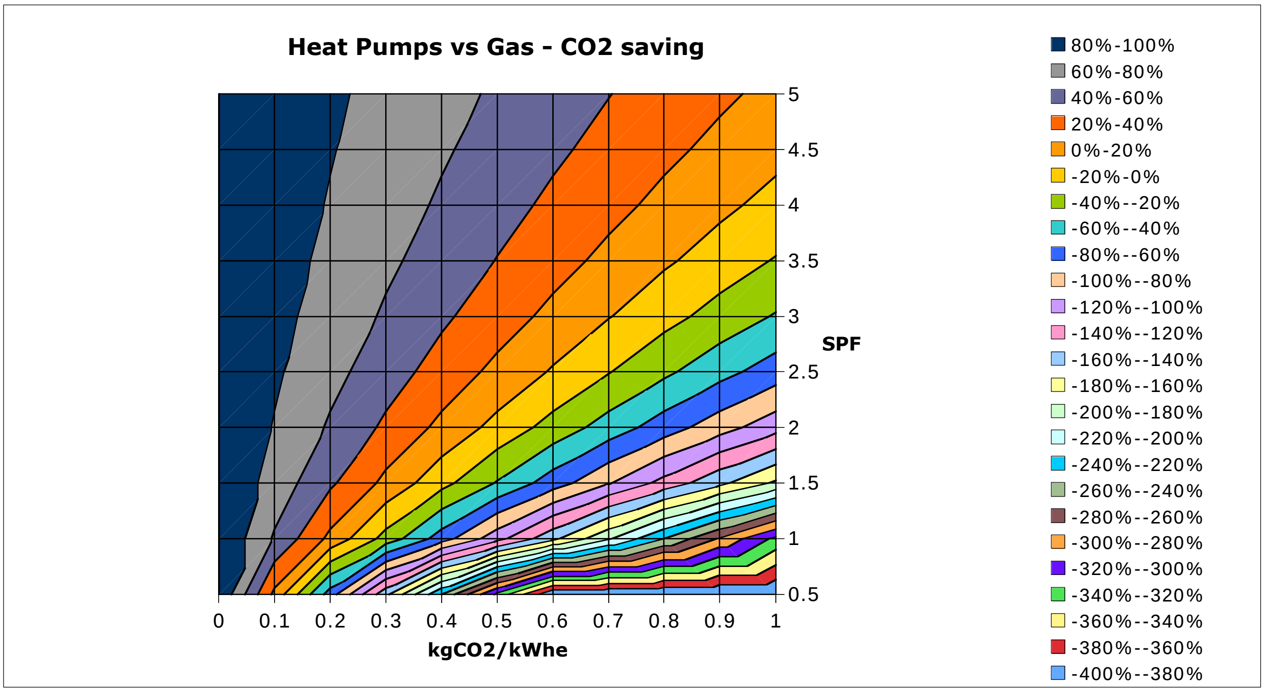

Figure 4: CO_2 savings – compared to gas boilers – for heat pumps using supplementary heating from direct electrical resistance heaters. (UK grid mix = 0.43kg CO_2/kWhe).

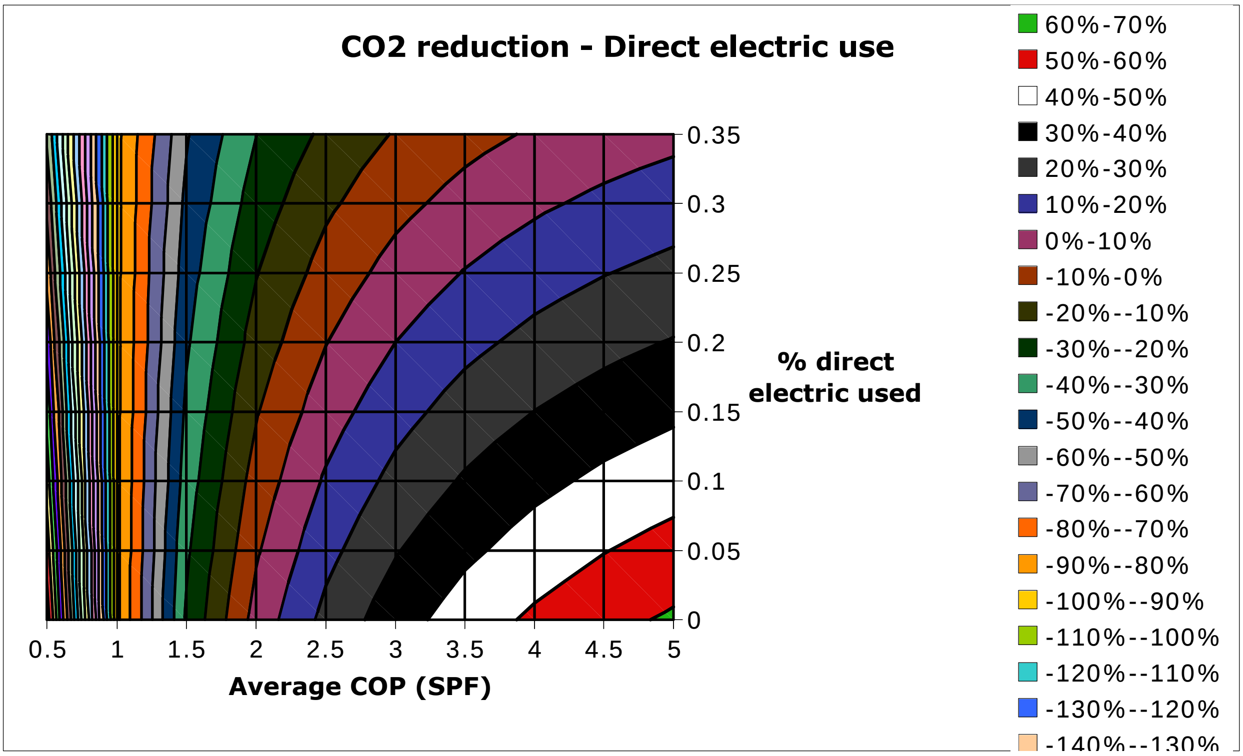

Figure 6: GSHP retrofit installation in rural Cornwall, UK

Table I : comparisons of several micro-generation technologies

(**Source: UK DTI report - Renewable Heat and Heat from Combined Heat and Power Plants – 2005)**

	Existing capacity	Capital cost £/kW	kWh/yr per kW	Payback (years)	Saving Tonne CO_2/yr per kW	Saving kgC/yr /£1000 CAPEX
Solar PV	8MW	6,300	750	120	0.32	14
Micro-wind		2,500 - 5000	1,700	30	0.7	47
Solar thermal	35MW 70,000 installations	1,250 - 2000	1,000	80	0.2	54
GSHP	5MW 600 units	1,000 – 1,500	3,000	15 - 20	0.4	91

Table II : Comparison of fuel costs and CO_2 emissions for GSHPs and fossil fuel boilers

System	Annual fuel costs	Annual CO2 emissions
GSHP	£ 215	1.6
Natural gas (condensing boiler)	£ 300	2.9
Natural gas (non-condensing)	£ 345	3.3
Liquid petroleum gas (bulk–non-condensing)	£ 500	4.3
Liquid petroleum gas (bottle – non -condensing	£ 670	4.3
Oil (35 sec) (non-condensing)	£ 300	4.4
Direct electric – storage and panels With night time low cost tariff	£ 510	6.5
House coal	£ 380	6.6
Smokeless coal	£ 515	7.5

(House = 100m2 - 12500kWh/yr as per SAP 2001)