`E.ON UK PLC

Performance of Whispergen micro CHP in UK homes

This report discusses the performance of the Whispergen micro CHP based on data from the Carbon Trust micro CHP Field Trial and complementary test work.

Summary conclusions are:

- In all homes significant Carbon savings were demonstrated
- Average CO_2 savings for the sample homes were 16% and up to 19%
- Family homes, typical of target market, save 1.1-1.5 tonnes of CO_2 annually
- The value of electricity generated can pay for the marginal investment in as little as 3 years in the typical family home

Executive summary

The Carbon Trust funded field trials of mini and micro CHP were initiated in 2003 with the intention of providing data to inform the debate on the application and benefits of these technologies and to provide context to the laboratory test procedure being developed by the Energy Savings Trust. Amongst the products on trial was the WhisperGen 1kWe micro CHP unit from E.ON UK (through their retail brand, Powergen).

In order to ensure validity of results, the units were installed on a commercial basis in customers' homes beginning in May 2004. They were installed both as gas boiler replacements in existing homes and in a number of developer built new homes and were operated to provide space and domestic water heating as usual. Gas and electricity tariffs were standard Powergen "dual fuel" tariff, the only exception being that an additional element, a credit for electricity export, was included.

Detailed monitoring of the thermal and electrical outputs of the units, together with energy consumption and ambient and internal temperatures was undertaken by EA Technology and audited by Gastec.

In November 2005, the Carbon Trust published an interim report based on the results then available from nine installations. As only limited data was available, with none of the units having run for a complete year, the Carbon Trust report was unable to draw substantive conclusions at this early stage.

However, with the benefit of additional data now available from a larger number of homes and over a full year, E.ON is able to present an updated and more detailed evaluation of the WhisperGen performance. This analysis also draws upon additional, complementary research undertaken by Gastec, EA Technology and E.ON laboratories in UK and Germany and makes use of recently developed industry standards (such as SAP2005) within its methodology.

The Carbon Trust is consulting with E.ON and other industry stakeholders in order to develop a new common methodology for use in future analyses. The Carbon Trust expects to be able to publish its next reports (interim in November 2006 and final in late 2007) using this new methodology.

The E.ON report concludes that, compared with a UK standard high efficiency (part L compliant, condensing) boiler providing heat and with electricity supplied from the grid, micro CHP offers significant energy, cost and carbon savings.

Carbon savings in the range of 13-19% were demonstrated, with up to 1.5 tonnes annual CO_2 savings for the highest energy consuming household.

Additional indirect benefits, such as the financial savings arising from the avoidance or deferment of network reinforcement, and enhanced security of supply are not discussed here as these are beyond the scope of the trial.

Background

The Carbon Trust funded field trials of mini and micro CHP were initiated in 2003 with the intention of providing data to inform the debate on the application and benefits of these technologies. It was not intended to be used as an accreditation process, such activity being carried out in parallel by the Energy Saving Trust, although it was anticipated that data might contribute to validating the laboratory test procedure being developed by EST.

Amongst the products on trial was the WhisperGen 1kWe micro CHP unit from E.ON UK (through their retail brand, Powergen).

In order to ensure validity of results, the units monitored within the trial were selected from those installed on a commercial basis in customers' homes beginning in May 2004. They were installed both as gas boiler replacements in existing homes and in a number of developer built new homes and were operated to provide space and domestic water heating as usual. Gas and electricity tariffs were standard Powergen "dual fuel" tariff, the only exception being that an additional element, a credit for electricity export, was included.

Detailed monitoring of the thermal and electrical outputs of the unit, together with energy consumption and ambient and external temperatures was undertaken by EA Technology and audited by Gastec.

Sample homes

The homes reported in the interim report do not represent those homes which are E.ON's target market, several being too small to achieve the level of savings we would expect for larger properties. Notwithstanding this, all homes in the trial have demonstrated significant carbon savings with relatively modest investment.

In the original programme agreed with the Carbon Trust, a schedule was agreed which would provide a representative cross-section of UK homes. It was not intended to represent the homes on which E.ON's marketing efforts were focussed, nor of those for which optimum savings could be achieved. It was instead, meant to confirm the types of installation for which micro CHP offered the greatest benefits, whilst at the same time, identifying the level of benefits which might accrue to other homes. It is therefore important not to consider the results from those non-target installations as being representative of the performance of micro CHP as a whole.

However, despite the inclusion of some non-target homes in the sample, the trial has identified average carbon savings of 850kg CO_2 for the range of homes included. This is broadly in line with the conclusions of previous trials undertaken by EA Technology and Power Technologies between 1999 and 2004. It was for this reason that E.ON decided to focus our efforts on addressing the family homes market where the greatest potential for savings existed and consequently where cost-effective installations were most likely. However, it is inevitable that some may still choose to invest in micro CHP even when there is an extended payback; just as with other carbon saving technologies such as Photo Voltaics, householders may be motivated by more than simple short term paybacks.

Results

The monitoring by EATL of the Whispergen installations appears to be of sound quality and has been thoroughly audited by Gastec. Both these contractors have, in our opinion, delivered robust results, which is evidenced by the increasingly consistent data emerging over the extended monitoring period.

The trial data is a valuable complement to the results from earlier trials; there have also been some useful outcomes relating to relative performance between summer and winter, the ability of the Whispergen unit to meet thermal comfort criteria in larger homes and the level of absolute savings which can be achieved for different house sizes.

These outputs confirm our earlier beta results and conclusions – in particular that the bulk of energy, financial and carbon savings from microCHP occur in winter months, and that owner-occupied homes with very low thermal requirements are not well suited to micro CHP on purely economic grounds.

However, this should not be interpreted as meaning that micro CHP cannot play a major role in overcoming fuel poverty. In many cases these households have substantial energy bills and may recover the investment relatively quickly; even for those households with more modest energy bills, the investment may be viable for public sector landlords where cost of capital is low and where social and environmental drivers are equally important.

These conclusions are particularly informative and will continue to be used to fine-tune product development decisions.

To conclude, now a full year's data is available a new set of results can be presented:

1. **The E.ON micro CHP offering does provide significant benefits both in carbon mitigation and energy savings for the householder.**

2. **Savings will improve even further over time - we are continually making improvements in performance to the current products as the technology matures. Indeed, we have already implemented features which increase the potential range of applications to larger homes for which greater savings are possible.**

Interpretation of results

In order to evaluate the relative merits of micro CHP, it is essential to understand the comparative performance of alternative solutions. This report assumes a baseline for comparison of a Building Regulations (part L as at time of trial) compliant, SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) B-rated gas central heating boiler providing space and water heating. Electricity is assumed to be provided by conventional means from the public electricity supply with a carbon emission factor as proposed for the forthcoming Building Regulations in the SAP 2005 methodology.

Most importantly, it is further assumed that the performance of the baseline product should be that when operating under the same conditions, i.e. field, not laboratory conditions. E.ON commissioned additional test work to gain a better understanding of the relative performance of micro CHP and boilers under laboratory full and part load conditions, as well as field operation in calibrated test houses. The following evaluation makes use of these test sources:

- Evaluation of normalised field performance of WhisperGen, SEDBUK A and SEDBUK B boilers in calibrated matched pair test house. (EA Technology, audited by Gastec)
- Laboratory test of WhisperGen under full and part load conditions; test to DIN standard similar to SEDBUK. (E.ON Ruhrgas)
- Laboratory test of SEDBUK A and SEDBUK B boilers to SEDBUK standard test procedure. (Gastec UK).
- Laboratory test of WhisperGen to proposed PAS67 procedure. (Gastec NL)

Taken together it can be concluded that not only do both gas boilers and micro CHP units suffer a reduction in efficiency under part load conditions, but that field performance of both is also several percentage points lower than would result from using the SEDBUK standardised test procedure.

Base case gas boiler

It is generally acknowledged when evaluating a new technology, that the base case for comparison is the *norm*, in this case, the minimum standard required to comply with current regulations. Under current Building Regulations, the minimum acceptable efficiency for a boiler is 86% (SEDBUK "B"); this also represents the boilers forming the benchmark for comparison with enhanced performance boilers[1]. It is for this reason that SEDBUK A-rated boilers are considered to offer benefits over the baseline norm (B) and are hence eligible for EEC support.

The SEDBUK performance standard is based on a series of tests of a boiler under a range of full and part load conditions. It is not based on tests in the field, but is intended to ensure that the test represents a fair comparison for all boilers under the same conditions. It cannot, however, be said to represent the actual performance of a boiler in the field and most certainly is not a valid comparator for performance of a different technology under field conditions. Many experts recognise that the difference between laboratory SEDBUK tests and field performance of gas boilers is in the range of 4-8 percentage points. This aligns well with independent tests commissioned by E.ON[2] as well as those undertaken within our own laboratories[3].

The first of these shows that the performance of a B-rated boiler (SEDBUK 86%) in a calibrated test house under simulated occupancy conditions was less than 80%. The same test in a thermally matched house with a Whispergen Mk4 micro CHP unit (86% to equivalent part load test regime) also resulted in a similar drop in performance. This same modification in performance is evident in the field trials for performance over a complete year, with relatively higher performance in full load (winter) conditions and lower performance under part load (summer DHW only and marginal heating season). Experts readily acknowledge this seasonal variation in performance and it is therefore inappropriate to compare the part year performance of the micro CHP unit with the idealised SEDBUK performance of an A-rated boiler. Indeed, it is also recognised that the higher efficiency A-rated boilers tend to suffer a disproportionately high deterioration under part load conditions[4].

However, not only is it inappropriate to use SEDBUK performance as a basis for comparison; SEDBUK considers only the gas consumed by the boiler and the resulting heat production. In a micro CHP unit, a significant proportion of the gas is converted into electricity, some of which is used to power the pumps, fans, controls etc which form an inherent part of the central heating system. These parasitic losses must also be considered for a gas boiler as they similarly form an unavoidable part of the boiler-based central heating system. Although at first sight they might seem rather small, a parasitic load of 100-150W represents over 10% of the electricity generated by the micro CHP unit, and around 3 percentage points in carbon terms.

Carbon mix

In order to understand the relative carbon performance of micro CHP and a conventional solution, it is necessary to establish the carbon content in the fuel used and of the displaced electricity consumption. The former is relatively uncontentious and is simply the carbon content of natural gas (0.19kg/kWh).

Carbon content of the displaced generation mix is, however, a highly contentious issue. There are a number of credible scenarios, based on the likely performance of micro CHP i.e. its generating profile and the alternative generating sources available within that same time profile. *These are considered further in the appendices*. However, in our opinion, the benchmark figure to use for evaluation of micro CHP in a home is that contained within SAP2005 and which is used to evaluate performance of an overall system to ensure compliance with the forthcoming Building Regulations. This figure (0.568kg/kWh) is used for all microgeneration technologies and recognises the benefits of generation occurring at the point of demand.

This carbon displacement value is the same for all electricity generated by the micro CHP unit, whether used in the home or exported to the public network and used by others. The carbon mitigating value should not be confused with the economic value of exported power, which does face some obstacles under current industry procedures.

Whilst the mechanisms for recovering the economic value of this exported power do not yet exist (other than through E.ON's micro CHP tariff), the electricity clearly has value and will be used by the nearest load, probably the house next door. Even in scenarios of very high micro CHP penetration, it does not cease to have carbon mitigating value and will always be used within close proximity to the point of generation, displacing remote generation and its associated line losses[5].

Summary of micro CHP performance benefits

E.ON's interpretation of data from the Carbon Trust field trial supports our earlier view that micro CHP offers considerable benefits in terms of carbon, financial and energy savings. It is a cost-effective carbon mitigation measure and should be supported by a range of policy instruments as a leading technology in support of UK Energy Policy.

For typical family homes, carbon savings of up to 20% are realistically attainable with economic payback of around 3 years. Absolute savings for homes typical of our target market (>20,000kWh annual thermal demand) range from 1.1-1.5 tonnes CO2 annually.

Carbon and other savings figures quoted previously by E.ON were based on data from beta trials which contained homes more in line with proposed target markets. These results will be reviewed alongside those from the Carbon Trust trial on completion of the trial to ensure consistency.

However, as noted earlier, although E.ON believes the baseline assumptions for boiler performance and displaced generation mix used in this analysis are appropriate for this purpose, some commentators may wish to consider the impact of alternative baseline scenarios. The following table therefore shows the variation for a range of displaced carbon factors.

Under no scenario does micro CHP result in annual performance worse than the conventional solution. Even in the "worst case" scenario of a perfectly operating 90% efficient gas boiler with no account taken of network line losses, average savings are around 2.2% on an annualised basis. For the more realistic scenario of carbon mix from SAP2005 and a typical B-rated boiler, average savings range from 12-19%, with an average just over 16% as shown in the table below.

Summary of carbon savings

Scenario*	Carbon savings (kg)	carbon savings range %	average carbon savings %
Carbon Trust with perfectly operating (lab conditions) 90% boiler, average UK generation mix	(-120)-300	(-3)-5	2.2
SEDBUK* B rated boiler, including parasitic losses, average UK mix	30-484	1-7	4.1
SEDBUK* B, SAP2005*	200-1040	7-14	11.7
SEDBUK* B under field conditions, SAP2005 carbon mix	290-1453	12-19	16.3

**see appendix for explanation and discussion of SEDBUK, SAP2005*

APPENDICES

APPENDIX 1

COMPARATIVE PERFORMANCE OF MICRO CHP

BASE CASE, including boiler parastic loss, as well as all WhisperGen™ internal consumption

Boiler efficiency	0.9	Assumed annualised boiler efficiency, best case SEDBUK Band A
Boiler size	8	Same size boiler as WhisperGen™
Boiler parasitics	0.15	Pump & fan during operating hours plus boiler controls (17W) continuous
NG C emission factor	0.19	DEFRA July 2005
Displ C emission factor	0.43	As used by Carbon trust, same for import and export electricity

	Heat input	Heat output	Net gen	Thermal Eff	Elec eff	Overall Eff	WhisperGen™ CO2 emiss	Boiler CO2	Boiler para elect CO2	Elec CO2 emiss	Total conv CO2 emiss	Savings with WhisperGen™	Savings with WhisperGen™
65COL	23878	16,498	1,704	69.1%	7.1%	76.2%	4537	3483	197	733	4412	-124	-2.8%
61RFU	7700	5,483	543.54	71.2%	7.1%	78.3%	1463	1157	108	234	1499	36	2.4%
69BRU	30477	22,075	2,365	72.4%	7.8%	80.2%	5791	4660	242	1017	5919	129	2.2%
68SDA	41365	29,051	3,285	70.2%	7.9%	78.2%	7859	6133	298	1412	7844	-16	-0.2%
62JTW	14692	10,789	1,184	73.4%	8.1%	81.5%	2791	2278	151	509	2938	146	5.0%
64GNO	17455	12,930	1,381	74.1%	7.9%	82.0%	3316	2730	168	594	3492	175	5.0%
63ECO	16924	12,036	1,336	71.1%	7.9%	79.0%	3216	2541	161	574	3276	61	1.9%
66PBO	34321	25,094	2,927	73.1%	8.5%	81.6%	6521	5298	266	1259	6823	302	4.4%
Average	**23351**	**16744**	**1841**	**71.8%**	**7.8%**	**79.6%**	**4437**	**3535**	**199**	**791**	**4525**	**89**	**2.2%**

BOILER EFFICIENCY 86%

Boiler efficiency	0.86	Assumed annualised boiler efficiency, SEDBUK Band B as per current minimum standard
Boiler size	8	Same size boiler as WhisperGen™
Boiler parasitics	0.15	Pump & fan during operating hours plus boiler controls (17W) continuous
NG C emission factor	0.19	DEFRA July 2005
Displ C emission factor	0.43	As used by Carbon trust, same for import and export electricity

	Heat input	Heat output	Net gen	Thermal Eff	Elec eff	Overall Eff	WhisperGen™ CO2 emiss	Boiler CO2	Boiler para elect CO2	Elec CO2 emiss	Total conv CO2 emiss	Savings with WhisperGen™	Savings with WhisperGen™
65COL	23878	16,498	1,704	69.1%	7.1%	76.2%	4537	3645	197	733	4574	38	0.8%
61RFU	7700	5,483	543.54	71.2%	7.1%	78.3%	1463	1211	44	234	1489	26	1.8%
69BRU	30477	22,075	2,365	72.4%	7.8%	80.2%	5791	4877	178	1017	6072	282	4.6%
68SDA	41365	29,051	3,285	70.2%	7.9%	78.2%	7859	6418	234	1412	8065	206	2.5%
62JTW	14692	10,789	1,184	73.4%	8.1%	81.5%	2791	2384	87	509	2979	188	6.3%
64GNO	17455	12,930	1,381	74.1%	7.9%	82.0%	3316	2857	104	594	3555	238	6.7%
63ECO	16924	12,036	1,336	71.1%	7.9%	79.0%	3216	2659	97	574	3331	115	3.5%
66PBO	34321	25,094	2,927	73.1%	8.5%	81.6%	6521	5544	202	1259	7005	484	6.9%
Average	**23351**	**16744**	**1841**	**71.8%**	**7.8%**	**79.6%**	**4437**	**3699**	**143**	**791**	**4634**	**197**	**4.1%**

CARBON EMISSION FACTOR AS PER SAP2005

Boiler efficiency	0.86	Assumed annualised boiler efficiency, SEDBUK Band B
Boiler size	8	Same size boiler as WhisperGen™
Boiler parasitics	0.15	Pump & fan during operating hours plus boiler controls (17W) continuous
NG C emission factor	0.19	DEFRA July 2005
Displ C emission factor	0.568	As used by SAP2005, same for import and export electricity

	Heat input	Heat output	Net gen	Thermal Eff	Elec eff	Overall Eff	WhisperGen™ CO2 emiss	Boiler CO2	Boiler para elect CO2	Elec CO2 emiss	Total conv CO2 emiss	Savings with WhisperGen™	Savings with WhisperGen™
65COL	23878	16,498	1,704	69.1%	7.1%	76.2%	4537	3645	260	968	4873	336	6.9%
61RFU	7700	5,483	543.54	71.2%	7.1%	78.3%	1463	1211	143	309	1663	200	12.0%
69BRU	30477	22,075	2,365	72.4%	7.8%	80.2%	5791	4877	320	1344	6540	750	11.5%
68SDA	41365	29,051	3,285	70.2%	7.9%	78.2%	7859	6418	394	1866	8678	819	9.4%
62JTW	14692	10,789	1,184	73.4%	8.1%	81.5%	2791	2384	199	672	3255	464	14.2%
64GNO	17455	12,930	1,381	74.1%	7.9%	82.0%	3316	2857	222	784	3863	547	14.2%
63ECO	16924	12,036	1,336	71.1%	7.9%	79.0%	3216	2659	213	759	3631	415	11.4%
66PBO	34321	25,094	2,927	73.1%	8.5%	81.6%	6521	5544	352	1663	7559	1038	13.7%
Average	**23351**	**16744**	**1841**	**71.8%**	**7.8%**	**79.6%**	**4437**	**3699**	**263**	**1045**	**5008**	**571**	**11.7%**

COMPARISON WITH LOWER EFFICIENCY BOILER

Boiler efficiency	0.8	Assumed annualised boiler efficiency, SEDBUK Band B but in field conditions
Boiler size	8	Same size boiler as WhisperGen™
Boiler parasitics	0.15	Pump & fan during operating hours plus boiler controls (17W) continuous
NG C emission factor	0.19	DEFRA July 2005
Displ C emission factor	0.568	As used by SAP2005, same for import and export electricity

	Heat input	Heat output	Net gen	Thermal Eff	Elec eff	Overall Eff	WhisperGen™ CO2 emiss	Boiler CO2	Boiler para elect CO2	Elec CO2 emiss	Total conv CO2 emiss	Savings with WhisperGen™	Savings with WhisperGen™
65COL	23878	16,498	1,704	69.1%	7.1%	76.2%	4537	3918	260	968	5146	609	11.8%
61RFU	7700	5,483	543.54	71.2%	7.1%	78.3%	1463	1302	143	309	1754	291	16.6%
69BRU	30477	22,075	2,365	72.4%	7.8%	80.2%	5791	5243	320	1344	6906	1116	16.2%
68SDA	41365	29,051	3,285	70.2%	7.9%	78.2%	7859	6900	394	1866	9159	1300	14.2%
62JTW	14692	10,789	1,184	73.4%	8.1%	81.5%	2791	2562	199	672	3434	643	18.7%
64GNO	17455	12,930	1,381	74.1%	7.9%	82.0%	3316	3071	222	784	4077	761	18.7%
63ECO	16924	12,036	1,336	71.1%	7.9%	79.0%	3216	2859	213	759	3830	614	16.0%
66PBO	34321	25,094	2,927	73.1%	8.5%	81.6%	6521	5960	352	1663	7974	1453	18.2%
Average	**23351**	**16744**	**1841**	**71.8%**	**7.8%**	**79.6%**	**4437**	**3977**	**263**	**1045**	**5285**	**848**	**16.3%**

APPENDIX 2 Description of scenarios

Comparative carbon savings for sample houses under range of scenarios

Boiler options.

There are two possible boiler types which could be used, SEDBUK A or B. SEDBUK B is the minimum standard specified in the building regulations and requires boilers to achieve simulated seasonal performance of >86% (HCV). However, it is widely acknowledged that field performance of boilers is somewhat less than this figure; independent tests commissioned by E.ON indicate a figure of 78-82% is more realistic.
Three boiler scenarios are therefore shown:

1. 90% representing idealised A-rated boiler performance
2. 86% representing idealised B-rated boiler performance
3. 80% representing realistic field performance, based on control group measurements from real houses.

Carbon mix options

A number of carbon mix values are used in carbon mitigation calculations, generally reflecting the issue under consideration. For example, average UK generation mix is valid for discussions concerning the relative merits of central coal generation when compared with other central (remote) generating options such as CCGT or large scale wind farms. For microgeneration discussions, consideration has to be given to the transport losses of the respective generation source, so that generation near the point of demand is credited with a higher value than remote generation.

1. UK average generation mix 0.43kg/kWh is simply the total UK carbon emissions from electricity generation divided by total kWh generated (not useful kWh). It includes both renewables at one extreme and high carbon (coal) at the other. Coincidentally it is very similar to CCGT carbon emissions.

2. EU CHP Directive requires comparison with conventional plant using the same fuel. In this case that would be natural gas and the same 0.43kg/kWh. However, it also assumes line losses of 5-15% depending on where the CHP unit is located; in this case, location at the very end of the LV network implies an enhanced value of 15%.

3. SAP 2005 is used to establish the overall carbon performance of a home to comply with forthcoming Building Regulations. This government-approved figure, (0.568kg/kWh) takes account of the likely displaced mix and line losses and applies to all microgeneration sources.

There are any number of alternative scenarios, depending on how the micro CHP generation is viewed. For example, is it the marginal plant or the next level of less flexible plant which is actually displaced? This will depend on a number of factors, not least of which is the level of micro CHP penetration and the extent to which this capacity is taken into account by NGT. However, a study carried out by Ilex matched generation profiles from micro CHP to actual marginal plant over a year and concluded that the displaced mix was very close to the SAP2005 figure.

In order to limit the number of options the following two were included; the first (average UK generation mix ignoring line losses) to provide reference to the Carbon Trust analysis, the second (SAP2005) as an indicator of the performance at the domestic level.

NOTES

[1] SEDBUK "A" – rated boilers are approved by OFGEM for support under the EEC2 scheme
[2] EA Technology matched test house evaluation of WhisperGen Mk4 and B-rated boiler, February 2006
[3] E.ON Ruhrgas tests of WhisperGen Mk4 and Mk5 micro CHP units to DIN
[4] The drop in efficiency is acknowledged within the SEDBUK test regime. However, the assumption that for a given part load condition the flow and return temperatures fall is not always valid. As TRVs close down as demand is satisfied, for example, the flow is restricted and return temperatures will actually rise, reducing heat transfer efficiency and the likelihood of conditions leading to condensation and the higher efficiencies this provides. This characteristic is less evident in lower efficiency boilers.
[5] SIAM study