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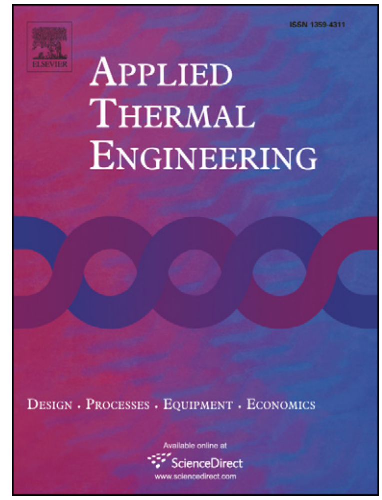

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MicroCHP: Overview of Selected Technologies, Products and Field Test Results

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Abstract
This paper gives an overview on selected micro-CHP technologies and products with the focus on Stirling and steam machines. Field tests in Germany, the UK and some other EC countries are presented, assessed and evaluated. Test results show the overall positive performance with differences in sectors (domestic vs. small business). Some negative experiences have been received, especially from tests with the Stirling engines and the free-piston steam machine. There are still obstacles for market implementation. Further projects and tests of micro-CHP are starting in various countries. When positive results will prevail and deficiencies are eliminated, a way to large-scale production and market implementation could be opened.

Keywords: Micro CHP; Stirling engine; field tests; market implementation

1. Introduction

Decentralized power generation combined with heat supply (CHP) is an important technology for improving energy efficiency, security of energy supply and reduction of CO_2 emissions. The EU and national governments encourage microCHP systems deployment to able meet international and domestic targets on carbon emissions. The UK government has lowered VAT from 17.5% to 5% for households that install microCHP systems and set out the targets for households to reduce carbon emissions by 60% by 2050. The Dutch government is backing microCHP deployment with similar initiatives and made public funding available for companies developing mass-market CHP systems. By 2050 microCHP systems could provide 30-40 % of the UK electricity needs [1]

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The larger and mini systems, for industrial application and for use in small organisations such as hospitals, schools and community centres or grouped households, have got proven track records. The microCHP systems applicable to domestic users in individual households still need further development to be widely acceptable. MicroCHPs are especially interesting for market of SFH (small family houses) and MFH (medium family houses), smaller buildings and SME (small and medium scale enterprises) due to their technical and performance features:

• A high overall energy conversion efficiency (e.g. in excess of 90% for Stirling engines)
• Low maintenance requirements equivalent to a domestic gas boiler
• Very low noise and vibration levels for installation at home
• Very low emissions of NO_x, CO_x, SO_x and particulates

Early adoption of CHP by utilities and manufacturers could lead to sales and service contracts worth over £1.5bn/a (€2.2bn) across Europe by 2010 [1].
Across the EU there is a potential for up to 50 million installations; with the key markets being the UK, the Netherlands, Germany, France, Italy, Belgium, Demark and Ireland. Manufacturers are already actively marketing systems in the UK, the Netherlands and Germany [2]. There are a few assessments of microCHP impact on the environment, see eg Fig. 1.

FIGURE 1 HERE

Only practical tests and field trials with statistically meaningful sets of data can give A proper understanding and prediction of how efficient these technologies are at present.

2. Methods

The paper benefits several sources:

- The German experience in Stirling machines and field tests of a special Stirling engine (power range 2 to 9.5kWel) of a German manufacturer,
- Field tests of a Stirling engine (about 1kWel) of a manufacturer from New Zealand in France and the Netherlands
- The UK field tests of a number of CHPs.

The market studies (Berger [4]) and the description of experiences with field tests in Germany (Forster [5]) and UK (The Carbon Trust [6]) were evaluated to get comprehensive information for this study. They focused on producers and conversion techniques with a high development status. These products are close to market introduction and either undergoes EC certification procedures or have been already matured. They are expected to enter the market soon.

The study used the following classification:

- Stirling engines,
- Hot air engines
- Combustion engines.

Fuel cells and micro gas turbines were not considered because of their problematic application in the small scale housing sector.

An output temperature close to 100 ^{o}C should be designed for a microCHP system as the minimum required temperatures in buildings may vary between 40 ^{o}C and 80 ^{o}C. There are several technologies in the micro scale that can be used for CHP generation:

(i) Reciprocating engines,
(ii) Micro turbines (electric power below 250 kW),
(iii) Stirling engines,
(iv) Fuel cells.

(i) Internal combustion - Reciprocating engines

A typical reciprocating engine (diesel, gas, multiple fuel) and a generator linked to the engine are quite efficient in producing electricity, have a large power range and choice of fuels. The applicability of gas engines is best in back-up systems. Diesel engines are recommended for continuous use. Their drawback is relatively noisy operation. This may render them unattractive for residential applications. The moving parts require regular maintenance which further contributes to the Carbon Footprint (CFP) [7] The type of fuel used affects CO_2 and SO_2 emissions. CHP based on reciprocating engines are more applicable to larger buildings with less peaked electricity and heat consumption profiles [8]. The most efficient performance can be achieved by the proper selection of the size of the internal combustion engine, the capacity of thermal and electrical storage systems and the operation scenario on the energy performance of the entire micro-CHP system [9].

(ii) ***CHPs using microturbines*** use gas turbines with electrical power generation from 25 to 250 kW. Such a plant generally consists of a generator, a compressor, a combustion chamber, and a turbine connected to each by a shaft. The high exhaust gas outlet temperature (450–550 ^{o}C) enables considerable heat generation. Among other advantages are their low noise levels, small size and lower emissions level (especially NO_x) compared with reciprocating engines [10]. Gas and liquid fuels are suitable for micro-turbines. Their low electrical efficiency, especially on part load, capital and maintenance costs are rather high. CHPs with microturbines are most applicable for steam production and similar applications. However they are not applicable for residential purposes because they are expensive and inflexible to load changes.

(iii)External combustion - Stirling engines

The Stirling Engine is a reciprocating engine with its cylinder closed and combustion taking place outside of the cylinder. Stirling Engines are characterised by rather low emissions (especially NO_x) and lower noise levels. External combustion also requires less maintenance which favourably influences the carbon footprint of the technology. The Stirling Engine is usually quiet because the combustion is not explosive and, it can use almost any combustible fuel and any source of heat, including biomass. This type of CHP has rather low electrical efficiency, about 25–30 % when natural gas is used as a fuel. When solid fuels (e.g. biomass) are used, the efficiency can be as low as 15 %. The total efficiency is not significantly lower than that of other CHP applications. Stirling engines are applicable to residential buildings, because the electricity/heat ratio. Their low efficiency supports their use as backup power supplies rather in continuous use [11].

(iv) Fuel Cells (FC)

A FC produces electricity electrochemically, by combining hydrogen and atmospheric oxygen. If the fuel is not available as pure hydrogen, it can be released from various fuels by means of a reformation process. The electrical efficiency of these systems can be as high as 45–55% [8]. If pure hydrogen is used, the only emission is water. If reformation is used, CO_2 and a minimal amount of oxides of sulphur and nitrogen are formed, depending on the fuel. Other benefits are noiselessness, reliability, modularity, and rapid adaptability to load changes.

According to assessment made by [11] of the carbon footprint of the Stirling engine and FCs applied for a single dwelling in Central England, the Stirling engine yields daily savings of 2.5+ kg CO_2 in winter and less than 1 kg CO_2 in summer. The reduced thermal output of the 1 kW FC system causes significantly less seasonal variation and yields daily savings of 3+ kg CO_2 in winter and 2+ kg CO_2 in summer. Micro-CHP systems can offer considerable CO_2 emissions reduction compared to a condensing boiler and network electricity. The promising advantages of FCs still remain as potential benefits because of the current stage of the technology development and the problems it faces:

- The important drawback is the investment cost. There is a very strong competition in the power generation market, and the costs of generation as well as risk and availability are the key factors in technology selection. So far, FC cannot compete with a modern conventional generating plant [12]. Costs should be driven down through technology development and economies of scale.
- The current economy is heavily carbon-based, so the inertia has to be taken into account which presumes that shift to FC en masse will not happen fast until the technology is developed sufficiently to force change.
- FC are more demanding in respect of fuel production, storage, and transportation. Therefore, a serious barrier to the wider spread of FC is poorly developed hydrogen infrastructure, and on the other hand, a hydrogen infrastructure will not develop until there is a sufficiently large adoption of hydrogen technologies.

3. Results

3.1 German market study

Within the market study for the market launch of microCHP between 1 to 5kWel (Berger [4]) 15 relevant microCHP products were identified and analyzed. To study feasibility and application of micro-cogeneration the following applications were chosen:

1. Lion Powerblock (free-piston steam engine)
2. WhisperGen MicroCHP (Stirling engine)
3. Microgen M-CHP (Stirling engine)
4. Ecowill (combustion engine)
5. Dachs (combustion engine)
6. Ecopower Mini-CHP (combustion engine)

Table 1 provides selected technical data of the chosen cogeneration products. Subsequent to the study the profitability was analysed considering a cost benefit calculation of the product application in single consumption mode different buildings in Germany, as SHF, semidetached houses, and MFH as well as in commercial-objects. The analysis included the viewpoint of different client-groups and manifested enormous differences between them. They were in most of the cases negative, a larger number of the case studies was analysed as cost inefficient. The electricity generation costs varied in a range from 38.0 to 9.8 Ct/kWh.

TABLE 1 HERE

But some of the CHP-products are already cost efficient regarding module costs and energy prices. The results for SFH vary from extra costs of 520 €/y to cost minimisations of 255 €/y. An essential criteria for the choice of a product is besides a high "number of hours in full usage" (equal total generated electricity p.a./max. electrical output capacity) the technical implementation of the monovalent operation mode. The "number of hours in full usage" differs according to client group and CHP product between 1,250 to 8,000 h. The small commercial companies could not attain a satisfying result of the chosen CHP technique despite optimal disposal structures. Reason for that are the low energy and electricity costs in small-scale companies.

For Stirling engines natural gas-fired WhisperGen microCHP and natural gas-fired Microgen microCHP savings of 10% of energy costs can be reached in SFH. Because of the less heat consumption (50%) in new build SFHs the feasibility of microCHP is much lower than in older buildings. For a newly-build SFH the Stirling engine is at its feasibility limit. The free-piston-steam engine natural gas-fired Lion Powerblock is the least cost efficient with electricity costs of 38 Ct/kWh, which derogates the yearly energy costs. All the figures are summarized in Table 2. In the variation of investment costs and energy price development it is clearly to see, that ample changing of the economic frame conditions are necessary to have cost efficient microCHP application. A good example are the better conditions for the feed-in tariffs for electricity which is produced by CHP applications with the use of bio-fuel in Germany.

Demand site the application of microCHP was estimated in a potential and scenario analysis for Berlin with the conclusion that the demand for microCHP will raise to 8,000 to 15,000 installations p.a. till 2030. This increase results from potential substitution and exchange of gas supplied objects during refurbishments and newly build houses including changes of energy used e.g. gas fired apartment heating. Table 3 shows the annual potential of microCHP in Berlin by different client groups with an average life span 20 years.

TABLE 2 HERE

TABLE 3 HERE

Taking into consideration these figures as well as the estimations of a Berlin gas utility company the CO_2 reduction potential is considerable. Up to 200,000 t/a of CO_2 can be reduced by the application of microCHP.

Conclusion of the study is, that under certain consumption structures micro-CHP turned out to be a comprehensive solution for energy supply. The feasibility is dependent on the operational mode and engine application according to the demand structure. Single task oriented products have a better feasibility, as modules designed with an additional "back-up" like a boiler or a gas fired thermae. For the launch to a mass market a lot of work in the technology development is still to be done. This lack could be overcome by the support of energy utilities.

3.2 German field tests with Stirling engines (Forster [5])

The manufacturer SOLO Stirling GmbH in Sindelfingen had started a serial production of a gas fired Stirling 161 engine in 2004. Over 120 units were sold. Unfortunately the manufactures had to close the company at in the beginning of 2007 because of funding problems. The new owner from Switzerland absorbed the technology rights, patents and assets and is preparing the full commercial launch of the Stirling 161 together with an own-developed 1kW Stirling module. Whereas currently natural gas is used as fuel, pellets might be used in the near future.

Berlin

One of the Stirling 161 engines was tested by the Berlin gas utility GASAG. A first Stirling CHP unit is used to power a state public institution building - the Kreuzberg fire station in the district Friedrichshain-Kreuzberg of Berlin. They have been checking the capability and client acceptance in a three years test (since November 2005). The first engines from the serial production run well, yet with some small problems. The electrical output has been underachieved, and a frequent faults lead to higher maintenance costs. Overall the gas distribution company is positive as the Stirling is a very efficient way to convert energy. It is a well-engineered technology on the way of market implementation, in comparison to fuel cells. This Stirling 161 (2 to 9.5kW$_{el}$; 8 to 26kW$_{th}$) was integrated in the existing heating system of the building. It is parallel spliced with the central heating boiler.

When it was no requirement for the heat the boiler was not used. The whole Stirling CHP unit can be taken offline with an automatic powered shut-off valve. As this fire station has a constant demand of energy and heat it is perfectly suitable for the test-run. The Stirling 161 can be operated at a full load about 5,800 h and part-load 7,800 h. The feed temperature 68° C in the heating circulation is judged as less efficient which reduces the electric power. The producer recommends a maximum feed temperature of 65 °C. After to serial production in 2004 several problems with material occurred. The company Solo investigated the reason for the defect of the connection rod. Meantime a new method was developed for precise measurement and evaluation of tolerances. There was also a change of a subcontractor and the piston rod is available with the requested quality and has been be refitted. The technical and performance data are summarised in Tab 4. Fig 2 visualises the influence of flow temperature on performance and efficiency related to the load (machine pressure) of the SOLO Stirling 161 engine.

TABLE 4 HERE

FIGURE 2 HERE

Fürth

Another testing run of Solo production Stirling 161 was proceeding in Fürth. In cooperation with the energy agency EAM and a local district heating provider a station was chosen, which is supplying heating for a residential area (79 buildings). For the combination of the district heating station (max. 4.5MWh) and the Stirling CHP unit, various modes can be measured, without having an impact on the supply of the client. Solo Stirling achieved a degree of efficiency of over 90 % and its optimum in part-load. Because of the high feed temperature from the district heating station the pre-conditions can be considered as suboptimal. Because of suboptimal conditions of the heating system the forecasted degree of efficiency could not be complied. Nevertheless the EAMs appraisal is positive stating that fundamental problems did not occurred but the testing of a larger number of Stirling engines is needed.

An EAM project manager has been questioning if the malfunctions like the defect of the connection rod were system systematic or occasional. The Solo maintains that the major part of the 120 Stirling engines runs without any problems.

Ditzingen-Hirschlanden

An ESCO (part of a large French utility) reports just satisfactory results using the Stirling 161. In the Swabian town of Hirschlanden a Stirling CHP unit integrated in a district heating station is supplying with heat 100 SFHs, a home for old people and a nursing home. The electricity produced by the Stirling CHP unit is predominantly used to provide the station supply of the boiler house.

The correlation between the high feed temperature and the derogation of electric efficiency has occurred also in this test-run. At a feed temperature of 60 °C an electric power of 6.5kWel is measured in Ditzingen-Hirschlanden. The total efficiency amounts up to 79 %. Because of the external combustion the interior of the Stirling engine remains free of residues. The pollutant emissions are much lower than the emission from the other engines.

The ESCO specified the following disadvantages:

- A limited operation experiences,
- A lack of a mass production
- A still high specific investment costs.

The technical potentials are still not taped fully. The service and support should be optimized. If the positive experiences will proceed, further projects with the Stirling will be encouraged.

Other locations

In 2006 the Berlin gas utility started the second two year test-run in a SFH and the embassy of New Zealand, where gas operated Stirling CHP units WhisperGen from a New Zealand manufacturer (1kW$_{el}$; 7.5kW$_{th}$) were installed. The same CHP unit was chosen by another German service company in Mannheim. Over 20 SFH started with voluntarily participation in the test. Furthermore a 2-year WhisperGen field test started in Berlin in summer 2007. Out of 1,600 candidates 20 housing and single-house units have been chosen. The Figs 3 and 4 are showcase of the degree of efficiency and the power supply of the WhisperGen filed test.

FIGURE 3 HERE

FIGURE 4 HERE

3.3 UK market studies

The UK market for micro CHP is assessed to be about 400,000 households (Carbon Trust [6]) within ca. 1 million households and SMEs which displace boilers per annum (Envocare [15]). Unlike mini CHP (which is regarded as a mature technology and have been applied for quite a long time), micro CHP technology is not yet available commercially and there are rather few data about its performance in UK. Mini systems used in industrial and commercial applications show advantages of their performance for quite a long time. On the other hand, the direct projection of mini-CHP experience to micro-CHP level turns counterproductive due to extra complexity at the micro level and lesser tried technologies (for example fuel cell technology) which still needs to get mature.

Overall CHP are intrinsically more efficient in comparison with other generating facilities and the grid with its 30-40% efficiency (Ecpower [16]) Potentially micro-CHP can have the competitive edge over condensing boilers, but still considerable work has to be done to implement this into real economic and environmental benefits.

The latest research shows that microCHP have to improve their performance to become widely accepted in the market. Since the potential market is quite large in terms of units, there are good incentives for improvements. By 2006, not much progress was made in microCHP penetration into the market. There are still very few micro-systems available, the public, architects and civil engineering community en mass are not much familiar with the technology.

Another factor of a rather poor microCHP market penetration was a successful campaign to promote energy-saving condensing boilers.

The UK government in 2001 stated that CHP was one of important ways to implement the Kyoto commitments. The UK target for installations set for the end of the year 2000 was 5,000 MW_{el} and by 2010 a further target of 12,000 to 19,000MW_{el} was set (Envocare [15]).

3.4 UK Carbon Trust field tests

Carbon Trust launched a trial in 2003 aimed to a comprehensive analysis of the current situation and development of recommendations to overcome the barriers that impede the implementation of this technology. The trial is expected to finish by mid/late -2007 and results will be published. Only preliminary data have been available so far.

The technologies assessed were Stirling engines, Organic Rankine Cycle Machines, Fuel Cells and Internal Combustion Engines. In total about 40 units (of those 31 microCHP, mostly in homes) have been assessed.

The performance indicators recorded were:

a) Overall thermodynamic efficiency,
b) The amount of electricity generated the carbon intensity of the electricity displaced from the grid.

A significant result of this trial is that the first two performance indicators differ very significantly for micro and small CHPs. The microCHP units assessed show very different performance characteristics in different environments. The carbon footprint and savings being important characteristics, the capital costs needed to be evaluated as well. So far the units are not manufactured at the scale sufficient enough to a give a final conclusion on the capital cost. The preliminary results of the Carbon Trust trial indicate that the performance of microCHPs was not as impressive as expected. Some of the reasons are:

- Actual efficiencies of was lower than assumed by existing models
- The amount of electricity generated is much lower than the forecast

The poorer than expected efficiency is caused by the current stage of the design and operation. The thermal inertia of the microCHP units seems to be still too high compared with the conventional boilers for a fluctuating demand for heat in buildings.

In many houses the demand is to a large degree irregular and the heat is required only for short periods but many times a day. The repeated warm-ups cause waste of energy which is not re-released in a useful way which reduces the efficiency. This makes a vast scope for improvements focused on reduction of thermal inertia and/or number of cycles. Another problem for microCHP performance is the assumption of constant average electricity demand.

The trial has proved that for the most of the time demand is much lower than average and also lower than typical micro-CHP output. This is also combined with short periods of very high demand (when some appliances are running, e.g. kettles, electric showers, etc). So far the significance of peaks and troughs has been neglected by the designers. With new design of low voltage networks which could cope with high levels of export, in addition to full load import when the units are not running, the microCHP industry needs to design units with the ability to modulate electrical output much more widely than currently. Summarising the preliminary test the Carbon Trust indicates that at the current stage of technology microCHP have limited contribution to CO_2 reductions and considerable improvements are required (Fig. 5).

FIGURE 5 HERE

Boatie et al [17] show that the financial benefit to consumers from microCHP is sensitive not only to the thermal properties of dwellings, but also to lifestyle and consequent choice of heating time and temperature settings. Because financial benefit is closely tied to local consumption of the electricity generated, the carbon mitigation benefits – to the extent that they are improved by reduction of national peak demand – have the same sensitivity. They also show that import and export profiles will vary substantially between households with microCHP.

3.5 Field tests with Stirling engines in France and the Netherlands

DEO Domestic Energy Optimisation

A DGTREN funded project DEO (Priaulx [18]) compiled a comparative study on innovative technologies of power generation in buildings, analysing pilot projects in 2001-2003. Partners were several European gas utilities. The study focused on the application of innovative gas technologies as micro-cogeneration, gas heat pumps; gas fired household appliances and combination-systems e.g. with solar heat.

The DEO project studied SFHs or apartments in for the period of a year. To compare the energy saving potential, other objects without the innovative technology were taken into consideration. MicroCHP units were installed by leading gas companies in France, Gaz France and the Netherlands, Gasunie. A WhisperGen module powered a test-run apartment in France and a SFH in the Netherlands.

In the Dutch test the microCHP unit was supported by applications of other innovative energy saving technologies, as gas heat pumps, gas fired household appliance and electronic thermostatic valves etc.

The French demonstration-run achieved satisfying results. No operational malfunctions appeared. The specific performance of the heat supply met the producer data. The electricity was close to the predicted performance 82 % efficiency (75 % thermal and 7 % electric). During the monitored test 55 % of the power demand was satisfied. The average value for the available electrical power was 0.2 kW considered over the year. Savings 13% of primary energy (gas) and 7% of final energy (electricity, heat) were achieved in comparison to a reference building.

The Dutch test example was in contrast disappointing. Several problems were observed in operation and with the start/stop mode and noise-emissions. The operation time was limited. Only 278kWh were generated overall by the micro-CHP - just 6% of the energy demand. By combination of actions savings of 13% primary and 12% end use energy were achieved.

4. Discussion and Conclusions

MicroCHP is already a maturing and comprehensive solution for energy supply for certain consumers according to the present market study (Berger [4]). In certain consumption structures micro CHP is already a comprehensive solution for energy supply, according to the present market study. As shown in the Berlin study potential customers for microCHP units exist and their attitude is in principle positive. The market introduction of microCHP has to be supported actively with the help of energy utilities, research institutes, producers and networks.

The installation and service networks are supposed to take a key function in designing a microCHP service package in the phase of market launch. The lack of these networks hindered the application of microCHP installations in the UK and in the Netherlands.

Supply side the design of a service package is promising due to the fact that the product microCHP installations ties services and binds the customer to a long-term usage.

Regarding the political framework it is to mention that legal regulations for power supply support an accelerated market implementation for CHP technologies, as in Germany the KWK ModG.

The need of further stimulation is the outcome of tests (Forster [5], Carbon Trust [6]). The conclusions are that with positive experiences of microCHP and the elimination of the deficiencies a mass production and full market implementation would start in the future.

Stirling engines are characterised by low electrical efficiency and high overall efficiency. They are typically designed to operate in a heat led mode where they dispatch at full output capacity for any period where there is a space heating demand. Minimum up-time is typically about 1 h. Stirling engines usually have a set of predetermined operating points [19]. Eg a 1.1kWe system could be controlled to dispatch at 500, 900, and 1,100 We. A warm Stirling engine is able to change electrical output level almost instantly. On–off operation according to a predefined program is possible [20].

Gas engines have higher electrical efficiency than Stirling engines. Minimum start up is similar to a Stirling engine These systems are also typically driven by heat demand [20]. Gas engines appear to be more inclined to ‘‘follow’’ an electrical load, and can ramp up and down rapidly. On–off operation according to a predefined program is possible.

FC have high electrical efficiency. They may benefit from avoidance of thermal cycling which creates stress on component parts and could reduce the lifetime of the stack, and are more inclined to operate continuously. Once operating they are able to respond rapidly to load fluctuations. No statistically meaningful field trials have been carried out regarding this type of technology.

A valuable idea for this review extension would be to include beside field test also related software and its implementation as eg Ameli at al [21]. The issues covering the trigeneration would be beneficial as well, see Klemeš and Friedler [22], Hennian at al [23]. They are obviously more test and pilots needed covering more countries' specific conditions and emerging products from various manufacturers [24] and renewables related options [25]. This contribution is targeting to raise this point and encourage more overviews for exchanging data and experiences in the filed.

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Nomenclature

CHP	Combined heat and power
SHF	Single family house
MFH	Multi family house
SME	Small to medium businesses
KWK ModG (German)	Law for the modernisation of cogeneration
EAM	Energy Agency Middle Franconia
FC	Fuel cell

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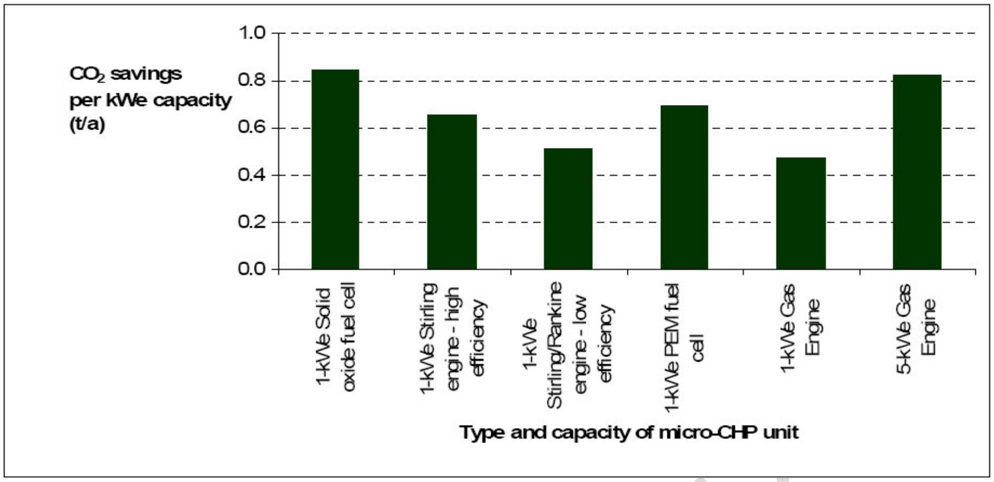

Figure 1. Annual microCHP CO_2 Savings Compared to Grid Electricity and Boiler Alternatives [3]

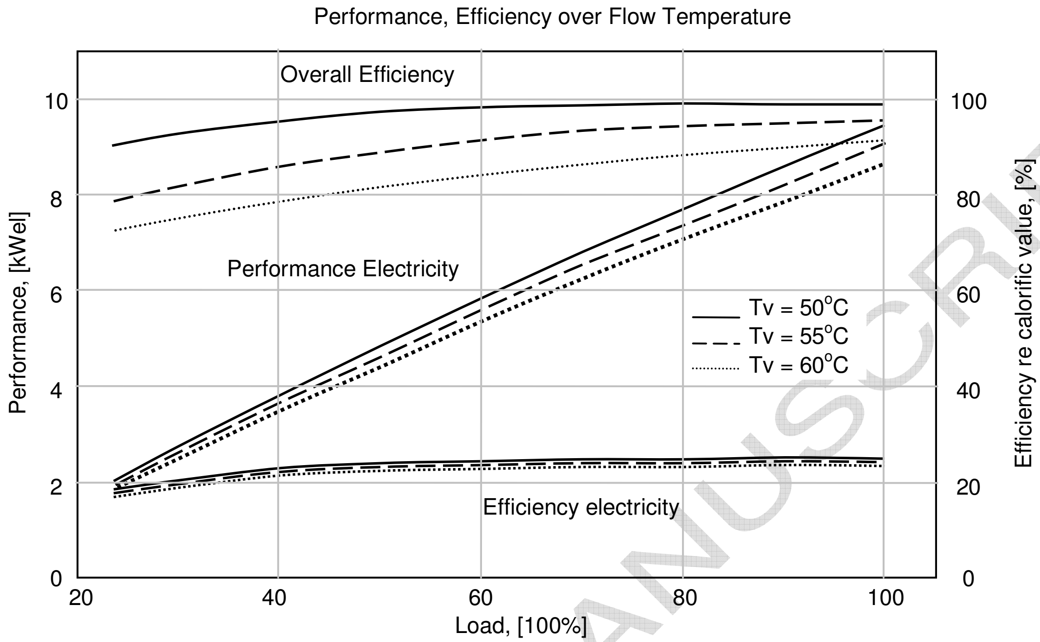

Figure 2. The influence of flow temperature on performance and efficiency related to the load (machine pressure) of the SOLO Stirling 161 engine [13]

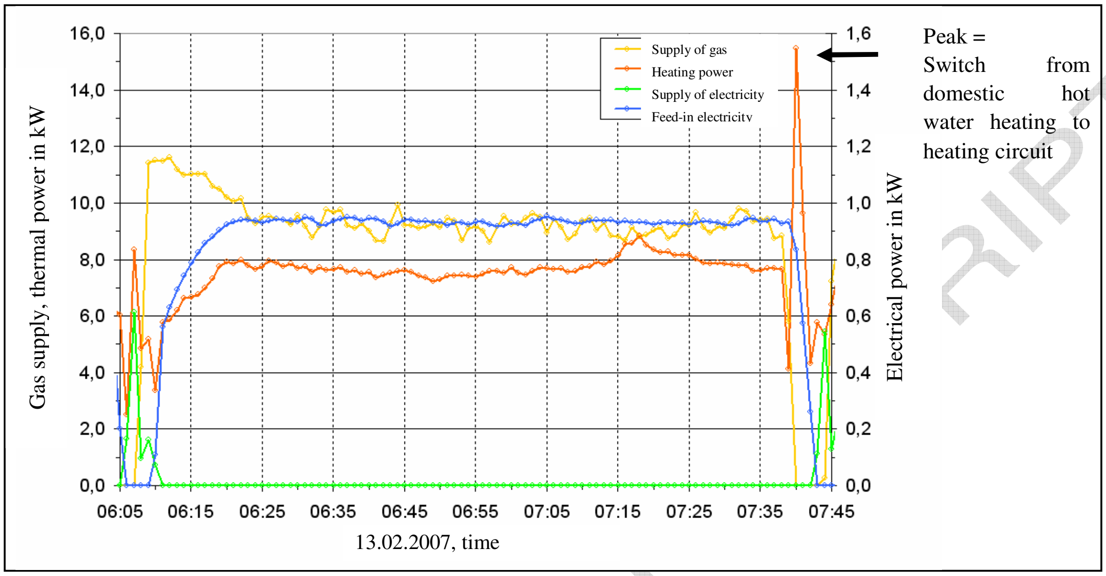

Figure 3. Power supply of WhisperGen, field test in SFH (Berlin/Brandenburg) [14]

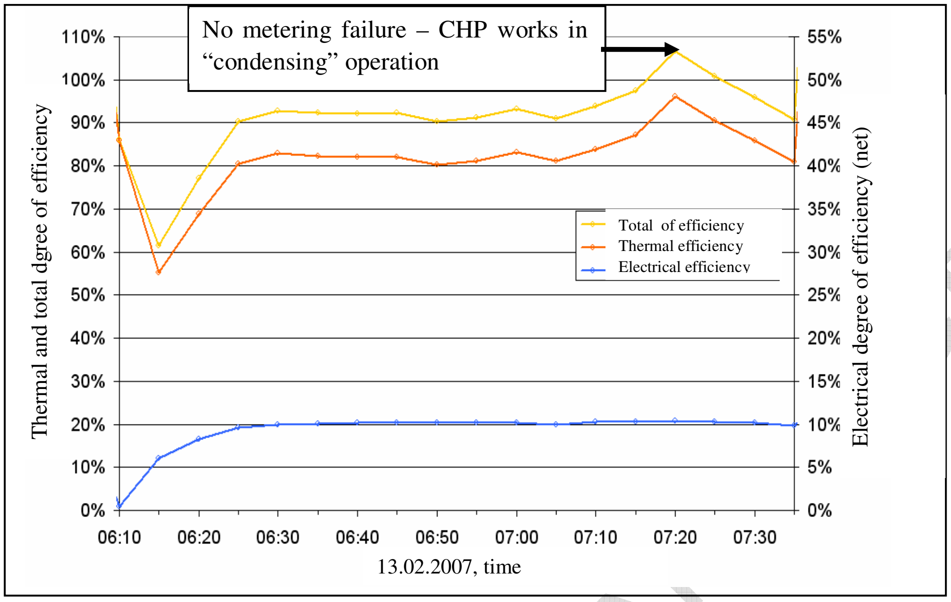

Figure 4. Degree of efficiency of WhisperGen, field test in SFH (Berlin/Brandenburg [14]

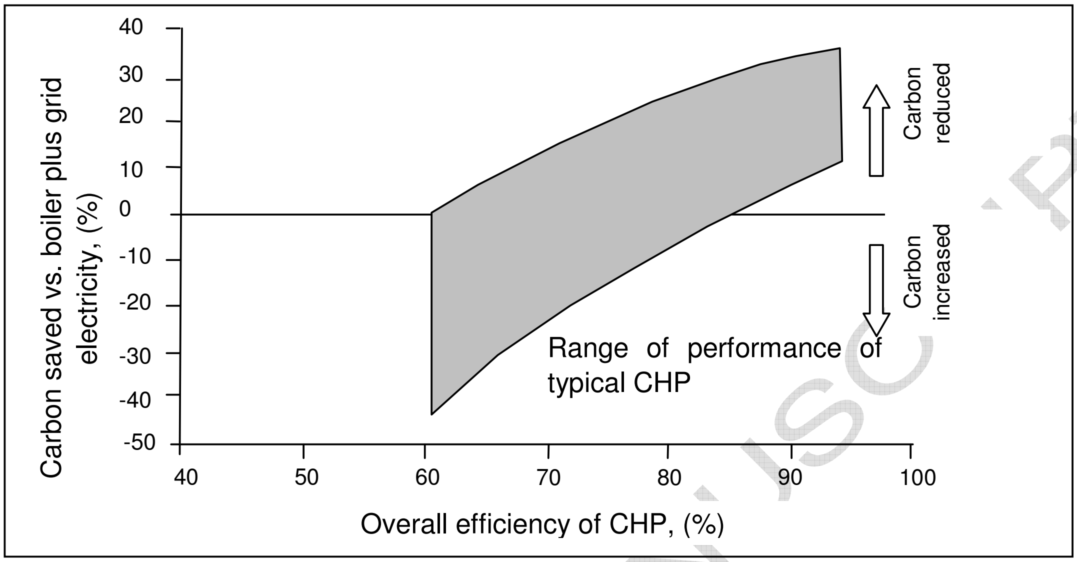

Figure 5. CO_2 reduction related to overall efficiency of the CHP, after [6]

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Table 1: Chosen micro-CHP products, by Berger [4]

Technology	Free-piston steam engine	Stirling engine	Stirling engine	Combustion engine	Combustion engine	Combustion engine
Electrical output capacity (kW)	0.2 - 3	1	1	1	5,5	1.3 – 4.7
Thermal output capacity (kW)	2 - 16	12	15, 24, 36	3.25	10.3 – 12.5	4 – 12.5
Costs/ unit (€)	12,500	6,000	4,500	5,600	15.000	15,000
Specific cost of unit (€/kWel)	4,170	4,500	4,090	4,170	3.272	3,829

Table 2: Total electricity generation costs, Berger [4]

	Microgen	WhisperGen	Lion Powerblock	Ecowill	Ecopower	Dachs
SFH refurbished	10.6 ct/kWh	11.0 ct/kWh	22.9 ct/kWh	22.9 ct/kWh	-	-
SFH new build	16.1 ct/kWh	17.3 ct/kWh	38.0 ct/kWh	31.9 ct/kWh	-	-
Semi detached house	9.8 ct/kWh	10.5 ct/kWh	20.9 ct/kWh	21.8 ct/kWh	24.5 ct/kWh	22.8 ct/kWh
MFH refurbished	-	9.9 ct/kWh	12.1 ct/kWh	-	12.5 ct/kWh	12.7 ct/kWh
Commerce	-	9.8 ct/kWh	12.2 ct/kWh	-	11.2 ct/kWh	11.7 ct/kWh

Table 3: Annual potential for microCHP (Berlin), Berger [4]

Client group	Refurbishment	Change	Newly build	Total
Central building heating (gas-fired)	5,700	4,000	0	**9,700**
SFH, semidetached houses	1,500	1,100	1,000	**3,600**
MFH (incl. housing and commerce)	500	400	100	**1,000**
Business/ trading companies	100	200	100	**400**
Total	**7,800**	**5,700**	**1,200**	**14,700**

Table 4: SOLO Stirling 161, by Berger [4]

Engine data	**General performance data**	**External dimensions**	**Burner and combustion chamber (kW)**	**Fuel consumption and emissions**	**Cooling system**
V 2- Stirling engine	Maximum exit temp. outer circuit: 65°C	L: 1,280mm, D: 700mm, H 980mm	Burner performance, min-max: 16-40	NO emissions: 80-120 mg/m3	Volume of cooling fluid, internal: 4.12 l
Cylinder capacity: 160 cm^3	Performance temperature at heating inlet: 50°C	Weight: 460 kg	Fuel: natural gas, liquid gas (pellets in near future)	CO emissions: 40-60 mg/m3	
Operating gas: Helium	Electrical output capacity: 2-9.5 kWel Electrical efficiency 22-24.5%		System: flameless oxidation	Fuel consumption (net calorific value 10 kWh/Nm^3): 1.2-3.8 Nm3/h	
Max. medium operating pressure: 150bar	Thermal output capacity: 8-26 kWth, Thermal efficiency 65-75 %				
Nominal engine speed: 1500 rpm	Total efficiency 92 – 96 %				