Verbundnetz Gas AG

Full paper IGRC October 2011

"Power-generating heating system for a single-family house, the CHP micro-unit as a sustainable alternative to the condensing boiler"

0 Introductions

The primary energy requirements in the private sector as well as the resulting CO2 emissions are at a comparatively high level in industrialised countries, including the Federal Republic of Germany. The cost of heating single and two-family houses and the provision of the necessary electric power account for a major share in this segment. Energy costs were disregarded for a long time by users, given the relatively low oil prices of less than $ 50 per barrel and moderate electricity prices.
However, this situation has changed fundamentally. The development of oil prices is apparently only heading in one direction. Crude has already been traded at considerably more than $ 100 per barrel on the oil markets for some time. According to leading economists, the time of cheap oil seems to be over for good. This development is not only driven by the specifically high consumption of the industrialised countries but also by the steadily growing demand of emerging nations such as China, India and Latin American countries.

Apart from the continually rising costs of energy for heating, the price of electricity will also rise, especially in Germany owing to its exit from nuclear energy. These facts alone are good reasons to use primary energy as efficiently as possible.

This problem has been further aggravated in particular by the aspects of the debate on climate protection, an area also requiring action to reduce CO_2 emissions.
Germany's private households account for a significant share of primary energy demand, consuming almost 50% for heat and power. Therefore, this makes innovative, energy-saving and environmentally friendly solutions a must.
The efficient use of cogeneration can ensure a very high potential for saving primary energy, thus reducing CO_2 emissions particularly in this sector.

1 The background

Until well into the 1990s, heating based on low-temperature boilers burning gas or oil was the standard solution in single-family houses. However, condensing boilers have been increasingly used for some years, replacing the conventional heating boiler. More recently, however, electric heat pumps and alternative heating systems have been playing an ever greater role.
By contrast, power supply in the private sector is based almost exclusively on the conventional solution using the 0.4 kV supply grid. Electricity is primarily generated in large-scale fossil or nuclear power plants and supplied to the private end consumer through the existing transmission networks.

Using a comparative example, the following sets out to show how the specific primary energy requirements and the associated CO_2 emissions can be reduced in a single-family house using CHP micro-unit technology.

Fig. 1 shows a typical, old single-family house which has been modernised to an average standard and serves as a basis for comparison. Taking average climatic conditions for central Europe, approx. 25,000 kWh of energy for providing heating and hot water as well as some 4,000 kWh of electricity are consumed per year in a single-family house with three people.
Allowing for the actual boiler efficiency of 90%, approx. 2,800 m³ of gas is therefore required per year for heating purposes, producing CO_2 emissions of some 6.1 tonnes.
The electricity consumed per year of 4,000 kWh produces further CO_2 emissions. Based on the average specific power station emissions in Germany of 0.5 kg CO_2/kWh, this results in CO_2 emissions of 2.0 t per year. Total emissions from heat and electricity consumption therefore amount to 7.6 t of CO_2 per year and per single-family house.

Relating the final energy requirement for the house to the use of primary energy produces the following picture:
Approx. 28,000 kWh per year is required to heat the single-family house (related to the net calorific value of the gas used). This equates a natural gas amount of approx. 2,800 m³.
Allowing for the average power station efficiency with a factor of 0.35 and taking into account the actual grid losses in transmission to the end user, 11,400 kWh of primary energy are used to generate 4,000 kWh of electricity.

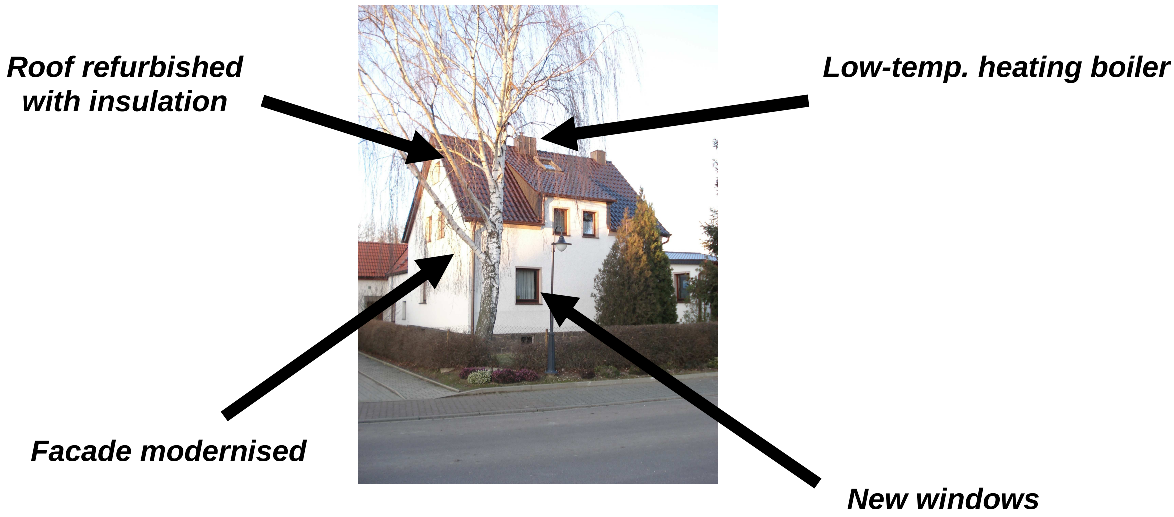


Fig. 1: Typical single-family house (built in 1960) with a living area of 160 m^2

2 Energy supply in a single-family house using a CHP micro-unit

Until now, single-family houses were mainly supplied with heat and electricity passively and therefore consumption-oriented. With the possibility of using so-called "micro" combined heat and power (CHP) technology in the private sector, the migration towards an active role can be initiated and systematically expanded. As a result of the generation of electricity in the single-family house, previously passive consumers become active producers.
From a technical point of view, various CHP systems are already available to the end user in a single-family house. In addition to the conventional engine cogeneration plants, the Stirling systems and also small fuel cells have made tremendous progress. The current challenge for launching these systems on the market is now much less a question of meeting technical requirements but mainly of explaining the cost-effectiveness to the user in the single-family house.

As part of technology monitoring, virtually all CHP basic technologies are examined at VNG AG. The findings so far can be largely summarised as follows:

- **Micro Stirling systems:** with approx. 15 %, relatively low electrical efficiency at comparably high costs, state-of-the-art technology
- **Small fuel cells:** very good electrical efficiencies (over 30 %) but costs still too high, stable technology
- **CHP micro-unit;** good compromise between electrical efficiency (25 %) and moderate costs, sturdy and time-tested technology

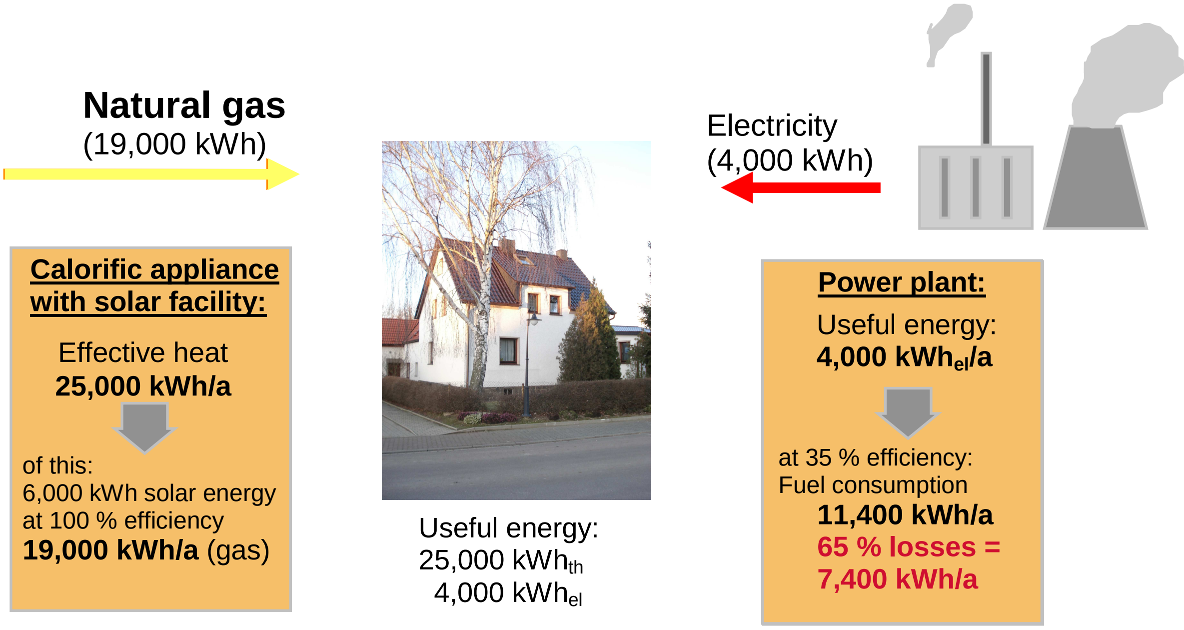
On the basis of the results achieved, VNG has already been involved for several years in the development and roll-out of CHP micro-unit technology for single-family houses.

By not installing a conventional low-temperature boiler but

a) a modern **condensing boiler with a solar facility**

b) a **CHP micro-unit**

in the aforementioned reference property, significant changes are achieved as regards the primary energy required and the resulting CO_2 emissions.



Primary energy consumption:	**30,400 kWh per application**
Resulting CO_2 emissions:	**3.8 t + 2.4 t = 6.2 tonnes**

Fig. 2: Condensing boiler heating supported by solar energy, conventional power supply

Condensing boiler heating in combination with a solar facility according to Fig. 2 can markedly improve energy efficiency in a single-family house. The increase in efficiency, however, only applies to the thermal and not the electrical energy. The possibilities of also improving electrical efficiency in the single-family house are, unfortunately, not exploited with this version.

As a "power-generating heating system", the CHP micro-unit exploits the efficiency potential both on the thermal and electric sides at the same time. As the CHP micro-unit solution according to Fig. 3 is solely heat-led, considerably more electricity is generated at an electrical efficiency of 25% than is consumed in the house. This energy can therefore be evaluated as credit.

Table 1 shows the values calculated for the various plant versions.

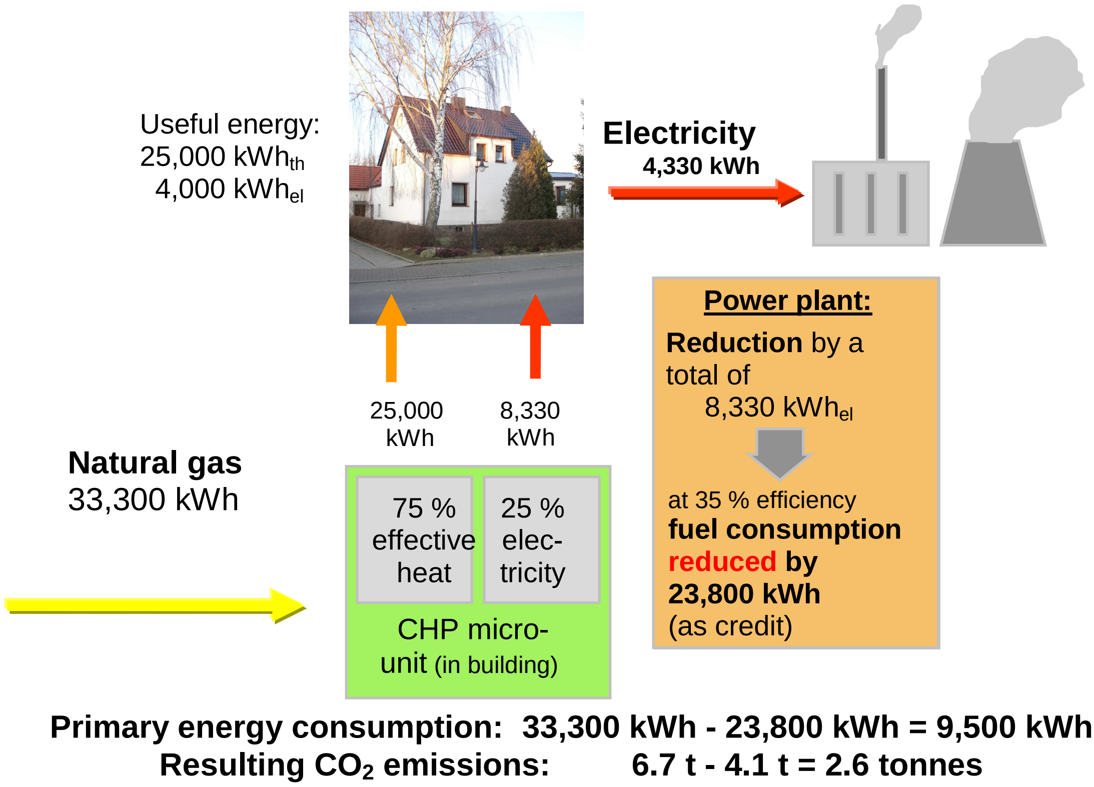


Fig. 3: CHP micro-unit in a single house

Plant version	Natural gas requirement (kWh)	Primary energy (kWh)	CO_2 (tonnes)
Low-temperature boiler	28,000	39,400	7.6
Condensing boiler + solar facility	19,000	30,400	5.8
CHP micro-unit	**33,300**	**9,500**	**2.6**

Table 1: Comparison of results obtained from different types of supply in a single-family house

As Table 1 shows, the CHP micro-unit solution provides the highest gain in efficiency and the best reduction in CO_2 emissions in the supply of energy to the single-family house. However, in order to optimally use the potential in the single-family house, a thermal storage device should be integrated into the system alongside the CHP micro-unit. It ensures as continuous operation as possible without the CHP micro-unit being continually switched on and off. It is advantageous if the production of hot water (shower, bath) is integrated in this storage device.

3 The state of the art of CHP micro-unit technology

3.1 Engine CHP system

CHP systems based on internal combustion engines represent the state of the art, particularly in the range of small outputs. Appliances such as the "Dachs" from SenerTec and the ecopower systems from Vaillant are the standard for CHP micro-units in Germany.

Fig. 4: CHP micro-unit with 55 kW electric power and 12 kW thermal output

Fig. 5: ecoPower with 4.7 or 3.0 kW electric power

Fig. 6: ecoPower 1.0 as a CHP micro-unit for a single-family house

From a technical point of view, the aforementioned CHP micro-units have the required maturity, reliability and stability to ensure the cogeneration of heat and electricity in the single-family house in accordance with Fig. 3. A backup system is no longer needed, especially in view of the system parameters and the unit's reliability. Heat-led, mono-fuel use is therefore also possible in the single-family house. However, one problem, especially in this application, has proved to be that in many cases 3,000 hours of operation per year can often not be achieved owing to the requirements placed on heat-led operation and the climatic conditions in central Europe and therefore cost-effectiveness is only reached in a few applications.
In order to take the crucial step forward here, the investment costs for the entire system in particular must be reduced substantially.

3.2 Stirling and steam technology

The CHP micro-units based on Stirling technology, with the "WhisperGen" from EHE, the Stirling SE from SENERTEC and steam technology with the "Lion" from OTAG, are in the phase of extensive field trials or direct market launch.

At a total efficiency of over 90%, the units exhibit good energetic performance but disappoint with electrical efficiencies of less than 15%.

Fig. 7: Stirling CHP micro-system from EHE with 1 kW electric power and 14 kW thermal output

Fig. 8: Steam-based appliance from OTAG with 2 kW electric power and 16 kW thermal output

Regrettably, these units have so far also been unable to establish themselves as genuine alternatives for supplying energy to a single-family house. One of the major obstacles is the price for the system investment which is too high compared with the CHP micro-unit. Here, an attractive system price must ultimately be offered by the unit manufacturers.

4 The activities of VNG - Verbundnetz Gas AG

4.1 Pilot plants of VNG

VNG - Verbundnetz Gas Aktiengesellschaft has already been working on the technology of the CHP micro-unit for several years.

During a two-year pilot project started in November 2007, two special CHP micro-units were examined for their fundamental suitability for their planned use in a single-family house.
The units were installed at VNG's underground gas storage facility in Bad Lauchstädt as there the CHP micro-units could reach over 10,000 hours of operation under defined conditions during the two-year test phase. The electricity and heat generated are used to run the technical systems of the UGS facility.
The special feature of the two pilot CHP micro-units is that they were designed exactly for use in a single-family house in terms of their parameters. With a variable thermal output of 5 kW to 10 kW, the conventional single-family house can, in conjunction with a hot water storage tank, be completely heated and supplied with hot water from a single energy source. The electric power produced by the CHP micro-units was max. 3.5 kW, which can be infinitely, varied down to min. 2 kW in part-load operation.

The concept is based on a gas-powered internal combustion engine which is connected to a highly efficient asynchronous generator. As a result, an electrical efficiency of 25% is achieved. The calorific value of the waste gases ensures a very high total efficiency of about 100%. The system runs in parallel network operation.

Fig. 9: Two VNG CHP micro-units with hot water tank and process interface equipment on the VNG test stand at the Bad Lauchstädt underground gas storage facility

A tailored monitoring system linked to the control system serves to record and stores the relevant process data and ensures the energetic balancing of the field test plants. The system is built around a powerful PC which uses Windows 7 as the operating system. This technical equipment also permits remote access to the fully automatic CHP micro-units.

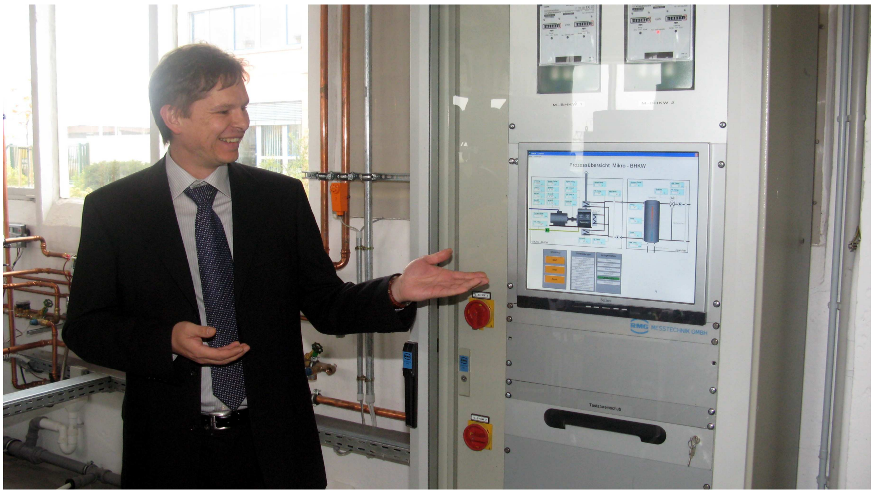


Fig. 10: PC-based monitoring system for data storage and evaluation

Apart from the technical parameters, the special feature of the pilot plants is that unit prices can be achieved which are relevant to the series production subsequently planned. The reasons for this are the main components used, such as the air-cooled IC engine in conjunction with the asynchronous generator, also air-cooled, which come from the industrial series production of well-known manufacturers.
This fact is important because the crucial factor in the presentation of the cost-effectiveness in a single-family house is ultimately the system price.

4.2 CHP micro-unit of the type L 4.12, near series production

VNG demonstration project with a total of 15 units, type L 4.12:

Proceeding from the results achieved with the VNG plants, near-series-production, air-cooled CHP micro-units were manufactured in a subsequent development stage in cooperation with a renowned engineering company.
In order to verify the use of the newly developed CHP micro-unit of the type L 4.12, a total of 15 demonstration units were installed and operated in single-family houses supplied by various municipal utilities, starting at the end of 2009.

Fig. 11: Demonstration CHP micro-unit with storage tank on the test stand of VNG AG (from 2009)

In addition to the air cooling of the engine and generator, the use of the calorific value is an important feature of the CHP micro-unit L 4.12.

Table 2 shows the technical parameters of the unit.

Electric power	2; 3; 4 kW (power levels)
Thermal output	5 to 12 kW (using calorific value)
Electrical efficiency	max. 25 %
Thermal efficiency	up to 75 %
Total efficiency	up to 100 % (as calorific value used)
Dimensions (H x W x D)	1,270 mm x 675 mm x 790 mm
Weight	approx. 200 kg
Mode of operation	heat-led

Table 2: System parameters of the CHP micro-unit L 4.12

The CHP micro-unit L 4.12 commissioned at the underground gas storage facility in Bad Lauchstädt on 1 October 2009 reached approx. 8,000 hours of operation by December 2010, including roughly 2,000 start-stop cycles.

All operating parameters are recorded systematically using the aforementioned monitoring system in order to make them available for subsequent evaluation.

The specified technical parameters in Table 2 were largely reached.

Highly efficient use of the calorific effect of the waste gas resulted in total system efficiencies which were sometimes over 100%. These effects were proven by measurements, in particular with return temperatures of up to 40℃.

Specific design features ensure that the CHP micro-unit reaches the specified performance parameters, such as the electric power and thermal output, very quickly after startup. Fig. 12 shows the performance curves during the startup process. As a result, the unit is also ideal for use in combination in the sense of a virtual power station.

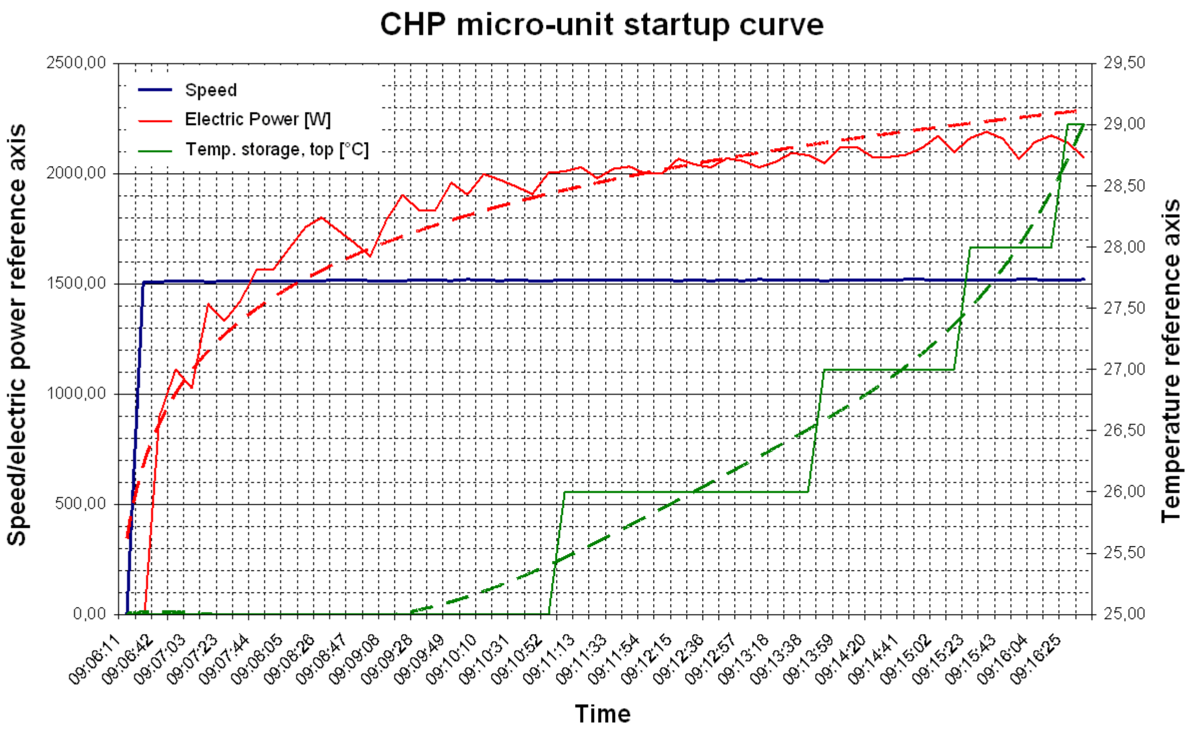


Fig. 12: CHP micro-unit startup curve

Field test with 150 units, L 4.12:

The results obtained during the demonstration project confirmed expectations in that the near-series CHP micro-unit of the type L 4.12 could be presented at the Hanover Fair in Germany in April 2010. This formed the technical basis for the start of the field trial in October 2010 with a total of 150 CHP micro-units of the type L 4.12. The units are primarily used in single-family houses.

The technical basis, in particular as regards the key machine components of the CHP micro-units, corresponds to the technology verified in the aforementioned preceding phases. However, the housing and the control system of the CHP micro-unit were fundamentally revised. Fig. 13 provides a visible impression of the series unit.

Fig. 13: Series CHP micro-unit L 4.12

The technical parameters are the same as those shown in Table 2. In addition to these technical values, which speak for the system concept owing to the unit's great compactness with a moderate weight and good key performance figures, the unit price of less than € 10,000 is very interesting for use in single-family houses.

With series production planned for October 2011, the user will have a viable alternative, also from economic aspects, to the condensing boiler with a solar facility as support.

5 Summary

Results obtained so far show that cogeneration based on the concept of CHP micro-unit technology can make an important contribution towards boosting energy efficiency in the private heating market.

Apart from the technical functionality, cost-effectiveness is of crucial importance for the end user to achieve successful and nationwide application in single-family houses. In this respect, the system price, comprising the CHP micro-unit itself and the heating buffer storage tank with integrated hot water production as well as the installation, ultimately plays the all-important role.

Proceeding from the system approach selected, the "VNG concept" of the air-cooled CHP micro-unit offers a very good basis for actually achieving cost-effectiveness in the target segment.

The theoretical potential to reduce CO_2 emissions and the potential for saving primary energy are of additional importance.

In the future, CHP micro-unit technology could also form a specific module, interacting with other decentralised and renewable energy conversion systems, e.g. wind and hydroelectric power stations as well as photovoltaic systems, in the development of virtual power stations down to virtual power storage units.

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