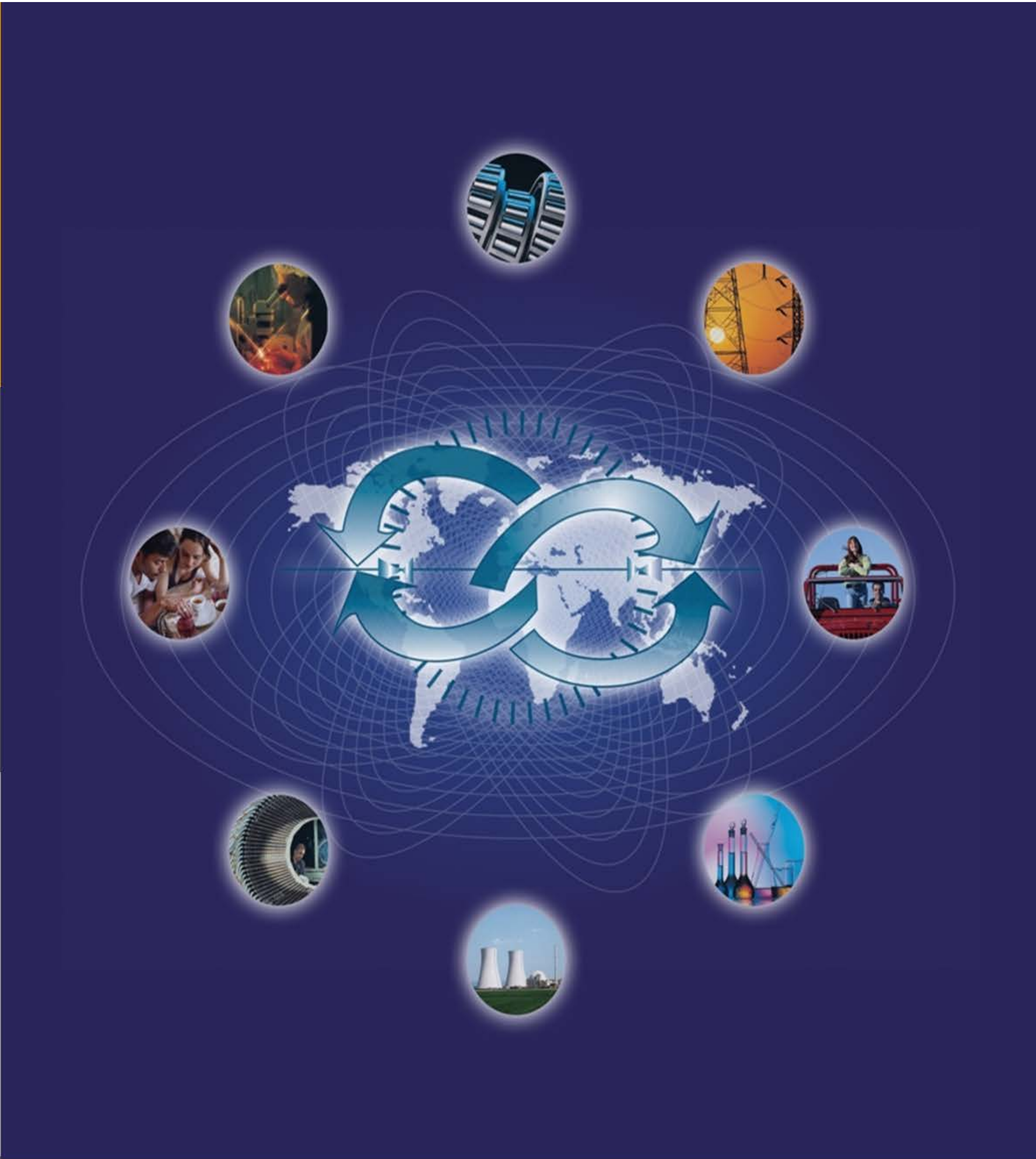

STE Research Report 02/2012

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Interim report: **Small CHP Appliances in Residential Buildings**
Subtask I, Annex 25 Fuel Cells for stationary application, IEA Advanced Fuel Cells

Institut für Energie- und Klimaforschung
Systemforschung und Technologische Entwicklung (IEK-STE)

JÜLICH
FORSCHUNGSZENTRUM

Small CHP Appliances in Residential Buildings

K. U. Birnbaum, IEK-STE, FZ-Juelich GmbH, February 2012

Abstract

This report describes and analysis the supply of the heat and power demand in a single family house representatively of the demand and covering possibilities in the residential sector in Germany.

Intention of the elaboration is the analysis of the general conditions for the application of new developed micro or nano CHP appliances and the consequences of the application with regard to costs, primary energy consumption/saving and possible impacts on the carbon dioxide emissions from the residential sector.

It shall be tried to collect country specific data for the home countries of the Annex 25 participants to contribute to a better understanding and knowing of the factors driving the market of house energy supply technologies.

Keywords

Micro CHP appliances, residential load curves, components of gas and electricity end user prices, electrical integration of CHP into the house supply, smart appliances, carbon dioxide emissions

Contribution to: IEA Advanced Fuel Cell, Annex 25 Fuel Cells for stationary application

Contents

I. Development of the use of Combined Heat and Power plant in Germany

The net power generation from CHP-plants increased between 2002 and 2010 by 14 TWh_{el} from 75,9 TWh_{el} to 89,9 TWh_{el}. That growth results from a by 2,3 TWh_{el} higher generation in public CHP plants (> 1 MW_{el}), from a by 4,2 TWh_{el} higher generation in industrial CHP appliances (> 1MWel) and from a by 7,5 TWh_{el} higher generation in "other" CHP plants. In that category a large amount of biogenic CHP appliances are operated which produced in 2010 nearly 6 TWh_{el}, compared to 0 TWh_{el} in 2004.

Table 1: CHP net power generation

	2002	2003	2004	2005	2006	2007	2008	2009	2010
CHP net power generation	**75,9**	**76**	**77,5**	**80**	**83**	**83**	**86,2**	**85,4**	**89,9**
Public generation (> 1 MW_{el})	51,0	50,5	52,4	51,5	54,0	51,9	53,8	50,5	53,3
of it communally operated	*16,5*	*17,4*	*17,5*	*19,5*	*21,8*	*20,9*	*21,3*	*22,5*	*22,9*
industrial generation (> 1 MW_{el})	23,0	23,5	22,9	25,6	25,8	25,8	25,7	26,6	27,2
other CHP plants (< 1MW_{el})	**1,9**	2,0	2,2	3,0	3,2	5,4	6,7	8,3	**9,4**
of it biogenic CHP plant	*0,0*	*0,0*	*0,0*	*0,5*	*0,6*	*2,7*	*3,9*	*5,0*	*5,9*

Source: [Wünsch 2011] IEK-STE 2012

Though the data in the undermost line of Tab 1 show a strong increase in power generation by biomass fired plants, the 2010-generation is only 6,6% of the total CHP net power production and compared to the total 2010 power generation of 583,3 TWh_{el} in Germany only ~1%.

Table 2 shows that the new-installation of < 10 kW CHP plants was clearly reduced in 2010 compared to 2009. That reduced new-installation of plants was compensated by the installation of plants with higher capacities in the other categories. The majority of the plants is of the <10 kW category, but these 2.900 plants hold only 5% of the in 2010 installed CHP capacity. In total ca. 27.500 old and new CHP plants were in operation at the end of 2010.

Table 2: New built or repowered CHP plants in 2009 and 2010

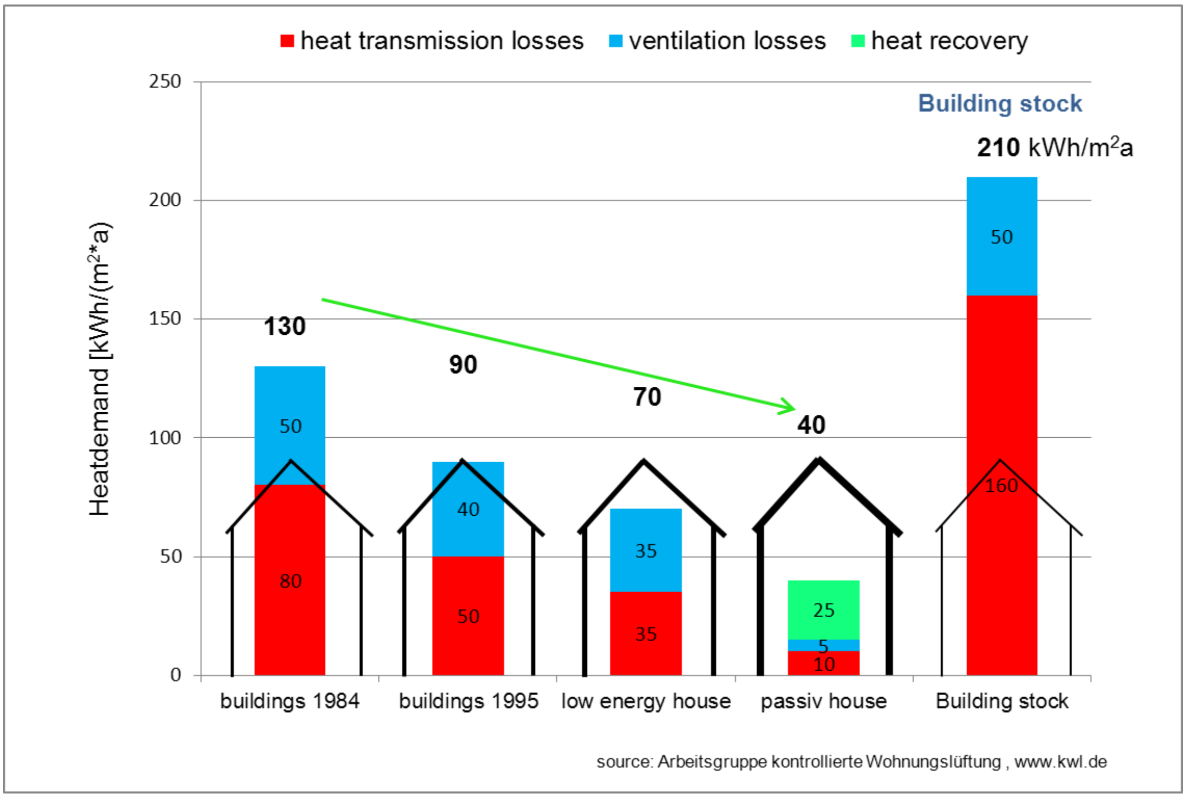
	2009		2010	
	number of plants	capacity [MW]	number of plants	capacity [MW]
Plants < 10 kW_{el}	2.794	16	1.888	9
Plants 10 kW_{el} to 50 kW_{el}	1.337	34	1.038	28
Plants 50 kW_{el} to 2 MW_{el}	259	104	333	130
Plants > 2 MW_{el}	24	369	24	594
Sum	**4.414**	**523**	**3.283**	**761**

Source: [Wünsch 2011] IEK-STE 2012

II. Residential heat demand and house heating systems

As consequence of the intensification of the Heat Insulation Ordinances, the specific heat demand of new buildings decreases essentially, see figure 1.

Figure 1: development of the specifique building heat demand in Germany



Source: [FGK 2011] IEK-STE 2012

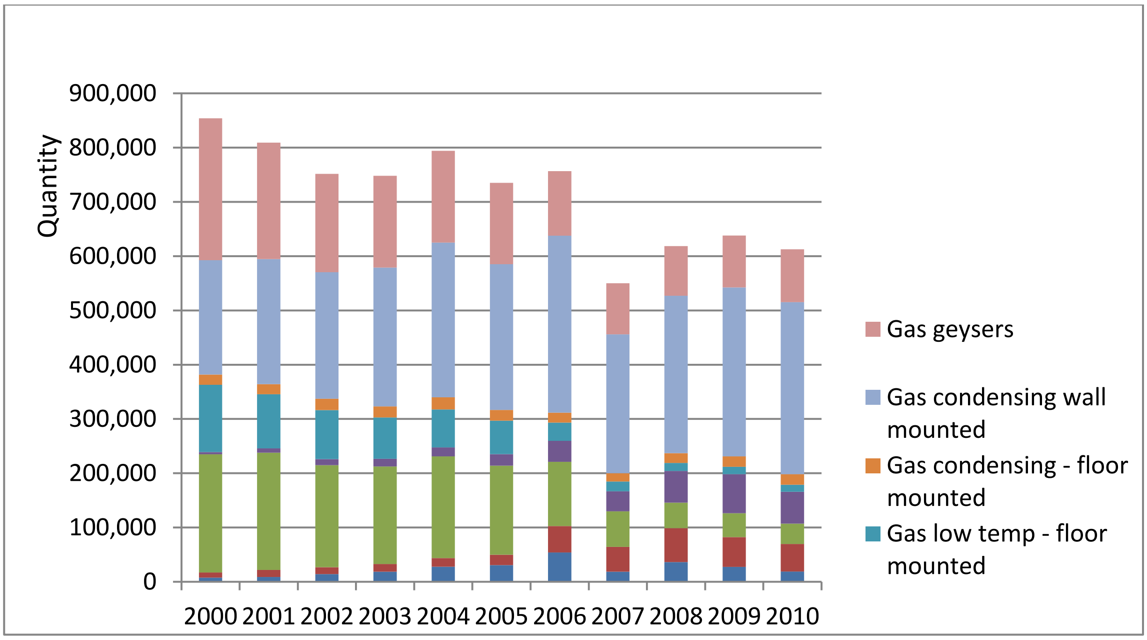
Though the new buildings have low heat demand, the average value for the building stock is still in the range of 210 kWh/m^2a. As the new-construction rate is in the range of 0,6%/a for both buildings and flats [dena 2011], the average heat demand will not decrease really fast, whereby the reduction of the building heat demand is an important aspect in the German strategy to reduce the residential CO_2 emission (~112 Mio t CO_2 in 2010 [BMWi 2011]).

But thermal insulation retrofitting or new energy efficient constructions are not exclusive measurements to reach the targets. A further contribution for an energy demand reduction is expected by the installation of new house heating technologies. Not only by smaller and more efficient ones or by the integration of solar thermal systems but also by new small combined heat and power technologies, which correspond to the idea of a decentralization of the power generation as they generate electricity near to the consumer by which transmission losses can be reduced.

The market volume of house heating systems corresponds more or less to the amount of buildings and when we are talking about small systems, we are talking about a market of nearly 19 million single and two family houses, whereby the actual sales of heating systems are in the range of 600.000 per year. Figure 2 shows that the sales are declining while the last years, which is traced back at the reduced construction activities. The survey of the Federal Industrial Association of Germany House, Energy and Environmental Technology [Breidenbach 2010] on the market development of heat generators (house heating boilers) documents the trend towards gas fueled appliances, especially wall mounted condensing systems, which need less space than other ones and partly no chimney which reduces the yearly maintenance effort and cost. The share of biomass fired heating appliances and of heat pumps is relative constant at a 10% level but it is in the range of 30% if only new built houses are regarded.

In total the German Federal Association of Chimney Sweeps balances 9 million gas fueled house heating systems in its 2010 report [ZIV 2010] of which 7,2 million belong to the performance class <25 kWth. Together with the data of Breidenbach (figure 2) is that a clue to a good gas infrastructure which is precondition for a high consumer acceptance not only for the fuel gas but also for the new gas fueled micro and nano CHP appliances. The strong market position was reached by expanding the gas-network to a length of totally 436.000 km of which 142.000 km are the low pressure grid by which typically the households are supplied. The connection density respectively market penetration is relatively high, as ca. 19 million flats of totally 40 million in single as well as in multi-family houses are using natural gas for heating and cooking. The Institute for Housing and Environment in Darmstadt (IWU) assumes for its calculation, that ca. 48% of the single family houses (18,7 million in 2007) are heated by gas. [Diefenbach 2007]

Figure 2: Development of house heating systems, 2000 – 2010



Source: [Breidenbach 2010] IEK-STE 2012

III. Micro CHP appliances for the residential sector

Micro CHP systems not yet appear in the statistics, though it is expected/hoped, that they can/will overtake an important role in the future energy supply system.

There are a couple of manufacturers which show a high engagement in developing and demonstrating the successful operation of these technologies.

The thermal capacity of these appliances is typically in the range of up to 5 – 10 kWth at an electrical capacity of 1 – 5 kW_{el}. As new systems like heat pumps, pellet systems (as of missing gas infrastructure) will not be substituted in the next future, the market volume is principally given by the older oil as well as gas house heating systems, of which ~63% belong to the category 10 – 25 kW_{th}.

Four technology routes are followed respectively offered at the market. That are small gas engines which are downsized from existing larger ones, that are stirling engines, based on the development of Whispergen respectively Microgen, that is the steam expansion machine based on an innovative free piston principle and that are fuel cells, the polymer electrolyte membrane fuel cell as well as the solid oxide fuel cell. As the heat capacity of the so called micro or nano CHP systems will not suffice to guarantee a secure heat supply or hot water demand peaks, an auxiliary boiler is normally integrated into the system. Corresponding to the state of the art condensing gas boilers are used.

Companies like Baxi-SenerTec, Vaillant, Viessmann, Bosch Thermo-Technik, Brötje, Hexis, Ceramic Fuel Cells Limited, Hexis, Riesaer Brennstoffzellentechnik GmbH, Whispergen and others like Volkswagen have developed or are developing such “power generating house heating appliances”, of which some are presented with table 3a, 3b and 3c.

The two first systems, the Dachs 5.5 and the EcoPower 3.0 in table 3a are designed for objects with a yearly heat demand of >25 MWh and operation hours of 4.000 or 5.000 h [Dachs 2012] [Jagenburg 2011]. That is the range of an economical operation. A higher heat demand is typical for multi-family houses, settlements, hotels or in the commercial sector and can by supplied by a combination of several CHP systems, if the capacity of one will not suffice.

The third one in that table, the EcoBlue gasengine of Lichtblick AG, is marketed at completely different aspects. The EcoBlue, which is using a gas engine of Volkswagen AG, remains in the ownership of Lichtblick AG and shall/will be operated via a central control center together with many more EcoBlue’s like a virtual power plant. Because of the flexibility of the engine a quick reaction at changing power demand and power availability, especially fluctuating wind power, is practicable. It is target to provide expensive peak power so that the virtual power plant reaches a high economy. The house owner, where a system is installed buys the heat and gets a rent for the set-up-room and he participates in the sales of power in form of a remuneration. Precondition for an installation is a yearly heat consumption of minimum 45 MWh, as otherwise the produced heat could not be used [Lichtblick 2012]. Up to now Lichtblick AG has installed and is operating 400 networked units with a total electrical capacity of 7,8 MW.

The EcoPower 1.0 nano CHP appliance was developed by Vaillant and Honda to complement the CHP product range of Vaillant by a small CHP system for single family houses with a heat demand in the range of 15 – 25 MWh/a [Jagenburg 2011]. Heart of the EcoPower 1.0 is the 1 kW_{el} Honda gas engine which is sold in large quantities in Japan and America as the Ecowill-system [Meissner 2010].

Table 3a: CHP-appliances with internal combustion engine

	CHP-appliances with internal combustion engine				
	SenerTec[S]: Dachs	**PowerPlus Tech [PPT]: Ecopower 3.0**	**LichtBlick AG [LB]: EcoBlue gasengine**	**Vaillant/Honda: Ecopower 1.0**	**Honda: ECOWILL**
	Operating principle: **Otto engine** with an internal combustion. Via a piston the combustion gas is driving a generator. The engines waste heat is recovered in heat exchangers for use as space heat or for heating domestic water.	Operating principle: **Otto engine** with an internal combustion. Via a piston the combustion gas is driving a generator. The engines waste heat is recovered in heat exchangers for use as space heat or for heating domestic water.	Operating principle: **Otto engine** with an internal combustion. (A 2 liter gasotto engine of Volkswagen, which is used in the Touran and Caddy models.)	Operating principle: 164 cm³ 4-stroke **Otto engine,** internal combustion.	Operating principle: 4-stroke **Gasotto engine,** internal combustion.
Fuel:	Natural gas	Natural gas	Natural gas		
Capacity el	5.5 kW_{el}	1.3 to 3.0 kW_{el}, modulating	20 kW_{el}	1 kW_{el}	1 kW_{el}
Capacity th	12.5 kW_{th} (14.5 kW_{th} @ condensing version)	4.0 bis 8.0 kW_{th}, modulating	36.25 kW_{th}, modulating	2.5 kW_{th} plus 12-30 kW by condensing peak boiler	2.8 kW_{th}
Efficiency	27% electrical	25% electrical	33% electrical	26.3% electrical	22.5% electrical
	61% thermal (72% @ condending version)	65% thermal	59% thermal	64% thermal	62.5% thermal
Fuel efficiency	88% (99% @ condensing version)	90%	92%	90%	85%
Power/Heat ratio	0.44	0.38	0.55		
parasitics load	? W stand by	? W stand by	? W stand by	? W stand by	? W stand by
	? W operation	? W operation	? W operation	? W operation	? W operation
Weight :	530 kg	395 kg		60 kg	
Service interval:	3,500 h	4,000 h (cost of service contract ~1.000 €/a + VAT)		6,000 h	
Market		multy family houses and sector Commercial/Trade/S	houses with a minimum heat demand of 40,000 kWh	single family houses	only Japan and USA, single family houses
Market status:	available	available	the first appliances are actually going into operation in Hamburg Dec. 2010	under development, first field tests are runnung	~100,000 units are installed in Japan and USA
Price:	20,491 Euro February 2010 (VAT included, but without transport, installation etc.)	~ 20,000 Euro (plus VAT, transport, installation etc.)	The house owner pays once 5,000 Euro for deinstallation the old system and installation of the new one. The plant remains the property of LichtBlick, which rents the customer's "boiler-room" for **5 €/m**. The customer pays a heat price (compared to district heat). The house owner gets **0.5 Cent/kWh electricity** fed into the grid. Minimum heat demand 40,000 kWh.	16,000 Euro (plus VAT etc.)	
specifics			daily operation hours: 1 to 5 hours	Cooperation between Honda and Vaillant to develop a micro CHP unit for single family houses and the European market	not sold at the European market
	[S] Since 2002 SenerTec is a subsidary company of the British BAXI Group. In 2009 BAXI Group and De Dietrich Remeha Group created the company BDR Thermea	[PPT] Subsidary company of Vaillant	[LB] LichtBlick AG is a utility which supplies 500,000 customers with electricity and gas. Its mission statement is: Offering clean energy at a fair price.		

Source: [Company's information]

Table 3.b informs about several Stirling house heating systems, which are actually introduced in the German and European market. The difference in the Stirling operating principle is that Whispergen uses a 4 cylinder double-acting cycle, while the others are using the free piston engine technology, developed by Microgen Engine Corporation. Today it is a joint undertaken of a couple of shareholder, of which BDR Thermea and Viessmann hold each a 42 per cent interest. Further shareholders are KD Navien from Corea, Innova Solar Energ from Italy, Vaillant and the employees. All companies are using the same stirling module, which is built in China. Its capacity range is 1 kW_{el} and 6 – 7 kW_{th} to supply a good share of the heat demand in new single family houses and parallel a certain amount of the electric base load. All systems are completed by a peak boiler.

The OTAG Lion Powerblock is a steam expansion system, built in Germany, but because of economic difficulties, the production was stopped and it is not yet clear, if it will be restarted.

Table 3b: CHP-appliances with stirling engines and steam expansion enigine

	Stirling CHP-appliances					Steam expansion machine
	EHE [E]: Whispergen EU1	**BDR Thermea[B]: eVita**	**Vaillant: Stirling CHP-unit**	**Viessman: Stirling CHP-unit**	**Dachs SE (Stirling)**	**OTAG: Lion Powerblock**
	Operating principle: 4 cylinder double-acting **Stirling** cycle	Operating principle: free piston **Stirling** engine technology	Operating principle: linear free piston **Stirling** engine technology	Operating principle: linear free piston **Stirling** engine technology	Operating principle: one-cylinder free piston **Stirling** engine coupled with a linear generator	Operating principle: The lion is driven by a **process steam operated double piston**, named LINATOR (linear generator). A gas burner heats up water in a pipe to process steam (approx. 350° C at 25 –30 bar). The steam enters alternately the two working cylinders, expands and generates electricity while driving the armature coil, which is fixed to the double piston through a strong magnetic field. A cooling circuit leads the heat from the LINATOR via a heat exchanger and gives it to the heating system and process water.
Fuel:	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural gas
Capacity el:	1 kW_{el}	0,9 kW_{el}	1 kW_{el}	1 kW_{el}	up to 1 kW_{el}	0.3 - 2 kW_{el} modulating
Capacity th:	7.5 kW_{th} plus 14.5 kW_{th} peak boiler	3 - 6.17 k\ plus 18 kW_{th} peak boiler	3 - 6.1 kW plus condensing peak boiler	6 kW_{th} plus 18 kW_{th} peak boiler (condensing boil	3.0 - 6.1 k plus 18 kW_{th} peak boiler (condensing boil	3.5 - 16 kW_{th} modulating
Efficiency:	7% electrical (10% - 11%)	13% electrical	~14% electrical	~14% electrical	~13% electrical	10% - 13% electrical (user report lower values)
	~ 85% thermal	~ 85% thermal		~80% thermal		~ 85% thermal
Fuel efficiency :	92%	93%		94%	97%	
Power: Heat ratio		0,17			0,16	~ 0.10
parasitics load	11 W stand by	4 W stand by	? W stand by	? W stand by		? W stand by
	60 W operation	80 W operation	? W operation	? W operation		? W operation
Weight :	140 kg	130 kg		100 kg	100 kg	195 kg
Service interval:						
market	single family houses	single family houses	single family houses	single family houses	single family houses	single family houses
Market status:	available	available	fieldtests in the Netherland; introduction in Germany i	available in September 2011	available in September 2011	available
Price:	17,000 Euro Offer in Germany, all inclusive (VAT, 800 l waterstorage, control unit, exhaust system, circulation pump etc.)	~ 15,000 I offer in Germany all inclusive	10,000 Euro (plus VAT etc.)		Dachs inclusive buffer storage: 14,450 Euro netto plus installation additional hot water modul SE 20: 1,450 Euro	~ 15,000 Euro (plus VAT and installation)
specifics		Stirling engine delivered by Microgen Engine Corporation (MEC), built in China. Shareholders of MEC are: BDR, Vaillant, Viessmann and KyungDong Navien Co., Ltd.	MEC Stirling component	MEC Stirling component	Microgen Stirlingmodul	available
					connection to the grid by a one-phase electric meter	
	[E] EHE (Efficient Home Energy) is a joint venture between Whispertech and Mondragón Corporation Cooperativa to distribute the "Wispergen EU"	[B] BDR Thermea was created by Baxi Group and De Dietrich Remeha (Brötje is part of BDR)		integrierte Gas-Brennwertkessel Vitodens 200, Wirtschaftlich ab jährlichem Gasverbrauch von min. 26000 KWh und einem Stromverbrauch von mehr als 3000 KWh.	Since 2002 SenerTec is a subsidary company of the British BAXI Group. In 2009 BAXI Group and De Dietrich Remeha Group created the company BDR Thermea	

Bosch Thermotechnik (D), **Enatec** micro-cogen (Netherland), **Merloni** TermoSanitari-MTS (Italy) and **Rinnai** (Japan) are developing a stirling engine based micro CHP house energy supply unit for application in single households. The stirling engine was developed in a cooperation of Enatec, Rinnai and Infinia Corporation. Within the next time, a huge amount of house energy systems shall be practical tested by Bosch.

Source: [Company's information]

Table 3.c gives an overview of the actual status in the case of fuel cell house energy supply systems. Hundreds of the Gamma 1.0 and the Galileo N are operated within the framework of the Callux Programme of the German Government which is actually in its 2nd phase. For the 3rd Callux phase Baxi has refined the Gamma 1.0 to the Gamma 1.3 also Gamma Premio called. By order of the utility EWE, Bruns Heiztechnik and CFCL have developed a system which is also in a governmental demonstration programme. And the company Sanvo is now selling the CFCL BlueGen as power generator which must be combined with an (already installed) heating boiler.

Table 3c: CHP-appliances on fuel cell technology

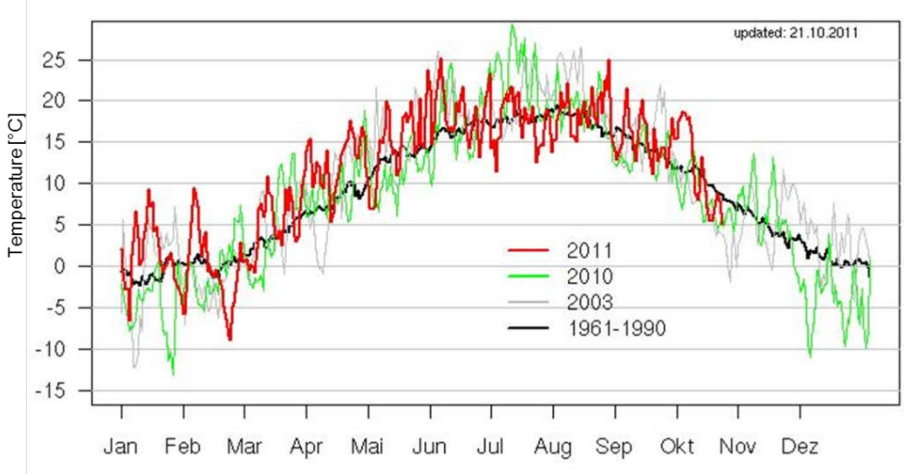
	Fuel cells				
	Baxi Innotech[BI]: Gamma 1.0	**RBZ[RBZ]: Inhouse 5000**	**Hexis[H]: Galileo N**	**Bruns Heiztechnik/CFCL[CF]: BZG F01**	**Vaillant and R&D partners IKTS, Delta, Staxera [St)]**
	Operating principle: Electrochemical reactions generate power. Baxi Innotec is using Proton Exchange Membrane Fuel Cell technology (PEMFC)	Operating principle: Electrochemical reactions generate power. RBZ is using Proton Exchange Membrane Fuel Cell technology (PEMFC)	Operating principle: Electrochemical reactions generate power. The fuel cell system of Hexis is based on the high temperature fuel cell technology (SOFC - Solid Oxide Fuel Cell).	Operating principle: Electrochemical reactions generate power. BlueGen™ is a modular style fuel cell generator that can be configured to suit a range of different markets and installations. It is of the type Solid Oxide Fuel Cell	Operating principle: Electrochemical reactions generate power. The fuel cell system is based on the high temperature fuel cell technology (SOFC - Solid Oxide Fuel Cell).
Fuel:	Hydrogen	Hydrogen	Natural gas	Natural gas	Natural Gas
Capacity el:	1.0 kW_{el}	5.0 kW_{el}	1.0 kW_{el}	up to 2 kW_{el}	1 kW_{el}
Capacity th:	1,7 kW_{th} plus 15 kW peak boiler	2 - 10 kW modulating	2,5 kW_{th} plus 20 kW peak boiler	300 - 1000 W_{th} plus condensing boiler (4.6 - 22.8 kV	2 kW_{th}
Efficiency:	~32% electrical	25 - 30% electrical	25-30% (target: >30%)	up to 60% electrical at 1.500Watt (~54% net efficien	30% - 34% electrical
modulation range				0% bis 100%	
Fuel efficiency :	~85%	60 - 90%	>90%	up to 85% (target for the overall system: >90%)	80% - 85% thermal
Power: Heat ratio	0.58%				
parasitics load	? W stand by	? W stand by	? W stand by	? W stand by	
	? W operation	? W operation	? W operation	? W operation	
Weight :	~200kg		170 kg	285 kg	
start time	~ 60 minu (from 0 Watt to 1,000 Watt: 5 hours)				cold start time: 2 -3 hours
load change time					
Service interval:	twice a year @ 5,000 operation hours/a				10,000 hours
Market	single family houses (residential dwellings)	application in multy family houses, in the sector commercial trade services	single family houses, in the sector commercial trade services	one/two family houses; introduction ~2014	
Market status:	demonstration tests, market introduction 2013	field tests with 12 units is running/starting	a large number is running in field and demonstration test	12 prototypes in fieldtest, 60 are going into test at EV	field test shall start in mid of 2011
retail price					in the range of the competitors
specifics	Modulation is possible between 100% and 30%. The power/heat capacity ratio enables more yearly operation hours: 5,000 h are the target			500 liter water storage system is integrated, including 45 liter drinking water and 3.8 liter fuel cell heat exchanger	multi start-stop procedures could be realised
	S) Baxi Innotec is a subsidary company of British BAXI Group. In 2009 BAXI Group and De Dietrich Remeha Group created the company BDR Thermea.	RBZ) Riesaer Brennstoffzellentechnik GmbH	H) Since January 2006 the company is independent and trades under the name of Hexis Ltd	CF) Ceramic Fuel Cells Limited and Bruns Heiztechnik	Fraunhofer IKTS Dresden; Delta Energy Systems Soest; Staxera GmbH Dresden (was overtaken in 2011 by SunFire GmbH)

Source: [Company's information]

IV. Heat and power demand in residential houses, yearly operation hours, load profiles

The residential heat demand is strongly influenced by the regional climate conditions. Germany's climate is moderate and normally without sustained periods of cold or heat. The average temperature in summer is in the range of 20°C at maximum values up to 30°C, see figure 3. The winter is influenced by relative mild south west wind so that the average temperature is around 0°C, whereby the last years longer periods at partly strong minus-degrees and snow occurred in January and February. The yearly mean temperature in Germany is about 9° C. [Climate 2011]

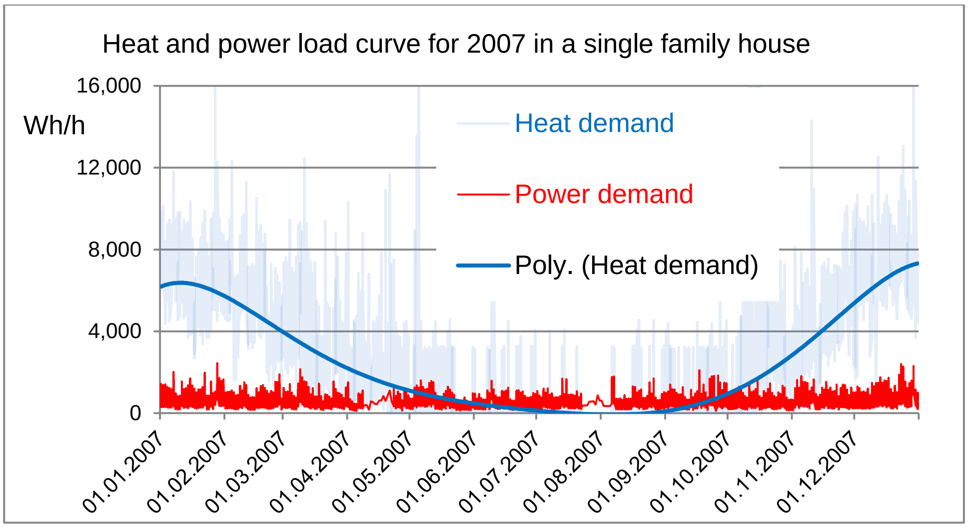
Figure 3: Average daytime temperatures for several years in Germany



Source: [Lasch 2011] IEK-STE 2012

Corresponding to these circumstances the heat load curve in residential buildings has typically its highest level between December and February and its lowest one in summer time, as demonstrated with the blue graphs in figure 4, which are calculated/measured for a single family house in 2007. The dark blue line is the polynomial regression of the pale blue heat load curve, which bases on 1 hour data, calculated from the heat demand value which were recorded in fifteen minutes intervals. (Basis for the red electricity load curve are 1 minutes values which are converted into 1-hour values.) Because of the heat storage capacity of a heavy house construction (stone/concrete walls and concrete floor/ceiling) the rate of temperature changing is relative moderate so that normally no peaks occur neither in short nor in long recording time intervals.

Figure 4: Yearly load curves heat and power of a single family house

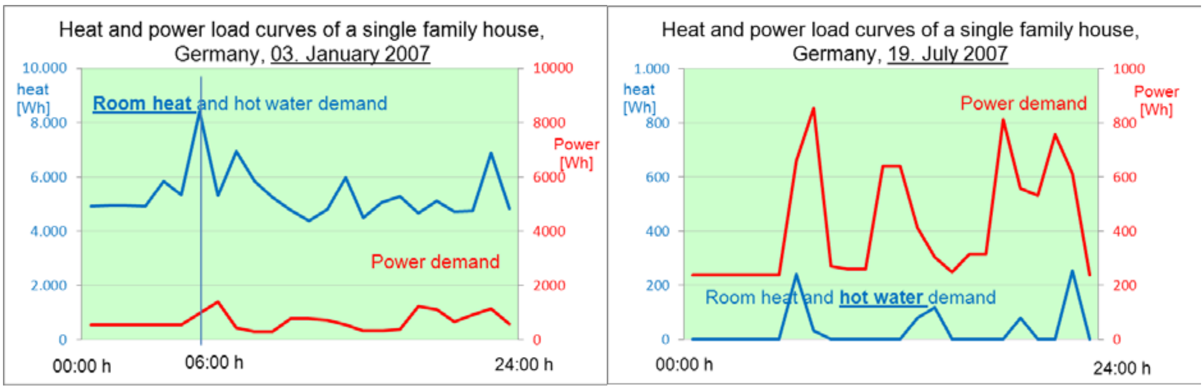


Source: [IEK-STE] IEK-STE 2012

In order to be able to evaluate the possibilities of an efficient operation of a micro CHP appliance in the market segment "single family houses" it is of interest to learn about the correlations between heat and power demand and options to influence them also with regard to the use of smart appliances and smart grids.

Exemplarily for a winter day, 3rd January 2007 with an average temperature of ~ 3°C, and for a summer day, the 21st July, temperature 21°C, figure 5 reflects the conditions in a single family house located in the western part of Germany, where the

Figure 5: Heat and power load curves of a single family house



Source: [IEK-STE] IEK-STE 2012

climate is determined by damp and mild Atlantic winds from the west. The house fulfills the requirements of the 2nd Thermal Insulation Ordinance [TIO 82/84] and has a reasonable insulation, double-glazed windows and so on. The specific heat demand is in the range of 100 kWh_{th}/m^2.

It is obvious, that room heating dominates the heat demand in wintertime, while water heating is the driver for the heat demand in summer time. The curve shapes in the two charts of figure 5 point clearly out the difficulty of designing/choosing/operating a CHP plant as an efficient, ecological and economical application in a single family house. You have very less heat demand in summer time, which cannot be compensated by changing the output, more power than heat. Consequently it is essential to find a use for the produced surplus heat in summer time.

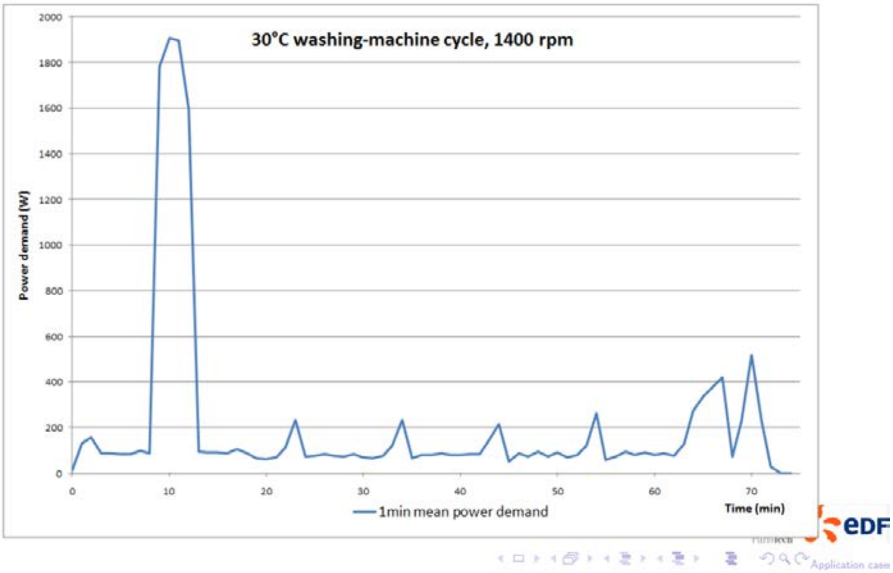
An emergency cooling is prohibited in order to ensure the ecological advantages of a CHP application in general and to fulfill the efficiency requirements for funding corresponding to the new German Directive on the promotion of CHP plants in particular (annual efficiency min 85%, primary energy savings of at least 15% for units <10 kWel and existing maintenance contract). [RFKWK 2012]

Opposite to the heat demand curve, the electricity load curve is more or less characterised by fluctuations with partly extreme variations by some thousand watt high and down within less minutes or even seconds. Take as example the one to three minutes operation time of a 2.000 Watt hair-dryer in parallel to a water cooker or coffee machine. Also the energy intensive heat-up phase of a washing machine is not to be seen in recording intervals of 1 hour, as it takes typically not more than fifteen to twenty minutes by new washing machines, which are using less water. Figure 6 shows the load curve of a 30°C washing cycle with an energy intensive heat-up time or only ~8 minutes.

But probably the fluctuation of the power demand or the power load is not really important for the dimensioning of a micro respectively nano CHP system. That is also a résumè of the subtask A report of the IEA ECBCS ANNEX 42 ’FC+GOGEN-SIM’ where the differences between load curves recorded at 1 minute respectively 5 minute intervals and consequences are discussed [Knight, Ribberink 2007].

The causers of the spikes may be of interest for the organisation of the future power supply as they can be identified by smart metering. It is one of the expected advantages of smart metering and smart grids to move a spike causing application to less critical times triggered even via online-price signals. With regard to these circumstances it should be tried to identify the smart-grid applicable household applications and appliances. It is fact, that there is a change in energy intensive appliances: While washing machine, dishwasher, refrigerator or freezer are becoming better and better, the entertainment electronics like TV and computer need more and more electricity and influence strongly the residential energy demand [Welt online 2012].

Figure 6: Electricity demand curve over the operation time of a washing machine

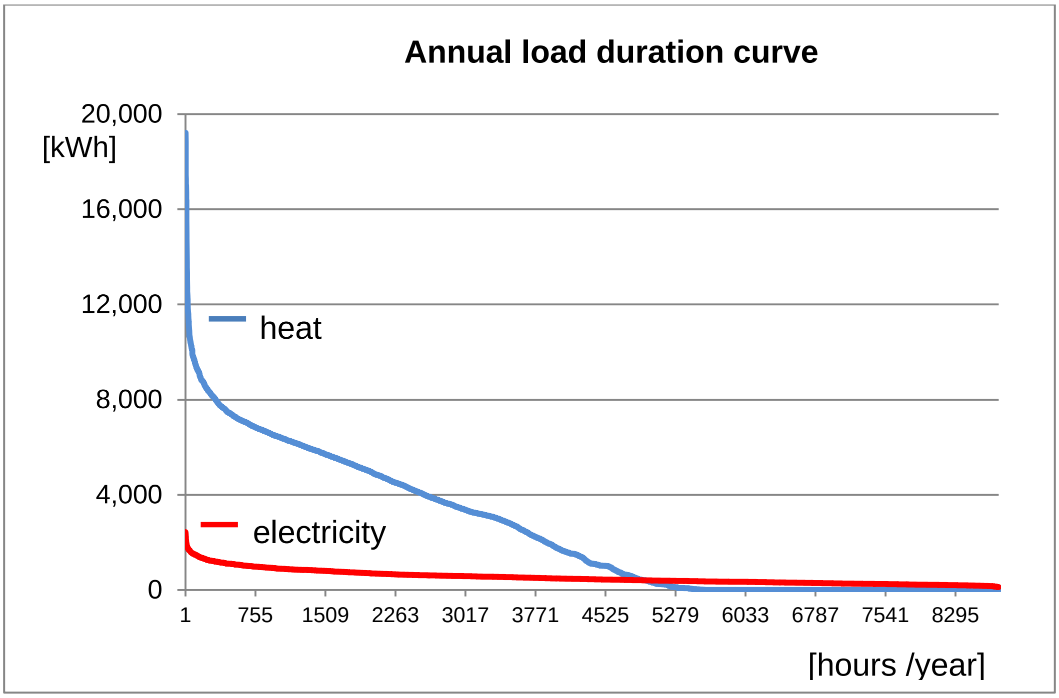


Source: [Grandjean 2011] IEK-STE 2012

Up to now it can be said, that domestic CHP plants normally are grid-connected so that the grid delivers that part of electricity which is not supplied by the CHP plant. So far it is consequent to design the micro and nano CHP appliances corresponding to the typical heat demand of a potential consumer or consumer category. Additional the annual load duration curves in figure 7 underline that it is difficult to find a system to meet exactly the demand or to operate it for an acceptable as economical time per year.

As the thermal capacity of the with table 3 presented CHP technologies normally does suffice to deliver the required energy for room heating and hot water preparation, the installed appliance contains an additional peak boiler (mostly gas condensing boiler) which can deliver missing heat. Inherent part of the package is a hot water buffer (also required by the new German CHP Act) to store surplus heat and to extend the operation time of the CHP in some respects. But in today’s houses, where

Figure 7: Yearly electricity and heat demand profiles of a single family house



Source: [IEK-STE] IEK-STE 2012

the heating systems are often installed in the bath room, in the kitchen or at the loft, the available space and the allowable static floor load are factors which limit the storage capacity. Additional must be mentioned, that the efficiency of a storage system is also a function of storage use and storage losses.

V. Calculations and results for the application of different CHP technologies

It is obvious, that the larger CHP appliances of table 3a can be operated to supply the demand in multi-family houses, especially in those cases in which also the hot water is prepared by the central heating system. That opens the possibility to use the CHP heat in summer time.

To find out some results for the operation of small CHP technologies, especially for the new fuel cell and stirling engine systems, the supply of single family houses is simulated/calculated.

The assumed data for gratification, fuel as well as electricity prices and for basic rates, shown with table 4, are taken from companies price announcements.

Table 4: Assumption for the simulation of a CHP installation in a single family house

Building:			
Single family house	Electricity demand	4.646	kWh_{el}/anno
	Room heating demand	18.668	kWh_{th}/anno
	Hot water demand	2.850	kWh_{th}/anno

Assumptions			
	Electricity prices		
kiloWatt-hour rate	22,86	ct/kWh	
plus basic rate	77,02	Euro/household	
	gratification		
feed-in tarif	11	ct/kWh	(5,11 ct chp bonus, ~5 ct EEX-price, ~1 ct avoided grid costs a.o.)
CHP bonus for self used power	5,11	ct/kWh	
internal compensation for self used electricity	27,97	ct/kWh	(5,11 ct chp bonus, avoided kilowatt-hour rate, which depends from supplier and the tariff, exemplarily 22,86 ct/kWh in Aachen (Aix la Chapelle))
	Gas prices		
gas price	7,1	ct/kWh Gas	$1m^3$ = 10,8 kWh
plus basic rate	138,66	Euro/household	

Source: [IEK-STE] IEK-STE 2012

The electricity price for domestic customers has three main components:

- 30% for power procurement and marketing
- 21% network charges
- 49% taxes and duties (renewable energies reallocation charge, CHP reallocation charge and others)

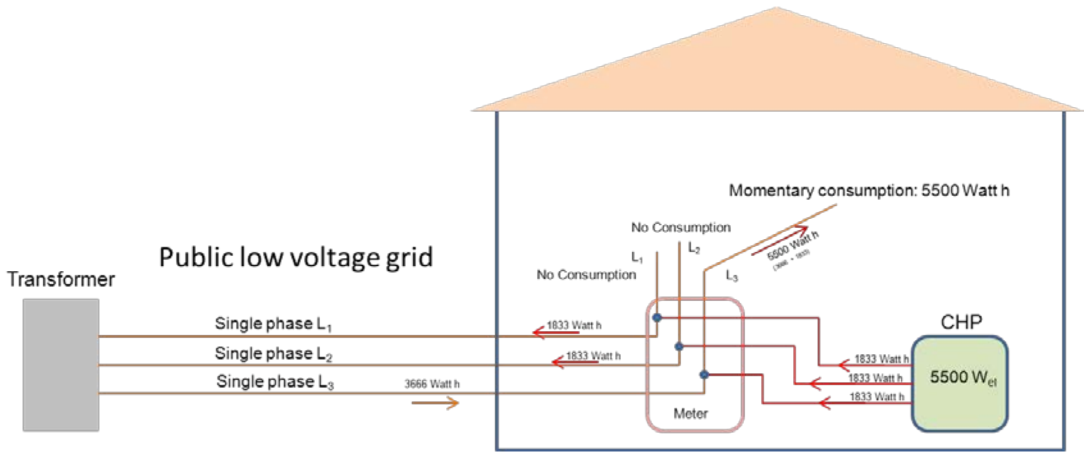
The structure of the domestic gas prices is comparable in principle:

- 45% for purchase
- 31% for network, transport, distribution and billing
- 24% for taxes and duties.

Appliance dependent data as capacity, efficiency and others can be found in the first lines of table 6 and table 7.

It is pointed out, that for the calculation no energy losses and no self-demand of the appliances are regarded, neither vessel heat losses because of downtimes nor fuel consumption for system starts or stops nor electricity for controlling and others . Furthermore no start-up waiting times were taken into account. So far the results mirror not reachable best cases with regard to fuel, electricity as well as heat production and to cost respectively gratification. The technical difficulty for the house internal use of the CHP-power is sketched with figure 9. Up to now the small scale

Figure 9: Electrical integration of a domestic CHP plant



Source: [IEK-STE] IEK-STE 2012

CHP appliances are normally connected via one power phase to the house internal grid, either to be used via that line or to be fed into the public grid. Even if there would be a three line connection, the contribution of the CHP-power to the house supply depends from the actual electricity demand at each phase. Typically the base load of a single family house is in the range of 100 to 300 Watt per hour, whereby there is a clear tendency to 100 Watt or less as there are the political, financial and ecological requirements for a reduction of the demand (no stand-by appliances, less watt bulb etc.).

Results of the calculations are presented with table 5a and 5b, whereby further details are given with table 6 and table 7. A condensing gas boiler with a buffer storage and an additional 5 m^2 solar thermal system is chosen to be the reference system, as it fulfills the requirement of the Renewable Energies Heat Act [REHA 2011]. Also other systems like heat pumps or pellet systems etc. fulfill the requirements which are predicted for new house constructions respectively comprehensive renovation measurements since 2011. But such systems are not regarded with this elaboration.

All included CHP systems have a 300 litre hot water buffer storage (= 3.488 Wh). That volume does not prove itself to store so much surplus heat that the operation time of the CHP can be extended significantly in situations with no heat demand. (The aspect of the allowable buffer dimension/weight is mentioned before.) In the simulation, the buffer storage is used to supply first the room heat demand. The remaining heat demand is supplied by the CHP and if necessary by the peak boiler. The buffer storage loading depends from the demand in the next hour which is known as calculated separately. That procedure was chosen to avoid non-essential heat work of the CHP unit or the peak boiler.

The yearly operation hours of the fuel cell systems vary between 4.700 hours for the Galileo and 5.200 hours for the CFCL-Sanevo (BlueGen), see table 5a. As the thermal capacity of these appliances is only in the range of 2.000 W, the peak boiler is operated for ca. 1.000 hours per year, except of the 574 hours in the case of the Galileo N and the 776 hours for the power driven CFCL-Bruns calculations. The power-driven case was simulated to find out the effects on the fuel demand, the costs, the CO_2-emissions and on the economy of that operation mode. It results in 8.317 operation hours which lead logically to a very high power generation (16.634 kWh/a) by which the domestic power demand can be supplied by 98%. The amount of self-used CHP power is calculated by comparing the hourly power demand, known from separate simulations/measurements, and the CHP generation at the same time period. The power self-supply share reaches 55% to 65% of the domestic power demand for all fuel cell CHP cases. The same range is reached by the Ecopower 1.0 with 57% and the Dachs 5.5 with a share of 60%.

Data of the costs, primary energy consumption (fuel for the appliance as well as primary energy factor for the purchased electricity) and emissions are collocated in table 5b. At the web sites of Sanevo you can get some price information for the BlueGen and its installation. Sanevo sells a BlueGen generator for 38.294 € (inclusive 19% VAT and installation). A peak boiler is not part of that offer. For this report it is calculated with ~7.000 € so that a retail price of 45.000 € results. As the retail prices for the Baxi and Hexis systems are unknown, the 30.000 € are guessed on the base of the quotation of the price by Sanevo. Reason for the lower price is the different power to heat ratio, which is seen as a price reducing factor.

Beginning in February 2012 a new CHP-subsidy program of the German government is starting. It is a single-payment for all CHP plants up to a capacity of 20 kW_{el} and graduates itself as follows: 1500 Euro for units up to 1 kWel; further 300 Euro for each kW from 10 kW up to 20 kWel. [RFKWK 2012] The values in the second row of table 5b are the resulting investment, official retail price minus CHP subsidy.

Table 5a: Results of the simulation "Micro CHP systems in a single family house"

Single family house, yearly heat demand: 21.518 kWh_{th} yearly power demand: 4.646 kWh_{el}	operation hours [h]		fuel consumption		Power generation			share of power self-supply	all-inclusive retail price	CHP subsidy corresponding to the CHP ordinance 2012
	CHP	peak boiler	CHP	peak boiler	generation by CHP	self consump	feed in			
	[h]	[h]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	[Euro]	[Euro]
Condensing boiler with solar thermal	-	992	-	19.844	-	-	-		10.000	0
Baxi-Gamma 1.0	4.879	970	14.892	14.854	4.630	2.671	1.959	57%	30.000	1.500
Baxi Gamma 1-3	4.845	925	13.978	14.162	4.710	2.665	2.045	57%	30.000	1.800
Hexis Galileo N	4.695	574	16.705	10.947	4.379	2.563	1.816	55%	30.000	1.500
CFCL-Bruns	5.078	5.078	17.322	17.908	9.756	2.975	6.780	64%	45.000	1.800
CFCL-Bruns power driven	8.317	776	29.535	14.259	16.634	4.565	12.069	98%	45.000	1.800
CFCL-Sanevo	5.229	1.077	12.602	19.782	7.605	3.030	4.575	65%	45.000	1.800
Otag Lion Powerblock	5.627	0	27.027	0	2.802	2.067	735	44%	22.500	1.800
Dachs 5.5	1.790	3	37.126	0	9.844	2.805	7.039	60%	24.000	2.600
Ecopower 1.0	4.487	623	17.643	10.668	4.487	2.666	1.822	57%	22.000	1.500
Whispergen EHE EU1 Stirling	4.074	523	24.068	3.204	2.415	1.836	579	40%	19.000	1.500
Viessmann Vitotwin300 Stirling	3.383	436	18.410	8.007	2.430	1.722	708	37%	19.000	1.500
Condensing boiler without solar	-	1.098	-	21.957	-	-	-		7.000	

Source: [IEK-STE]

Table 5b: Results of the simulation "Micro CHP systems in a single family house"

	resulting costs	fuel an pow er cost	yearly capital consumption @ 10 years; real interest rate 4,9%; annuity=0,1288	maintenance	yearly cost fuel + pow er + capital + maintenance	extra cost versus reference	CO_2 emission of appliance	Primary Energy consumption (PE factor of grid power in 2010: 2,46)	Reduced primary consumption compared to reference	avoided CO_2 emission compared to reference
	[Euro]	[Euro/a]	[Euro/a]	[Euro/a]	[Euro/a]	[Euro/a]	[t CO_2]	[kWh_{PE}]	[kWh_{PE}]	[tCO_2]
Condensing boiler with solar thermal	10.000	2.687	1.289	150	4.126	0	6,684	31.281		0,000
Baxi-Gamma 1.0	28.500	2.427	3.673	250	6.350	2.225	4,603	23.211	8.070	2,081
Baxi Gamma 1-3	28.200	2.305	3.635	250	6.190	2.064	4,232	21.421	9.860	2,452
Hexis Galileo N	28.500	2.324	3.673	250	6.248	2.122	4,376	22.001	9.280	2,307
CFCL-Bruns	43.200	2.201	5.568	523	8.292	4.166	2,670	15.327	15.954	4,013
CFCL-Bruns power driven	43.200	1.783	5.568	523	7.874	3.748	-0,342	3.042	28.239	7,026
CFCL-Sanevo	43.200	2.226	5.568	523	8.317	4.192	3,267	17.641	13.640	3,417
Otag Lion Powerblock	20.700	2.538	2.668	250	5.456	1.330	5,415	26.479	4.802	1,269
Dachs 5.5	21.400	2.355	2.758	400	5.513	1.387	4,684	17.422	13.859	2,000
Ecopower 1.0	20.500	2.342	2.642	1.000	5.984	1.858	5,893	22.138	9.143	0,791
Whispergen EHE EU1 Stirling	17.500	2.637	2.256	150	5.042	917	5,814	28.246	3.035	0,870
Viessmann Vitotwin300 Stirling	17.500	2.594	2.256	150	4.999	874	5,693	27.632	3.649	0,990
Condensing boiler without solar	7.000	2.837	902	150	3.889	-237	7,117			no reduction

Source: [IEK-STE]

The yearly capital consumption of the investment is calculated with a real interest -rate of 4,9%/a and for 10 years. Maintenance costs are accounted as the subsidy payment is coupled to a maintenance contract [RFKWK 2012]. The yearly operation costs for the house owner result from the addition of that costs and the payment for gas as well as electricity, whereby the CHP-bonus and feed-in payment are deducted.

The next row shows the extra costs of each technology compared to the reference “condensing boiler with solar thermal support”. The highest “extra costs” are calculated for the CFCL systems. It is caused by the high retail price respectively the high yearly fix and variable costs which cannot be compensated by the high electricity generation (7.600 kWh_{el} – 16.600 kWh_{el}) which provides for a high CHP bonus and a high feed-in gratification.

For the calculation of the primary energy consumption the natural gas consumption, the grid power purchase and the CHP generation of power are taken into account. The CHP power substitutes grid power which has a primary energy factor of 2,46 (2010). That procedure leads to a significant reduction of the primary energy of all CHP-using households in comparison to the reference. The reduction reaches its maximum for the power driven operation of the CFCL system, caused by the high electrical efficiency and the resulting high power generation.

A comparable procedure is done with the CO_2-emission. The CO_2-emission factor of the CHP power is clearly lower than the average value of grid power. The difference between grid power emission and CHP power emission is subtracted from the CO_2-emission of the house energy supply system. That procedure explains the partly very high amount of avoided CO_2-emissions.

Table 6 and table 7 give some detailed results on the operation hours of the CHP and the peak boiler, on the gas consumption for CHP power and CHP heat, on the expenses and gratifications as well as on the allocation of the CO_2 emissions.

Up to now, the results are still incomplete, as sensitivity analysis are not yet done. Furthermore the function “modulating operation” is not yet regarded correctly, it may have a greater importance than thought and calculated up to now.

Table 6: Results of the simulation of the Fuel Cell CHP cases

Technology	Baxi-Gamma 1.0 modulation 100%-30%		Baxi Gamma Premio (Version for Callux Phase III) modulation 100%-30%		Hexis Galileo N modulation 100%-30%		CFCL-Bruns modulation 100%-30%		CFCL-Sanevo modulation 100%-30%		Condensing boiler with solar thermal panel ($5m^2$, roof 40°, south) – Reference appliance		power driven CFCL-Bruns	
	Capacity CHP	efficiency	net Capacity	efficiency	Capacity CHP	efficiency	Capacity CHP	efficiency	Capacity CHP	efficiency	Capacity	efficiency	Capacity CHP	efficiency
CHP [Watt th]	**1.700**	53%	**1.866**	62%	**2.500**	63%	**1.000**	26%	**600**	26%			**1.000**	26%
CHP [Watt el]	**1.000**	32%	**1.028**	34%	**1.000**	30%	**2.000**	59%	**1.500**	59%			**2.000**	59%
hot water storage (300 ltr)	3.488		3.488		3.488		3.488		3.488				3.488	
peak boiler [Watt th]	**15.000**	98%	**15.000**	98%	**20.000**	98%	**0**	98%	**18.000**	98%	**20.000**	98%	**18.000**	98%
solar panel usable energy											2.070	kWh/a		
Results														
Operation hours														
CHP modulated	**4.879**	h	**4.845**	h	**4.695**	h	**5.078**	h	**5.229**	h			**8.317**	h
peak boiler	**970**	h	**925**	h	**574**	h	**975**	h	**1.077**	h	**992**	h	**776**	h
Gas consumption														
CHPel	5.516	kWh	4.965	kWh	4.773	kWh	5.774	kWh	9.002	kWh			19.690	kWh
CHPth	9.377	kWh	9.013	kWh	11.932	kWh	17.322	kWh	3.601	kWh			9.845	kWh
CHP system	14.892	kWh	13.978	kWh	16.705	kWh	23.096	kWh	12.602	kWh			29.535	kWh
peak boiler	14.854	kWh	14.162	kWh	10.947	kWh	17.908	kWh	19.782	kWh	**19.844**	kWh	14.259	kWh
	29.747	**kWh**	**27.351**	kWh	**27.652**	**kWh**	**41.004**	**kWh**	**32.384**	**kWh**	**19.844**	kWh	**43.793**	**kWh**
Power generation														
CHP	**4.630**	kWh	**4.710**	kWh	**4.379**	kWh	**9.756**	kWh	**7.605**	kWh			**16.634**	kWh
self consumption of it	2.671	kWh	2.665	kWh	2.563	kWh	2.975	kWh	3.030	kWh			4.565	kWh
feed in of it	1.959	kWh	2.045	kWh	1.816	kWh	6.780	kWh	4.575	kWh			12.069	kWh
purchased electricty	**1.975**	kWh	**1.981**	kWh	**2.083**	kWh	**1.671**	kWh	**1.616**	kWh	**4.646**	kWh	**80**	kWh
Cost														
gratification for feed in power	*215*	*Euro*	*225*	*Euro*	*200*	*Euro*	*746*	*Euro*	*503*	*Euro*			*1.328*	*Euro*
chp bonus for chp power generation	*137*	*Euro*	*136*	*Euro*	*131*	*Euro*	*152*	*Euro*	*155*	*Euro*			*233*	*Euro*
cost of purchased electricity	*-528*	*Euro*	*-530*	*Euro*	*-553*	*Euro*	*-459*	*Euro*	*-446*	*Euro*			*-95*	*Euro*
electricity	-176	Euro	-169	Euro	-223	Euro	439	Euro	212	Euro	-1.139	Euro	1.465	Euro
gas	-2.251	Euro	-2.137	Euro	-2.102	Euro	-2.640	Euro	-2.438	Euro	-1.548	Euro	-3.248	Euro
Energy cost	**-2.427**	**Euro**	**-2.305**	**Euro**	**-2.324**	**Euro**	**-2.201**	**Euro**	**-2.226**	**Euro**	**-2.687**	**Euro**	**-1.783**	**Euro**
avoided electricity purchase cost	*611*	*Euro*	*609*	*Euro*	*586*	*Euro*	*680*	*Euro*	*693*	*Euro*			*1.044*	*Euro*
	negative Euro amount means expenditure, positive Euor amount means income													
CO_2 emissions	*emission factor natural gas 0,205 kg CO2 / kWh*				*emission factor power plant mix 0,563 kg CO2 / kWh*									
from gas consumption	6,098	t CO_2	5,769	t CO_2	5,669	t CO_2	7,222	t CO_2	6,639	t CO_2	4,068	t CO_2	8,978	t CO_2
from purchased electricity	1,112	t CO_2	1,115	t CO_2	1,173	t CO_2	0,941	t CO_2	0,910	t CO_2	2,616	t CO_2	0,045	t CO_2
avoided CO_2 by self generation	-2,607	t CO_2	-2,652	t CO_2	-2,465	t CO_2	-5,492	t CO_2	-4,281	t CO_2			-9,365	t CO_2
resulting emission	**4,603**	**t CO_2**	**4,232**	**t CO_2**	**4,376**	**t CO_2**	**2,670**	**t CO_2**	**3,267**	**t CO_2**	**6,684**	**t CO_2**	**-0,342**	**t CO_2**

Source: [IEK-STE]

Table 7: Results of the simulation of engine CHP cases

Technology	**Dachs 5.5** no modulation		**Ecopower 1.0** no modulation		**Whispergen EU1 Stirling** modulation 100%-20%		**Viessmann Vitowin300 Stirling** modulation 100%-50%		**Condensing boiler** example for existing systems		**Condensing boiler with solar thermal panel** ($5m^2$, roof 40°, south)	
	Capacity CHP	efficiency	Capacity CHP	efficiency	Capacity CHP	efficiency	Capacity CHP	efficiency	Capacity	efficiency	Capacity	efficiency
CHP [Watt th]	**12.500**	61%	**2.500**	64%	**8.300**	85%	**6.000**	80%				
CHP [Watt el]	**5.500**	27%	**1.000**	26%	**1.000**	10%	**1.000**	14%				
hot water storage (300 ltr)	**3.488**		**3.488**		**3.488**		**3.488**					
peak boiler [Watt th]	**20.000**	98%	**18.000**	98%	**6.000**	98%	**18.000**	98%	**20.000**	98%	**20.000**	gas consump
solar panel usable energy											2.070	kWh/a
Results												
Operation hours												
CHP	**1.790**	h	**4.487**	h	**4.074**	h	**3.383**	h				
peak boiler		h	**623**	h	**523**	h	**436**	h	**1.098**	h	**992**	h
Gas consumption												
CHPel	11.344	kWh	5.041	kWh	2.588	kWh	2.630	kWh				
CHPth	25.782	kWh	12.602	kWh	21.480	kWh	15.780	kWh				
CHP system	37.126	kWh	17.643	kWh	24.068	kWh	18.410	kWh				
peak boiler	0	kWh	10.668	kWh	3.204	kWh	8.007	kWh	**21.957**	kWh	**19.844**	kWh
	37.126	**kWh**	**28.311**	kWh	**27.272**	**kWh**	**26.417**	**kWh**	**21.957**	kWh	**19.844**	kWh
Power generation												
CHP	**9.844**	kWh	**4.487**	kWh	**2.415**	kWh	**2.430**	kWh				
self consumption of it	2.805	kWh	2.666	kWh	1.836	kWh	1.722	kWh				
feed in of it	7.039	kWh	1.822	kWh	579	kWh	708	kWh				
purchased electricty	**1.840**	kWh	**1.980**	kWh	**2.810**	kWh	**2.924**	kWh	**4.646**	kWh	**4.646**	kWh
Cost												
gratification for feed in power	*774*	*Euro*	*200*	*Euro*	*64*	*Euro*	*78*	*Euro*				
chp bonus for chp power generation	*143*	*Euro*	*136*	*Euro*	*94*	*Euro*	*88*	*Euro*				
cost of purchased electricity	*-498*	*Euro*	*-530*	*Euro*	*-719*	*Euro*	*-745*	*Euro*	*-1.139*	*Euro*	*-1.139*	*Euro*
electricity	420	Euro	-193	Euro	-562	Euro	-579	Euro	-1.139	Euro	-1.139	Euro
gas	-2.775	Euro	-2.149	Euro	-2.075	Euro	-2.014	Euro	-1.698	Euro	-1.548	Euro
Power and Gas cost	**-2.355**	**Euro**	**-2.342**	**Euro**	**-2.637**	**Euro**	**-2.594**	**Euro**	**-2.837**	**Euro**	**-2.687**	**Euro**
avoided electricity purchase cost	*641*	*Euro*	*609*	*Euro*	*420*	*Euro*	*394*	*Euro*				
	negative Euro amount means expenditure, positive Euor amount means income											
CO_2 emissions	*emission factor natural gas 0,205 kg CO_2 / kWh*				*emission factor power plant mix 0,563 kg CO_2 / kWh*							
from gas consumption	7,611	t CO_2	5,804	t CO_2	5,591	t CO_2	5,416	t CO_2	4,501	t CO_2	4,068	t CO_2
from purchased electricity	1,036	t CO_2	1,115	t CO_2	1,582	t CO_2	1,646	t CO_2	2,616	t CO_2	2,616	t CO_2
avoided power plant CO_2 by self ger	-3,963	t CO_2	-1,026	t CO_2	-1,359	t CO_2	-1,368	t CO_2				
resulting emission	**4,684**	**t CO_2**	**5,893**	**t CO_2**	**5,814**	**t CO_2**	**5,693**	**t CO_2**	**7,117**	**t CO_2**	**6,684**	**t CO_2**

Reference appliance

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VII. Appendix

As this elaboration is destined for the work in Annex 25 IEA Advanced Fuel Cells Stationary Application Subtask I, it would be of interest, to collect similar data for other countries, i.e. potential market situation and volume (like tab 1 and tab 2), typical competitors (Table 3), typical application (heat and power or additional cooling), typical heat and electricity load curves for single family houses (Figure 4 and Figure 5), information on the gas network (length, share of connected houses/flats) - as the CHP technologies need a connection to the gas grid - and data on the energy prices, its components (taxes, duties etc.) and of course information on feed in gratifications, chp boni, investment subsidies and others, which will enable us to upgrade our knowing of the situation in the residential sector in the countries of the annex members.

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