Comparison of Heat Pump and MicroCHP for Household Application

Dr. Péter Kádár, member of IEEE

Óbuda University, Dept. of Power Systems
Bécsi u. 94, H-1034 Budapest, Hungary
Phone: +36 209 447 241; fax: +30 1 250 0940
kadar.peter@kvk.uni-obuda.hu

Abstract — **Nowadays two new types of household heating appliances can be found in the households: the heat pumps and the microCHP (small scale Combined Heat and Power generation unit) devices. In this paper we investigate the application possibility of these devices in continental climate conditions, e.g. in Hungary. Heat pumps use electricity generated mainly from natural gas. We compare the natural gas consumptions and the CO_2 emissions, too. Natural Gas is widely used for small scale urban heating purposes in its original form, by the gas-electricity – heat pump conversion and by the microCHP-s, as well. The microCHP offers several advantages compared to the traditional gas boiler devices. We introduce also an experimental petrol/Natural Gas/Propan Butan fueled CHP unit made from a second hand car engine and a squirrel cage induction motor.**

Keywords: microCHP; induction motor; heat pump; natural gas consumption

I. Domestic Heating Alternatives

A. The usage of natural gas

In Hungary 70% of of and public heating is based on natural gas. [13] The total natural gas consumption in 2010 was over 15 billion m^3/year. 45% of it is the household consumption part [14]; it is close to 7 billion m^3/year. The average yearly household gas consumption five years ago was 2000-2200 m^3/year, it dropped to 1200-1300m^3/year (2009) [16]

In 2008 39% of the electricity was generated on natural gas base [17].The electrical efficiency of the old gas fueled plants is 36%, the most recent ones reached 59%. Nowadays the average of the gas plants' efficiency exceeds 40%.

B. The heat pump applications

The heat pump is a device that transports heat from a low temperature medium to high temperature environment with the help of external heat or mechanical energy. Heat pumps are characterized by the COP (Coefficient Of Performance) that is the quotient of the current heat output power and the current electricity power input. This value used to be between 3-4 in an average application (e.g. air/water pump). The best settings run by COP 7 (e.g. thermal water/water pump).

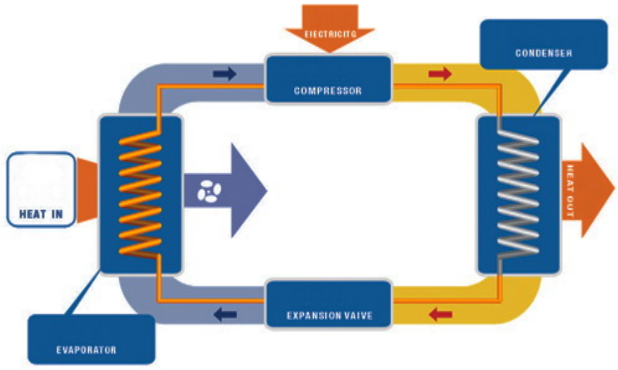

Fig. 1. The structure of the heat pump [15]

Nowadays, instead of COP rather SPF (Seasonal Power Factor) is used, it is calculated from the yearly heat energy output and electric energy input. In fig. 2 [12] we can see, that the SPF is only approx. 0,6 times the COP. In Hungary at an average application the SPF is about 2,2 – 2,3. It means, that 45% of the output heat comes from electricity.

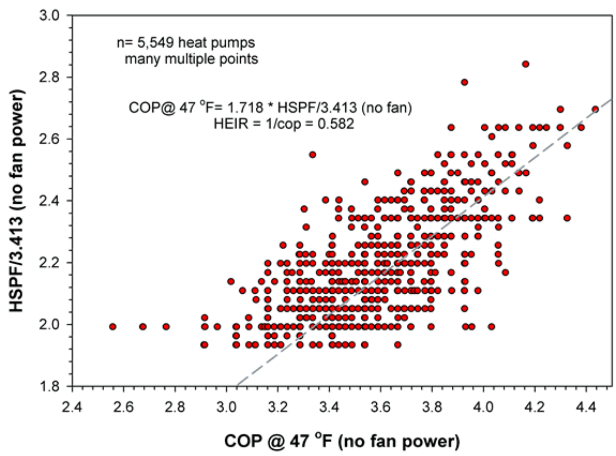

Fig. 2. The experimental relation between COP and SPF [12]

In table I. we compared how much heat can be retrieved by 1 m^3 natural gas by a gas boiler with 87% efficiency and by a heat pump with SPF 2,2. We calculated with average 40 % electrical efficiency of the gas fueled power plants and 10 % loss on the electrical network.

Table I. Energy ratios of heat pump application

	used gas m^3	produced/used electricity MJ	heat output MJ	waste heat MJ
Gas boiler	1		29,6	4,4
Power plant	1	13,6		20,4
Heat pump		12,24	26,93	1,36

The heat pump is far better than the clear electric heating but is worse than a local gas boiler. It has advantages in case of warm external heat sources or by applying it in summer in reverse mode (cooling). By the way, the new condensing boilers' efficiency is over 95%.

C. *The micro CHP application*

The microCHP (small scale Combined Heat and Power generation unit) provides electricity and heat mainly on open cycle Otto piston engine base. The heat of the exhaust gas warms the water or air through a heat exchanger.

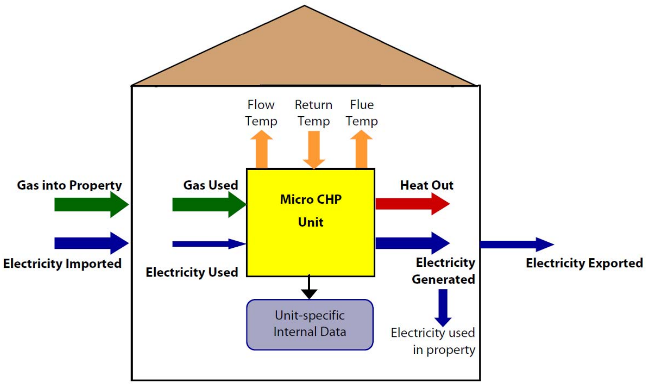

Fig. 3. The structure of the microCHP applications [applying 11]

A survey on the commercially available microCHP-s stated an average of 82% operating efficiency, taking into account both electricity consumed by the appliance and electricity generated by it. When considering thermal and electrical efficiencies independently, the average thermal efficiency for all sites is 58% and the average electrical efficiency is 24%. There was little seasonality". [11]

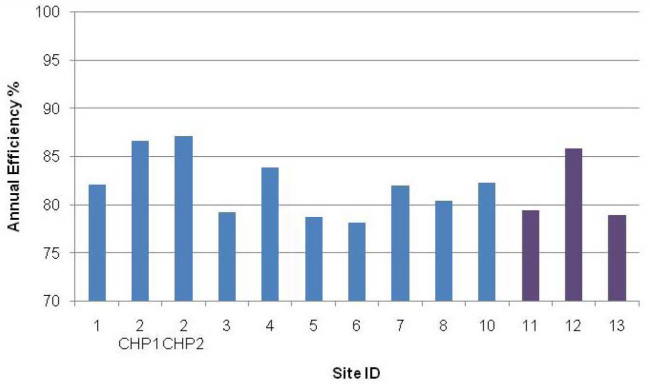

Fig. 4. Efficiencies of CHP-s [11]

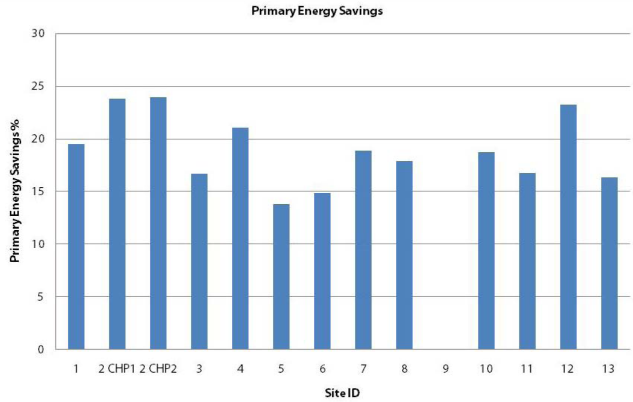

Fig. 5. Primary energy savings by usage of the waste heat [11]

If we are interested in the national energy efficiency we can investigate the alternatives, where to burn the gas. In a short calculation we compared the performance of the central electricity generation and the local heat production (gas heated boiler for heating purposes) with the distributed small CHP engines.

The up-to-date bulk Combined Cycle Gas Turbine (CCGT) power plants works with over 50% electrical efficiency.

The traditional gas boiler has 85-87% average heat efficiency. A typical microCHP has 26% electrical efficiency and 61% heat usage efficiency.

Table II. Advantage of the microCHP

	used gas m^3	heat MJ	electricity MJ	waste MJ
Gas boiler	1,00	29,44		4,56
CCGT	0,42		**7,14**	7,14
MicroCHP	1,42	29,44	**12,95**	5,89

The calculation shows that the small scale co-generation produces more electricity from the same input gas by heat constraint than the simple gas boiler and the separate good efficiency CCGT. This encourages us to investigate and foster the microCHP development. The energy performance analysis did not take into account the investment into the devices.

II. THE GREEN BALANCE

The comparison covers the effect of the national CO_2 emission, too. The following table shows the amount of the gas burned and the CO_2 emitted in case of producing the same amount of heat and electricity by different methods. We calculated with 50% efficiency of the CCGT plant, 87% of the boiler, 2.3 SPF for the heat pump and 1.73 kg CO_2 emission by 1 burning 1 m^3 natural gas.

Table III. CO_2 balance comparison

	used gas m^3	*generated /used electricity MJ*	*heat MJ*	*Total CO_2 emission in kg*
Gas boiler +	1		29,44	
external electricity generation in CCGT	0,761	12,95		**3,04**
Power plant for heat plant +	0,828	14,08		
Heat pump +		12,8	29,44	
external electricity generation in CCGT	0,761	12,95		**2,74**
MicroCHP	1,42	12,95	29,44	**2,45**

It's clear that the microCHP has the best CO_2 balance. The good position of the heat pump comes from the good efficiency of the CCGT.

III. THE GRID IS SMARTENING

The Smart approach infiltrates into the existing grid, more and more smart solutions and devices will perform the future's smart operations. Beside other important features all the Smart definitions mention that this grid enables

- loads and distributed resources to participate in operations [7]
- the large-scale deployment of DG (Distributed Generation) and renewable resources. [9]

There are some distributed electricity generation units that produce only electricity (PhotoVoltaics or Wind turbines), but there is a huge area where we produce a lot of heat energy waste permanently. That is the gas heating, where we produce only heat but electricity could be generated by the mechanical volume extension, too. The principle of the CHP (Combined Heat and Power generation) is

- first the electricity generation (mainly on mechanic base internal combustion engines such as the micro-gas-turbine or the Otto engine. Electricity can be generated in fuel-cells [1], Stirling engines or Rankine cycle engines, as well. [4])
- second the usage of the heat of the exhaust gas

By this methodology operate a lot of

- bulk power plants (over 100 MW, mainly with gas turbine) a
- medium category plants (0,5-3 MW mainly with multi cylinder gas engines).

The (bulk) CHP based electricity generation ratio was over 22% in Hungary in the year 2008. [8]

IV. THE MICRO CHP TREND

The applications of CHPs have spread over also in Europe and in the last decade the small scale micro CHP (typically 1-10 kW) became commercially available. They can supply the individual households by heat and electricity, too.

In Germany 3,000 eco-power micro-CHP units have been installed, using the U.S. based Marathon Engine Systems long-life engine. [2] Furthermore over 23,000 DACHS mini-CHP units (typically 5,5 kW units) have been installed based on reciprocating engine technology. [3]

Honda's 1 kW (electrical power) system – named Ecowill – mainly is used in single-family home applications. In Japan more than 30.000 units have been installed. [5]

In Europe by the year 2020 over 10 million microCHPs are forecasted. For Central and Eastern Europe the installation potential is 700.000 units. [6] If we count an 1,5 kW average power per CHP and assume 10 million devices, it makes 15.000 MW, that is the 3,5 % of the 400 GW operational power of the European system. This huge unit number can cooperate only as controlled "virtual power plant" that will be realized by the Smart Grid philosophy.

V. THE TEST DEVICE

In the last half decade the world's yearly car production was over 50 millions [10]. Roughly, this is the number of the cars withdrawn from circulation yearly, as well. Having seen the huge amount of industrial waste, we made a trial to use an old car engine to drive a 3 phase squirrel cage induction motor. Motor (not a generator) because it operated decades in a small plant, and we looked for a second hand device. The basic approach is:

- a large number of engines are available
- they are low cost
- it is a low speed operation
- 12 V DC output is built in
- electrical efficiency is not so important for most of the heat waste is captured for heating purpose

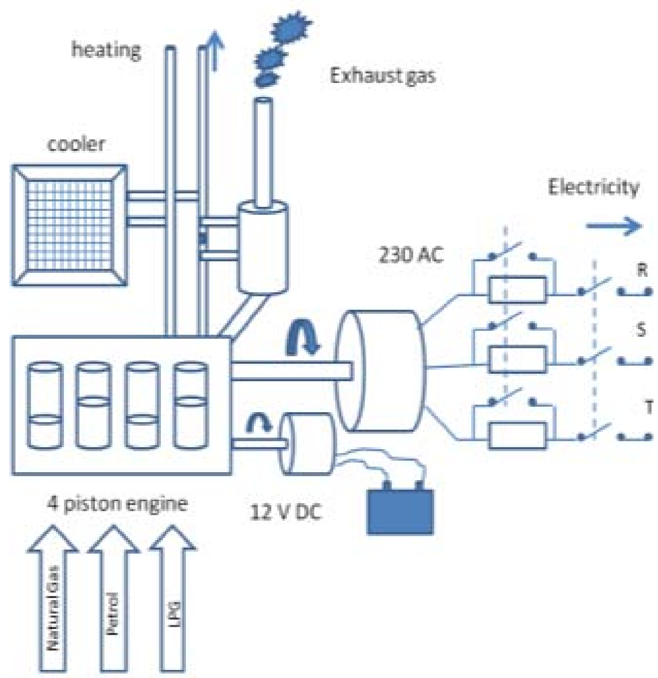

Fig. 6. The test microCHP system

We built a test microCHP with the following parameters:

- used car engine, former GDR produced Wartburg 1.3 VW-Engine, 43 kW (58 HP) for gasoline and LPG
- 7,5 kW 3 phase squirrel cage induction
- resistors for starting / synchronization
- connection to 3 phase 230/400 V AC 50 Hz utility network
- 12 V DC battery for the self start and for DC output

The material cost of the devices was approx. 2000 USD. A new device's price in the same power range is over 20 000 USD.

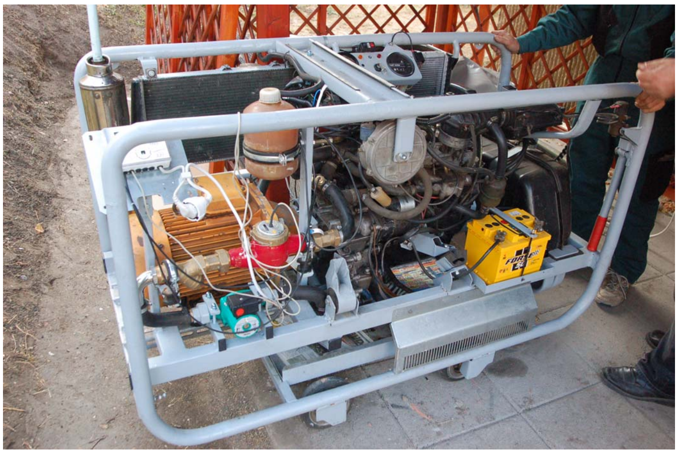

Fig. 7. The demonstrational microCHP

The first rough measurements brought the expected results. The output power is closely linear function of the speed.

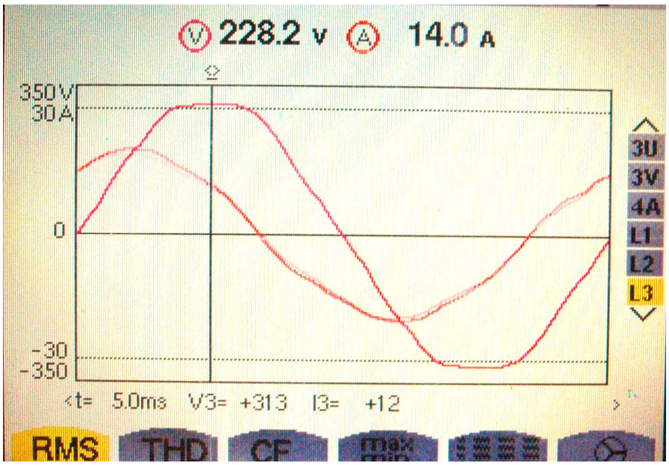

Fig. 8. Screenshot of the generator measurement

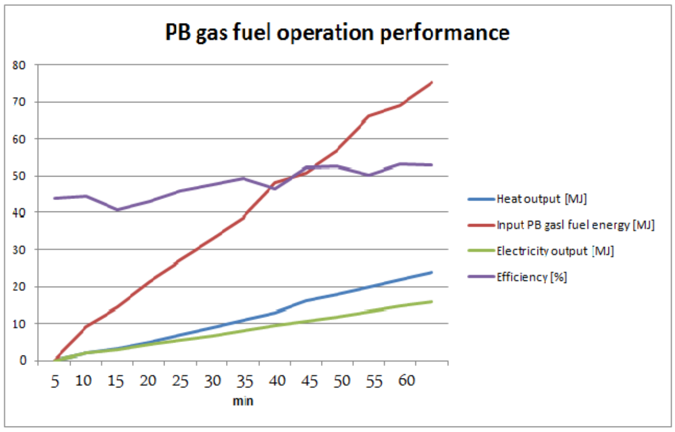

Fig. 9. Measurements of gas operation

The electrical measurements showed that an electronically not controlled "natural" induction motor consumes a lot of reactive power. In the next measurements we shall investigate the simple condenser compensation, de free run operation and the island mode start too.

The thermal data were monitored by Sontex Supercal 531 device, the energy fed back by a traditional Ferraris-wheel energy meter.

The demonstration device operates but some questions are left open:

- emission control – in the future we are going to run this device by natural gas that limits the harmful emission. The CO content must be controlled.
- lubrication oil consumption
- long term operation – we have no long-term aging experiences, but the low speed (1500 RPM) spares the car engine (peak power about at 3500 RPM)

Present development:

- Power regulation – in order to control the power output by the RPM (approx. 0-3% of over speed) a fine speed

control and stabilizer must be developed for the constant output. Also the over-speed protection functions must be solved in case of the load drop.
- Reactive power compensation – because we applied a squirrel cage induction motor, the internal voltage is over the nominal voltage so the machine's iron core can be closer to the magnetic saturation. This is one cause why our motor has relatively high reactive power consumption. The appropriate compensation method is under investigation.
- Other fuel (biogas) [18]
- Appropriate heat isolating casing – the electrical efficiency has not great importance, because the heat loss is used. The leaking heat must be caught by special coating and a cooling system.
- Remote control – the microCHP can operate as member of the virtual power plant. That is why it must be remotely controlled or at least remotely started/stopped

VI. CONCLUSION

Comparing the heat pump and the microCHP the last one has more energetic advantages. Also the CO_2 emission is favourable. It is recommendable to all gas heated household boiler positions. By spreading over these devices the manufacturing costs decrease. We demonstrated that these appliances can be built also by second hand car engine too.

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