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IMPLEMENTATION OF MICRO CHP IN SINGLE-FAMILY HOUSES

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ABSTRACT

This paper presents results from a series of analyses made at Danish Gas Technology Centre (DGC) concerning implementation of micro CHP in single-family houses.

Analyses are presented concerning:

- Consumer profiles, single-family houses.
- CHP unit size (power).
- Operation strategy.
- Heat storage
- Grid connection
- Market perspectives.

The paper includes data on household consumptions of electricity, heating and hot water heating based on various literature sources.

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BACKGROUND

Combined heat and power production (CHP) is an effective tool for achieving the highest degree of fuel utilisation and for achieving CO_2 savings. Using gas as fuel for CHP means a very wide power range, high efficiencies and low investment costs per kW installed.

Gas fired units are normally used for large-, medium- and small-scale CHP production. During recent years, also micro CHP units have been introduced on the market. The units are based on well-known technologies like reciprocating and Stirling gas engines. The pre-commercial or field-test units are based on fuel cells.

The introduction of CHP units this small meant for single-family houses opens new perspectives for increased gas utilisation in this customer segment. Increased gas utilisation is important in the domestic sector. The annual gas consumption for heating typically diminishes in new houses according to stringent building regulations, and satisfactory economic return on connecting costs, metering/billing etc. of gas for new houses can be hard to obtain.

ENERGY CONSUMPTION-USER BEHAVIOR

Data from single-family houses /1/

Data from early 90'ties measured as 15 minutes average from 25 single-family houses concerning electricity consumption, room heating and energy for hot tap water has been analysed. Table 1 shows the annual consumptions in the above categories.

House	**Room heating (kWh/year)**	**Hot tap water, (kWh/year)**	**Electricity, (kWh/year)**
1	10571	1524	3115
2	10863	2456	3877
3	10657	3690	3817
4	2968	1857	3597
5	8081	3254	5670
6	11558	2275	10951
7	7108	1512	4503
8	5042	3672	7989
9	16730	2883	3314
10	11086	2194	2920
11	5664	2894	6338
12	10250	2316	6194
13	8915	5435	7140
14	17627	2932	7846
15	11683	3354	3622
16	8369	887	4767
17	7829	2338	5141
18	9543	3245	3929
19	14761	3073	3677
20	9639	2031	4002

House	Room heating (kWh/year)	Hot tap water, (kWh/year)	Electricity, (kWh/year)
21	12807	7521	2438
22	11372	3444	4936
23	15038	2531	3965
24	9216	2616	4088
25	9032	1738	3399

Minimum	2968	887	2438
Maximum	17627	7521	10951
Average	10256	2867	4849
Stand.dev.	3434	1335	1965

Table 1: Annual energy consumptions in 25 houses.
Dark and light shadows indicating minimum/maximum consumption.

Table 1 shows a large variation in consumption between the houses. It also shows that it is not the same house that has the lowest (or highest) consumption of all the three categories.

Figures 1 and 2 show for February and July, respectively, examples of electricity consumption on weekdays, Saturdays and Sundays measured in the 25 houses. The electricity consumption shown is household electricity; heating and hot tap water production are excluded. The houses have electric stoves and ovens for cooking/baking. The values shown are 15 minutes average.

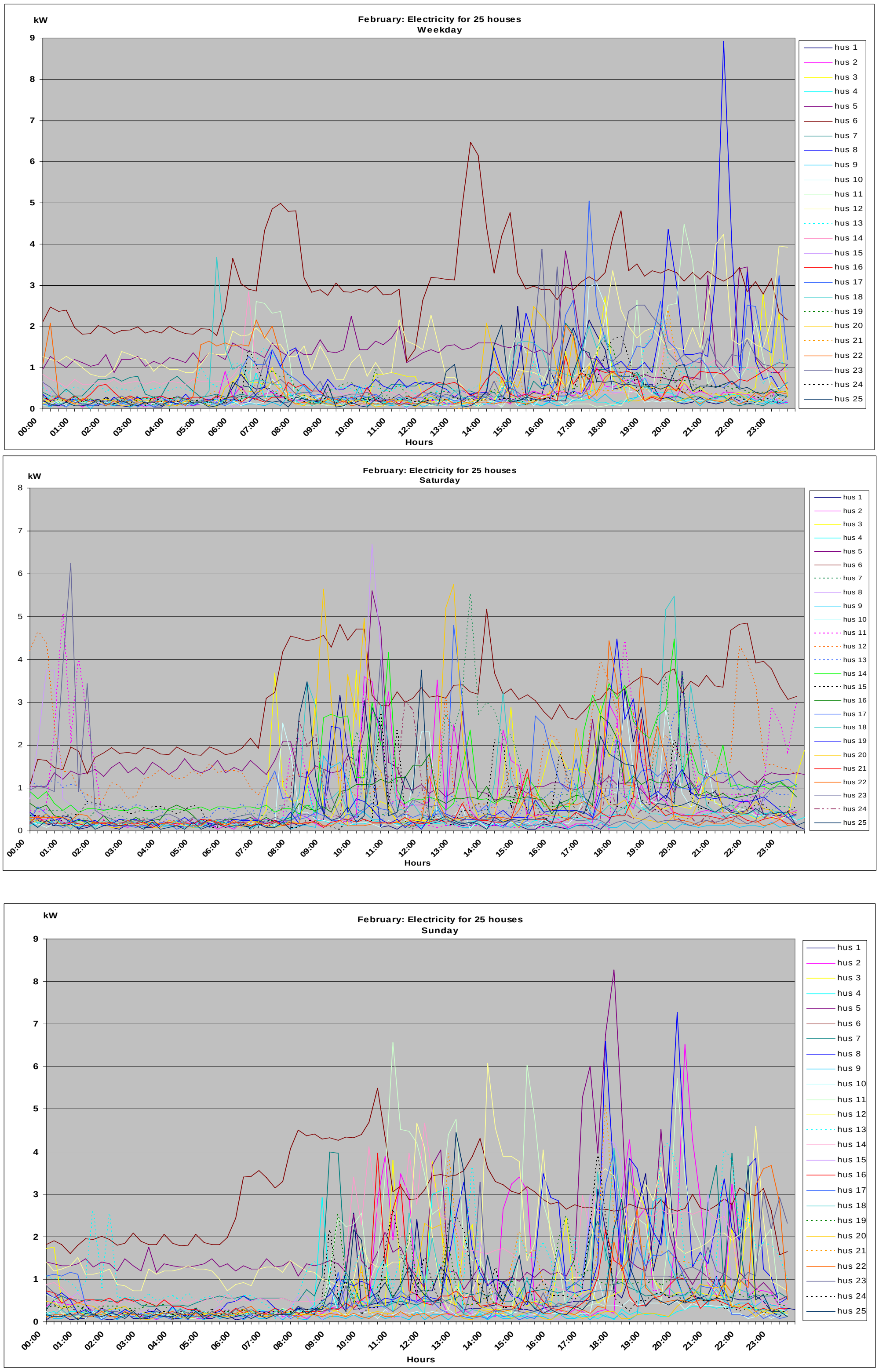

Figure 1: Electricity load profile examples for 25 houses, weekdays, Saturdays, Sundays in February (15 minutes average)

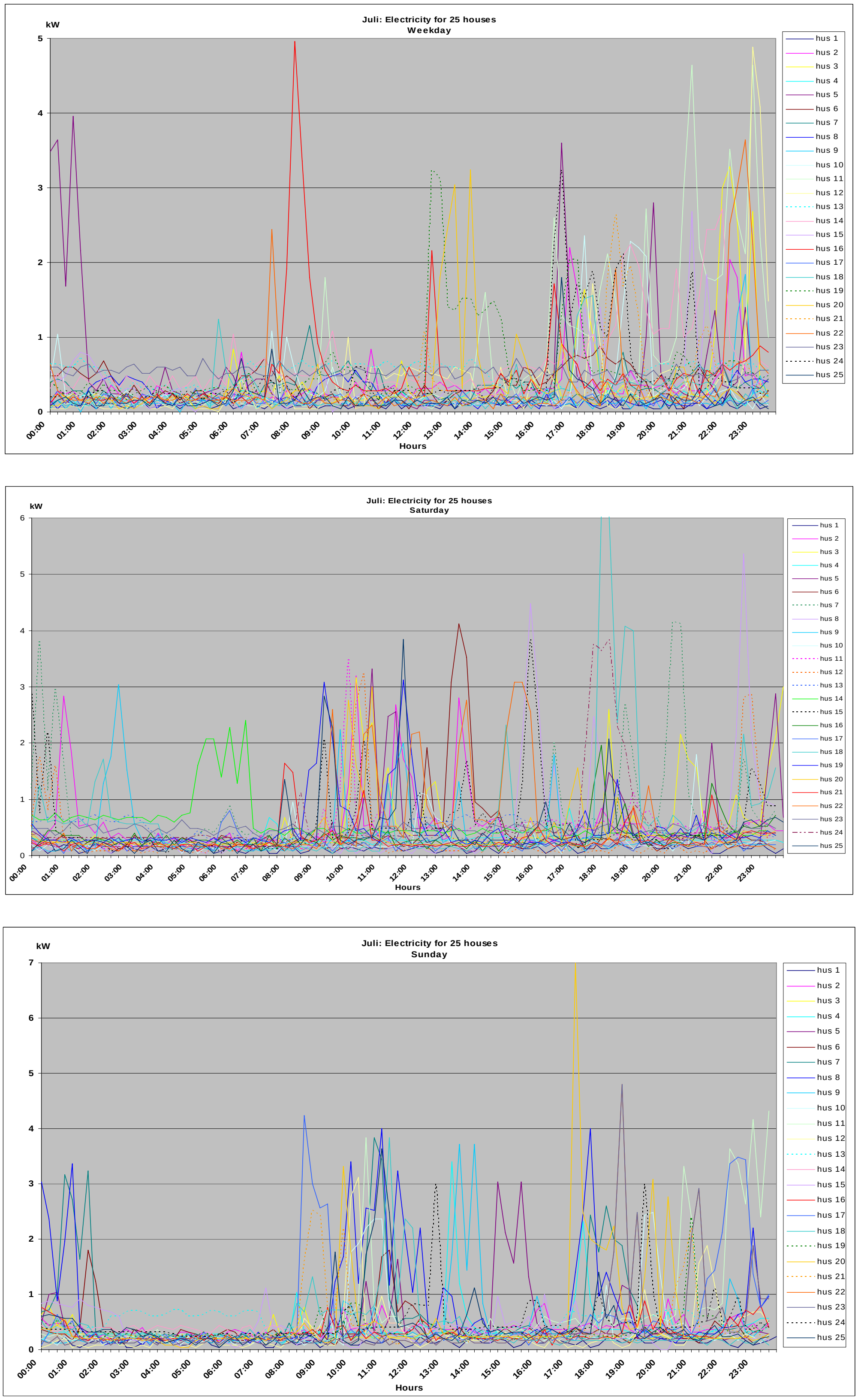

Figure 2: Electricity load profile examples for 25 houses, weekdays, Saturdays, Sundays in July (15 minutes average)

Data from 10 houses in Sweden

A measurement series from 10 Swedish houses /2/ covering the entire year 2003 also concluded that energy consumption to a large extent is driven by user/inhabitant behaviour. Particularly electricity depends on user behaviour. The only trend seems to be lower electricity consumption during nights. This night base load varies from some 100 W to 1200 W.

CONTROL STRATEGY ANALYSIS

The following operation strategies have been analysed by DGC both from an electricity and from a heat governing perspective:

- Base load operation
- Load following
- Peak shaving

The analysis was carried out to identify the operation strategies that give a high number of annual operation hours and the highest value for the electricity and heat production from the CHP unit. The analysis was made for a single-family house with the following annual energy consumptions:

- Electricity consumption: 5000 kWh/year
- Room heating: 12000 kWh/year
- Energy for hot tap water: 5000 kWh/year

No. of inhabitants: 4

The analysis was made on an hourly basis; load profiles for weekdays, Saturdays and Sundays were implemented to distribute monthly average consumption.

In Tables 2 and 3 the analysis results can be seen. The numbers in parenthesis express own production percentage relative to the need (consumption) of the house. Heating need for the house includes both room heating and heat for hot water consumption.

	Electricity production kWh_e**/yr (%)**	**Heat production kWh/yr (%)**	**Max. power CHP unit** kWh_e**/h**	**Annual operation hours h/yr**	**Full load Eq. h/yr**
Base load 1[1)]	535 (11)	1070 (6)	0.1	8760	5350
Base load 2 [2)]	~ 1070 (21)	~ 2140 (13)	0.2	8760	5350
Load Following	4675 (94)	9350 (55)	5.3 [3)]	8760	880
Peak Shaving > 2 kWh_e/h	2000 (40)	4000 (24)	3.3 [3)]	610	600
Peak Shaving > 1 kWh_e/h	2850 (57)	5700 (34)	4.3 [3)]	1120	650

1) Based on all time lowest 24 hours demand (=night).
2) Double up base load during daytime compared to Base load 1.
3) More peak-power is presumably needed; calculations are made on an hourly basis.

Table 2: Electricity governed operation strategy; results concerning CHP production

The load following basis might derive some surplus heat in periods. A heat storage for heat surplus with a capacity of some 6-12 hours of surplus heat is assumed available. During low heat season period the electricity production is down-scaled in periods so that that the heat production fits the average heat demand.

Table 3 shows the results of the analysis with heat governed operation strategy. No peak shaving strategy analysis was made here as there is no beneficial cost saving connected with the limited peaks in heat production/needs. Again, the numbers in parenthesis express self-supply degree related to electricity and heat needs for the house.

Strategy	**Electr. prod.** **kWh_e/yr**	**Electr. export to grid** **kWh_e/yr**	**Electr. prod. in-house use** **kWh_e/yr (%)**	**Heat prod.** **kWh/yr (%)**	**Max. power CHP-unit** **kWh_e/h**	**Actual operation hours** **h/yr**	**Full load Eq. hours** **h/yr**
Base load	4545	2307 [2)]	2238 (45)	9090 (53)	1.0	8760	4545
Load following	8500	5175 [2)]	3325 (67)	17000 (100)	3.3 [1)]	8760	2575

1) More peak-power is presumably needed; calculations are made on an hourly basis.
2) If a sophisticated predictive control/algorithm is available, some of the heat production might be moved even more to release less electricity for export.

Table 3: Heat governed operation strategy; results concerning CHP production

The results shown in Tables 2 and 3 indicate that a heat demand governed operation strategy (load following) will generally give highest self-supply and highest annual production, thus giving also highest gas consumption for a limited CHP unit power. Also the load following electricity based strategy will lead to high self-supply of electricity and heat. However, it also leads to a quite high power output from the CHP unit; a power output that will only be needed for a limited time. In general, the load factor of the unit to follow this strategy will be unfavourable and quite demanding concerning the dynamic performance of the CHP device.

The analyses made here indicated a CHP unit power of approx. 1 kW_e if heating base load strategy is used, approx 3 kW_e if some (heat-) load following is done. Self-supply of electricity and heat will be in the range of 45-65 and 55-95 %, respectively. Still an extra supplementary heating device is needed for peak load situations. This strategy will give a high annual operation time and acceptable part load ratio (approx 1:2 or 1:3) need as indicated by actual operation hours and full load equivalence operation.

For comparison, some of the electricity governed strategies results in 1:10 load ratio which gives little use of the full load capacity of the unit and leads to high unit costs. The peak shaving electricity governed operation strategy leads to low annual utilisation, low production and the highest output powers; the latter potentially leading to the most costly CHP unit installation turnkey costs.

MARKET POTENTIAL

New houses

A number of analyses /4/ were made concerning the annual natural gas consumption in typical houses meeting existing and coming Danish building regulations. The analyses assumed that the houses are some 130 m^2, inhabited by 4 persons, heated by a condensing gas boiler and that hot water is supplied via a 60-100 l insulated tank.

Key figures from these analyses can be found in Table 4.

Building Code[1)] **(yr)**	**Max heating**[2)] **power needed (kW)**	**Annual natural gas consumption (m^3n/yr)**
1985	10	1810
2006	6[3)]-10[4)]	1030
2010	4[3)]-10[4)]	820
Low Energy House, 2006, class 1	4[3)]-10[4)]	740
Low Energy House 2006, class 2	4[3)]-10[4)]	515

1) Danish Building Code reference.
2) Room heating and heating of hot tap water (via 60 l tank).
3) Without bath tub installed. Showers using less hot water than stored in the tank are assumed.
4) With a bath tub installed.

Table 4: Key figures concerning max. heating requirement and annual gas consumption

Table 4 shows that annual natural gas consumption is expected to be less than 1000 nm^3 a year for a short time for new buildings. Following 2010 building regulations or dedicated low energy houses the gas consumption will be as low as approx. 500-800 m^3n a year.

Introduction of gas fired micro CHP (and possibly other gas fired appliances) in these houses would increase the annual gas consumption to possibly make gas grid connection still profitable for the non-dedicated low energy houses.

Existing houses

Analyses were made /5/ to identify best micro CHP sizing and installation potentials based on heat consumption data for some 660.000 existing Danish houses in the domestic sector. The criteria for these houses were:

- Year-round use (summerhouses excluded).
- Only domestic sector (houses for living, “light offices/industry” etc.).
- Not connected to district heating grids.
- Water based heating already installed.

These houses are either heated by gas or oil fired boilers. Wood/pellet boilers might also be represented.

The criteria for identifying (sizing) the installation potential for small CHP units were:

- CHP operation more than 4500 full load equivalence hours a year.
- Heat-to-power ratio of 2:1.
- Only units < 15 kW_e are taken into consideration.

The results show that the largest installation potential exists within single-family houses. The units fitted according to the above citeria for this housing segment must have an average size of some 2.4 kW_e and a total installation potential of some 1500 MW_e. Also, non-detached houses count for some additional 126 MW_e.

Among the 660.000 houses analysed some 600.000 will fit a micro CHP unit in the power range of 0,7-3,5 kW_e.

PRODUCT, CHALLENGES

Products have been launched that meet the criteria for the analysis presented here, such as the Japanese ECOWILL micro CHP unit and a number of prototype/pre-commercial fuel-cell based units.

Key issues for this market segment will be

- Low cost (investment and O/M costs).
- High reliability.
- Low noise.
- Little space requirements.
- Easy operation for the customer/host.

There are huge market potentials for both production, installing, servicing and possibly intelligent remote operation (Virtual power plant/Energy Services) of micro CHP units.

CONCLUSION

The analyses made show that:

- Energy consumption in single-family houses is to a large extent influenced by the inhabitant/user behaviour. This regards the absolute consumption and the load profiles as well.
- Micro CHP units with a net electrical output of 1-3 kW_e and a heat-to-power ratio of approx 2:1 will have a significant installation potential.
- A heat demand governed operation strategy (load following) give the highest self-supply and the highest annual production, thus giving also the highest gas consumption. The analyses made here indicated a power of approx. 1 kW_e if heating base load strategy is used; approx 3 kW_e if some (heat-) load following is done. Self-supply of electricity and heat will be in the range of 45-65 and 55-95 %, respectively. Still an extra supplementary heating device is needed for peak load situations.
- Electricity based operation strategy and base-load layout will most likely lead to very small units which will not utilise the cogeneration potential in most EU single-family houses. Self-supply of electricity and heat will only be in the range of 10-15 % of household demands.
- Grid connection to public power is necessary to buy power during electricity consumption peaks and periods with low heating needs. Some electricity will have to be exported to the public grid as well if the above recommendation concerning operating is followed.
- The CHP unit should be fitted with heat storage, e.g. stratified water tank of min. some 250 l. This would enable the most flexible production and loosen the tight link between electricity and heat production most common with today's technologies.
- Hot tap water production could beneficially be made via hot water tank to reduce peak hot water production power.
- CHP units based on fuel cells (both PEM and SOFC) under development will fit very well with the power required, costumer segment and load conditions for the recommended operation strategies/layout.

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