Title: Domestic gas hybrid technologies and their interaction with the Danish energy system

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The decision to remove fossil fuels from the Danish space heating market necessitates a development of electrification of the residential heating and greening of the district heating. Removing gas boilers and replacing them with electric heat pumps may, however, not be simple. It will require investments costs both for the end users and in the development of the infrastructure needed for supplying electricity to all users also in the coldest days of the year.

Therefore, hybrid solutions (combining a gas boiler with an electric heat pump) are attractive: gas can take over during the very cold days of the year, making the costly development of an infrastructure needed for a limited time unnecessary. Considering also that electric heat pumps' efficiency is not very high for low external temperature, the use of gas will bring better overall energy efficiency to the system.

The paper describes the results obtained until now in Denmark from the introduction of the technology and from the first field test, obtained both on integrated technologies and with the so-called add-on technologies where a new electric heat pump is installed together with an existing gas boiler.

The field tests carried out are part of a national programme aiming to promote the implementation of heat pumps in Denmark, and the results should be used not only to evaluate the performances, but also to find solutions to practical issues encountered and to uncover general feasibility, to bring the technologies into use in Danish houses.

Gas hybrid – how does it work, and how does it look?

As shown in Figures 1 and 2, a gas hybrid is constructed with a boiler and a heat pump.

During periods of cold weather and hot water production, a typical boiler is started to provide energy. During the transition period when the heat pump has a high efficiency, or when there is much wind power or solar power, the heat pump is in operation. Sometimes, both the boiler and the heat pump are in operation.

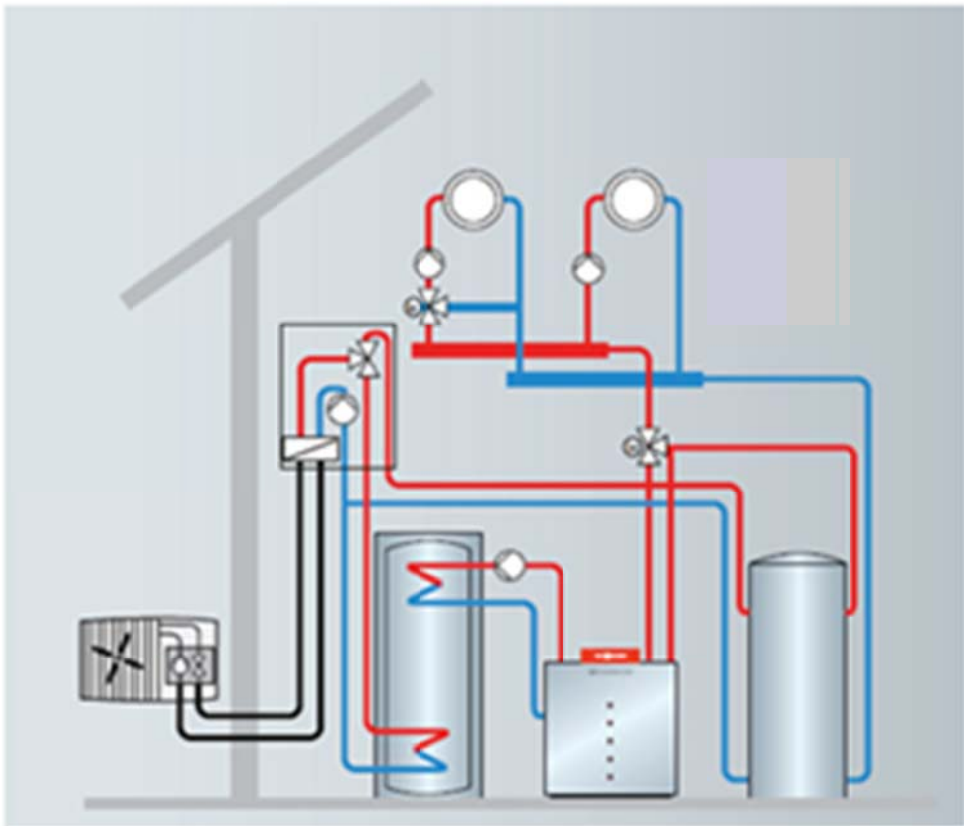

Figure 1

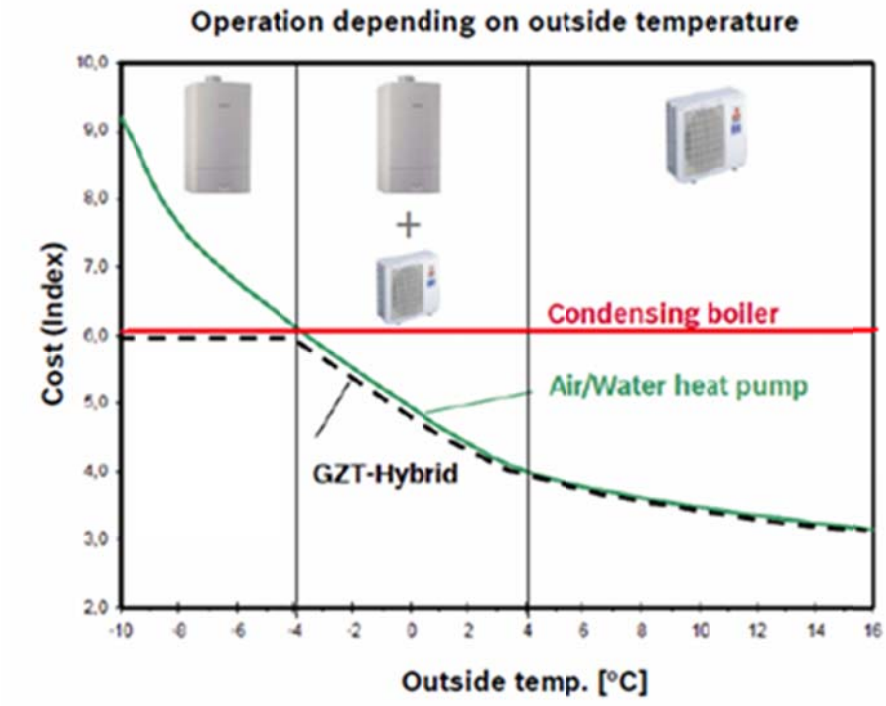

Figure 2

There are several variations. The simplest solution is an add-on solution, where an immersion heater or electric heat pump is installed in an existing gas boiler installation.

In other solutions, the gas boiler and the electric heat pump are integrated in one unit, which typically requires replacement of the entire supply system.

The boiler can also be replaced with more energy-efficient gas heat pumps, such as gas adsorption heat pumps (zeolit) with green energy from solar or gas absorption heat pumps with green energy from soil, water or air.

The history of the Danish gas hybrid activities

In 2009, the Danish gas companies' and Danish Gas Technology Centre's (DGC's) strategy development focused on bridging the gap between domestic gas boilers and renewable energy systems. The gas companies' Technical Committee on Gas Utilisation and Installations sponsored a framework programme for the documentation of the new solutions, such as hybrid solutions, which the product suppliers wanted to demonstrate.

Since then, almost all product suppliers have been developing new solutions, and a few years ago the first residential solutions were ready for demonstration on-site. DGC was asked to measure and document the operation.

As previously mentioned, in this period the Danish energy authorities realised that a national focus on electrification of residential heating was needed in order to absorb renewable energy from a rapidly growing production of wind and solar power.

The authorities want to promote the electric heat pumps in particular. But considering that capital investment and payback time for a complete electric heat pump system are relatively high, the hybrid solutions are viewed as a realistic solution to bridge the gap to increased residential utilisation of renewable energy.

This provided the background for starting up the mentioned national demonstration project in 2013. The preliminary results are presented below.

Plan and preliminary results of the national demonstration project

First of all, the national demonstration project is on the road and follows a roadmap (Figure 3).

	2013	2014		2015	
Task 1 - Description of gas hybrid systems and their implementation potential	*OK!*				
Task 2 - Investigation of perspectives of hybrid solutions in connection with Smart Grid	*OK!*				
Task 3 - Support of the phasing out of fossil fuels	*OK!*				
Task 4 - Experience from abroad	*OK!*				
Task 5 - Finding suitable hosts for field tests	*(OK!)*				
Task 6 - Planning of measurements	*OK!*				
Task 7 - Installation of hybrid units					
Task 8 - Installation of measurement equipment					
Task 9 - Identification of practical problems during installation					
Task 10 - Measurements					
Task 11 - Identification of operating economy					
Task 12 - Reporting					

Figure 3

Task 1 described the gas hybrid systems and their implementation potential

The advantages of the gas boiler are low cost of installation, constant output and high efficiency at low outdoor temperatures. The gas boiler can be installed in old, uninsulated houses with requirements of high flow temperature to ensure a high comfort temperature. The disadvantage is that most gas boilers are based on fossil fuel.

The advantages of the heat pump are high efficiency at moderate outdoor temperatures and a high share of renewable energy. The disadvantages are lower output and efficiency at lower outdoor temperatures and high flow temperature.

The two types of plants are complementary technologies if integrated in a gas hybrid solution. The advantages of this gas hybrid solution are low cost of installation, constant output and efficiency at low outdoor temperatures. The solution can be installed in old, uninsulated houses and has high

efficiency at moderate outdoor temperatures as well as a high share of renewable energy, especially in periods with a high share of wind or solar power in the grid.

See /1/ for further documentation.

Task 2 investigated perspectives of hybrid solutions in connection with Smart Grid.
The rationale is the energy authorities' wish to have 70 % renewable energy in 2020, which entails a demand for preventing overload of the electricity grid ("peak shaving") without adversely affecting the residential heat supply. See the example in Figure 4.

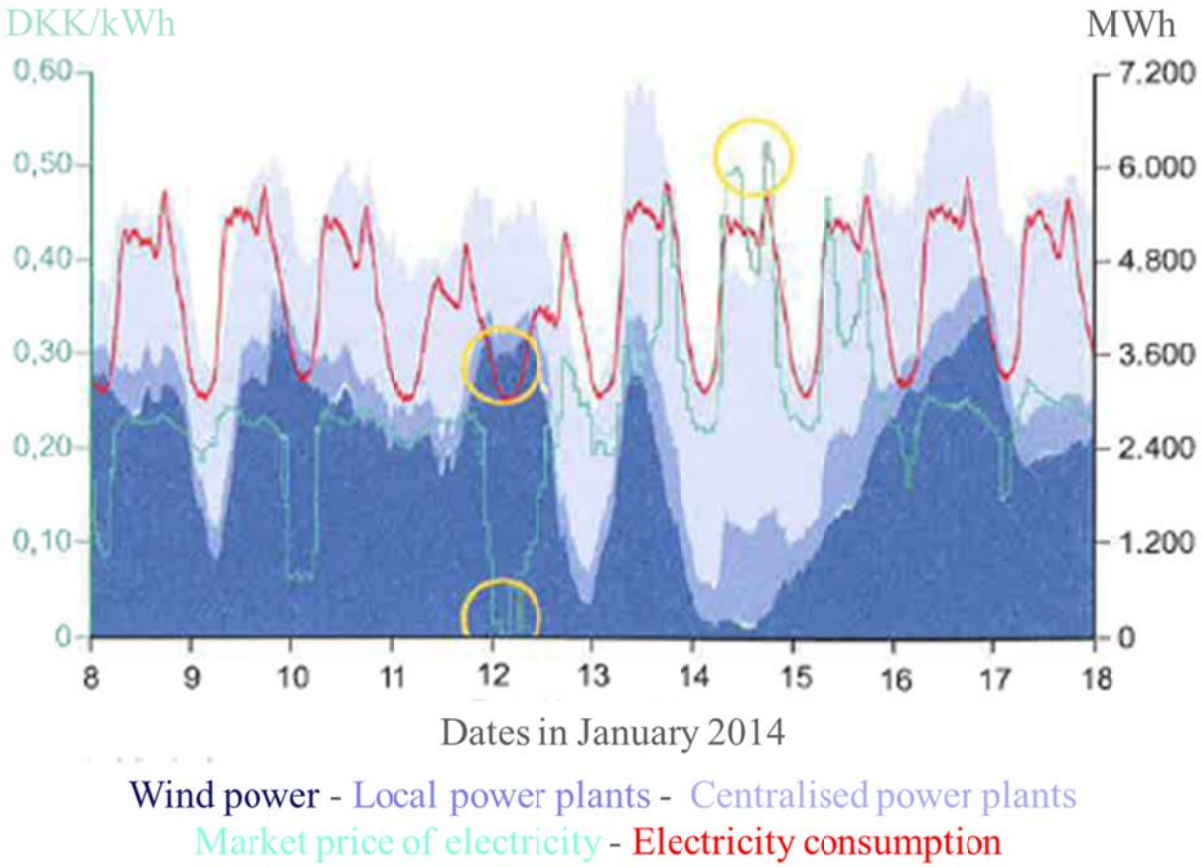

Figure 4

According to the Danish Energy Agency, the Danish electricity capacity in 2012 was 14,166 MW, so the flexibility added to the overall electricity grid gained by being able to connect/disconnect 400,000 heat pumps will average only approx. 3.11 %, or at peak load 6.59 %, of the total capacity during the heating season.

The actual electricity consumption in Denmark in 2012 was 112,119 PJ, corresponding to an average load of 3,555.27 MW over the 365 days of the year. Based on the actual average consumption in 2012 the gas-hybrid heat pumps would add an average flexibility of 12.38 %, or at peak load 26.25 %, during the heating season.

The electricity price at market terms accounts for a relatively small share of the total expenses/costs including distribution costs, electricity duties to the government etc., so even after the duty cuts caused by use of electricity for heating of all-year residence it would be reasonable to consider regulation of duties according to the electricity production. See Figure 5.

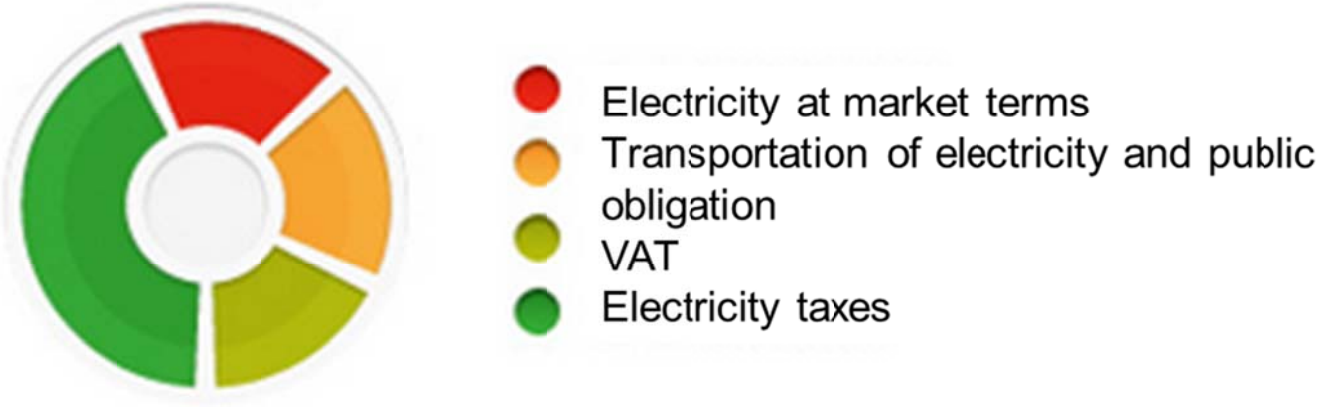

Figure 5

See /2/ for further documentation.

Task 3 investigated if hybrid solutions can support the phasing out of fossil fuels
Figure 6 and Figure 7 show that hybrid solutions can support the phasing out of fossil fuels, although not to the same extent as for solutions with heat pumps only.

Another question, though, is whether the consumers are motivated. Typically, this is a question of the personal financial situation. As Figure 7 shows, in this connection only one of the solutions will make sense, namely the add-on solution with a heat pump added to an existing gas boiler installation.

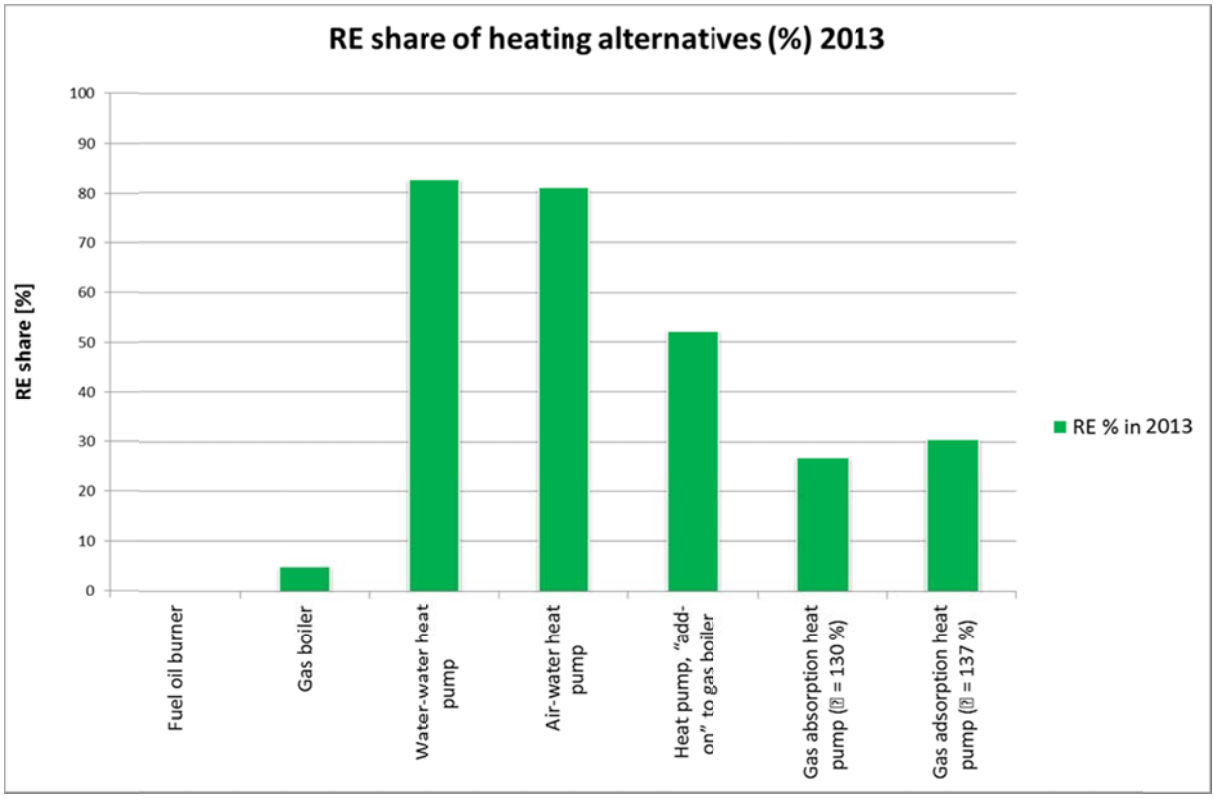

Figure 6

Parameter	**Unit**	**Alt. 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
Heating system		Gas boiler	Water-water heat pump	Air-water heat pump	Gas hybrid heat pump (new installation)	Heat pump as "add on" to existing gas boiler
Energy input		Natural gas	Electricity	Electricity	Gas (40 %) Electricity (60 %)	Gas (40 %) Electricity (60 %)
Net heat demand	kWh/ year	16.800	16.800	16.800	16.800	16.800
Total installation costs	DKK	30.300	118.200	95.200	69.900	35.700
Expected lifetime	Year	22	20	20	20	20
Plant efficiency	%	102	330	300	102/350	102/350
Service and maintenance	DKK/ year	2.200	1.900	1.400	2.200	2.200
Total annual costs	DKK/ year	17.328	18.150	16.973	16.813	14.636
Index	[-]	1,00	1,05	0,98	0,97	0,84
CO_2 emission	kg/ kWh	0,205	0,478	0,478	0,369	0,369

Figure 7

See /3/ for further documentation.

Task 4 identified experience from abroad
This task primarily found information on gas heat pumps.

See /4/ for further documentation.

Task 5 Finding suitable hosts for field tests
These field tests are in the initial phase. Two plants with measuring equipment have been installed in the Copenhagen area. One plant is with an add-on solution where a new air/water electric heat pump is installed at an existing gas boiler installation. The other plant is with a conceptual solution with a new boiler as well as a new hat pump.

In addition, 15 add-on solutions from Insero's demonstration project in the Horsens area (Jutland), 3 larger gas absorption heat pumps and 1-2 gas adsorption heat pumps will be included in the measurement programme.

The current status of the measurements is that we have carried out the first analyses of the first plant. The gas boiler efficiency is in the order of 95-105 %, the air/water heat pump COP is between 3.7 and 4 in the period January 2014-April 2014.

Other projects
In December 2013 show a interview with product suppliers, to which at that time was sold 86 pcs. Gas hybrid in Denmark.

Apart from the above projects the Danish energy authorities have just started a new project to develop and demonstrate a simple electric element solution for domestic gas boilers in a partnership including several Danish stakeholders, including DGC.

Furthermore, a new National Smart Energy Network was established in 2013 between universities and the relevant stakeholders in Denmark, and the activities of this network also cover hybrid technologies. DGC is participating and is acting as chairman at the moment.

On behalf of the energy authorities, Insero and other Danish stakeholders have launched a demonstration project focusing on business models. DGC and TI is participating in the expert monitoring group.

Conclusions

The Danish experience shows that:

- Efficiency optimization of installations is possible with Gas Hybrid (personal financial situation, greenhouse effect).
- The use of Gas Hybrid is a realistic way of bridging the gap to a society with a higher share of renewable energy in existing residences.
- Gas Hybrid can make comfort and safety in a new business concept (leasing contracts).
- Green wind and solar power consumption in Danish residential Gas Hybrid installations is possible in periods with high power production.

Next steps

In addition to the previously mentioned activities we are considering to;

- Focus on weak points and recommendations to the industry. E.g. Installer education.
- Development is needed - It would be reasonable to consider regulation of taxes according to the electricity production.
- Establish specialist groups for exchange of experience about test facilities, standardisation and ECO-design. We will also working to ensure that hybrid solutions become a part of the national Danish product list and Technology Catalogue.

Reference list

1. Task 1 report: Beskrivelse af gashybridvarmepumpeteknologier, December 2013, Karsten Frederiksen, Danish Gas Technology Centre.
2. Task 2 report: Undersøgelse af perspektiver ift. Smart Grid, December 2013, Mads Junker, Danish Technological Institute.
3. Task 3 report: Understøttelse af udfasning af fossilt brændsel, December 2013, Emil Jacobsen, Danish Technological Institute.
4. Task 4 report: Udenlandske erfaringer, November 2013, Michael Näslund, Danish Gas Technology Centre.