Potential of Gas Hybrid Systems

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Keywords: Energy Efficiency, Natural Gas Appliances, Renewable Energy

Background

The heating market, which is central to German climate policy and to the efficiency of the national energy supply system, is today dominated by gas-based technologies (gas boilers, gas-fired condensing boilers). Given the German government's objective to cut greenhouse gas emissions by 80% - 95% until 2050 and reduce primary energy consumption by 50% over the same period, it will be necessary to further develop these proven technologies to meet increasingly stringent requirements. Another part of the German energy concept focuses on the share of renewables in gross final energy consumption, where the target is roughly 60% until 2050.

Given this set-up, the direction for the heating market is clear: further efficiency improvements and integration of renewables. Both of these aims can be addressed by gas hybrid systems, a concept explored by the Gas Competence Centre of E.ON Ruhrgas as part of a project aiming to examine their potential as future heating system technologies.

Aims

The main objective of the project is to systematically examine a range of gas hybrid solutions for the residential heating market. The criteria looked at include energy efficiency, emissions and costs. The idea is to use a theoretical approach to identify the most promising concept(s) which can then be technically optimised in a subsequent second step as part of the practical implementation process.

The long-term objective is the further development of gas-fired efficiency technologies so as to remain competitive in the domestic heating market against the backdrop of future political requirements and climate protection needs. The main focus will on the practical side of these developments, with the long-term objective being the implementation of the most promising approaches in the form of new products for the end customer market.

Methods

The project is divided into two steps. The first step will be to take stock of available gas hybrid technology on the basis of the systems selected for the project so as to obtain an overview of any technology options and/or concepts already available. This will be followed by a systematic, theoretic evaluation of the individual variants using a closed analysis model.

The hybrid variants (see components in Figure 1) are examined for a model single-family home built to different standards. They include:

- Gas-fired condensing boiler + solar thermal collectors (for domestic hot water production and/or space heating support)
- Gas-fired condensing boiler + photovoltaic panels (PV)
- Gas-fired condensing boiler + pellet boiler
- Gas-fired condensing boiler + air-source electric heat pump
- Gas heat pump + solar thermal collectors (for domestic hot water production and/or space heating support)
- Electric heat pump + micro-combined heat and power unit (micro-CHP)

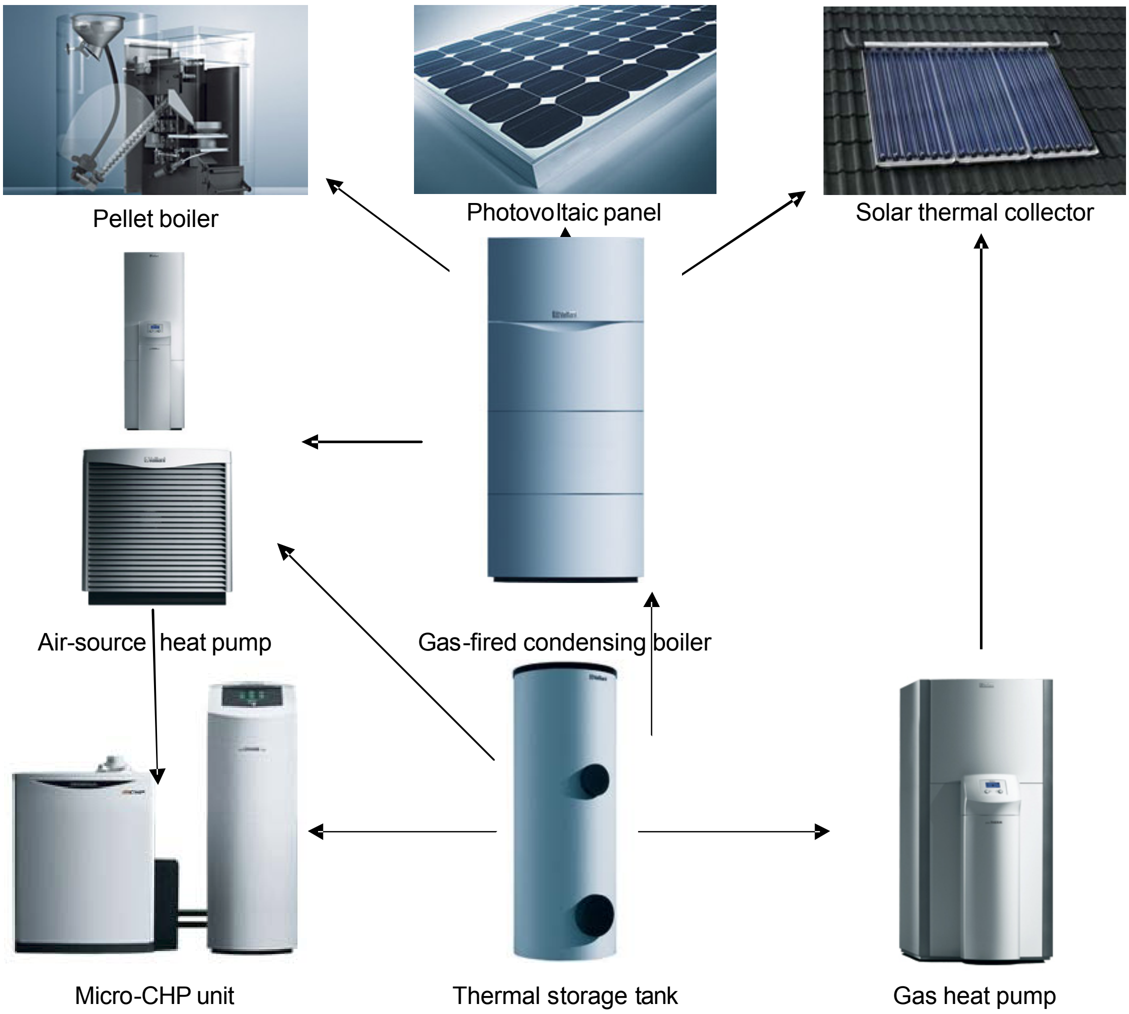

Figure 1: Illustration of components for gas hybrid systems

Using statistical calculations applying the boundary condition that at least 14% of the energy used arises from a renewable source, the hybrid systems are assessed in terms of their efficiency potential (energy, CO_2), possible fields of application and market opportunities (costs).

Numerical analyses based on the model house are performed for the systems under investigation. The purpose of the dynamic system simulation carried out using the programming language Modelica is to analyse the interaction of the energy system components over a one-year period. After that it will be possible to assess the influence of individual components on the system as well as total system efficiency.

The models used have a modular structure, which enables easy expansion to include alternative parameters such as climate, market structure, requirements, etc.

Preliminary[1] Results

Since the project to investigate the potential of gas hybrid systems has not been completed, there are no simulation-based findings as yet. Nevertheless, it is possible to draw initial conclusions for most systems on the basis of the initial survey undertaken:

Condensing boiler + solar thermal collector:

For this hybrid system there are basically two ways of using solar thermal energy, one is to only support domestic hot water production (CB + Solar DHW), the other is to use the energy also for space heating (CB + Solar DHW/Heating) .

The first variant where solar thermal energy is used for domestic hot water only is already an established solution in the German heat market. The climatic conditions in Germany (especially the number of sunshine hours) typically allow some 60%[2] of the domestic hot water required over a year to be heated using solar thermal energy. Another advantage here is the reduced number of operating hours for the gas-fired condensing boiler during the summer months when there is no baseload for the heating system and only occasional peak loads due to hot water use. With a hybrid system, these peaks no longer have to be met by the gas boiler because solar thermal storage tanks can cover up to 100 % of hot water demand (see Figure 2)

[1]The theoretical investigation of the above-mentioned systems is still in progress.

[2]Thermal losses are neglected in this estimate.

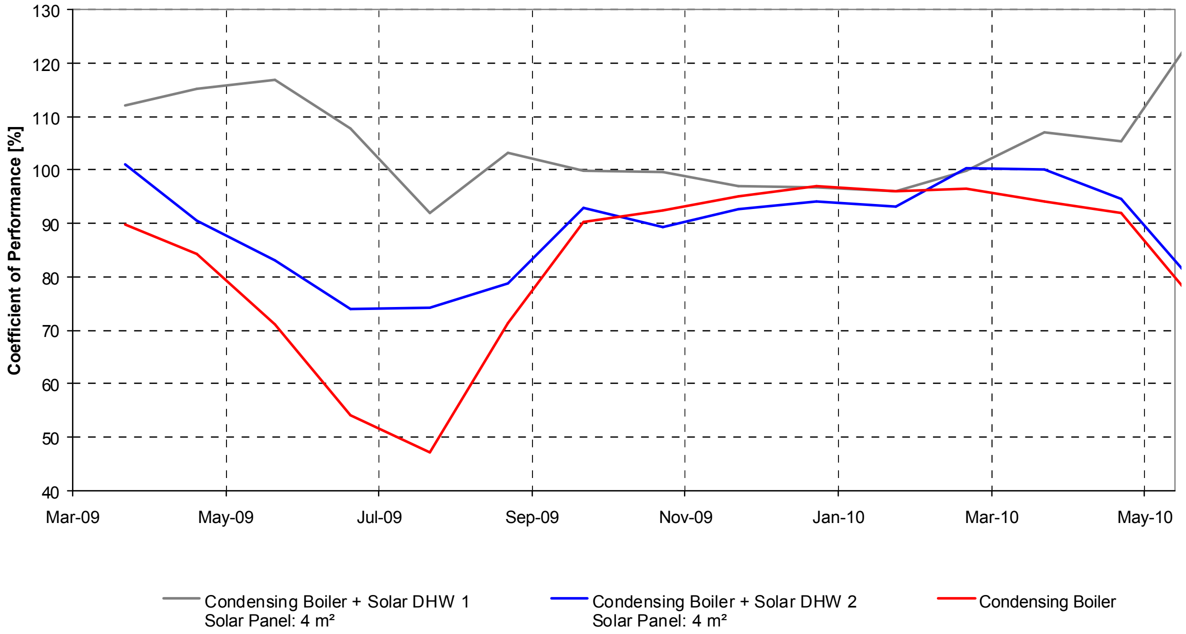

Figure 2: Effect of the combination of a condensing boiler with solar panels

This ultimately also increases the annual fuel use efficiency of the gas-fired condensing boilers, as already been shown in long-term field tests. These tests have demonstrated that gas-fired condensing boilers operated independently (one energy source only) typically achieve annual fuel use efficiencies[3] of some 95 % while boiler systems used in combination with solar panels for domestic hot water achieve efficiencies of 98 and 99 % (Table 1). As regards the efficiencies determined for the combined systems, it is important to note that the losses from these combinations – especially (solar) storage – have also been taken into account. This may even mean (as shown by example 2 in the table) that higher losses can cause less favourable annual fuel use efficiencies in the field, although at 9.2 %, the renewable energy accounts for a considerable share of the overall heating demand. The unfavourable effect of heating losses due to storage tanks and poorly insulated piping can also be recognised by the fraction of solar energy that has been fed into the storage system being approximately 38% for the examples given in table 1. Consequently the bigger share of energy fed into the storage tank has to be supplied by the gas fired condensing boiler in opposition to the above-mentioned 60% share of renewable energy supply to the domestic hot water demand that is usually expected (without thermal losses).

[3] All fuel use efficiencies refer to the lower (inferior) calorific value H_i !

Table 1: Examples of energy efficiency data for existing buildings [1]

Type	Long-term coefficient of performance [%]		Share of renewable energy input [%]	
	CB only	Overall System	per DHW storage load	per total demand
CB + Solar DHW 1	98	100	38,4	2,5
CB + Solar DHW 2	99	93	37,5	9,2

The second variant, which involves additional solar thermal energy use for heating system support, is already available on the market in Germany. However, because of the larger panel sizes and the associated costs, this technology is still not as popular as the panels used for domestic hot water production only. In new buildings, these systems can cover up to 20 % of the annual heat demand (for space heating and hot water production). This share can be much lower for existing building stock because the overall heat demand of older buildings is much higher and the share of energy required for domestic hot water much lower, in relative terms, than in the case of well-insulated new homes.

For this system variant, it is important to take into account that there are limits to panel size. This is because from a certain collector panel capacity onwards output is no longer matched by equivalent demand and storage capacities are limited and may even cause losses that overcompensate the advantages. Long-term performance tests have also failed to show any real system benefit from extended solar thermal energy use when compared with domestic hot water production only (see Table 2). Heating systems with solar support require larger storage tanks while systems used exclusively for domestic hot water heating (see Table 1) have a much more compact design.

Table 2: Fuel use efficiencies and shares of renewable energy in long-term performance tests [1]

Type	Long-term coefficient of performance [%]		Share of renewable energy input [%]
	CB only	Overall System	
CB + Solar DHW/Heating 1	n.a.	96	18.8
CB + Solar DHW/Heating 2	95	85	12.8

For direct use of solar thermal energy, it is important to take into account differences in user profiles and hence correlations between environmental energy input and demand, which means that the energy savings actually achieved may vary in a very wide range. Another important aspect is to adjust the system controls to the specific user behaviour. For example it would be counterproductive if a major share of stored hot water was used early in the morning and afterwards refilled by the condensing boiler, avoiding any injection of solar energy later on. Therefore it is crucial that the dimensioning and overall planning of any solar system is carried out by professionals, otherwise high efficiencies will not be achievable.

Wood pellet boiler + gas-fired condensing boiler:

According to a study by the German research institute ZAE Bayern, a system configuration comprising a wood pellet gasification unit and a condensing appliance (Cleanfire) can indeed compete with systems such as the classic, natural gas-fired condensing boiler, and even produce much fewer emissions (see Figure 3) because of the dominant use of renewable raw material (wood). Combining wood pellet firing with a gas-fired boiler offers the advantage (as does the gas boiler/electric heat pump hybrid solution) that critical operating conditions (e.g. heat-up), which are typical of pellet firing, can be avoided. This way, dust emissions can be reduced quite substantially.

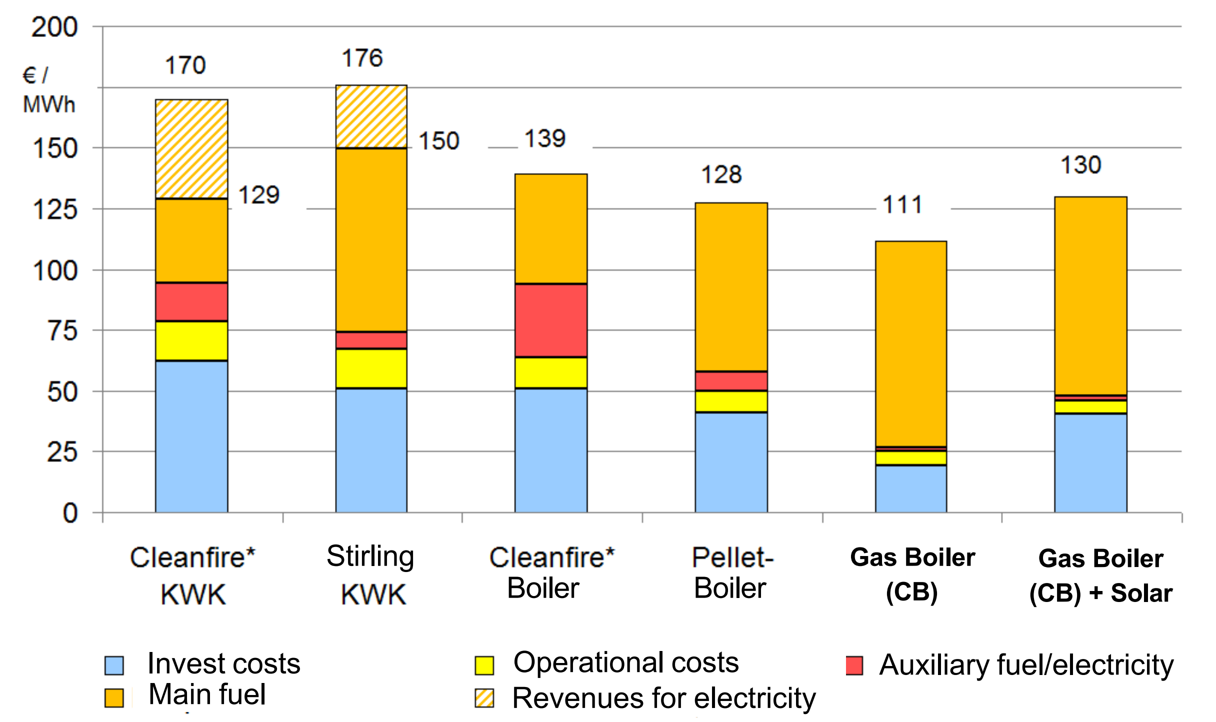

Figure 3: Economic viability comparison of Cleanfire system with competing systems [4]

Gas-fired condensing boiler + photovoltaic system:

A study looking into overall economic viability, climate-forcing emissions and energy efficiency has investigated combinations of gas-fired condensing boilers with PV panels in comparison to various competitor products in the heat energy market ranging from simple condensing boilers to micro-CHP solutions that also generate electricity. The results show that depending on panel size the hybrid system can even compete with, and achieve a cost advantage over, the more favourably priced gas-fired condensing boiler variant (see Figure 4).

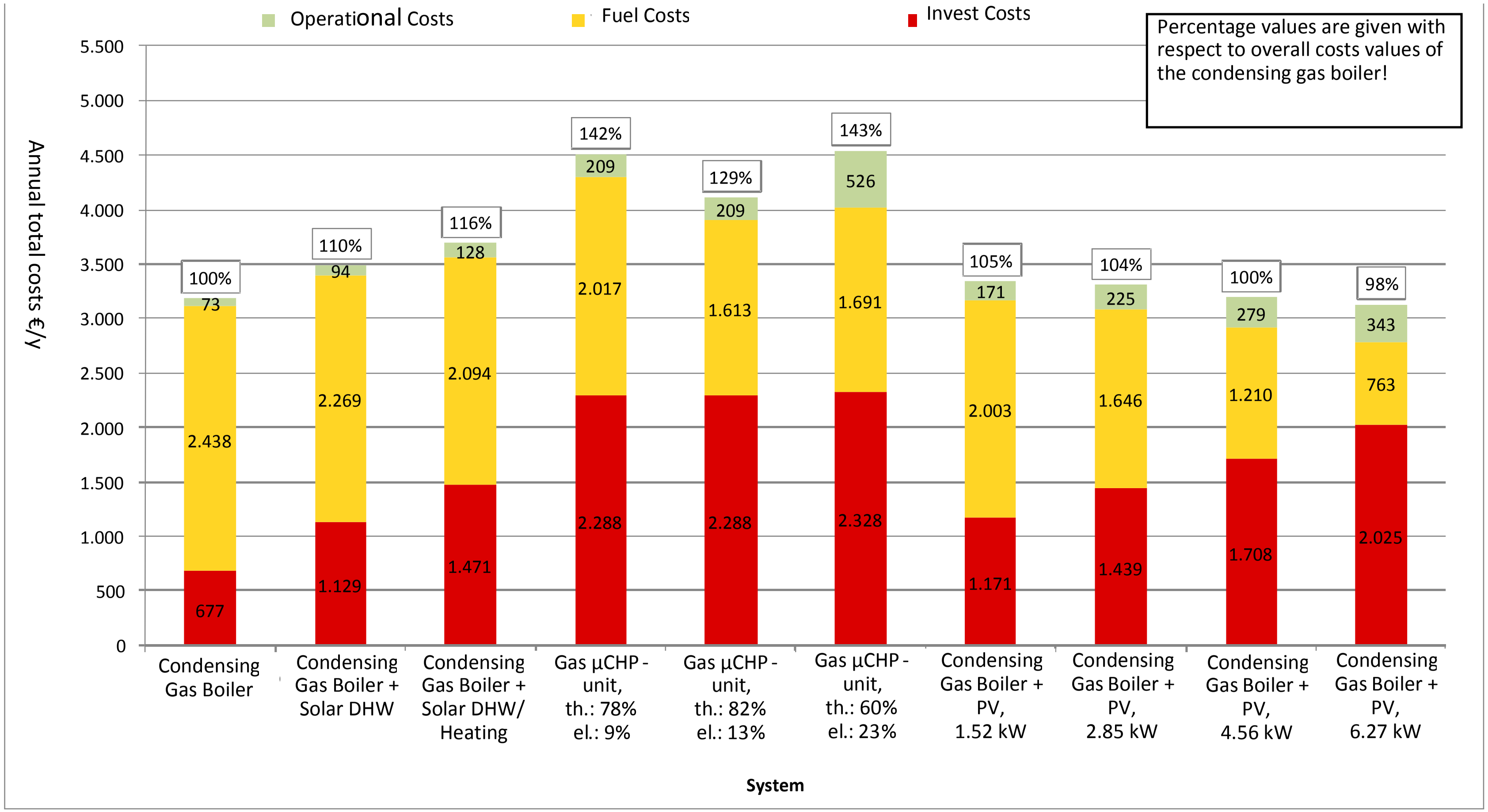

Figure 4: Comparison of the overall economic viability of different system variants [5]

Figure 5 shows that in terms of greenhouse gas emissions, the credits for the solar power generated offer clear advantages in most cases over competing technology variants.

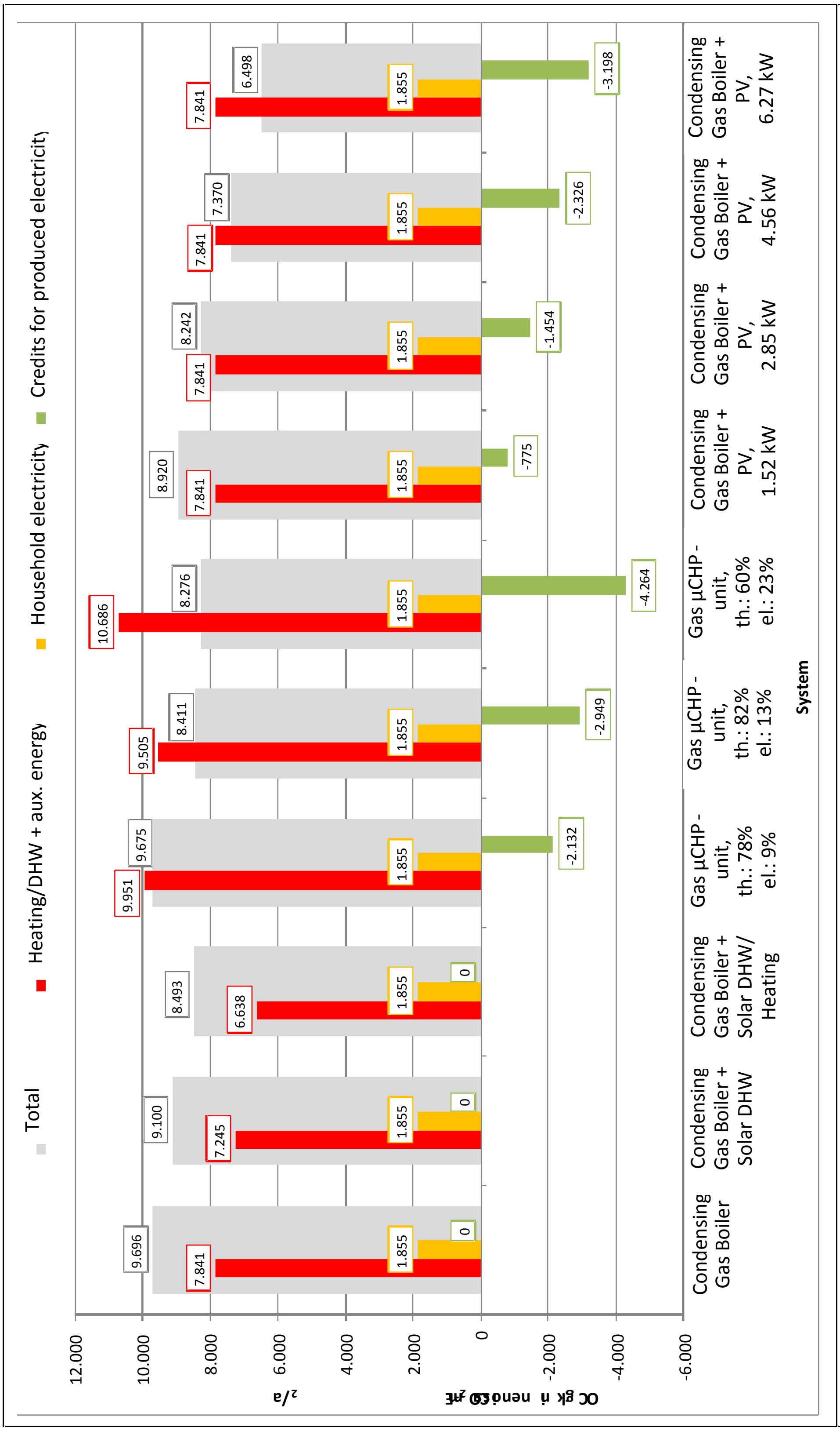

Figure 5: Comparison of CO_2 emissions of different system variants [5]

Hybrid air/electric heat pump:

This hybrid system is a combination of an electric heat pump using ambient air as the environmental energy source and a gas-fired condensing boiler. A study [6] has taken a first theoretical look at the potential for improving system efficiencies by selecting the right operating mode (alternating, partially parallel, parallel) and the bivalence point (see Figure 6).

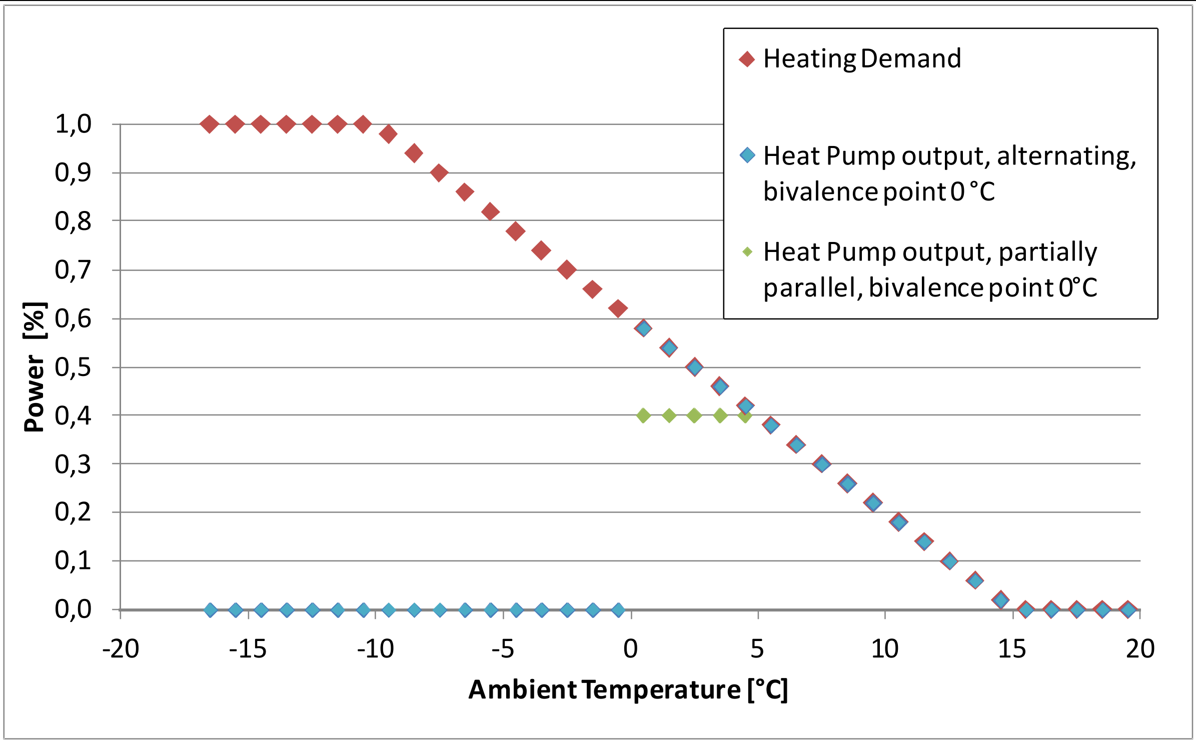

Figure 6: Illustration of operating modes for the hybrid air/electric heat pump [6]

In this framework the bivalence point defines the ambient temperature when the heat pump is shut off to prevent inefficient working conditions for the thermodynamic cycle. The choice of alternating (operation of either heat pump or gas fired condensing boiler alone) or partially parallel (there are conditions where both heat pump and gas fired condensing boiler are operating at the same time) operating mode influences the dimensioning of the heat pump with respect to the heating demand (load curve) of the supplied building.

The results, given in Figure 7, show a marked dependence of the achievable primary energy system efficiencies on the selected parameters, with a low bivalence point and low heating temperatures proving to be positive. Also the alternating operation mode appears to be superior to the partially parallel mode. In this case, simulation-assisted testing is to help identify the optimum design parameters to ultimately allow the potential of these hybrid system variant to be evaluated.

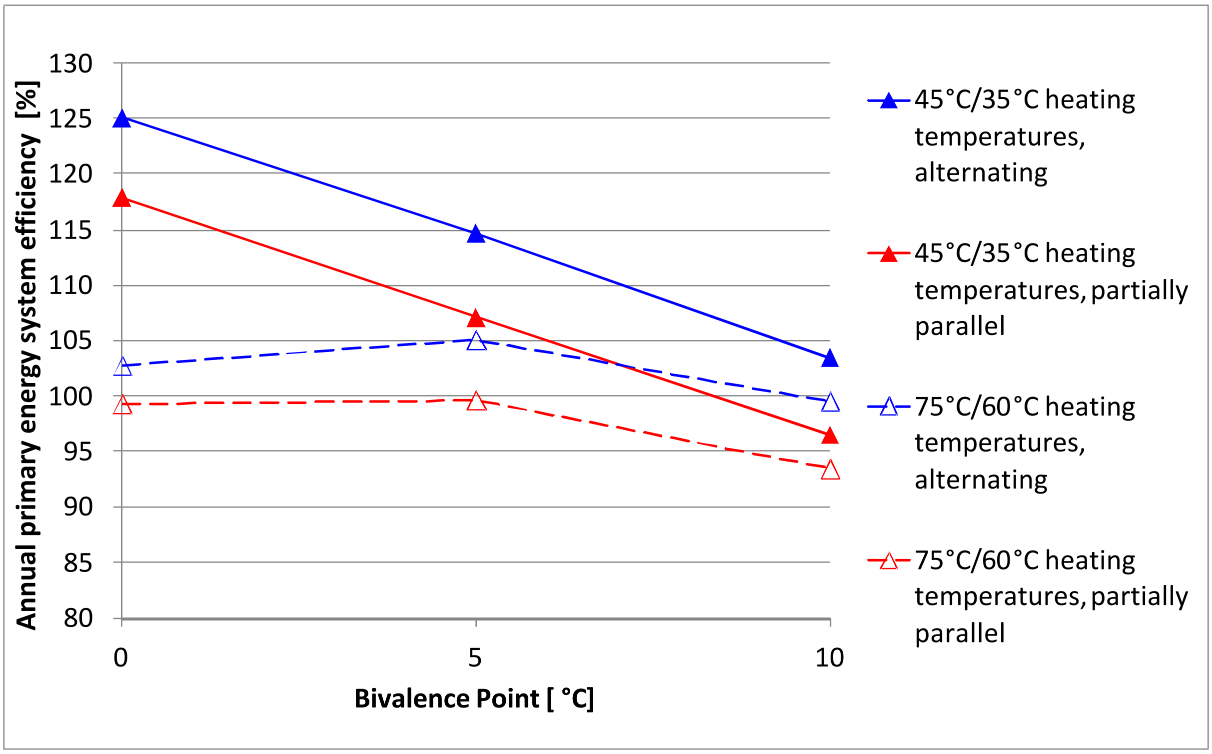

Figure 7: System efficiencies of hybrid electric heat pump [6]

Hybrid gas heat pump:

Since autumn 2011, a German system manufacturer has been offering a gas heat pump solution that draws on solar thermal energy as an environmental heat source for the heat pump while also allowing this energy to be used directly for domestic hot water production or heating system support - see Figure 8.

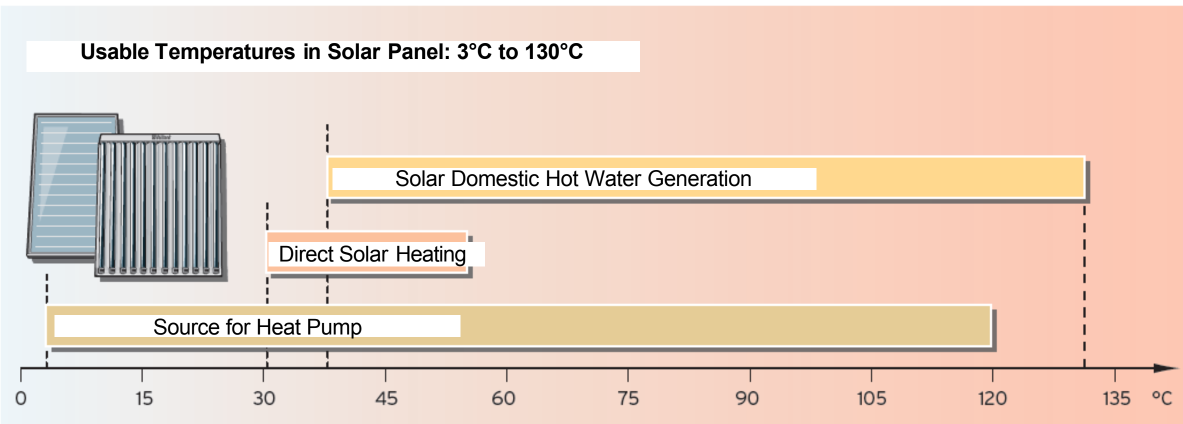

Figure 8: Triple use of solar energy in hybrid gas heat pump concept [2]

This concept can increase the annual solar thermal energy yield quite substantially when compared with the solution featuring a gas-fired condensing boiler in combination with solar collectors. Using the solar energy as a source for the heat pump process also allows drawing on this energy e.g. during the transitional periods when the energy yield is insufficient for feeding it directly into the solar storage system (low temperature level in solar circuit). This solution also comes with a gas-fired condensing boiler for back-up when there is insufficient environmental heat, especially during the heating season. It therefore offers the additional potential of being deployed in accordance with the hybrid air electric heat pump principle.

The arithmetical standard efficiencies of this system are given in Table 3. They show the significant efficiency improvement potential of hybrid technologies in comparison to the standard gas-fired condensing appliance, which is dominating the market today.

Table 3: Standard efficiencies of hybrid gas heat pump [3]

Temperatures in heating circuit (supply / return)	35°C / 28°C	55°C / 45°C
Efficiency without auxiliary power [%]	140	133
Efficiency with auxiliary power [%]	137	129

Thermal storage tank

In all hybrid systems, the storage unit is central to optimising operation, be it for effectively incorporating fluctuating renewables into the system or for achieving maximum power generation times for CHP units. The analysis of field test results [1] of different standard heating systems has shown that some of the storage concepts currently used lead to considerable thermal losses, which has an adverse impact on overall system efficiency. Depending on system design and user behaviour, average losses may be as high as 60 %, with permanent average loss rates of 400 W. Thermal energy storage is therefore expected to offer a huge optimisation potential, particularly for the even more complex hybrid systems.

Summary/Conclusions

With energy supply concepts expected to meet increasing primary energy efficiency standards and become more climate friendly, there is an urgent need for technical improvements, especially in the heating market. Hybrid concepts are an important starting point for maintaining the prominent role of natural gas as an energy source in the heating market of the future. Hybrid technologies generally allow efficiency improvements relative to the state of the art (and especially in comparison to the current situation in the field) and offer a meaningful way of integrating renewables through the use of natural gas.

Literature

[1] E.ON Ruhrgas AG – Results from own long-term field trials

[2] Source: Vaillant GmbH; illustration modified by E.ON Ruhrgas AG

[3] VDI 4650, Sheet 2

[4] Cleanfire potential study – ZAE Bayern, for E.ON Ruhrgas AG

[5] Study by Professor Oschatz, ITG Dresden, for E.ON Ruhrgas AG

[6] Study by Professor Adam, Düsseldorf University, for E.ON Ruhrgas AG