Practical Experience of Gas Heat Pump Technology in both Domestic and Commercial Heating Sector

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Introduction

Before the background of ever-tightened regulatory requirements issued both on a European and a national level, striving to meet climate policy's targets, the heating sector, representing a dominant demand of European society, has come into focus. One approach to take a step forward on the long way to decarbonise the heating sector is the gradual exchange of existing appliance technology by more efficient variants also introducing significant shares from renewable energy sources.
This conceptually rather logical step faces a number of challenges when being brought into practise. Especially for the large building stock and its technical limitations both to install sufficiently large solar thermal collectors and to run electrical heat pumps with satisfyingly high efficiencies, alternative solutions are needed. The upcoming gas heat pump (GHP) technology has the potential to provide part of the answer for the building stock, not only for residential buildings, but also to cover the space heating demand in the public buildings and light commercial segment. Nevertheless GHPs could also conquer a market share in the newly built segment, for instance by providing an enhancement over the classical condensing boiler plus solar thermal collector option if a gas connection is readily available.
Starting from an initial portfolio of market-ready products in Germany E.ON has been engaged in two major activities. One is the development of a gas absorption heat pump for the retrofit single-family home within a large collaborative European project. The other the realisation of two demonstration sites equipped with commercial-scale gas heat pumps to test practical challenges.

Political and Regulatory Framework

An important driver for the market entry of new efficiency technology today is associated with regulatory boundary conditions. This is quite natural keeping in mind that state-of-the-art boiler technology, be it gas- or oil-fired, is unrivalled cost-efficient. While more sophisticated appliances provide a benefit on running costs they struggle to be competitive due to high upfront costs.
The major regulatory influences accounted for by the EU are the Energy Performance of Buildings Directive (EPBD), the Energy Labelling Directive (ELD) and the Eco-Design Directive for Energy related Products (ErP). Goals include to have so-called nearly zero energy buildings, for newly built houses by 2021, while public buildings are supposed to reach this level by 2019 already. Moreover, increased transparency for the end-customer should be realised through signal labelling on a device level with more

fundamental efficiency requirements also being set. Overall a driver towards increased efficiency and the utilisation of bigger shares of renewable energy is established.
On a national level for Germany the most relevant directives are the Energy Savings Ordnance (EnEV) and the Renewable Heat Energy Act (EEWärmeG). These mainly set targets for newly built (or substantially renovated) houses regarding primary energy efficiency limits. An important consequence is, that a heating system purely based on a stand-alone condensing boiler is close to impossible to realise, thus, higher efficiency solutions are needed. Moreover, a requirement exists to introduce a certain share of renewable energy when retrofitting public buildings.

Current Market Situation in Germany

In Germany, as essentially everywhere else, the building stock comprising some 18 million residential homes represents by far the largest share of the space heating and domestic hot water (DHW) demand, while newly built high efficiency houses only accounted for approximately 140.000 a year in 2012 and the number is ever decreasing since [1].

The distribution of heating technologies currently used in the building stock is shown in figure 1. It is obvious that the market is dominated by long-established and well-proven boiler technology fuelled by fuel oil or natural gas, accompanied by a small share of electrical heat pumps and biomass systems. Therefore renewable energy is mostly not present today.

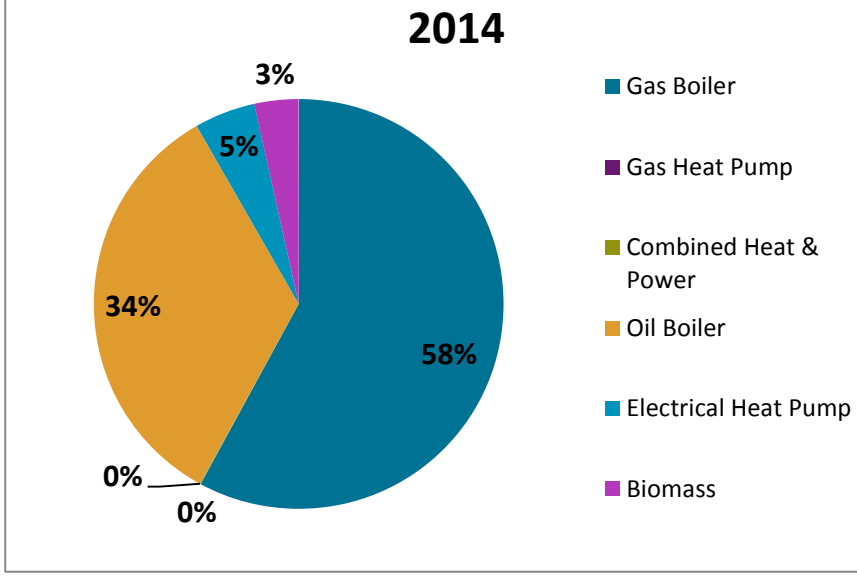

Figure 1: Heating appliances in the German market by technology and fuel (data based on [1], own representation).

By studying the age structure of these appliances (see figure 2) it also becomes apparent that about 10 million devices have been 17 years or older in 2011 already while the technical life expectancy is assumed to be 15 to 18 years. This will at some point in the near future force a significantly increased replacement rate and thus a huge potential to exchange old boiler systems by new efficiency technology.

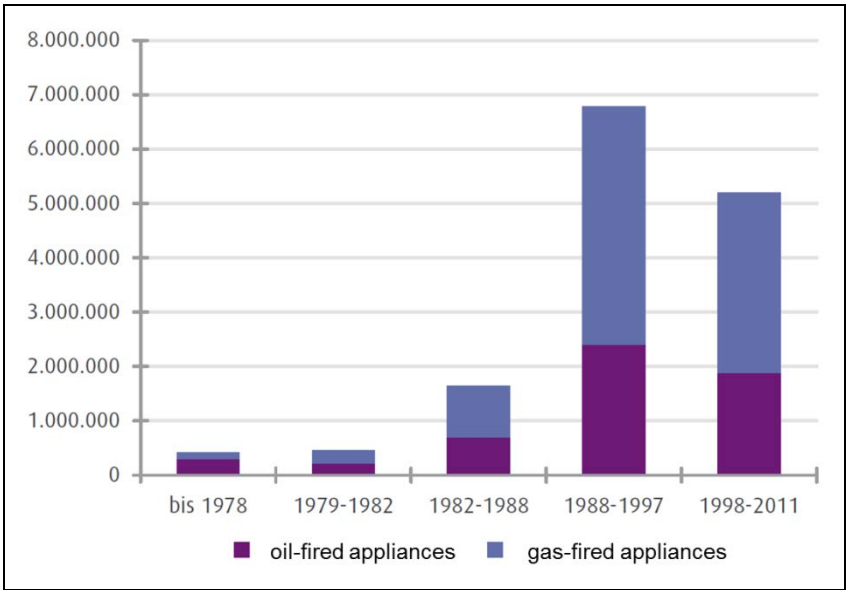

Figure 2: Age structure of heating appliances in the German market [2].

The gas heat pump technology as a new option on the heating appliances market has been pushed in Germany through the Initiative Gas Heat Pump (IGHP) that brought together a unique consortium of major manufacturers and utilities (see figure 3) with the clear goal to bring gas sorption heat pumps to the market.

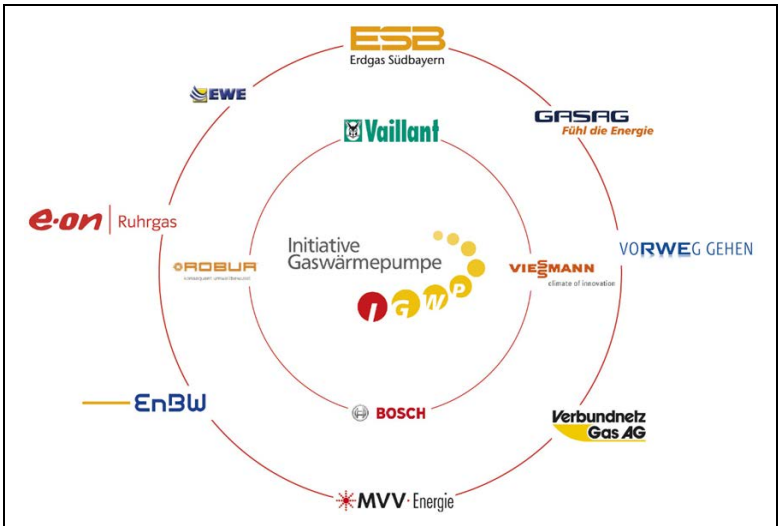

Figure 3: Participants of the Gas Heat Pump Initiative (existing 18.02.2008 – 31.12.2012) [3].

As a result a number of products have been available on the German market ever since comprising of single-family home-scale gas adsorption heat pump devices - designed for the newly built segment by Vaillant and Viessmann, one using solar energy as ambient source, the other ground heat - in addition to the larger scale gas absorption heat pump based on an ammonia-refrigerant by Robur that has been around for quite a while (see figure 4). The latter has eventually also been adopted by Bosch as an

additional product line, especially designed for the German market using Bosch's complementary components like thermal storages and their control system.

Figure 4: Gas heat pump products available on the German market after the IGHP – from left to right: Vaillant / Viessmann / Robur / Bosch [4]

As part of the work, GHPs were also meant to be introduced to German regulatory schemes. Some success was made in this regard, e.g. with respect to incentives through the market stimulation program (MAP), but the full recognition, especially in relation to the energy savings ordnance, is still pending.

Since the end of the IGHP in 2012 E.ON has mainly been active in two follow-up activities (projects) aiming to gain more insight in practical applicability of this technology and the extension of the product portfolio.

Latest E.ON Activities

1. HEAT4U – EU-funded Project to Develop a GHP for the Retrofit Single-Family-Home Market

Background
The efficiency of energy using products becomes more and more important regarding the environmental issues and the impact of regulatory requirements. To give an appropriate solution for existing residential buildings, the HEAT4U European consortium comprising 14 partners has the objective to develop a new size of gas absorption heat pump (GAHP), a highly efficient solution for heating and domestic hot water (DHW) supply. This gas technology which is using the outside air and natural gas as energy sources combines different advantages. Among them, it can ensure a stable performance at low ambient temperatures, it uses a natural working fluid without global warming potential (Ammonia) and achieves 30 % to 40 % energy savings compared to a condensing boiler. The project started in October 2011.The manufacturer Robur developed GAHP prototypes well matched with already existing system components. Both Robur and Bosch are responsible for the integration of the GAHP into the heating system, including the development of the control strategy. The HEAT4U project will end in October 2014 with the mission "dissemination".

Activities
The GAHP has been tested under laboratory conditions according to German standard VDI 4650/2, as well as European standards EN12309-3 and EN12309-6. A number of tests were carried out in the climate chamber of the E.ON laboratory in Altenessen. Some tests were used for the purpose of estimating the seasonal performance factor according to Eco design and labeling directives. The

results underpin the feasibility of retrofitting residential buildings with the newly developed GAHP system.
During the demonstration phase, five pilot systems have been installed in different buildings and countries. The first pilot unit was installed by E.ON on the property on a private elderly building in the area of Innovation City Ruhr, Bottrop. The main objectives of the field trial were:

- demonstrate reliable, comfortable and efficient heating and DHW service
- improve the installation guideline and have first feedback from installers
- optimize the GAHP system control
- optimize the GAHP appliance control
- obtain measurements of primary energy efficiency under real conditions and energy savings compared to the previously installed system

Results: Lab and field test
A large number of measures aimed at increasing the efficiency were undertaken during the field trial (e. g. additional modifications in the hydraulic system). Eventually our main objective with regard to the project was reached. The comparison of the lab (see figure 5) and field test (see figure 6) results illustrates that even a slightly higher efficiency was achieved during the field test. This is due to ongoing optimization of the GAHP from the first prototype tested in the lab to the second prototype in the field. Further improvements with respect to performance are expected in the next GAHP generations. But already now a device efficiency of round about 130 % with respect to net calorific value (NCV) could be realized in spite of the following obstacles:

- only radiator system in the house → high temperature level
- only an air/water heat pump → always less efficient than ground-source
- including DHW service
- high share of part load conditions (warm winter and building load mismatch)

Since completion of commissioning the GAHP system operated reliably without any failures during the monitoring phase. The end user was highly pleased with the gas heat pump system and wants to continue the field trial because the family feels no comfort losses, while the natural gas demand could be reduced by round about 40 % compared to previous years (this value is corrected with the daily temperature figure already).

First GAHP Prototype

Lab test in the climate chamber with respect to standards
EN12309 – 3
EN12309 – 6
VDI 4650 - 2

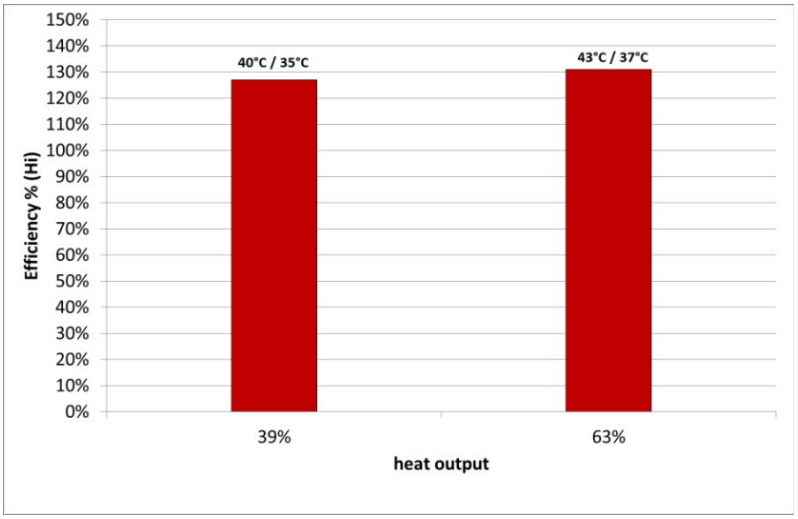

Figure 5: Results of the first GAHP prototype

Second GAHP Generation

Field Trial in the area of Innovation City Ruhr, Bottrop; Semi-detached existing house

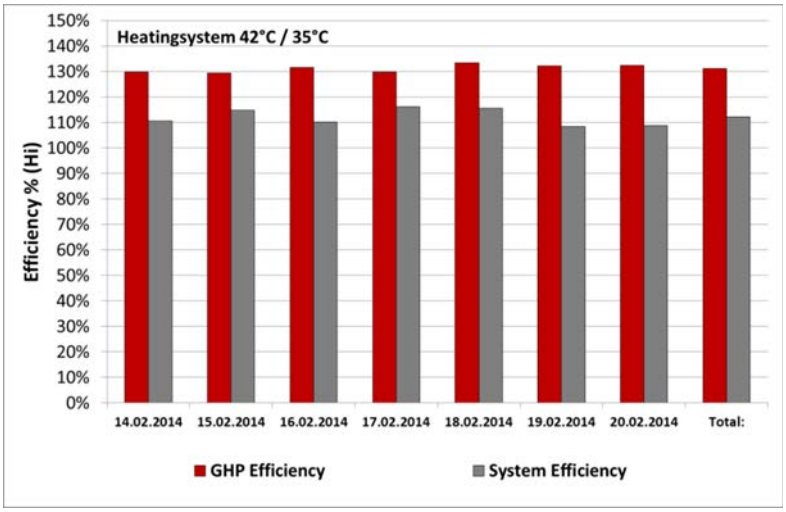

Figure 6: Results of the second generation GAHP prototype

In comparison with the efficiency of 100 % (with respect to NCV) of the condensing boiler (back-up boiler) which was also measured at the same boundary conditions, an increase of 30 % (based on the condensing boiler) could be realized. For the further steps there are some recommendations to increase the system efficiency and to link it to the existing heating system like modification of the hydraulic and control system and especially the buffer tank concept.

These results demonstrate that the adaptation of the GAHP technology to a retrofit residential house has been successfully achieved by providing a solution able to deliver substantial energy savings and to integrate a high share of renewable energy.

2. Commercial-scale Demonstration Sites

Since late 2011 E.ON has been active to realise the first demonstration site of the Bosch gas absorption heat pump that had just entered the German market. An important aspect of this activity was to install the first gas heat pump in a public building in Germany. Therefore a consortium comprised of Bosch, the local utility company ELE (Emscher-Lippe-Energie GmbH) and E.ON applied for a contribution to the Innovation City Ruhr | Model City Bottrop, which is an urban planning project aiming to transform a city based on climate friendly concepts and to halve the CO_2 emissions by 2020.
As a result of these efforts a primary school (see figure 7) was chosen to serve as the site for the demonstration of the 40 kW thermal output air-source gas absorption heat pump, supplemented by a peak load gas-fired condensing boiler of 150 kW thermal output.

Figure 7: The primary school in Bottrop, equipped with an externally placed Bosch gas absorption heat pump – pictures by E.ON (2011).

Using extensive measurement equipment E.ON monitored the heating system for two full years, gaining valuable insight on both performance and optimisation potential that was used by the consortium to tweak the system.
As a result of these efforts very satisfying performance values could be reported for the monitoring period with the GHP itself achieving > 138 % of thermal efficiency and the entire system still delivering approximately 115 % (compare figure 8). **This was found to be an improvement over the original low-temperature gas boiler of roundabout 40 % in emissions and primary energy consumption.**

But the major challenge of this demonstration site proved to be the installation in a public building and, on top of that, a primary school with passers-by (including children) having mostly free access to the externally-placed GHP device on the school's parking place. Consequently the city of Bottrop was highly sensitised regarding safety issues both on behalf of people and the device. To overcome these challenges the heat pump was placed inside a fence enclosure to prevent physical harm in both directions. Moreover a risk assessment has been conducted by an independent expert to ensure that operation of an ammonia-filled device is safe in this environment.
Another challenge occurred when a complaint regarding noise nuisance was filed by a next-door neighbour. Only then it was realised that the area in which the school is located is nominated by the city of Bottrop as a purely residential neighbourhood. This causes very strict requirements, especially on the night-time limits for noise levels. Measurements conducted by E.ON showed noise values significantly beyond these limits, thus proving the complaint valid. In an effort to overcome this problem an update of the ventilation system, now capable of modulation, was implemented. In addition to that a time control was set to check the power output during night-time and shut off the

GHP if noise nuisance was to be expected, leaving the boiler to cover the heating demand.

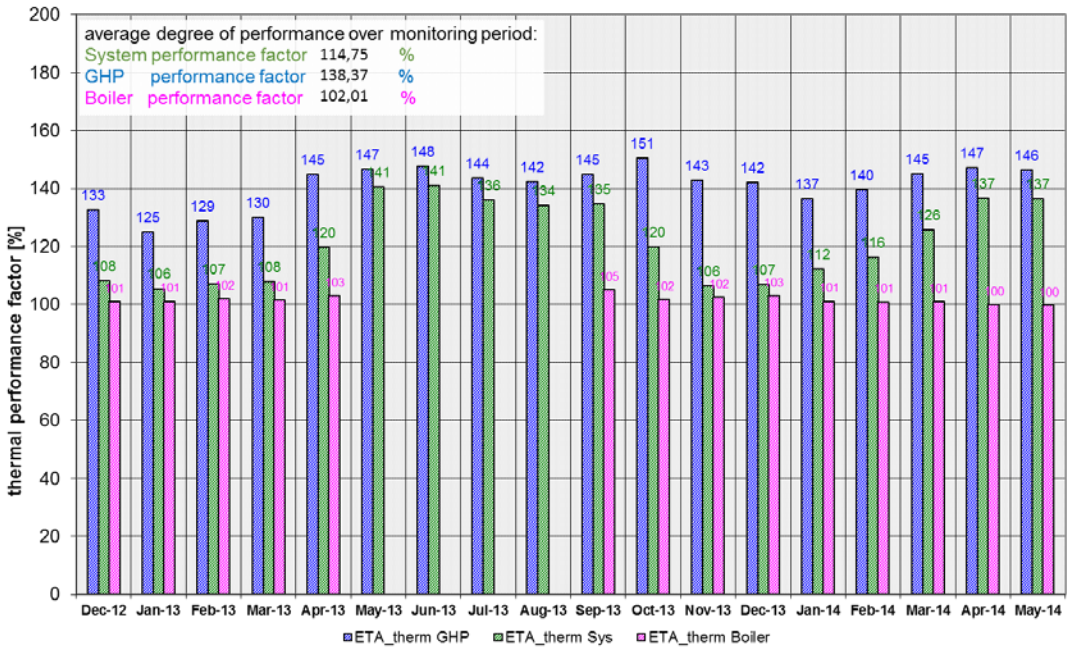

Figure 8: Monthly thermal performance of the gas heat pump, peak load boiler and overall system over the monitoring period.

In retrospective a lot of practical experience could be retrieved from the demonstration site and finally both customers (being the school itself in this case) and surrounding residents could be satisfied with an efficiently and reliably running system clear of disturbances.

In order to test the very same system under different conditions and to optimise the auxiliary power consumption, a second demonstration site, located in Remscheid, has been explored. In this case a 7-flat multi-family-house was equipped with a very similar setup of the 40 kW absorption air-source GHP combined with a peak boiler and a storage tank. Fundamental differences to the school project lie in the need to cover DHW demand and the stronger influence due to user behaviour that is mostly avoided in the school environment.
Figure 9 shows the development of auxiliary power consumption over the monitoring period. It can clearly be recognised that optimisation measures on both the ventilation and the engine of the refrigerant pump applied throughout the first heating season lead to significant reductions in auxiliary power consumption. These were found to sum up to about 60 % decrease compared to the initial installation.

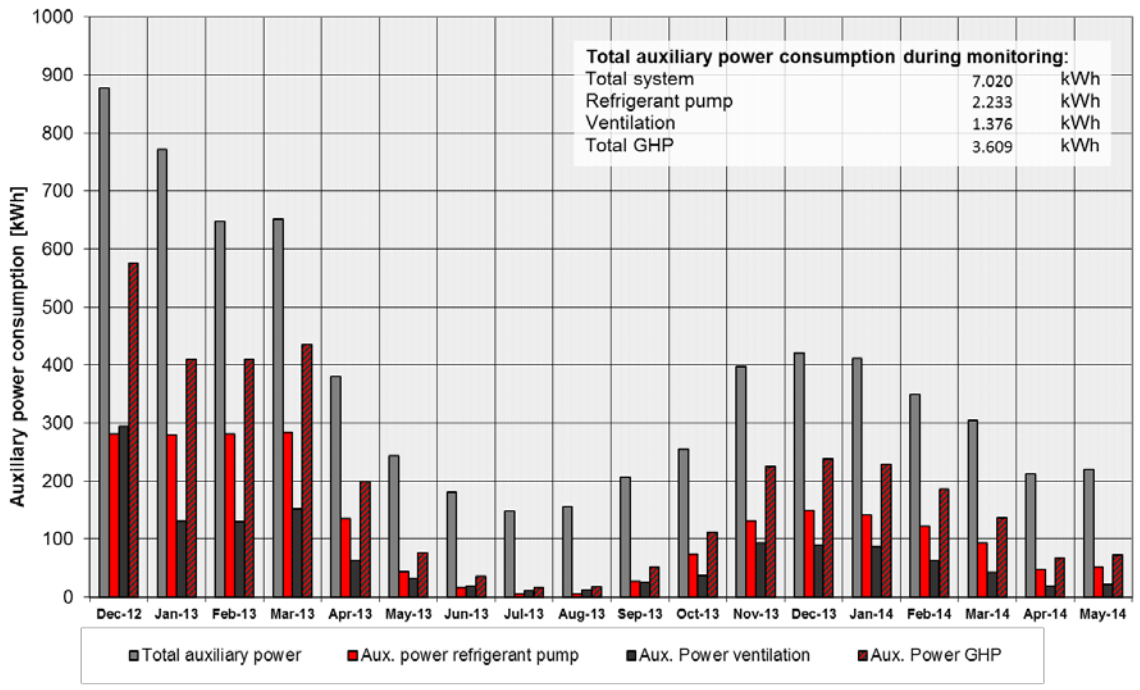

Figure 9: Monthly values for auxiliary power of the GHP system in a multi-family home at the Remscheid site.

The potential impact through user behaviour could also prominently be observed in this demonstration project. The profile in figure 10 shows the efficiencies of the GHP and the peak boiler alongside the flow temperature levels in both the heating circuit and the GHP circuit between 2nd November 2013 and 9th December 2013. In the beginning of this period the GHP runs on a, for this site, satisfying efficiency of above 120 % in average. Then, on 18th November, the inhabitants were no longer satisfied with the comfort experienced and thus substantially raised the heating curve. This instantly led to a drop in GHP efficiency to an average level of approx. 105 %.
This, alongside the need to provide a significant amount of DHW, also results in much lower overall efficiency figures of only a little above 107 % for the GHP itself and rather disappointing 90 % for the overall system.
Nevertheless, calculations covering the entire system and considering all energy flows including auxiliary power, still showed potential for economic benefits on running costs, if a proper compromise between customer comfort and appliance performance can be realised. In either case a share of renewable energy is introduced to the system and CO_2 emissions are reduced.

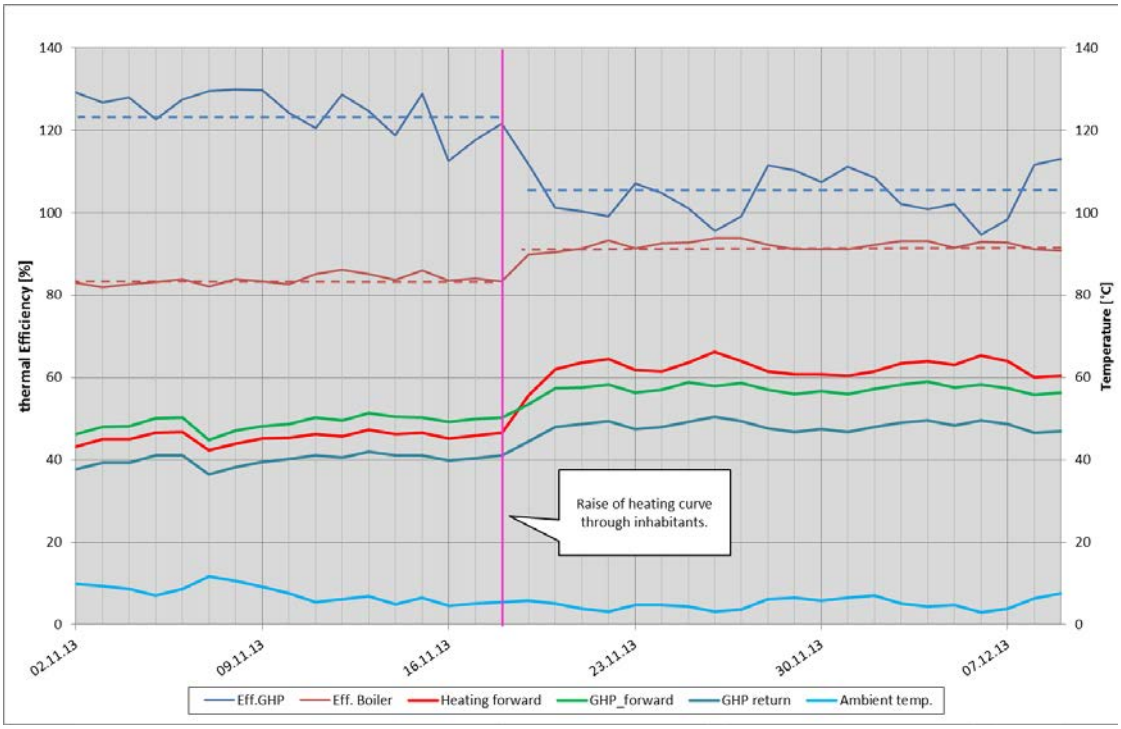

Figure 10: Impact of user behaviour on GHP efficiency at Remscheid site.

Conclusion & Future Prospect

The gas heat pump technology bears the potential to bring the retrofit segment of both residential and commercial scale buildings - still running on relatively high flow temperature levels - to the next level of efficiency while simultaneously introducing significant shares of renewable energy. Keeping in mind the development of regulatory schemes GHPs will be able to meet requirements at least for the next 10 to 15 years for the retrofit sector. Today GHPs are also suitable for newly built houses with respect to the energy savings ordnance. A further raise in requirements for renewables can still be met by introducing a certain share of biogas.

Lately the product portfolio has been extended by developing a suitable GHP for the retrofit single-family home (HEAT4U) and more products becoming available for the larger scale retrofit demands of multi-family homes, public buildings and small to mid-sized enterprises (Bosch 40 kW air-source gas absorption heat pump).

Practical experience proved GHPs to be reliable and efficient. An important prerequisite is a system setup appropriate for the specific requirements like hydraulics, control schemes, customer's comfort need and so on. This leads to a higher installation effort compared to a simple boiler.

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