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GAS HEAT PUMPS IN EUROPE.
EMERGING GAS TECHNOLOGY INTEGRATING RENEWABLE ENERGY

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ABSTRACT

Renewable energy will play an important role in the future energy supply not only in Germany and Europe, but also worldwide. The German government has adopted a very ambitious energy concept with significantly growing percentages of renewable energy in the areas of electricity production, space heating and transport. The gas industry with its highly developed infrastructure supports the German government's targets in a multitude of ways.
E.ON Ruhrgas is engaged in the production, transmission and sale of renewable energy such as biogas, and in supporting the development and marketing of gas appliances integrating on-site renewable sources including solar energy, ground heat and ambient air heat.
As part of its marketing initiatives and technical development efforts, it promotes condensing gas boilers used in combination with solar energy. Field tests have shown that solar panels can provide about 60% of the energy needed for hot water production, which results in annual efficiencies of 105% or even 115%, depending on system design and user behaviour. This technology is now widely available on German market. While further development work is required in areas such as storage tank and control system design, there will always be limits to the use of thermal solar technology.
The next technological step is the gas heat pump which can use low-temperature ambient heat and energy sources such as ground heat and ambient air heat. In 2008, a group of German gas utilities and heat pump manufacturers established the Gas Heat Pump Initiative to promote laboratory and field tests of three newly developed gas heat pumps. Long-term performance and stress tests have since demonstrated the high reliability of these appliances. Efficiencies were measured in the lab under different conditions, and the method used for calculating annual efficiencies is currently undergoing standardisation in Germany. The gas utilities involved in the Initiative have embarked on a series of field tests, and first results for the gas absorption heat pump developed by Robur suggest that the previously calculated figure of about 140% can actually be achieved. However, efficiencies are very much dependent on local site conditions, system design and user behaviour. Further data analysis is ongoing. The results are discussed in detail with respective manufacturers and may be incorporated into the optimisation process. The Initiative will continue its work.

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INTRODUCTION

The German government is continuously developing its energy concept, adapting it to the combined challenges of climate change, energy affordability and security of supply. One of the main objectives is to give renewable energies a central role in the future energy mix in three sectors: power generation, heat supply and transport. The different scenarios underlying the energy concept provide a detailed description of the targets for these three sectors.

The gas industry with its well developed infrastructure supports the government's targets in a multitude of ways. Considerable efforts are being made to step up biogas production. E.ON Biogas, for example, develops, builds and operates a growing number of biogas plants, which feed their biomethane directly into the existing natural gas pipeline system. This increases the percentage of renewables in private and public transport, space heating and especially combined heat and power generation involving systems of different sizes.

In future, it will be possible for excess renewable capacity from sources such as wind and solar to be converted by electrolysis to hydrogen or, in a second step, to methane. Unlike electricity, these renewable gases can easily be stored and transported to end users, providing them with an additional way of integrating renewables into their heating applications.

In the heating sector, appliances designed for the combined use of gas and on-site renewable energy such as solar, near-surface geothermal heat or ambient air heat offer a second important avenue for increasing the percentage of renewable energy used in Germany. E.ON Ruhrgas is supporting the development and market launch of these technologies through lab and field tests, support for German standardisation work and by developing marketing measures in cooperation with other gas utilities.

RENEWABLE ENERGY IN THE HEAT SUPPLY SECTOR

The German government's new energy concept will cause overall energy consumption in the heating sector to decrease continuously as appliances and buildings are made more energy-efficient. With natural gas being the cleanest fossil energy, it will not be affected by this trend in the same way as the other conventional energy sources. Gas demand for 2025 is therefore predicted to be about the same as in 1990 [1].

Use of renewables such as biomass, biogas, solar and geothermal energy in the heating sector will increase significantly. According to the new energy concept their share is set to grow substantially (see **Figure 1**).

In view of the important role natural gas plays for the energy future, the gas industry bears a great responsibility in offering highly efficient gas technologies with the ability to integrate renewable energy at reasonable cost.

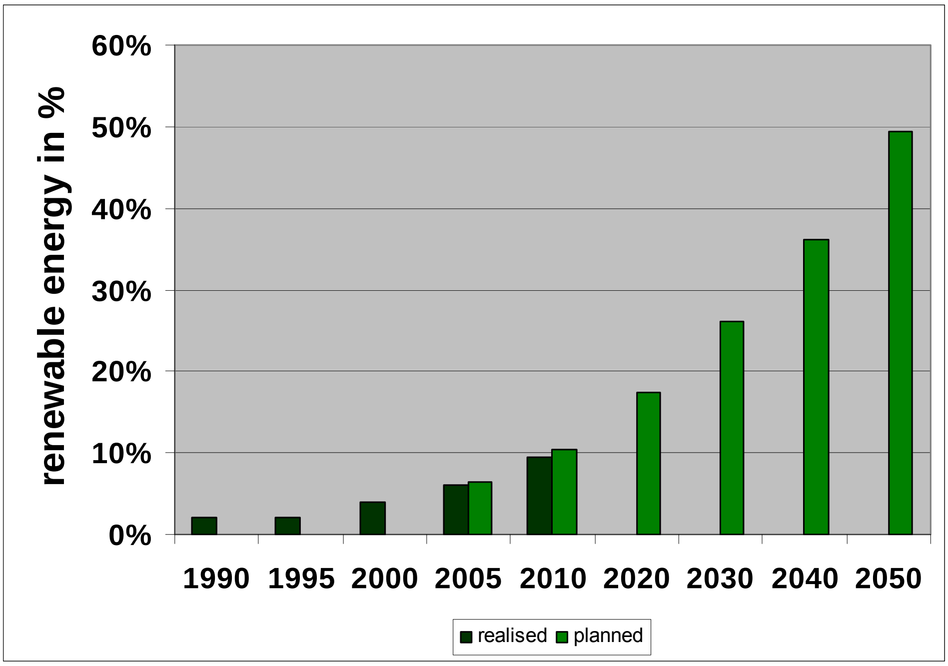

Figure 1: Share of renewable energy in the heating sector in Germany [2]

Today, condensing boilers with solar panels for hot water production provide a marketable and economic solution that is highly appreciated by end users. It is one way of complying with the statutory rules and regulations for new buildings introduced in Germany in 2009. E.ON Ruhrgas supports the development and marketing of condensing boilers with solar panels through various technical and marketing activities. Field tests done by E.ON Ruhrgas have shown that solar panels can deliver up to 60% of the hot water needed by a household. For these field tests overall efficiencies are calculated as heat output for the heating system and hot water production over the gas input (lower heating value). Depending on the type of heating system, hot water demand and user behaviour, overall efficiencies of 95 % to 105% or even 115% are detected.
The limiting factors are the minimum temperature of the produced hot water, the restriction to one renewable source and the availability of surface area with the right orientation to the sun. Although this heating technology is highly developed, there is still room for further optimisation, especially on the storage and control system side.

GAS HEAT PUMPS: THE ADVANCED TECHNOLOGY FOR RENEWABLE ENERGY USE

A fundamental advantage of gas heat pumps is their ability to use energy at low temperature levels, which means that all renewable energy sources including ground heat, ambient air heat and solar heat can be integrated into the heat pump cycle and be brought to the temperatures required for heating. This choice of energy source allows home owners to pick the technology that best fits their circumstances and requirements.

Since 2008, considerable progress has been made in gas heat pump development, with different technologies being continually optimised. Today, the German market offers a range of systems using solar energy, ambient air, geothermal heat or water heat as the heat source.

INTEGRATION OF SOLAR THERMAL ENERGY

The gas heat pump developed by Vaillant uses solar thermal energy both directly to heat the hot water storage tank and the heating system, if the temperature is sufficiently high and indirectly through the heat pump cycle. It is designed for new single-family homes with floor heating systems rated at 1.5 to 10 kW and was first introduced to the German market in March 2010. **Figure 2** show today’s design and a sketch of the functional principle.

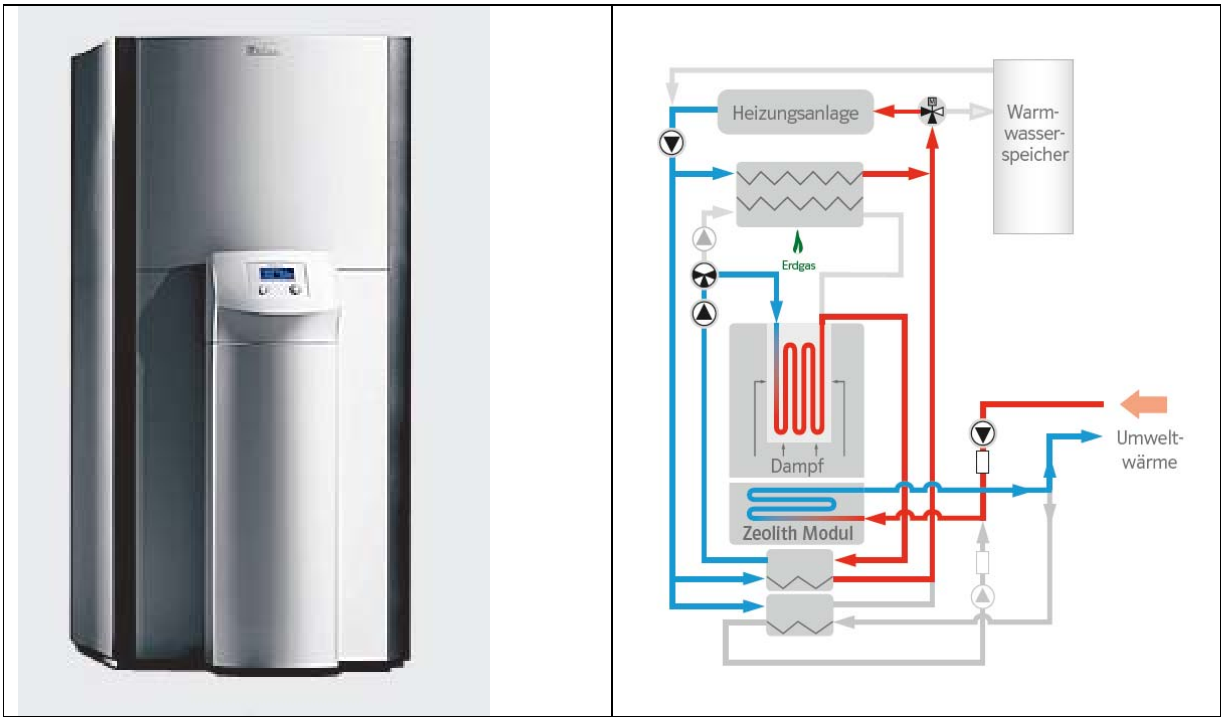

Figure 2: Adsorption gas heat pump from Vaillant rated 1.5 kW to 10 kW designed for new build single houses with floor heating systems and its functional principle.(Source: Vaillant)

The heat pump process is an adsorption process with a solid zeolite material in the shape of small bullets as the adsorber and water as the refrigerant. Zeolite, water and two heat exchangers for ambient heat input and heating system output or driving heat input are placed in a pressure vessel operated at pressures lower than 5 mbar (during adsorption) and about 80 mbar (during desorption). Since 2008, the core technology has been reduced to a single-module system working in two phases. For a detailed description of the function see [4] and [5]. In the new generation the additional direct use of solar energy is integrated.

INTEGRATION OF GEOTHERMAL HEAT

A second gas adsorption heat pump using a ground spike as the ambient heat source is in development by Viessmann. The basic technology is similar to that of Vaillant, but the hydraulic concept as depicted in **Figure 3**, the construction of the heat pump module and the zeolite form and application to the heat exchanger are different. This future gas heat pump designed for use in single-family homes is scheduled to be launched in Germany in 2012. In future this gas heat pump will be designed to use solar thermal energy too.

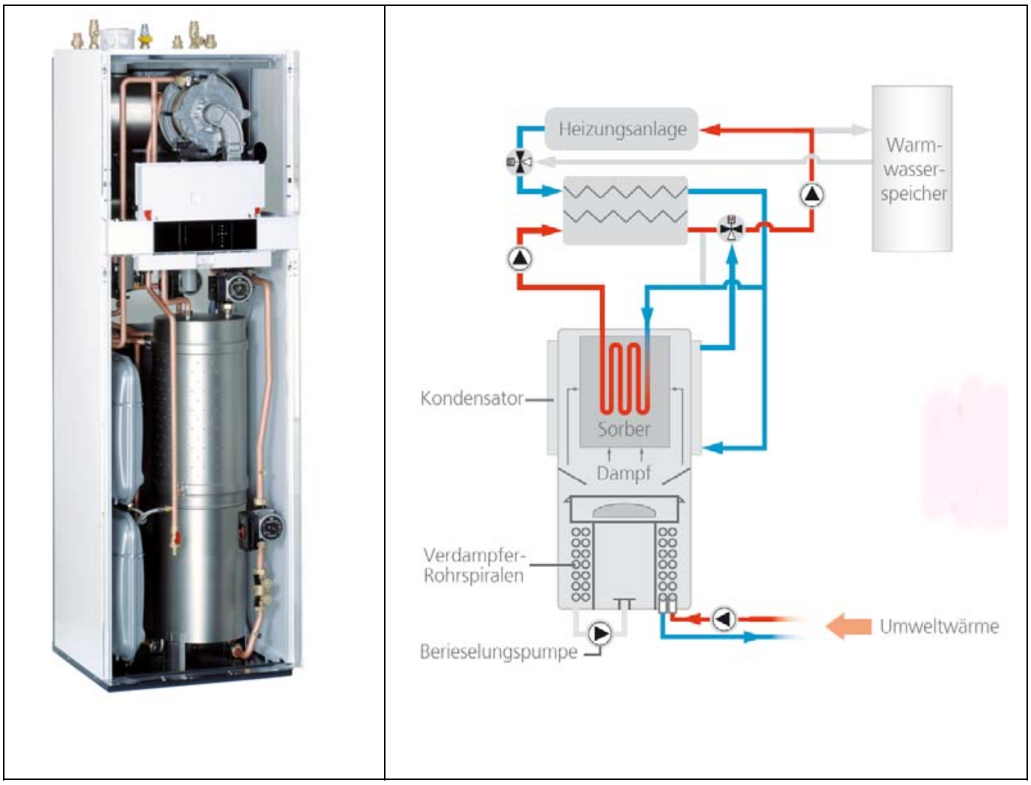

Figure 3: Adsorption gas heat pump from Viesmann rated 1.6 kW to 10 kW for use with a ground spike designed for newly built single houses with floor heating systems and its functional principle. (Source: Viessmann)

A gas absorption heat pump, based on the established and reliable technique of the ammonia/water heat pump cycle in gas driven cooling systems has been developed and is continuously being optimised by Robur. **Figure 4** shows the version for using geothermal energy. The latest development includes a condensing flue gas heat exchanger and a modulating burner. The appliance with an output of about 40 kW output is designed for multi-family houses or commercial applications and was introduced to the German market in March 2009.

Figure 5 shows the principle of the realised absorption process, with water serving as the absorber and a natural refrigerant. The pressure in the system is about 4 bar in the evaporator and the absorber and about 25 bar in the condenser and generator.

Appliances with a lower heat output for existing single-family homes are under development.

Figure 4: 40 kW absorption gas heat pump from Robur for use with a ground designed for multi-family houses and commercial applications, 40 kW, similar versions are available for use as water/water heat pumps. (Source: Robur)

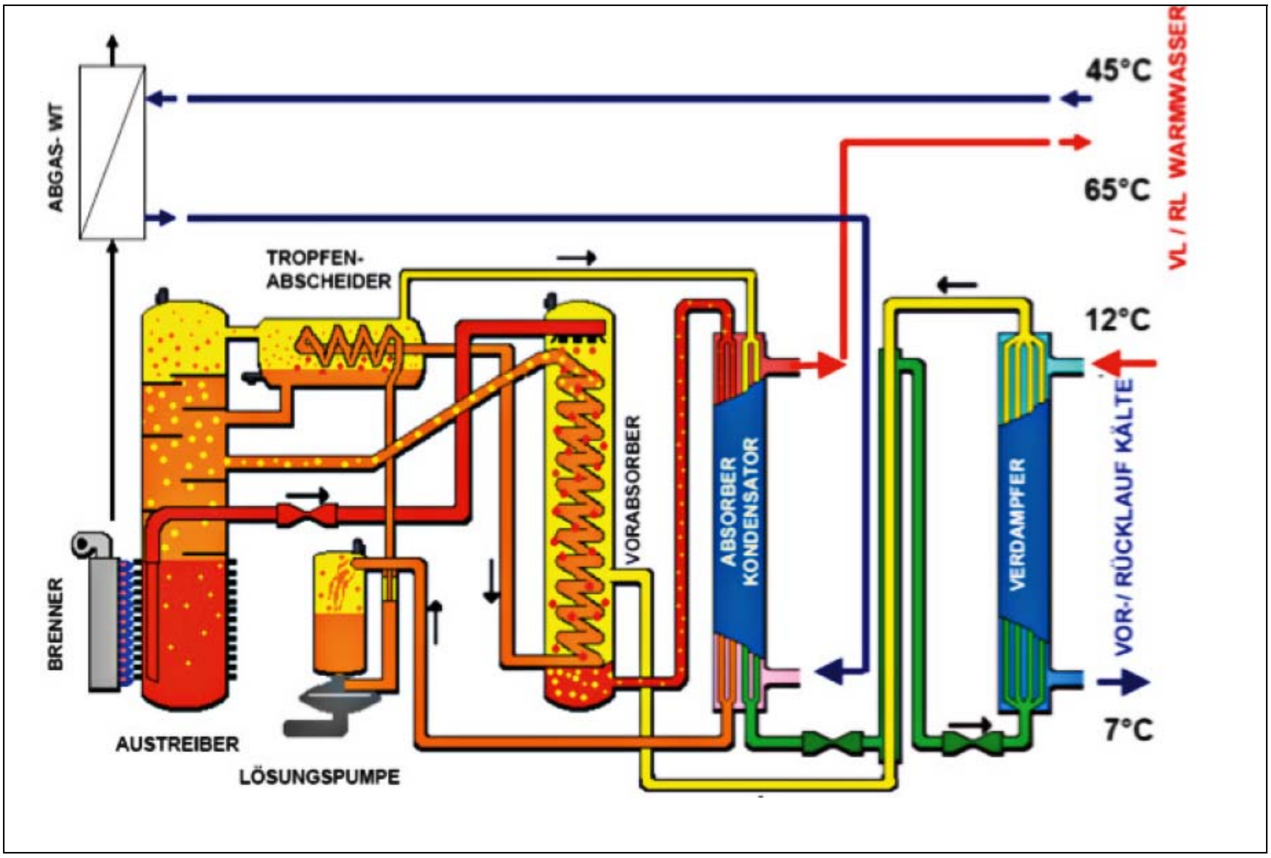

Figure 5: Functional principle of the absorption gas heat pump from Robur, (Source: Robur)

INTEGRATION OF AMBIENT AIR HEAT

For retrofit installations, an air source gas heat pump is often the best choice. Robur also offers gas absorption heat pumps with an integrated air heat exchanger for outdoor installation (see **Figure 4**). The same system will be launched by Bosch Thermotechnik in 2011.

Figure 6: Absorption gas heat pump from Robur with air heat exchanger for outside installation, (Source: Robur)

For commercial applications, air/air or air/water gas engine heat pumps fitted with air heat exchangers are a second system using ambient air as the heat source (see example in **Figure 7**). These gas engine heat pumps developed by the Japanese manufacturers Sanyo, Aisin and others for a heat output range from 22 kW to over 70 kW first appeared on the German market in 2005. Today, they have a small but steadily growing market share.

Figure 7: AISIN gas engine heat pump with air heat exchanger in a field test installation

WORK IN PROGRESS: THE GAS HEAT PUMP INITIATIVE

The importance of heat pumps as an advanced technology combining gas with the use of renewable energy gave birth to the "Gas Heat Pump Initiative" in 2008. Members include gas utilities EnBW, E.ON Ruhrgas, ESB, EWE, GASAG, MVV, RWE and VNG and manufacturers Bosch Thermotechnik, Robur, Vaillant and Viessmann. The Initiative's prime target market is the domestic heating market. Responsibility for the development and market launch of the gas heat pumps lies with the manufacturers. The other partners support the Initiative by conducting lab and field tests, promoting the new technology, helping to draw up technical standards and regulations and producing information material. Monitoring of the heat pumps installed in private homes all over Germany yields valuable information, allowing the manufacturers optimise their technical designs, control systems and installation support.
The Gas Heat Pump Initiative is unique in Europe. It is a constant source of new ideas and concepts, giving momentum to other European countries through workshops, knowledge sharing and support in developing European standards.

Lab tests
The Initiative's main technical work includes lab tests and the installation and monitoring of the manufacturers' gas heat pumps in the field. As the focus on domestic applications the developments by Vaillant, Viessman and Robur were chosen. Most of the lab tests have been conducted at the E.ON Ruhrgas labs. The different types and versions of gas heat pumps were operated for a total of over 150,000 hours (**see Table 1**).

Type	Version	Operation hours
Adsorption HP Solar	1	21,049
	2	19,368
Adsorption HP brine/water	1	8,900
	2	3,500
Absorption HP brine/water	1	19,577
	2	12,320
	3	15,004
	4	18,378
	5	16,929
	6	18,728
Absorption HP air/water	1	1,500
Absorption HP brine/water	1	2,200
GHP total	6	157,453

Table 1: Operating hours of gas heat pumps at the E.ON Ruhrgas lab

The very first experiments provided the manufacturer with a number of very useful hints on how to optimise individual components. Subsequent results showed a very high level of operational reliability for all of the heat pumps investigated, even during long-term performance testing and special stress programmes. The long-term test of the adsorption process and the respective zeolite confirmed the high stability and efficiency of this component.
In the next step, the whole range of stationary efficiencies for heating temperatures of 20°C to 45°C (adsorption systems) and up to 70°C (absorption heat pump) were measured as a function of the load, the heating system temperatures, the ambient heat source, and the water and brine flow rates, etc. **Figure 8** is an example showing the absorption heat pump results for loads of 50% to 100%, for three heating system inlet temperatures and for brine temperatures of 0°C, 5°C, 10°C. Under optimum conditions, i.e. heating system temperatures of about 30°C and brine temperatures of 10°C, which are not

unusual for floor heating systems, efficiencies can reach up to 170%. Even under worst-case conditions, i.e. 0°C brine and a heating system temperature of 70°C, efficiency in the field is never below about 120%.

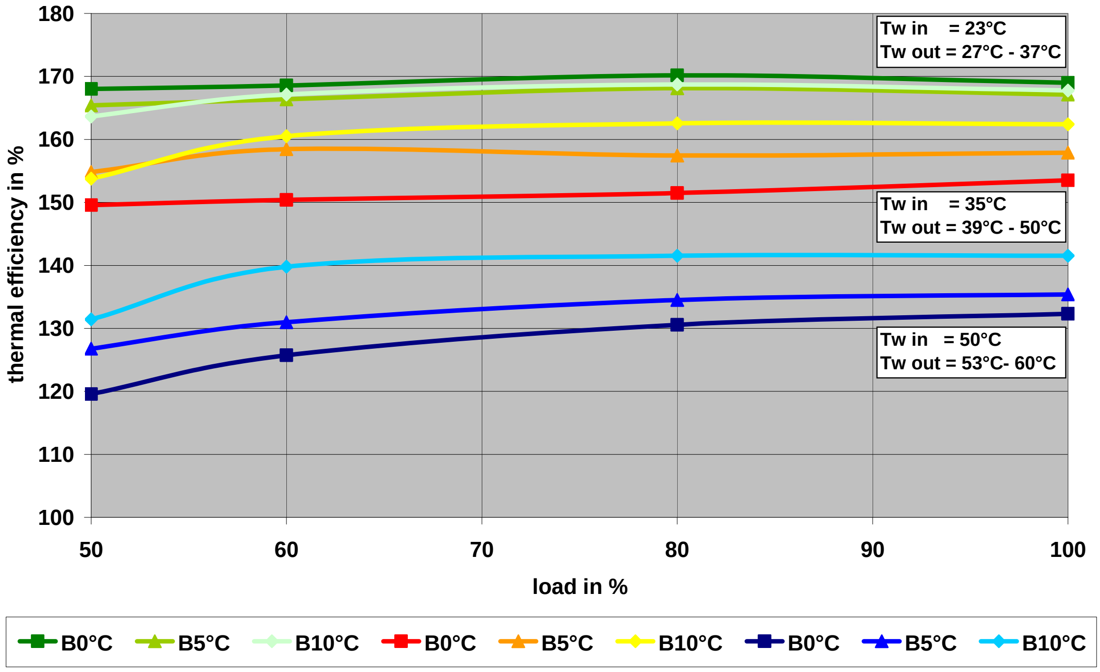

Figure 8: Robur absorption gas heat pump efficiencies measured during lab tests.

While a European standard for the calculation of the annual efficiency of gas sorption heat pumps is in preparation (EN12309), an interim calculation method is being discussed in Germany and a first draft has been prepared (VDI4650-2)
According to this method, the efficiencies of the two ground source heat pumps have been measured at five points, each representing 20% of the annual energy consumption. The annual value may be calculated as a mean value (see **Figure 9**).

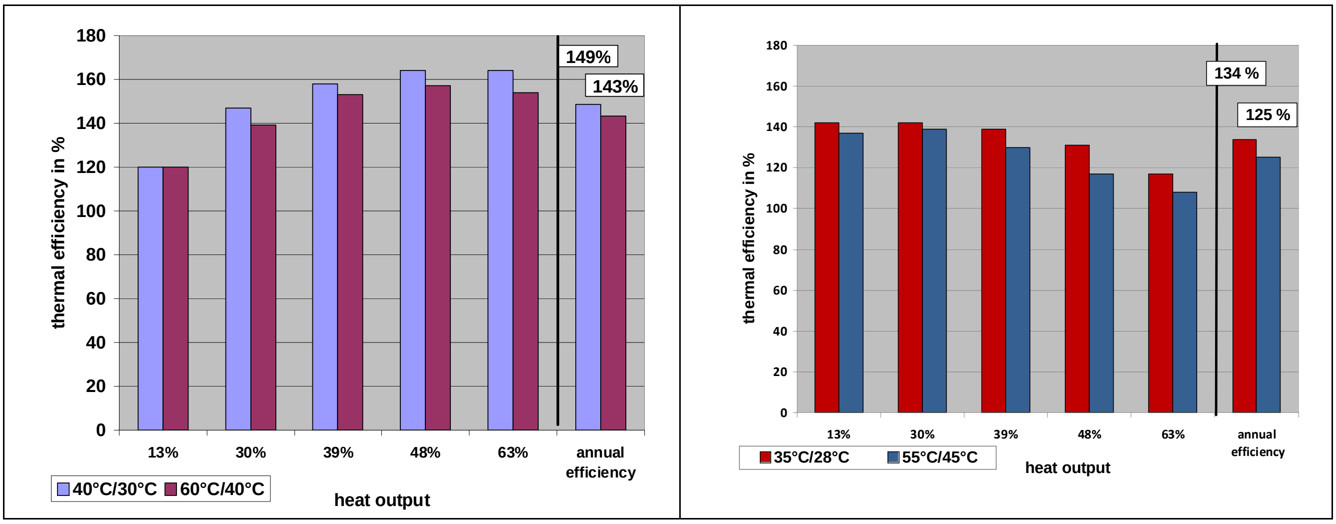

Figure 9: Efficiencies of the gas absorption heat pump (40kW, Robur, left) and of the gas adsorption heat pump (10kW, Viessmann, right) measured at 5 representative points and the calculated annual efficiencies for two heating systems

The gas absorption heat pump for a ground heat source (Robur, 40 kW), which is designed for multi-family houses (new or renovated) or commercial premises has been tested for two different heating systems (60°C/40°C and 40°C/30°C) in the E.ON Ruhrgas lab. Annual efficiencies of 143% and 149% have been achieved.
The gas adsorption heat pump for a ground heat source (Viessmann, 10 kW), which is designed for single-family houses and floor heating system, was measured for two heating systems (35°C/28°C) and (55°C/45°C). Annual efficiencies of 134% and 125%, respectively, were achieved (see Figure 9).

For the adsorption gas heat pump with a solar panel as the ambient heat source (10kW, Vaillant), which is designed for single family houses and floor heating systems, the same measuring method has been used. To achieve the on-site annual efficiencies additional calculation steps are needed to take account of the direct use of solar energy. **Figure 10** shows the calculated annual efficiency according to VDI 4650, part 2 as a black dot at 100% heat demand for a single-family home with floor heating system. The orange and green curves represent the calculated results for two different solar panel technologies as a function of the home´s of heat demand.
The lab tests have shown that there are three heat pump systems at different stages of development, all of which have proven extremely reliable in the lab and offer the prospect of significantly improving the efficiency of gas-fired heating appliances. The results were discussed in detail with the respective manufacturers and the Initiative's gas utility partners, and the ultimate aim – which was to get the go-ahead for field tests – was achieved.

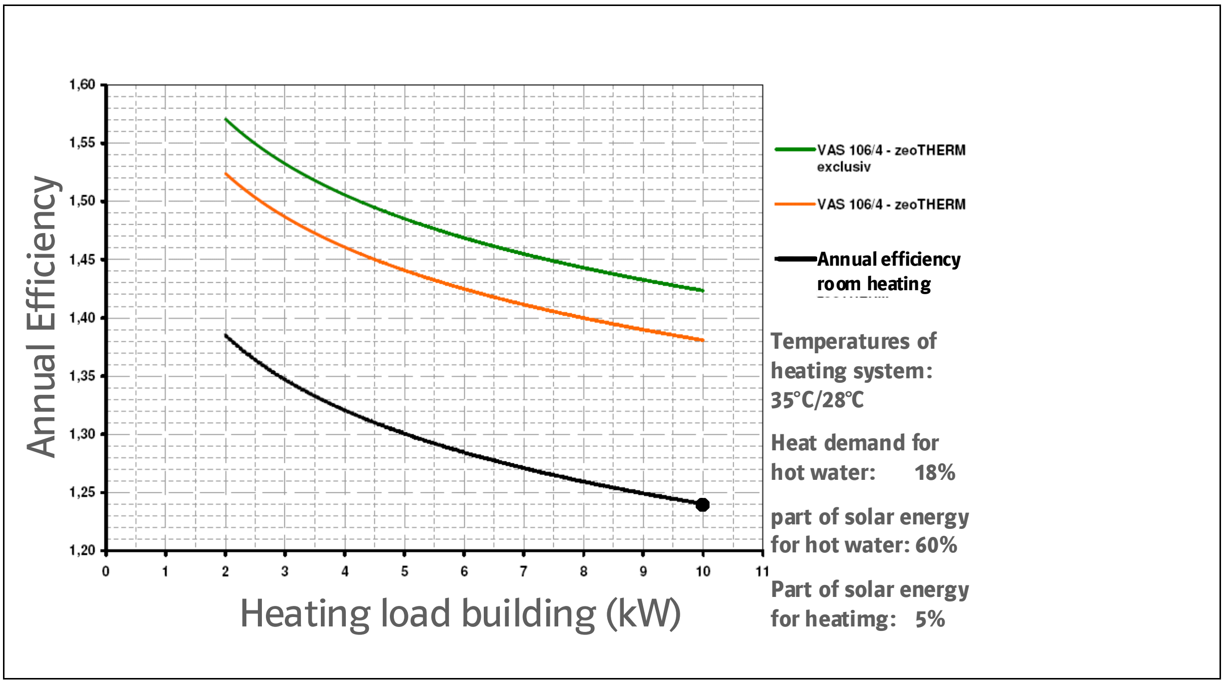

Figure 10: Results for adsorption heat pump with solar energy showing the annual space heating efficiency calculated from measuring points during the lab tests and the calculated annual efficiency (incl. direct solar energy use) for two solar panel technologies over the heat demand of the house

Field tests
As part of the Gas Heat Pump Initiative, each gas utility agreed to install one or several gas heat pumps from each manufacturer. So far, 46 installations have been completed. Another 22 installation sites are planned (see **Figure 11**). Each test site is equipped with sophisticated instrumentation (see **Figure 12**) and is continuously monitored.

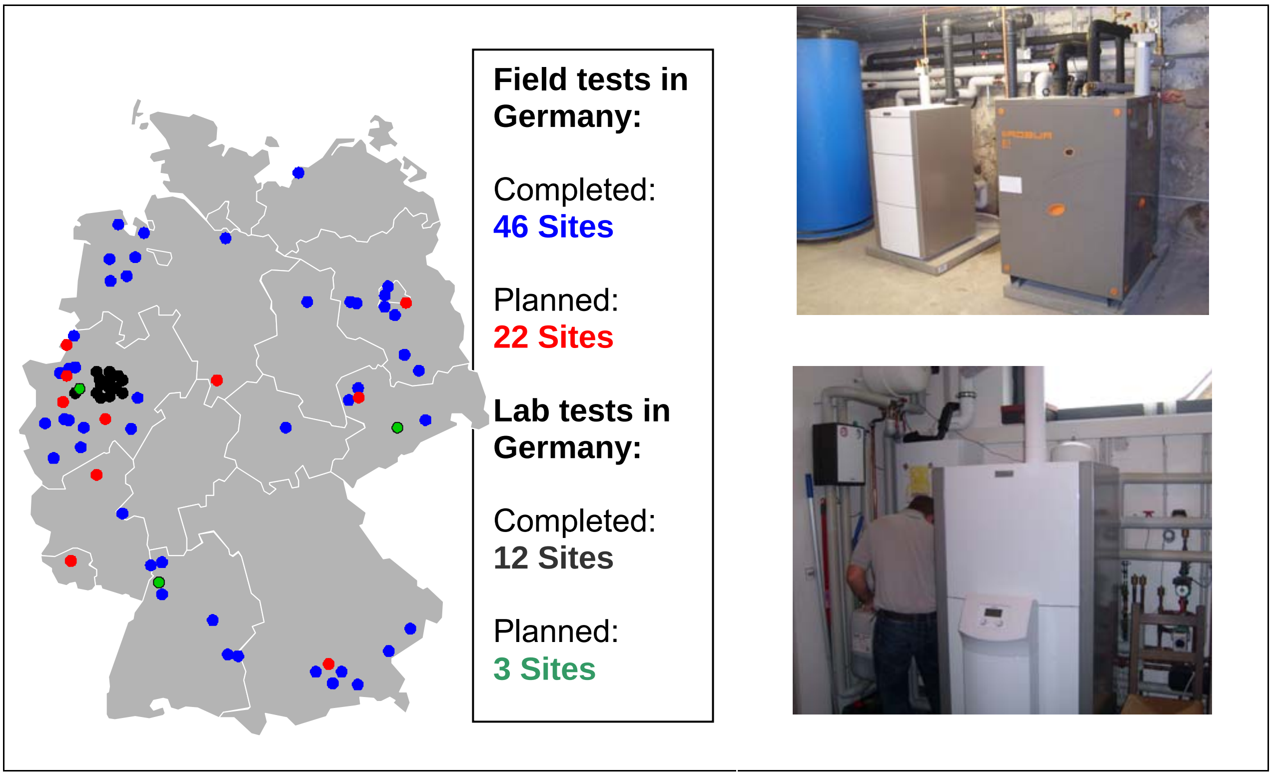

Figure 11: Gas heat pump tests sites in Germany (completed sites in blue, planned sites in red) and typical installation layout of two gas heat pumps

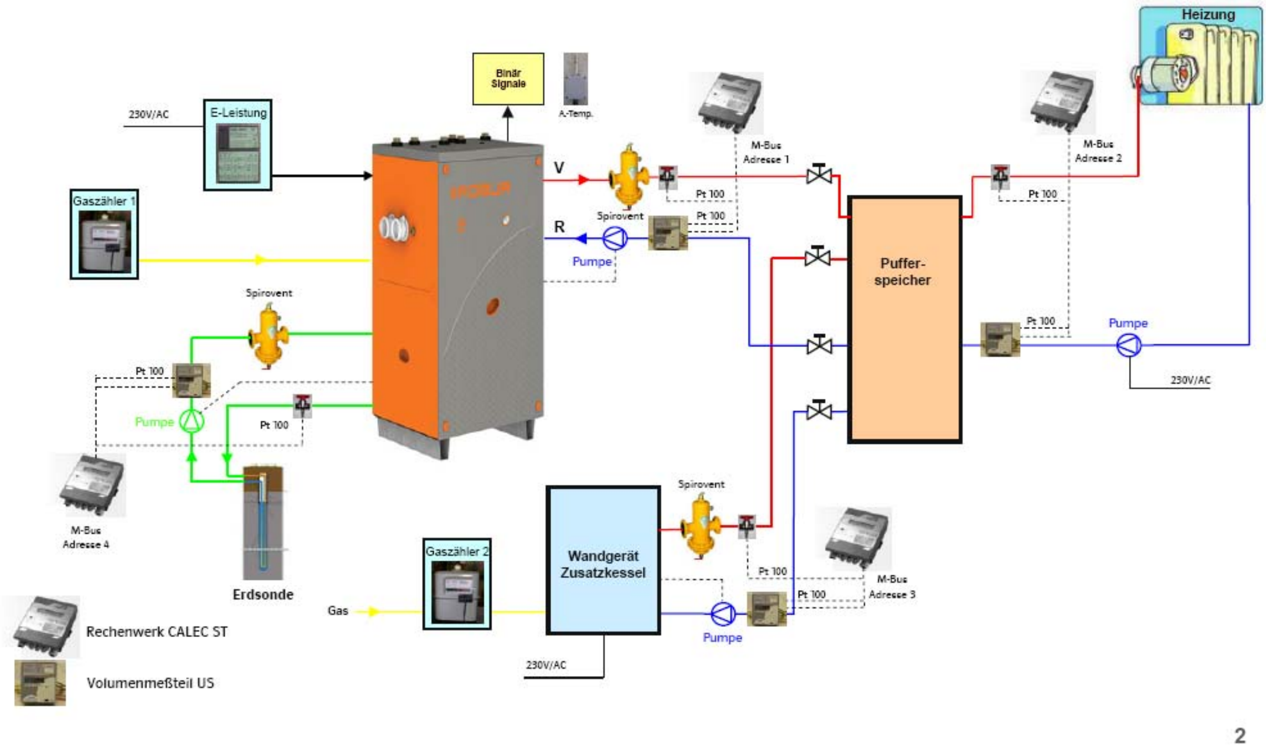

Figure 12: Measuring equipment used in the field

FIELD TEST RESULTS

The first results from five sites with multi-family houses or integrated buildings with private and commercial users equipped with absorption gas heat pumps with ground spikes as the ambient heat source have been evaluated. Over the course of the project the number of field installations grew continuously. The periods over which readings were taken vary from site to site. Two of the appliances have already been monitored for a complete year, two have been monitored over an entire heating season and one has been monitored for four months. The overall efficiencies are shown in **Figure 13**.

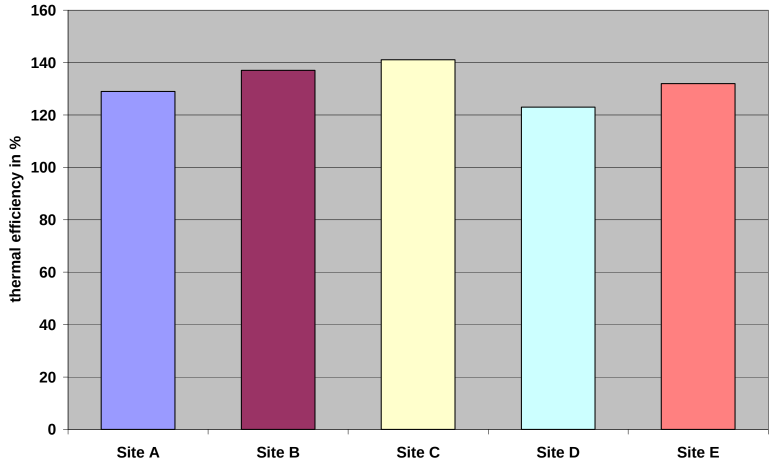

Figure 13: Overall efficiencies of the gas absorption heat pump (40 kW, brine/water) at 5 different sites with private and commercial users

The values include heating and hot water production reflecting typical on-site behaviour incl. on/off cycles due to low energy demand, high and low-temperature heating systems, cold winter days as well as warmer spring days with low heat demand. Depending on the site, efficiencies reach 123% to 141%. The efficiency measured for the best site corresponds to the value calculated during the lab tests. At this site the end user will be able to cut energy consumption by more than 30%, while the other sites can achieve savings of at least 20%.
An in-depth review of the data and operating conditions for the different sites will help to understand the variation in results and continue the optimisation process. A first step will be to analyse the monthly values (see **Figure 14**).

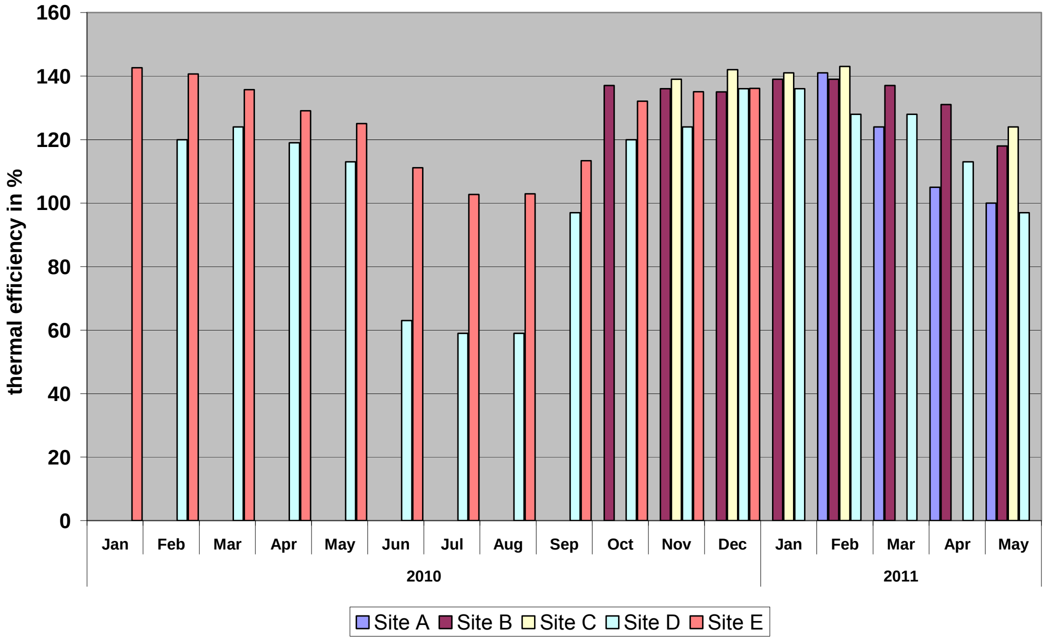

Figure 14: Monthly efficiencies for the gas absorption heat pump (40 kW, brine/water) measured at five sites

Obviously, the maximum efficiencies are observed in winter when heat demand reaches its peak. During this time the heating temperatures are the highest and the ground spike temperatures are the lowest, which according to the lab measurements, gives the lowest stationary efficiency. But the operating time of the heat pump is the longest, so seasonal efficiencies are close to those of the measurements taken during the stationary lab tests. During the summer months the efficiency is noticeable reduced and depend considerably on the sites. Up to now only two field test sites have been measured during summer. The reason for this efficiency reduction is the considerably reduced heat demand during summer. Quite often the heat pump only provides for enough hot water. During this time the system usually has to operate in on/off mode. **Figure 15** shows both the reduced heat output of the gas heat pumps during summer and the strong dependence of efficiency on the output. For more than about

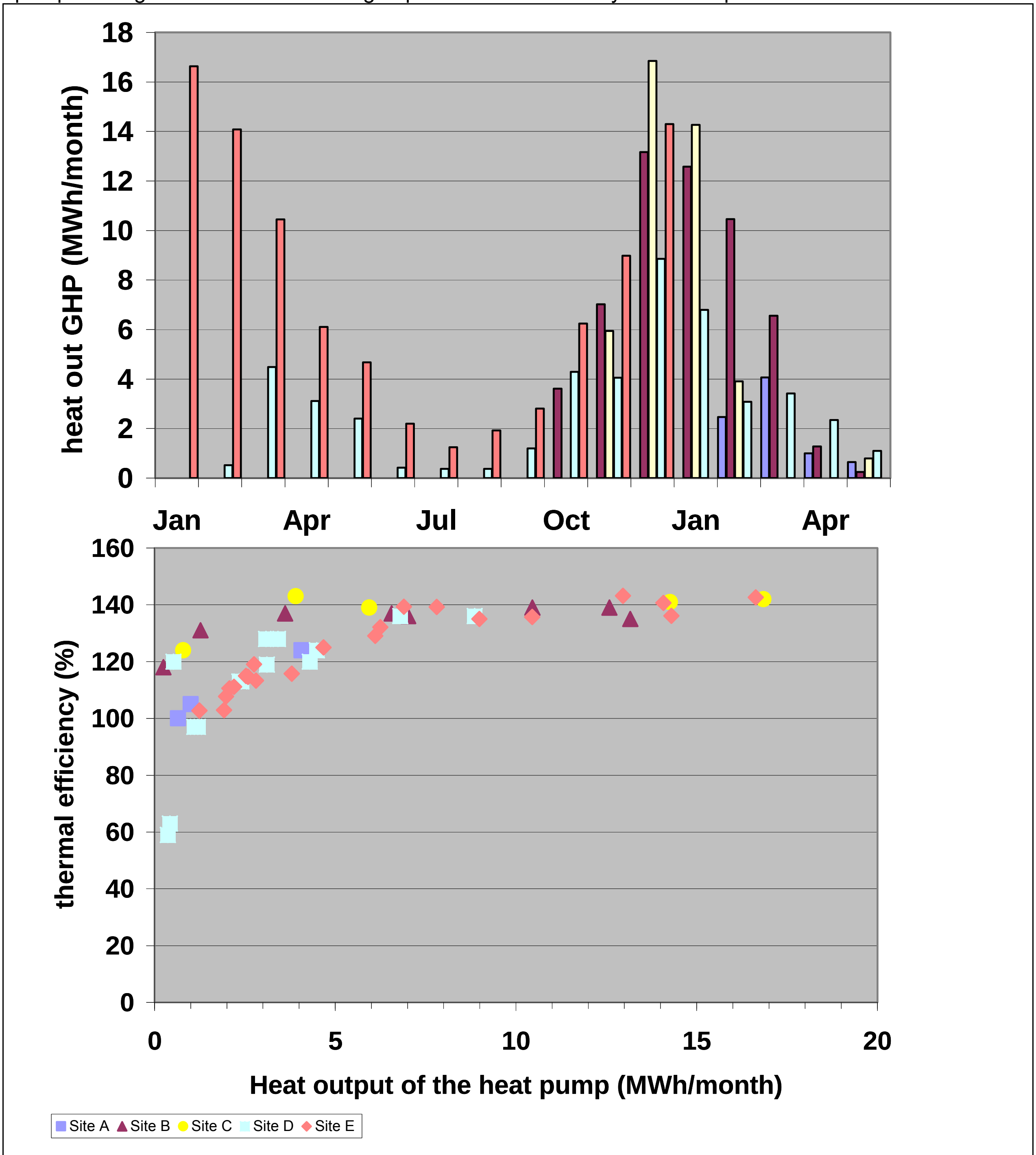

Figure15: Monthly heat output of the gas heat pumps (40 kW, brine/water) at the five field test sites and efficiency over the monthly heat output of the gas heat pump.

6 MWh heat output per month the efficiencies for all sites achieve more than at least 135%. For less than 6 MWh monthly heat output the measured efficiency values depend obviously more on the different sites. These results confirm that it is important to get the dimensions right. Integration of a storage tank, the proper design of the control system and the user behaviour has also a big influence on the efficiency. Since all these considerations are done for seasons, when less heat is produced, the reduced efficiency does not significantly affect the annual efficiency, as can be seen in Figure 13.

Outlook

As part of the Gas Heat Pump Initiative the field tests will be continued and evaluated carefully for all three types of gas heat pump. In addition to evaluations involving the automated interpretation of results and the charts, particular attention will be given to the analysis of detailed results to determine the most important influences on real efficiencies in the field. All data will be exchanged with the respective manufacturers, who may use them to optimise their systems.

New types of gas heat pumps for existing single-family houses are currently being developed by two manufacturers.

Summary

The Gas Heat Pump Initiative’s work has been instrumental in the development and market introduction of gas heat pumps in Germany. Two models are already available, a third one will be launched in 2012 and another two types are under development by the manufacturer. The Initiative conducted lab and field tests on three types of gas heat pumps. The first results for the heat pump designed for multi-family houses and commercial premises are encouraging and show that end users may cut their energy consumption by as much as 20% to 30%. Further development work will focus on new types of heat pumps for existing buildings and on optimising pump design and control system features.

REFERENCES

[1] Manfred Kleemann, Beratungsbüro für Energieeffizienz und Umweltschutz, 2011 „Auswirkungen des Energiekonzepts der Bundesregierung auf den Wärmemarkt", unpublished Study for E.ON Ruhrgas,

[2] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) Referat Öffentlichkeitsarbeit , 15.12.2010, „Erneuerbare Energien in Zahlen Internet Update ausgewählter Zahlen",: ▪ www.erneuerbare-energien.de,

[3] Rolf Albus, Tatjana Müller , 2010, Gasbrennwerttechnik und Solarthermie – eine hocheffiziente Kombination mit Zukunft, GWF – Gas,

[4] Werner Weßing, 2010, „Erdgas Heiztechnologie „Gaswärmepumpe", gwf – Gas, 2010

[5] Rolf Albus, Werner Weßing, Stefan Ramesohl, 2009, World Gas Conference 2009, Buenos Aires

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