TWO LARGE FIELD-TESTS OF NEW HEAT PUMPS IN GERMANY

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Abstract: In 2006, two large field test campaigns of newly installed heat pumps have been launched under the direction of the Fraunhofer ISE. Each project deals with the measurement of a large number of heat pump units under real operating conditions in one-family or multiple-family-houses. Values of volume flows, temperatures, heat quantity and electricity consumption are collected at relative high time resolution (every minute). The data are sent to Fraunhofer ISE headquarter on a daily basis and automatically checked with respect to their plausibility. The first phase of the projects was dedicated to the choice of adequate test houses with heat pump units, to the installation of measurement and storage devises and to the verification of their proper functioning. The first outcomes of the "Heat Pump Efficiency Project" confirm a high efficiency of the ground-source heat pumps. The assessment of the measurement data for heat pumps providing both space heating and domestic hot water supply, obtained during the first months data acquisition including a heating period, reveals a seasonal performance factor (SPF) of approx. 3.7 for ground source heat pumps, 2.8 for air-to-water heat pumps and 3.4 for water-to-water heat pumps.

Key Words: ***heat pumps, field test, monitoring, efficiency, seasonal performance factor***

1 INTRODUCTION

Heat pumps have been taking a fast increasing share of the heating market for years now. They are more and more often installed in new low-energy and passive-house buildings but also in standard and retrofitted houses.
Within the monitoring project „Heat Pump Efficiency", Fraunhofer ISE studies the efficiency of modern heat pumps in buildings of contemporary standards. The investigation shall provide an answer to the question whether heat pumps are a sustainable alternative to fossil fuels. Heat pumps installed in very efficient low energy houses, with a yearly heating load of 20 to 50 kWh/m² - equals 2 to 5l of heating oil, are examined from an optimization point of view. Considering that existing buildings built before 1980, require 90% of the total heating energy consumed in Germany, their energy savings potential is the largest. The efficiency of heat pumps in un-retrofitted or partly retrofitted houses is assessed within the project „Replacement of Central Oil-Boilers with Heat Pumps in Existing Buildings".

2 DESCRIPTION OF THE PROJECTS

2.1 „Heat Pump Efficiency" Project

The Heat Pump Efficiency Project addresses heat pumps with a small output capacity between 5 to 10 kW thermal, with outdoor air (air/water HP), earth (ground/water HP) and groundwater (water/water HP) heat sources. At present, the examination deals with 75 heat pump units provided by 7 producers. The installation of next 35 units is scheduled for spring and summer 2008. The aim of the project is to assess their efficiency under varying

operating conditions and in different system configurations. The results will serve as a contribution to a further concept development concerning the usage of smaller capacity heat pumps in newly built Low-Energy-Houses (KfW-40, KfW-60 and 3-Liter-Houses). In addition, in some units the loss of the refrigerant agent will be examined under real conditions over a period of four years. The results constitute, among others, the input into the activities of the new IEA Heat Pump Program Annex 32 „Economical Heating and Cooling Systems for Low Energy Houses".
The project is funded by the federal German Ministry of Economics and Technology and seven producers, as well as by the utility companies EnBW and E.ON. The heat pumps assessed in the projects are of the trade names Alpha-InnoTec, Buderus, Junkers, Hautec, NIBE, Stiebel Eltron, Tecalor, Vaillant and Viessmann.

2.2 Replacement of Central Oil-Boilers with Heat Pumps in Existing Buildings Project

Within the Replacement of Central Oil-Boilers with Heat Pumps in Existing Buildings Project, 75 heat pump units of the major producers are measured under real operating conditions. Due to their high supply flow temperatures, these heat pumps are particularly suitable for the use in older buildings. The measurement technology and the scope of data collection are comparable with these in the before mentioned project. The focus is set on a comparison of heat pumps with alternative central oil heating boilers as to their economic aspects and greenhouse gas emissions. The general aim of the field tests is to assess the limits of heating-energy consumption and insulation standards, up to which the use of a heat pump is economically reasonable and beneficial for the environment. The results will be made available to a broad public, such as potential customers, mechanics, producers, heat pump planners, universities, politicians and NGOs. The project has been commissioned to the Fraunhofer ISE by the E.ON Energie AG, a German utility.
The Institute will assess, among others, what are the minimum requirements to be be met by the building envelop and by the heat distribution system. It will compare from a economic and environmental point og view the use of a heat pump to the use of an central oil heating boiler. In particular, the Institute will define prerequisites for an optimal sizing and placement of heating bodies. The heat pumps are to be run with an supply temperature of 55°C. Most of the selected heat pumps are approved for supply temperatures of up to 65°C, leaving room for norm-deviating user behavior –e.g. producing higher room temperatures. On particularly cold days the increase in temperature beyond 55°C need not to be provided by an electric heater but can be achieved by a heat pump.

3 ASSESSMENT CONCEPT

In the Heat Pump Efficiency Project, 10 to 13 heat pumps of each of the seven producers are to be assessed in the first phase and 5 further systems of each manufacturer will be installed by the summer 2008, giving a total of 110 heat pumps. In the Replacement of Central Oil-Boilers with Heat Pumps in Existing Buildings Project a total of 75 heat pump systems will be assessed during two heating periods (cf. Figure 1).

Figure 1: Map of Germany indicating the placement of measured heat pump units in both projects

3.1 Measurement technology

Ultrasonic heat measuring devices in combination with data loggers are used to measure the produced heat. The heat necessary for space heating and for providing domestic hot water are measured separately. The temperatures, the volume flows and the amount of accumulated heat can be measured by means data loggers, facilitating an analysis of the system's behavior dependent on the system's parameters. The loggers enable also a detailed measuring of the heating source's capacity, the brine volume flow, its temperature before and behind the vaporizer for ground heat pumps and the outside air temperature and humidity for outside air heat pumps. The electricity consumption of the supportive pumps is also closely monitored (Figure 2).

Figure 2: Various heat measuring devices used in the framework of the described projects

3.2 Data storage

The data collection is based on an embedded system, using a computer with a Linux system as a data logger. The data loggers save the entire system's behavior on a minute-basis, rendering the most important temperatures, the flow quantities, heating quantities and electrical consumption of heat pumps and the supportive pumps. The Institute saves daily and automatically verifies the measurement results, received by a wireless connection. The stored measurement data is remotely accessible by a GSM modem and transferred to the ISE by GPRS. The connection to all heat pump systems is constantly online and the costs are calculated on the basis of the amount of the transferred data.

4 BASIC DATA ACQUISITION AND MESURED DATA PROCESSING

4.1 Questionnaires

The basic data are collected be means of a standard questionnaire filled-up during an on-the-spot visit. The questionnaire consists of three parts, containing information about:

- Inhabitants and house (filled in by inhabitants): User, building, heating demand, heating distribution system, dates.
- Technical aspects of the building (filled in by producers and technicians): technicians, system's scheme, heat storage, heat pump, further components.
- The heat pump in detail (filled in by the producers): additional information of the heat pump, compressor, cooling fluid, COP on test-site, heat load, planned volume flows.

4.2 Papers, manuals, check-lists

Several instructions and documents were drafted, containing the possible variants of the implied heat pump system and the corresponding systematic schemes. The installers receive detailed manuals which help them to install sensors properly and smoothly. Each type of heat metering system was provided with its technical data and detailed technical indications and assembly instructions.

4.3 Dealing with the basic data

A data base was programmed to store and process the date obtained from the questionnaires and later on acquired in the course of the project. All entries from the questionnaires for each entity (houses and heat pump systems) are compiled and sorted. The data base contains also the sensors´ characteristics, their delivery, the stage of the project and the installation of the measurement technique. Accordingly, the data base indicates what action is to be taken and when and facilitates the control of what was done, when and by whom. It helps maintaining a control over the installed measurement technique, indicating what has to be sent/ordered in a particular moment. By means of that, a fast and reliable processing and analysis of a considerable amount of data can be assured. The data base is structured in a way allowing a fast information access to various data at the same time.

4.4 Measured values and their processing

All values obtained in the monitoring process are stored every minute, transferred and processed at the Institute. Following an automatic saving and sorting of the data, an automatic test of plausibility is run by a specifically programmed software.
Following key values are rendered:

- Calculation of the average and sum values of all data per hour, per day, per month, per year.
- Energy-result processing: domestic hot water, heating, storage loss in selected projects.
- Seasonal performance factor calculation for a heat pump and for the entire system over selected periods.
- Calculation of the „Carnot“-performance ratio in monthly values dependent on the temperatures.
- Various time-dependent curves over the year of a heat pump and its heating capacity.

4.5 Data Access via the Internet

The producers have a password-secured access to the data of their specific heat pump system. The project partners have an option to select particular data compilations, download them and convert them automatically into a graphic presentation (e.g. daily temperature and capacity-flows and system operating times). In addition, the basic data and the systematic schemes are available online.
Further information regarding the both projects can be found at the respective websites (http://wp-effizienz.ise.fraunhofer.de, http://wp-im-gebaeudebestand.de). Following the link „Messdaten“, there is also an option to access the location and the basic information for each heat pump system. The access is restricted to the contract partners. Selected systems are also visualized on the Replacement of Central Oil-Boilers with Heat Pumps in Existing Buildings Project’s website. They show momentary values, such as the capacity of individual electricity consumers, produced heat, temperatures and volume flow. Figure 3 serves as an example of one of the above mentioned visualizations.

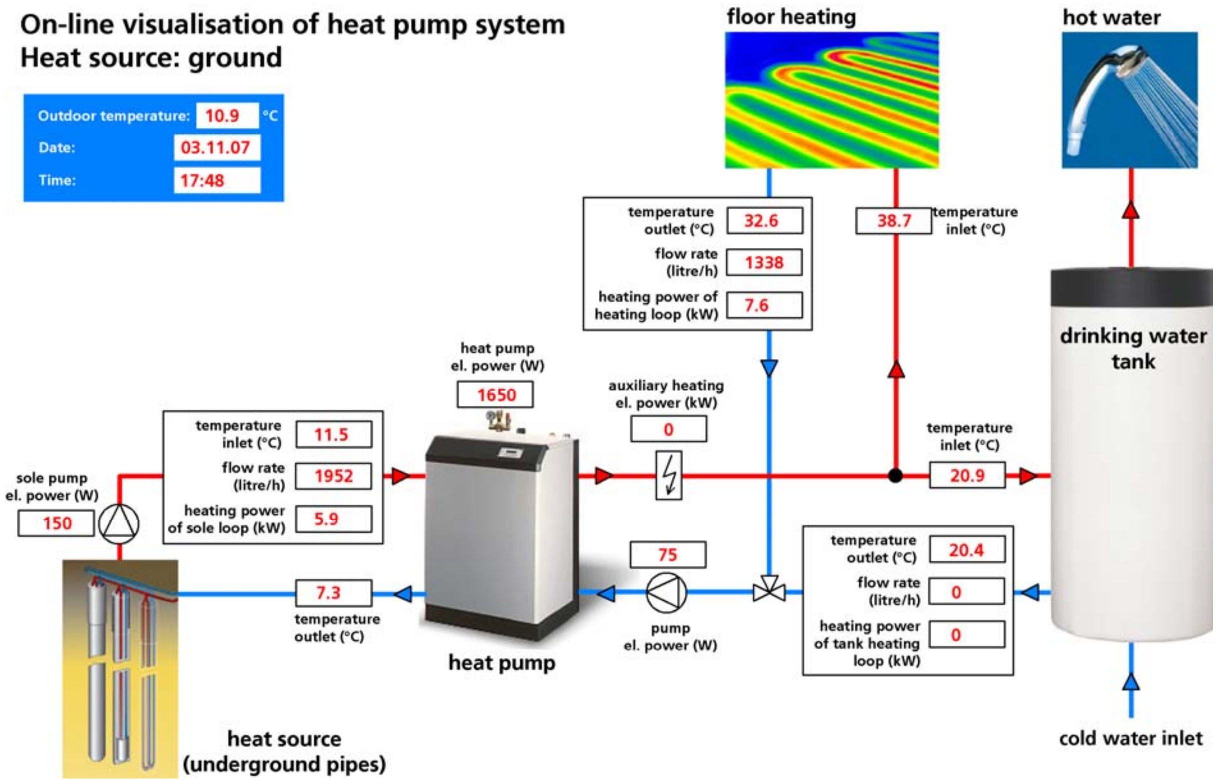

Figure 3: Example of one of the online visualizations of heat pump system

5 DEFINING THE LOSS OF REFRIGERANT

Within the Heat Pump Efficiency Project, the Institute also measures the real loss of refrigerant which occurs in stationary heat pump systems due to leaks of the devices. Up to present, the TEWI-value (total equivalent warming impact) was estimated at approximately 2% of the total filling per year. However, if this value proves to be incorrect and the TEWI is assigned too high, the effects of a heat pump on the environment would be seen too negatively. In framework of the Fraunhofer ISE ´s Project, the refrigerant loss is to be measured in several systems continuously monitored over the period of 4 years. For that purpose, the heat pumps are equipped with additional temperature and cooling liquid sensors in the cooling liquid circuits. Following a successful installation, on-site measurements in representative stationary point of operation are conducted. The loss of refrigerant is to be deduced from the changes in the operation states. Heat pumps showing a significant cooling refrigerant are examined on the spot to establish the source of losses and to propose solutions for their future avoidance.

6 CHARACTERISTIC OF HEAT PUMPS AND OBJECTS PARTICIPING IN THE PROJECT HP-EFFICIENCY

78 objects were registered in the first stage of measurements and equally distributed among the heat pump producers. The measurement technic, including the data retrieval system, has already been prepared for these objects and to a large extent it has already been installed. The first analysis has been conducted for the installed heat pump systems.
The following diagrams show examples of statistical evaluation derived from the basic data.

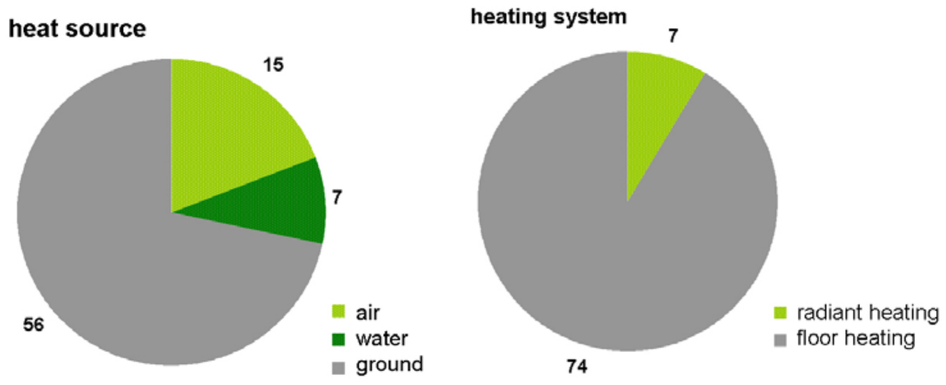

Figure 4: Distribution of the participating heat pump types (according to heat source and heat distribution system) (as of: 25.09.2007)

Fig. 4 represents the distribution of the heat sources and the heat distribution systems of the registered objects. 56 of the assessed heat pumps (72%) use ground as heat source. In addition, 34 (69%) systems use bore holes and 15 (31%) use ground collectors. 15 systems use air as the heat source. Among them, 9 systems (60%) are variants with the outside set-up and 6 (40%) with the inside set-up. The remaining 7 systems (9%) are water to water heat pumps.
Considering the heat distribution system, the predominance of the favored system is evident. 74 systems (91%) are equipped with a floor heating and only 7 (9%) use radiators. Three objects have combined systems.

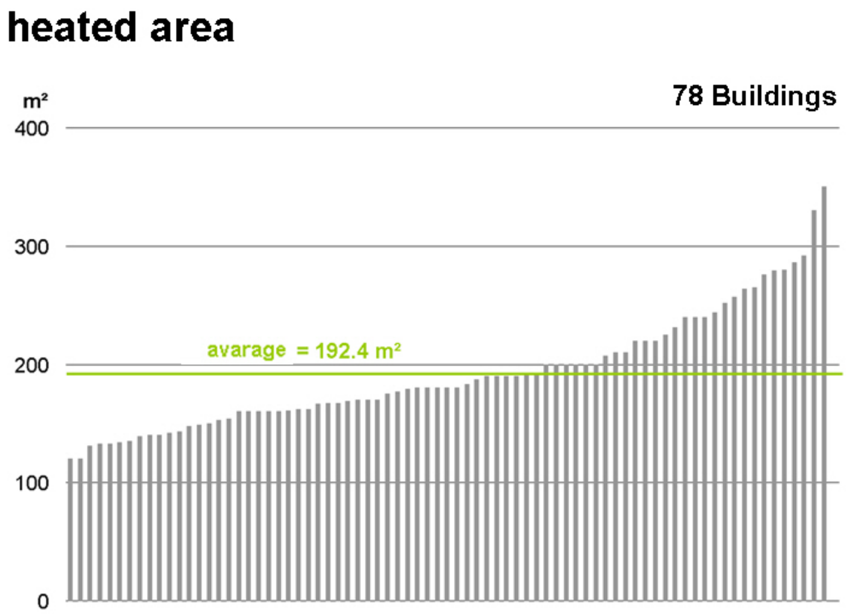

Figure 5: Distribution of the objects participating in the monitoring project (according to the heated living space), (as of: 30.08.2007)

The table Fig.5 shows the distribution of the objects according to the heated living space, which ranges from 120 to 350 m². The average space amounts to approximately 192 m². Out of 78 objects, 57 stand alone, 4 are row houses and 17 are semidetached houses.

7 COMPUTATION OF SESONAL PERFORMANCE FAKTOR (SPF)

7.1 System boundaries and characteristic numbers

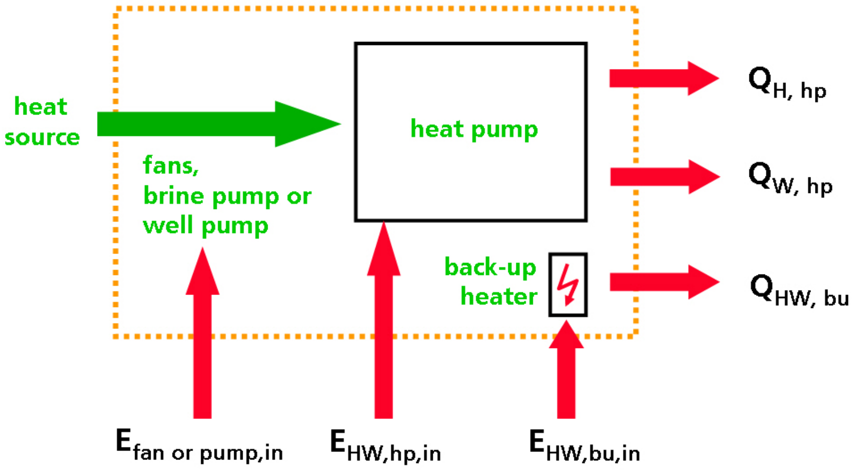

Figure 6: System boundary and characteristic numbers

Figure 6 shows the system boundary and characteristic numbers used for the assessment of the air-to-liquid, ground source and water-to-water heat pump systems.
The following equation was used for the computation of the seasonal performance factors SPF, shown in the section 7.2:

$$SPF = \frac{Q_{H,hp} + Q_{W,hp} + Q_{HW,bu}}{E_{fan\ or\ pump,in} + E_{HW,hp,in} + E_{HW,bu,in}} \quad [-]$$

The SPF is the ratio of the heat energy produced by the heat pump and the back-up heater and the corresponding energy need of the heat pump, back-up heater and source fans in case of the A/W heat pump, brine pump in case of the B/W heat pump and well pump in case of W/W heat pump.

Nomenclature:

SPF	seasonal performance factor of the heat pump system (including electrical back-up heater)	[-]
SH	space heating	
DHW	domestic hot water	
$Q_{H,hp}$	produced heat energy of the heat pump in space heating operation	[kWh]
$Q_{W,hp}$	produced heat energy of the heat pump in domestic hot water operation	[kWh]
$Q_{HW,bu}$	produced heat energy of the electrical back-up heater for SH and DHW	[kWh]
$E_{fan\ or\ pump,in}$	electrical energy use of the HP source: fan (air-to-water HP), brine pump (ground source HP) or well pump (water-to-water HP) for SH and DHW	[kWh]
$E_{HW,hp,in}$	electrical energy use of the heat pump for SH and DHW	[kWh]
$E_{HW,bu,in}$	electrical energy use of the electrical back-up heater for SH and DHW	[kWh]

7.2 Analysis of the measured data

The analyzed systems in this section were investigated in the frame of the "Heat Pump Efficiency Project".

7.2.1 SPF of the ground source heat pumps

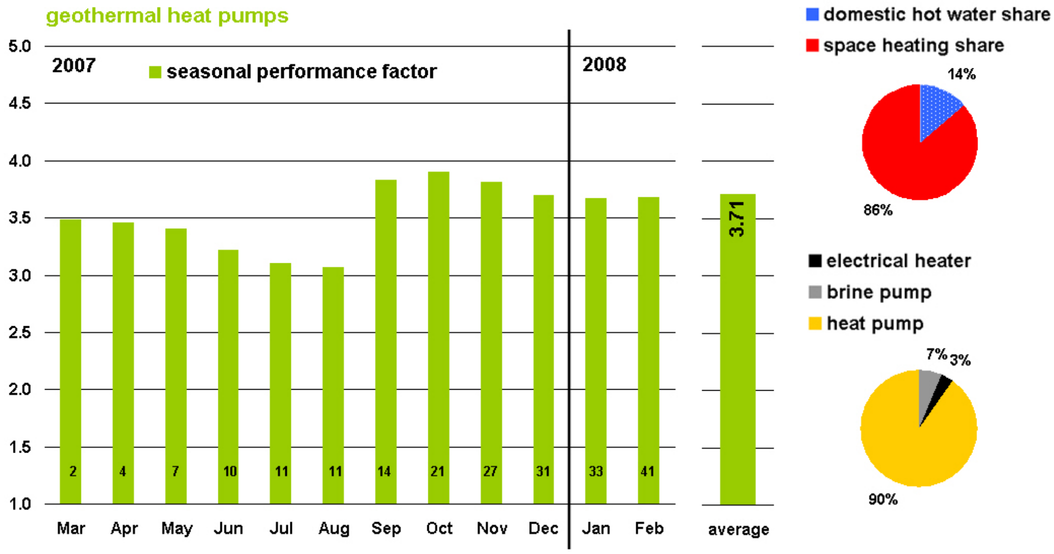

Figure 7: Seasonal Performance Factor of the ground source heat pump.

Figure 7 shows the SPF for individual months including February 2008 and an average value for the total time. The share of the produced heat energy of the heat pump in space heating operation and domestic hot water operation is shown in the top right corner. The share of the electrical energy use of the heat pump, electrical back-up heater and brine pump is shown at the bottom right corner. The numbers in the bars indicate the number of analysed heat pumps for each month. This number grows with time, since heat pump systems are equipped step-by-step with a measurement system. For example the average value from February includes 41 heat pumps systems. In the coming months the number of the analysed heat pumps systems will increase to 56.

The assessment of the measurement data for ground-source heat pumps providing both heating and domestic hot water supply, obtained between March 2007 and February 2008, reveals a seasonal performance factor (SPF) of 3.7. The SPF of the individual system was in the range of 3.0 to 4.6.

The share of the produced heat energy in domestic hot water operation with supply temperatures about 55°C was 14% and 86% for the space heating operation, with supply temperatures in the range 35-45°C.

The share of the electrical energy use of the heat pump was 90%, of the brine pump was 7% and 3% of the back-up electrical heater. The back-up electrical heater was significantly active only in 6 of the analyzed systems. In the majority of case, the back-up heater wasn't active at all.

7.2.2 SPF of the air-to-water heat pumps

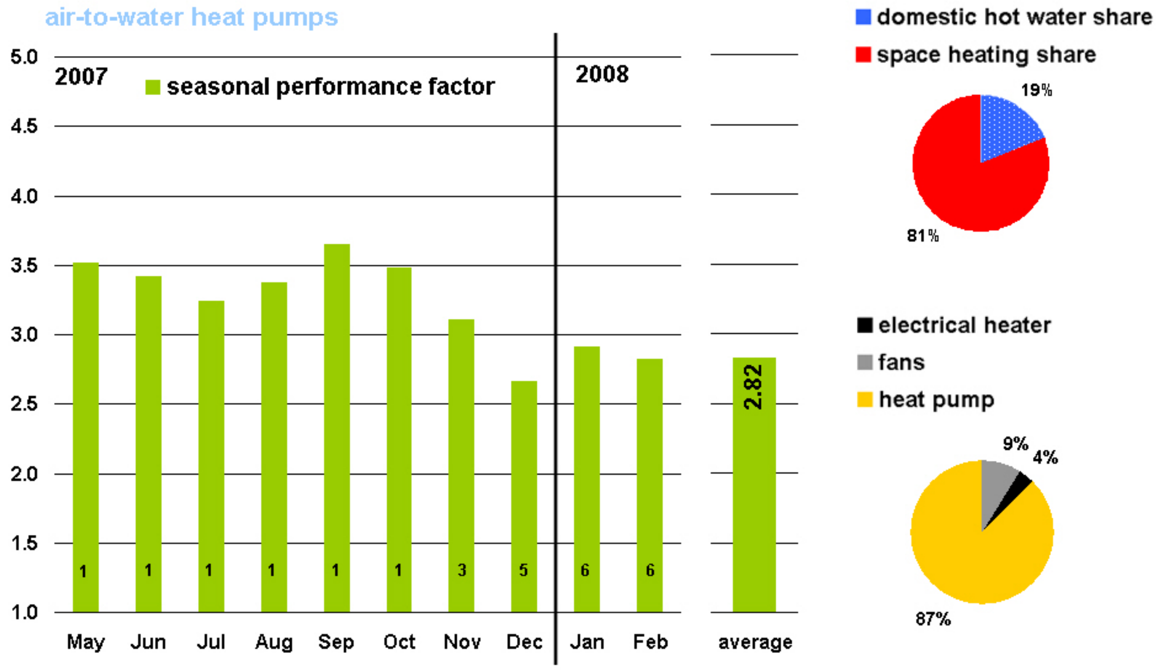

Figure 8: Seasonal Performance Factor of the air-to-water heat pumps

Figure 8 shows the SPF for individual months including February 2008 and an average value for the air-to-water heat pumps. The share of the produced heat energy of the heat pump in space heating and domestic hot water operation is shown in the top right corner. The share of the electrical energy use of the heat pump, electrical back-up heater and fans is shown at the bottom right corner. The numbers in the bars indicate the number of the analysed heat pumps for each month. The data between May and October 2007 represent only one system. During the last four months the number of analysed systems increased, and since January 2008 totals six. In the coming months the number of the analysed heat pumps systems will increase to 15.

The assessment of the measurement data for air-to-water heat pumps took place in the coldest part of the years, with low average outside air temperatures. In this quite unfavorable period for data assessment, the preliminary average seasonal performance factor reaches a value of approx. 2.8.

The share of the produced heat energy in domestic hot water operation was 19% and 81% for the space heating operation. The share of the electrical energy use of the heat pump was 87%, of the fans was 9% and 4% of the back-up electrical heater. The back-up electrical heater was not active in two of the six systems.

7.2.3 SPF of the water-to-water heat pumps

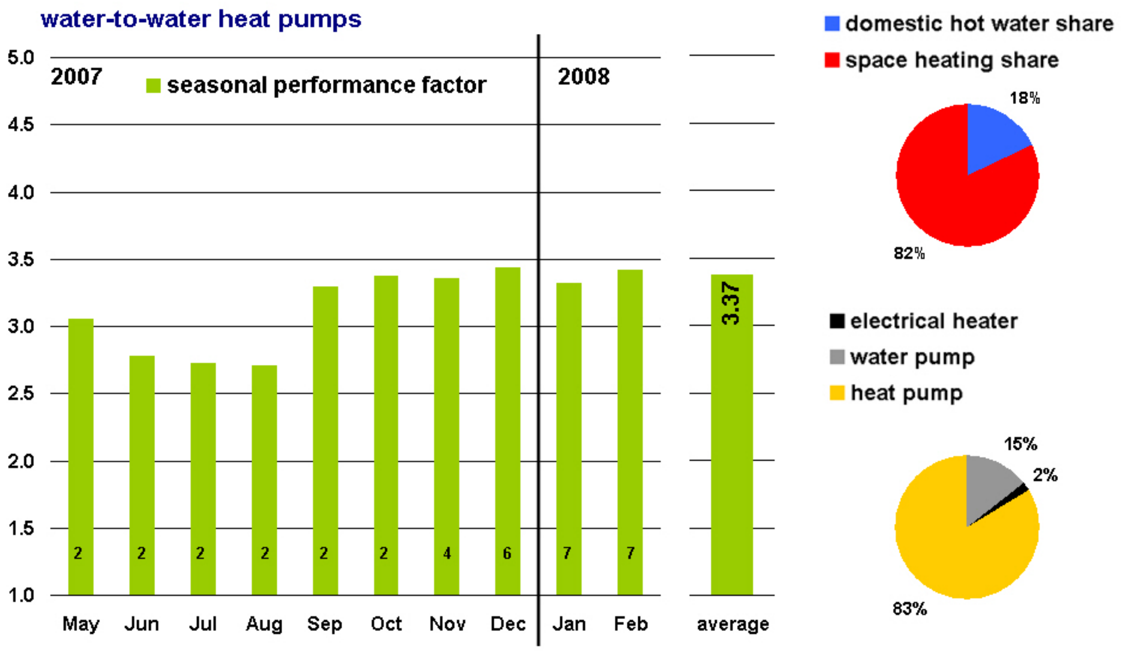

Figure 9: Seasonal Performance Factor of the water-to-water heat pumps

Figure 9 shows the SPF for individual months including February 2008 and an average value for the water-to-water heat pumps. The share of the produced heat energy of the heat pump in space heating operation and domestic hot water operation is shown in the top right corner. The share of the electrical energy use of the heat pump, electrical back-up heater and well pump is shown at the bottom right corner. The numbers in the bars indicate the number of the analysed heat pumps for each month. The data between May and October 2007 represent two systems. In the last two months the number of analysed systems totals seven.

The average seasonal performance factor was 3.4. This efficiency value is lower than expected for water-to-water heat pumps. Low heat load of the analyzed systems and high electrical consumption of well pumps (see electrical consumption share chart in Figure 9) may be an explanation for the mentioned SPF. Additional factor influencing the efficiency of the water-to-water heat pump systems might be a low quality of the ground water resulting in the fouling of the water filter.

The share of the produced heat energy in domestic hot water operation was 18% and 82% for the space heating operation. The share of the electrical energy use of the heat pump was 83%, of the well pumps was 15% and 2% of the back-up electrical heater. The back-up electrical heater was significantly active only in one of seven systems.

8 REFERENCES

Miara M., Russ Ch., Becker R. 2007 “Wärmepumpen im Feldtest“ *KI Kälte Luft Klimatechnik*, 9/2007 p. 24-27