Heat Pump Efficiency

Analysis and Evaluation of Heat Pump Efficiency in Real-life Conditions

Abbreviated Version

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Contents

1 Summary and Content of the Report

The present English version of the final report of the “Heat Pump Efficiency”-Project (“HP-Efficiency”) is mainly a reduced und translated version of the full version. It includes the main outcomes such as the determined efficiencies of the evaluated ground and air source heat pumps considering different time periods and system boundaries. The full version also includes detailed evaluations of efficiency influencing aspects. Furthermore the full version contains chapters dealing with refrigerant loss and the introduction of the written theses within the framework of “HP-Efficiency”-project. Nevertheless the summary and chapters 6 and 7 of the present report are the original ones of the full version.

The project “HP Efficiency“ was conducted from October 2005 to September 2010. The main object was the independent determination of the efficiency of heat pump systems. About 110 heat pumps were evaluated. Within the anonymous evaluation 56 ground source, 18 outside air and 3 water source heat pumps were taken into account. The majority of the installed heat distribution systems were underfloor heating systems. The heated area of the evaluated buildings reached an average value of 199 m². In the year 2009, the average energy usage for space heating of these buildings amounted to 72 kWh/m².

As main outcome of the project it was detected that carefully planned and correctly installed heat pump systems reach efficiency which enable ecological and economic advantages compared to fossil heating systems. However, the variety of aspects concerning planning, installation and operation led to a large range of results.

The entire evaluation period lasted from July 2007 to June 2010. Within this period ground source heat pumps reached an average seasonal performance factor (SPF) of 3.9, air source heat pumps a SPF of 2.9. Within the second phase of the project an average SPF of 4.1 was reached by ground source heat pumps and 3.0 by air source heat pumps. The SPF of three evaluated water source heat pumps was determined at 3.7.

Within the framework of the field test a variety of efficiency-influencing aspects were proven, whereas the most of the aspects are connected to the temperature differences between heat source and heat sink. Air source heat pumps have the most obvious disadvantages compared to ground source and water source heat pumps. These disadvantages result from the large spectrum of operating points which furthermore influence the efficiency negatively on a wide scale due to great differences in temperatures. An investigation of efficiency in terms of space heating and domestic hot water (DHW) showed significant differences between these operating modes in case underfloor heating with low temperature was used as distribution system. Heat pump systems with combined buffer storage (space heating and DHW) reached lower SPF values compared to other storage concepts. The decrease of the energetic quality of the building influences the SPF positively up to a space energy usage of about 70 kWh/m², whereas higher values influence the SPFs negatively. Over a period of one year ground source heat pumps work more efficiently by using bore holes instead of collectors. Heat pumps with ground collectors reach the highest efficiency during autumn. The share of the energy usage of brine pumps and fans are very different, thus also the influence on the efficiency.

In the overall evaluation electrical back-up heaters reach averagely low energy shares and therefore have low influence on the efficiency. Due to back-up heater activity the SPF of ground source heat pumps dropped by 0.05 and the SPF of air source heat pumps by 0.06. In contrast individual heat pumps with massive energy usage reach very low SPF values. In general back-up heater activity occurs more often with air source heat pumps than ground source heat pumps. However, the energy share of the back-up heater of ground source heat pumps is relatively high and its activity occurs more often without any relation to weather conditions compared to air source heat pumps.

The heat source temperature and its constancy during a year depend very strongly on the type of heat source. Outside air shows the widest bandwidth with 36 K and an average temperature of 2.8 °C. The collectors of ground source heat pumps provide the evaporator with brine of averagely 3.7 °C and the temperature range amounts to 17 K. Heat pump systems with bore holes reach an average value of 7.1 °C, whereas the bandwidth is about 9 K. The inlet temperatures of water as heat source reaches average values of 10.8 °C with a range of 4 K.

Investigations of aspects regarding the control of heat pumps led among other things to negatively influences through permanent operating charge pumps, incorrect charging of combined buffer storage und unnecessary space heating operation during summer time. Furthermore, negative influences because of additional heat generators such as solar thermal systems or electrical back-up heaters were detected.

Heat pumps with solar thermal systems are widely balanced by a system seasonal performance factor (SSPF). Hereby, it became clear that an increasing cover ratio of the solar thermal system influences the SSPF positively.

The SPF of a heat pump only shows the efficiency of the energy supply. To evaluate the supply system, the knowledge of framework conditions of heat pump operation and the effectiveness of the whole system has to be taken into account additionally. Hereupon, the energetic quality of the building has to be considered.

Contrary to the defined objective of the project, the refrigerant losses could not be determined. Instead different methods for the experimental determination were researched intensively in this project.

2 Project Objectives and Framework Conditions

With the main objectives being the independent determination of heat pump efficiency and the analysis, comprehension and optimization of system behaviour of electric driven compression heat pump, the project "HP Efficiency" took place from 1-10-2005 to 30-9-2010. The project was conducted by the Fraunhofer Institute for Solar Energy Systems ISE (Fraunhofer ISE). It was supported in terms of finance and content by seven heat pump manufacturers (Alpha-Innotec, Bosch Thermotechnik, Hautec, Nibe, Stiebel Eltron, Vaillant und Viessmann) as well as the energy supply companies EnBW Energie Baden-Württemberg AG and E.ON Energie AG. A funding of 50 % was contributed by the Federal Ministry of Economics and Technology (reference 0327401A). Further objectives were defined in advance of the project and could be extended during the project.

The project was realized in two phases. During the first phase about 75 heat pumps of the mentioned seven manufacturers had been evaluated since January 2007. Within the second phase, five further heat pumps of each manufacturer had been evaluated since October 2008. Overall about 110 heat pumps had been evaluated.

The study's focus was on measuring heat pumps in mainly new energy efficient residential buildings. Finally, objects were chosen with an annual heat demand in 2009 between 32 and 169 kWh/m² with an average of 72 kWh/m². Originally a building standard was supposed to be investigated whose heating demand is one between passive houses[1] and KfW-60-houses[2].

Another ambitious goal of „HP Efficiency" was the metrological quantification of refrigerant loss as a result of leakage in the devices. So far an average loss of 2 % of the filling quantity per year is used to calculate the TEWI-value (total equivalent warming impact). However, the accuracy of this value has not been experimentally verified, so the environmental impacts due to refrigerant loss cannot be assessed reliably. During the project's progress the quantification of refrigerant loss moved more and more in the background while the verification of different possibilities to reach this goal became more important instead.

[1] Annual energy demand for heating is less or equal 15 kWh/m² according PHPP Standard
[2] Annual primary energy demand for heating is less or equal 60 kWh/m² according EnEV 2004

The results and experiences of „HP Efficiency“ contributed to further national as well as European projects such as the cooperation in Annex 32 (Economical heating and cooling systems for low energy houses) of the Heat Pump Program of the International Energy Agency (IEA). Fraunhofer ISE could contribute relevant partial results and exchange experience with other project members. On a national level, partial results could contribute to the work of the committees for technical standards and guidelines, e.g. to the VDI 4650[3] and the new VDI 4645[4].

Prior to this project, Fraunhofer ISE already had long-term experience with the realization of plant-oriented monitoring in residential buildings. One example is the 4-year long monitoring project in more than 50 passive-houses equipped with heat pumps. The buildings were partly equipped with intensive, permanent data logging remote readout systems. With the help of the data much knowledge for the further development could be won, for the exhaust air heat pump in particular.

[3] Existing guideline for the calculation of the SCOP based on design values and COP of the heat pump
[4] Planning and dimensioning heat pump systems (guideline in preparation)

3 Realization of the Project

3.1 The Monitoring Process

This chapter describes the different steps of the project from the beginning to the evaluation of the measured data. The text corresponds to the flow chart in Figure 1. On 3 different levels the tools (red), the tasks (blue) and the people involved (green) are illustrated. Details regarding balancing of the seasonal performance factor (SPF) (chapter 5.1) and the used measuring technique (chapter 3.3) are described further below.

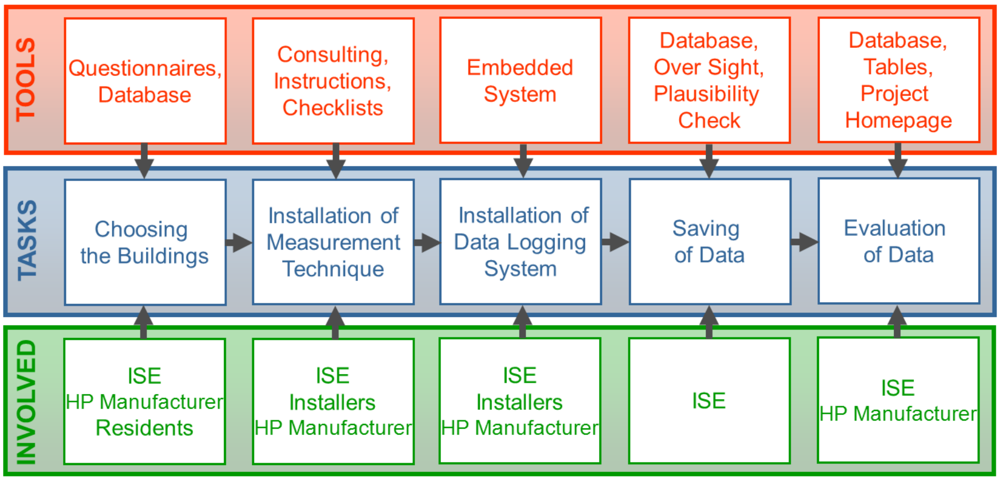


Figure 1: the monitoring process

Task 1 – Choosing the Buildings

The project started with the selection of buildings. Fraunhofer ISE, the manufacturers and the residents took part in the selection process. In a first attempt the manufacturers made suggestions to the Fraunhofer ISE and so appropriate objects were chosen. During a long start-up time Fraunhofer ISE and the manufacturers began to search for a sufficient amount of buildings together.

Task 2 – Installation of the Measurement Technique

In a second step the objects were equipped with the measurement technique. For this purpose manufacturers made the plant scheme and technical documentation available to the Fraunhofer ISE. Based on this data, the positions and the required measurement technique were planned. After consulting the manufacturers and getting their permission, Fraunhofer ISE got in touch with the local installer. The installer and an electrician were responsible for the installation of the tools and prepared them for the connection with the measurement system.

Task 3 – Installation of Data Logging System

The installation of the measurement data logging system and its connection with the M-bus line (thermal values) as well as the impulse line (electrical values) was carried out by the Fraunhofer ISE. In order to react quickly in case of missing or wrong electrical installations, the responsible electrician was present during this phase. During the second project phase, especially, a check of the measurement components in form of a so-called relay-test was carried out. This ensured absolute clarity concerning the correct assignment between the meter and the energy consumer. In order to realize the relay-test the manufacturer's technician was present. Furthermore every acceptance test was journalized.

Tasks 4 and 5 – Saving and Evaluation of Data

The measurement data logging system of every single evaluated object daily sent a raw-data-set via GSM to the server of Fraunhofer ISE. Then the data was filtered and checked for plausibility. In different Excel files the SPF values were calculated and afterwards brought together and compared. This procedure enabled high security when it comes to the determination of correct SPF values.

The project partner could retrieve detailed monthly evaluations of SPF as well as all other measured values from the project homepage. In addition, they were able to visualize desired values for a chosen period of time. The residents could also benefit from the project as general evaluations of SPF values and SPF influencing values were made available.

3.2 First and Second Project Phase

During the first project phase about 75 heat pumps had been measured, some of them since the heating period 2006/07. This phase led to learning effects for the manufacturers as well as the Fraunhofer ISE. The gathered experiences were realized within a second project phase with 35 further measured heat pump systems.

Fraunhofer ISE was responsible for the correct measurement of the heat pumps and the independent evaluation of the acquired data. In the field of measurement technology, above all, one could benefit from the experiences made in the first phase. As a consequence, the organization as well as the measurement technique itself could be improved. When it comes to the organization, manuals for the installation and connection of the measurement technique were improved. Furthermore the documentation in form of minutes was expanded. The most significant quality step was achieved due to the local acceptance test of the measurement technology. Together with the electrician and the manufacturer's technician a so-called relay-test was carried out on every measured heat pump in order to check the correct assignment between energy consumer and the corresponding meter. In the field of measurement technique basically two changes were made. Firstly, the counter board for counting the impulse values was replaced by a WAGO-system. This robust industrial solution enables an improved handling with measurement data. Secondly, the electricity meters of Saia-Burges were replaced by meters of EMU Elektroniks.

The manufacturers could also benefit from the experiences of the first project phase. During the first phase many efficiency decreasing problems were detected and thus could be eliminated in the second project phase. These problems were primarily connected with design and installation. Moreover, a few manufacturers had the opportunity to use a heat pump of their current series.

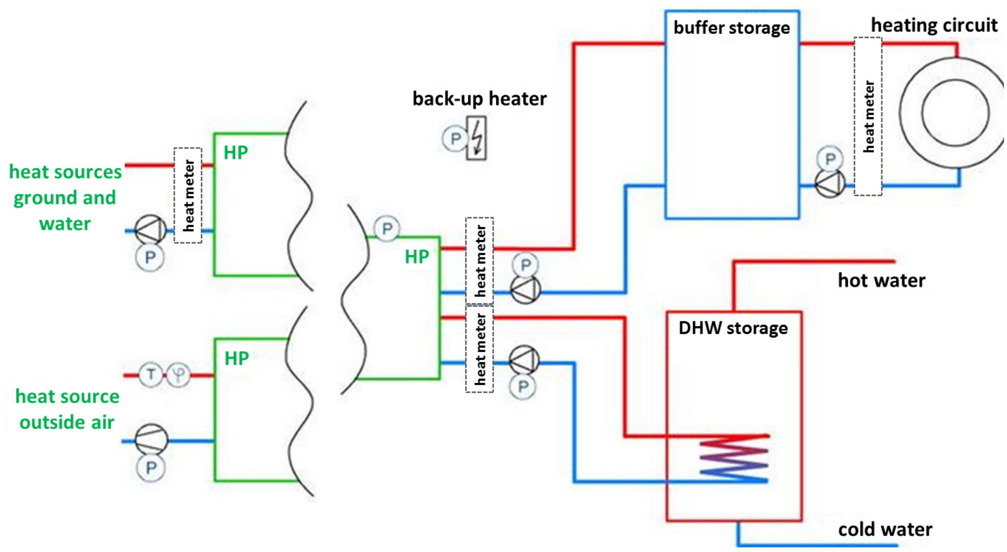
During the second phase, the focus was placed on the evaluation of air source heat pumps. As a consequence, the share of these heat pumps increased from a quarter in the first project phase to about a half during the second project phase.

3.3 Measurement Technology

The present chapter deals with the measured components as well as the measuring technique used. The error limits of the measurement technique are dealt with in the long version of the report (in German language).

The Figure 2 shows in a simple schematic diagram the measured components whereas even those measurement points are shown which are not necessary for the determination of efficiency. The letter P marks the electrical consumer. These include the heat pump (compressor and control unit), the brine pump, the ventilator as well as the charge pump and the electrical back-up heater. When it came to more individual systems, circulation pumps and solar thermal circuit pumps as well as exhaust air fans were partly measured. Thermal and hydraulical values were measured with heat meters. Representative for the heat sink, the scheme in Figure 2 shows the circuits for charging the buffer storage and for charging the DWH storage. Additionally, the charging of the heating circuit is optionally measured and shown in the scheme. The heat source is represented by the brine circuit and measured as well. Further measured components of thermal and hydraulical values are the tapping of DHW, the solar thermal circuit or separated ground source brine circuits where one circuit is warmed up by the exhaust air. As far as air source heat pumps are concerned, it was originally intended to measure the indrawn air temperature and the humidity. However, problems with the measurement technique led to the uninstalling in the first heat pumps and were not considered in later pumps anymore.

Figure 2: schematic diagram of a heat pump system with obligatory and optional measuring points



3.3.1 Electricity Meter

The electrical values were measured by electricity meters which were equipped with a mechanical counter as well as an impulse interface. Depending on the consuming components, either AC or DC meters were used. The rated output of the components determined the necessary resolution of the impulses per kilowatt hour. This adaption ensured the determination of values for each minute in order to illustrate the system behaviour. Ultimately electricity meters with resolutions of 100, 1000 and 10000 impulses per kilowatt hour were used.

At the beginning of the project, electricity meters of Saia-Burges were used. For the second project phase the measurement technique was revised which led to the replacement of the electricity meters by those of EMU Elektroniks.

3.3.2 Heat Meter

Heat meters consist of a flow sensor, a temperature sensor pair and an arithmetic unit. The arithmetic unit determines the thermal energy and thermal power and hereby considers the volume flow and the difference between inlet and return temperature as well as stored temperature-dependent property values. For measuring the temperature according to DIN EN 1434-1, pairwise calibrated Pt100 temperature sensors were used. The arithmetic unit had to be equipped with an M-bus interface.

Both the heating circuit and the DHW circuit were equipped with ultrasonic heat meters of the type F 96. These heat meters are the only ones used with an integrated arithmetic unit. When it came to compact heat pump systems with integrated DHW storage, the measuring was more complicated. These types often lack the necessary space between condenser and DHW storage. The solution was to measure the tapping of DHW and afterwards also take into consideration a certain loss for keeping the system boundaries. To measure the tapped drinking water, certified oscillating piston meters and the arithmetic unit F 22 were used.

For measuring the heat source for ground source heat pumps, industrial meters of the type MTH-I and an arithmetic unit MF 4 were used. In the case of ground source heat pumps with the F 96, the same ultrasonic heat meters as used with the heat sinks were applied. Solar thermal energy was measured with impeller flow meters of the type ETDA-KGmHM and the arithmetic unit F 4.

4 Characterization of the Monitoring Objects

A note in advance: for reasons of simplification, the heat pumps are named after their heat source. A distinction by type of the heat transfer medium used in the heat sink is not reasonable as the heat circuits of all measured objects used water anyway.

4.1 Project Scope and Database for Evaluation

The Fraunhofer ISE examined about 110 heat pumps systems. Among the manufactures there was a well-balanced relation with at least 14 and a maximum of 18 heat pumps. During the project the different anonymous evaluations similar to the evaluations shown in chapter 5 comprised 88 heat pumps. The following reasons led to the decrease of the evaluated scope of heat pumps:

- every manufacturer could choose two heat pumps which were not to be considered in the anonymous evaluation. These were often devices used for testing purposes. However, the opportunity of deletion was not used by every manufacturer.
- incorrect installation of measurement technique with heat pumps of the first project phase
- plants with non-comparable heat sources
- solar thermal system and integrated DHW storage did not allow correct balancing
- heat pumps only working in heating mode (no DHW)
- a lack of cooperation of the residents

The remaining 88 heat pump systems were constantly evaluated and the results presented. In these evaluations no distinction between heat pumps with or without solar thermal systems was made. Only in cases of extremely deviating values which occurred due to solar thermal energy, the values were not considered in the average monthly SPFs. Significant influences on the annual SPFs could not be detected. However, not taking the objects with highly deviating results into consideration was not a satisfactory solution because the influence these objects on the individual results were not quantifiable. As a consequence, solar supported heat pump systems in the anonymous evaluation in chapter 5 of the present report are not considered anymore. Due to this deleting process, the database was decreased by further 11 objects; however, at the same time the evaluation is more reliable. Moreover there was the opportunity to evaluate six combined systems (heat pump and solar) in form of a System-SPF (SSPF). The remaining five combined systems could not be evaluated because of missing measuring points.

4.2 Database for the Anonymous Evaluation

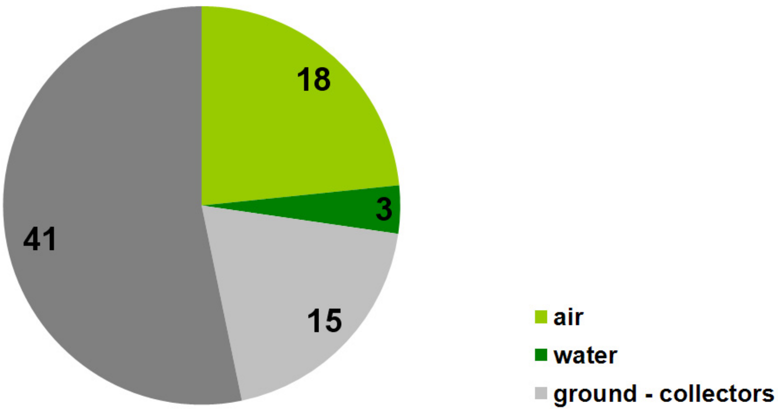
The following anonymous evaluation of the measured data could not be made for all 110 measured objects of the project (cf. chapter 4.1). In this chapter the properties of the 77 evaluated objects without solar thermal support are described.

The information is based on master data provided by manufacturers, residents and installers.

4.2.1 Heat Sinks and Heat Sources

The classification of the evaluated heat pumps according to the heat sources used is shown in Figure 3.

Figure 3: distribution of the heat sources



It was intended to have a well-balanced distribution of the heat sources among the evaluated objects. However, the share of ground source heat pumps predominates clearly. They comprise almost 75 % of the objects examined, whereas only 15 heat pumps are equipped with horizontal collectors and 41 heat pumps with boreholes. About a quarter of them are air source heat pumps. As only 3 water source heat pumps could be measured, this type cannot be evaluated profoundly. Not least because of the unequal distribution of heat pumps, the priority in the second project phase was to increase the share of air source heat pumps.

With regards to the heat sink, it could be detected that primary underfloor heating was installed, which is the favourite heating system in terms of efficiency (cf. Figure 4). More than 90 % of the heat pumps were equipped with floor heating. Only one heat pump used radiator heating and four heat pumps used combined systems. The heat pump with radiators did not influence the result negatively as their average heating temperature of 36 °C was relatively low.

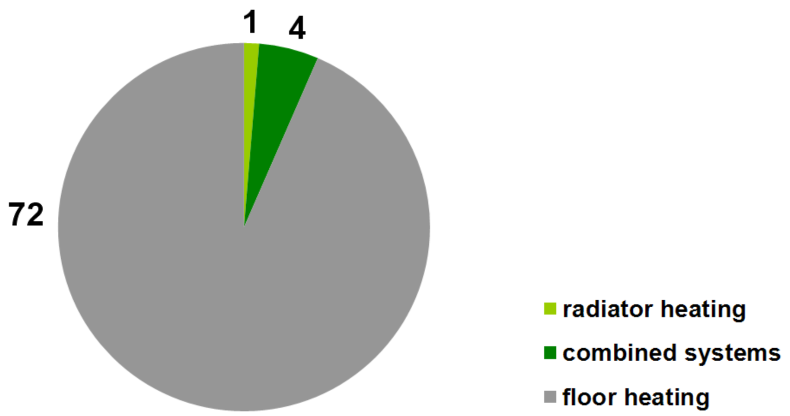
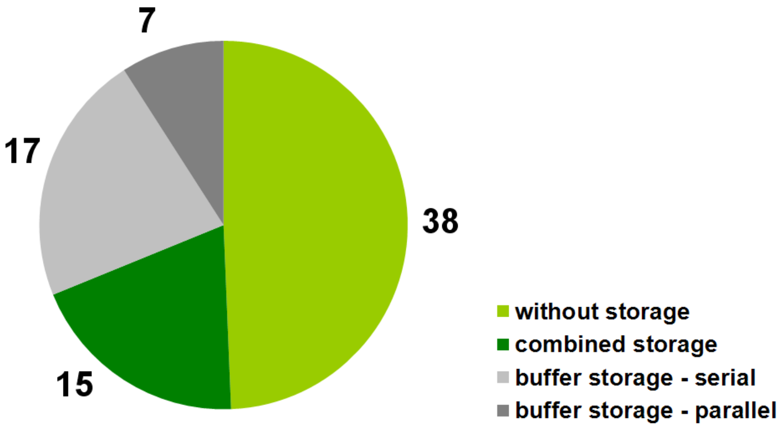


Figure 4: distribution of the heat transfer systems linked to the heat sink

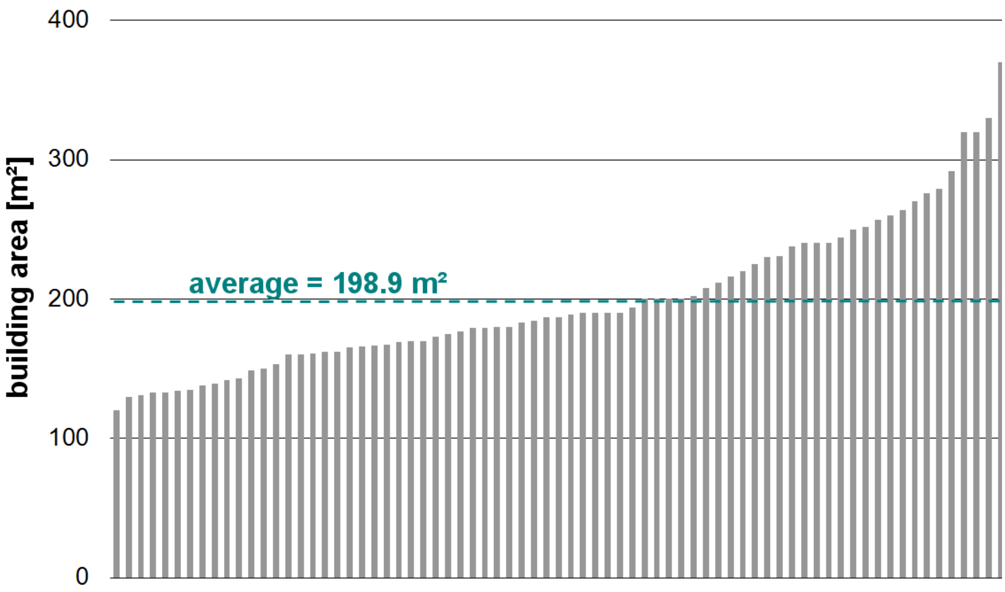
Another possibility for the characterization of the heating circuit can be made by distinguishing between different storage concepts. An overview is presented by the diagram in Figure 5. About half of the heat pumps (38) charge the heating circuit in a direct way without any additional buffer storage. A combined storage (heating and DHW) was used by 15 systems and almost every third system was equipped with buffer storage in the heating circuit. Heat pump systems with the last-mentioned storage concept could be further divided into parallel and serial installed buffer storage. During the field test, 17 systems with parallel and 7 systems with serial buffer storage could be observed.

Figure 5: distribution of the different storage concepts



As far as the building area is concerned (cf. Figure 6), there are significant differences in size. The values range from 120 m² for the smallest up to 370 m² for the largest building. On average, the building area amounts close to 200 m².

Figure 6: building areas of 73 objects



4.2.2 Coefficients of Performance (COPs)

Each heat pump has its individual efficiency which is measured at different predefined points of operation and referred to as "Coefficient of Performance" (COP). These COPs of the evaluated heat pumps within the field test are illustrated in Figure 7.

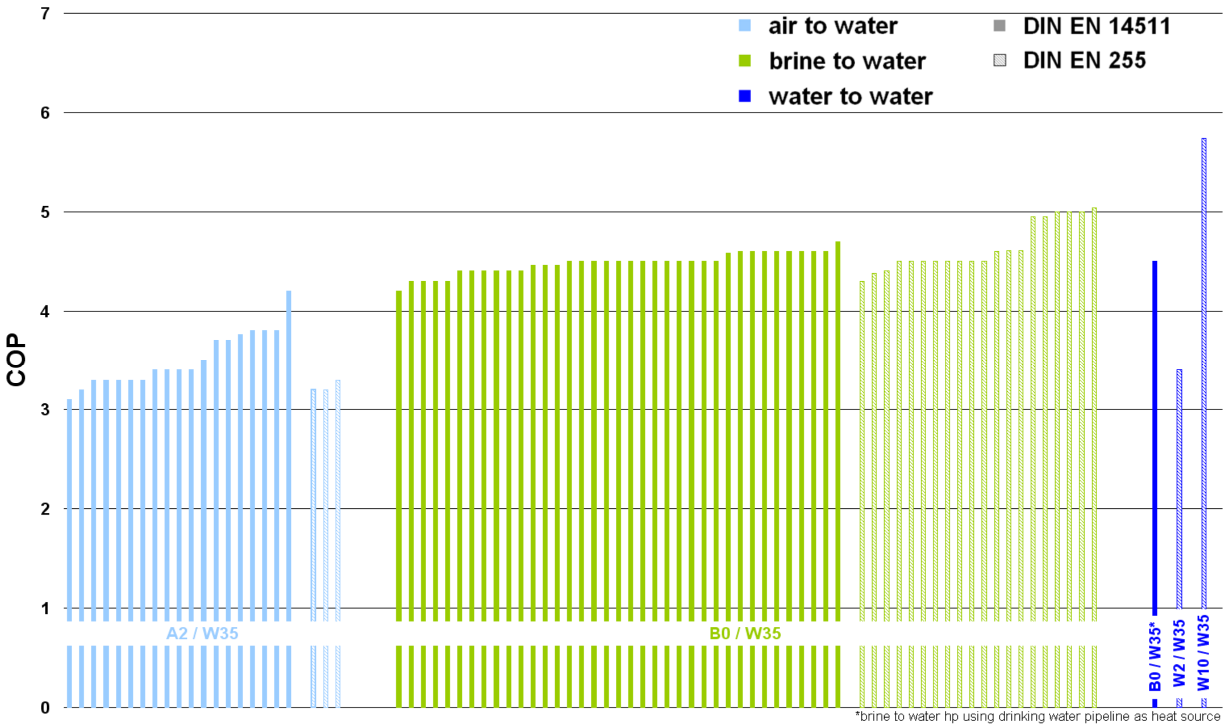


Figure 7: Coefficients of performance (COPs) of the evaluated heat pumps displaying the heat sources and the underlying certification standard

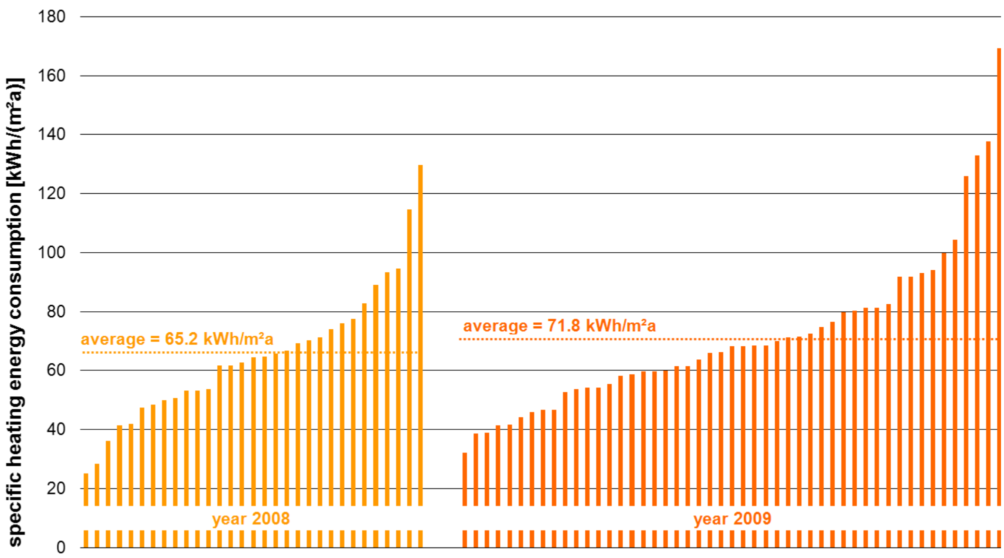
The COPs of the air source (light blue) and water source heat pumps (dark blue) were known, the values of ground source heat pumps (green), however, were only available for 51 of 56 devices. The operation points of the COPs are presented in the figure's first column. The number preceding the slash stands for the temperature of the heat source, whereas the number following the slash represents the temperature of the heat sink. In case of availability, the COPs are based on the current certification standard DIN EN 14511. If not available, the COPs according to the former DIN EN 255 were adopted. The main difference between these standards lies in differing temperature differences of heating inlet and return flow. According to DIN EN 255, this value amounted to 10 K, while the current DIN EN 14511 determines a value of 5 K. The increasing temperature difference and the remaining constant inlet temperature at the same time led to lower COP values because of the resulting higher average temperature in the heating circuit. The COPs of air source heat pumps based on DIN EN

14511 lie between 3.2 and 4.2 (average 3.48) and between 3.2 and 3.3 based on the former certification standard DIN EN 255. Ground source heat pumps naturally reach higher values; based on DIN EN 255 between 4.30 and 5.04 (average 4.66) as well as between 4.20 and 4.70 (average 4.49) based on DIN EN 14511. Among water source heat pumps the COPs are not comparable as different operation points and even the media differ. The very right column illustrates the theoretically high potential of water source heat pumps with a COP value of 5.76.

4.2.3 Space Heating Energy Consumption

In order to classify the evaluated objects concerning the space heating energy demand, their consumption of heating energy was used as reference point. Due to a constant expansion of the database and measured data of only half of the year 2010, it is expedient to use the values for 2008 and 2009. In Figure 8, the values for 2008 are presented on the left side of the graph and those for 2009 on the right side. In 2008, the average value amounts to 65 kWh/m², whereas the individual values ranged between 25 to 130 kWh/(m²a). In 2009, values between 32 and 169 kWh/m² with an average of 72 kWh/m² could be measured.

Figure 8: measured heating energy consumption of evaluable objects in the years 2008 and 2009

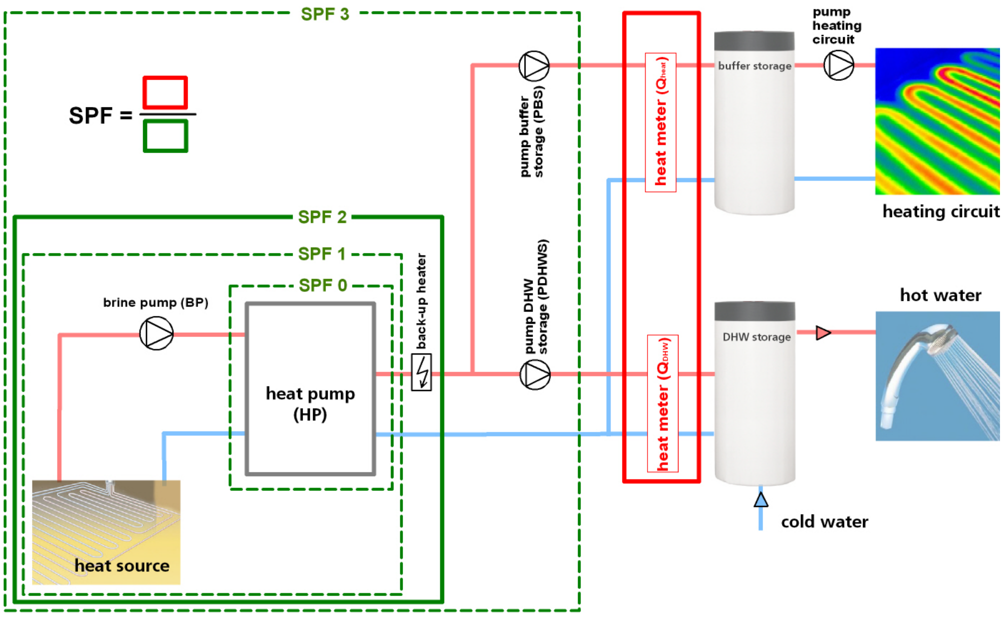


5 Anonymous Evaluation of Measured Data

5.1 System Boundaries and SPF Calculation

The efficiency of heat pumps in real operation is defined by the Seasonal Performance Factor (SPF) which is represented by the quotient of produced thermal energy and the consumed electrical energy. In principle, different system boundaries for the input as well as the output energy are possible depending on whether individual subsystems are to be evaluated or the comparability with other technologies shall be enabled. Within the framework of the project both aspects should be taken into account. Figure 9 therefore illustrates four system boundaries for the calculation of SPFs.

Figure 9: schematic diagram of a heat pump system with different system boundaries to calculate the SPF



In order to explain the system boundaries, an illustration of a heat pump's standard hydraulic scheme is used. The red frame marks the produced thermal energy. The heat meters allow the separate measurement of heating and DHW energy. Both values are usually measured directly after the heat pump, i.e. before it is actually stored. Heat pumps with integrated DHW storage, however, constitute an exception as due to missing space the installation of heat meters could not be realized. In this case, the tapping of DHW was measured and the storage loss was calculated and added afterwards in order to keep the same system boundary and to ensure the comparability with the remaining systems.

If the storage capacity was known, the loss values[5] (if necessary interpolated) of [1] were used. If the storage capacity was not available, an assumed annual storage loss of 645 kWh was used[6].

As Figure 9 shows, the system boundaries vary depending on the different electrical consumers. Illustrated below, the system boundaries are explained with the formulas of the SPFs as well as in text form. In this connection, it is important to note that all mentioned SPFs without any specific labelling correspond to the third system boundary, i.e. the SPF 2.

$$SPF0 = \frac{Q_{heat,HP} + Q_{DHW,HP}}{W_{comp+cont}} \tag{1}$$

$$SPF1 = \frac{Q_{heat,HP} + Q_{DHW,HP}}{W_{comp+cont} + W_{BP/Fan/WP}} \tag{2}$$

$$SPF2 = \frac{Q_{heat,HP} + Q_{DHW,HP} + Q_{heat/DHW,back-up}}{W_{comp+cont} + W_{BP/Fan/WP} + W_{back-up}} \tag{3}$$

$$SPF3 = \frac{Q_{heat,HP} + Q_{DHW,HP} + Q_{heat/DHW,back-up}}{W_{comp+cont} + W_{BP/Fan/WP} + W_{back-up} + W_{PDHWS+PBS}} \tag{4}$$

SPF	Seasonal Performance Factor
$Q_{heat,HP}$	heating energy produced by heat pump
$Q_{DHW,HP}$	DHW energy produced by heat pump
$Q_{heat/DHW,back-up}$	energy produced by electric back-up heater
$W_{comp+cont}$	energy consumed by compressor and control unit
$W_{BP/Fan/WP}$	energy consumed by brine pump, fans or well pump
$W_{back-up}$	energy consumed by electric back-up heater
$W_{PDHWS+PBS}$	energy consumed by charge pumps

[5] Power loss according to the storage capacity: 100l, 0,43W/l; 200l, 0,34W/l; 500l, 0,25W/l
[6] usual value for 300l storage in simulations

SPF 0 considers the compressor and the control unit of the heat pump only. It is primarily used to compare it to the SPF 1 in order to quantify the influence of the energy consumer in the primary circuit (heat source circuit). When it comes to the present report, it is the SPF 2 in particular which is determined and commented. The difference to SPF 1 is due to the additional consideration of the electrical back-up heater. In general, only its consumption of electrical energy has to be added. In case the produced thermal energy is not considered by the heat meter (e.g. electrical back-up heater installed in the storage), this energy has to be added in addition using comparable values measured for the consumption of electrical energy. The demand of electrical energy in the formula's denominator considers the compressor, the control unit, the energy consumer of the heat source circuit (brine pump, ventilator and well pump) as well as the electrical back-up heater. When considering the mentioned components, determining the heat pump efficiency largely conforms to the determination according to the certification standard DIN EN 14511. The certification standard additionally considers the electrical energy of the pump which results from the pressure loss in the condenser. As the pump's consumption is not considered, the measured efficiency values (and resulting values) can be compared to conventional technologies more easily such as gas condensing boilers. There is another deviation in the primary circle from the DIN EN 14511 because the consuming components in the primary circuit only consider the proportionate energy consumption resulting from the pressure loss in the evaporator.

Another efficiency value is SPF 3 which additionally considers the charge pumps. As there are many possibilities when it comes to the amount and positioning of the pumps, the SPF 3 has to be explained in more detail. Generally, there is as distinction between systems which charge the heating circuit in a direct way, i.e. without any buffer storage and systems with buffer storage. The latter is considered to be a typical heat pump construction because conventional heating systems usually do not include buffer storage. This model heat pump system is shown in Figure 9. SPF 3 is calculated by considering the energy consumption of both, the pump for the heating buffer storage circuit and the pump for charging DHW storage. In case of a shared charge pump, the entire energy usage has to be taken into consideration. SPF 3 does not include the pump installed after the buffer storage because this pump is usually needed in a conventional system too. Cases where the heating circuit is charged directly or where serial installed buffer storage is used are not shown in Figure 9. In these cases, one pump for the whole heating circuit has to be used and is not considered in SPF 3. Nevertheless, the SPF 3 includes the energy usage of the DWH storage pump. In case there is only one pump, its energy consumption is decreased by the share of energy used for charging the heating circuit.

For the illustration of the system behaviour more components than actually necessary for the efficiency calculations are measured, however, at the same time the values are determined for each minute. As far as the electrical components are concerned, power and energy consumption are calculated. Besides power and energy, the inlet and return temperatures as well as the volume flow are determined in the hydraulic system. A supplementary component observed is the heat source circuit: in cases of ground and water source heat pumps, the thermal and hydraulical values as well as the electrical values of the brine, respectively the water pump, are measured. At the project's beginning, it was intended to measure the air source heat pumps' temperature and humidity. In the end, though, this could not be accomplished due to inadequate measuring techniques. In order to illustrate the system behaviour adequately, the charge pumps were measured, to some extent even those pumps installed after buffer storage.

5.2 Heat Pump Efficiency According to Various Criteria

An important value for the quantification of the heat pump efficiency is the Seasonal Performance Factor (SPF). In this value all operating conditions occurring in the course of a year are to be considered. For a well-founded evaluation, several years should be examined as the weather conditions vary from year to year. In contrast, small observation periods serve as the basis for the illustration of SPF influenced by individual circumstances. As the operation conditions in the primary circuit significantly depend on the type of the heat source, the following SPF values are divided accordingly and illustrated for different time periods (day, month, year, 3 years). Furthermore, SPF values for different system boundaries (cf. chapter 5.1) are determined.

With regard to the anonymous evaluation, it is important to group comparable systems only. In particular, this applies to heat sources which are integrated additionally. Consequently, all heat pumps combined with solar thermal systems are evaluated separately. The results are presented in the long version of this report.

In the following sections, various values are often interpreted with the help of the outside air temperature. Figure 10 therefore shows the average temperature on a daily basis for the entire observation period from July 2007 to June 2010. These values are based on data representing the average temperature measured by 44 weather stations of the German Meteorology Service (DWD) [2].

Furthermore, it is important to mention that the installed measurement technique allows the presentation of SPF values with a maximum of one decimal place only due to the individual measuring accuracy. For the illustration of tendencies, however, sometimes two decimal places are shown.

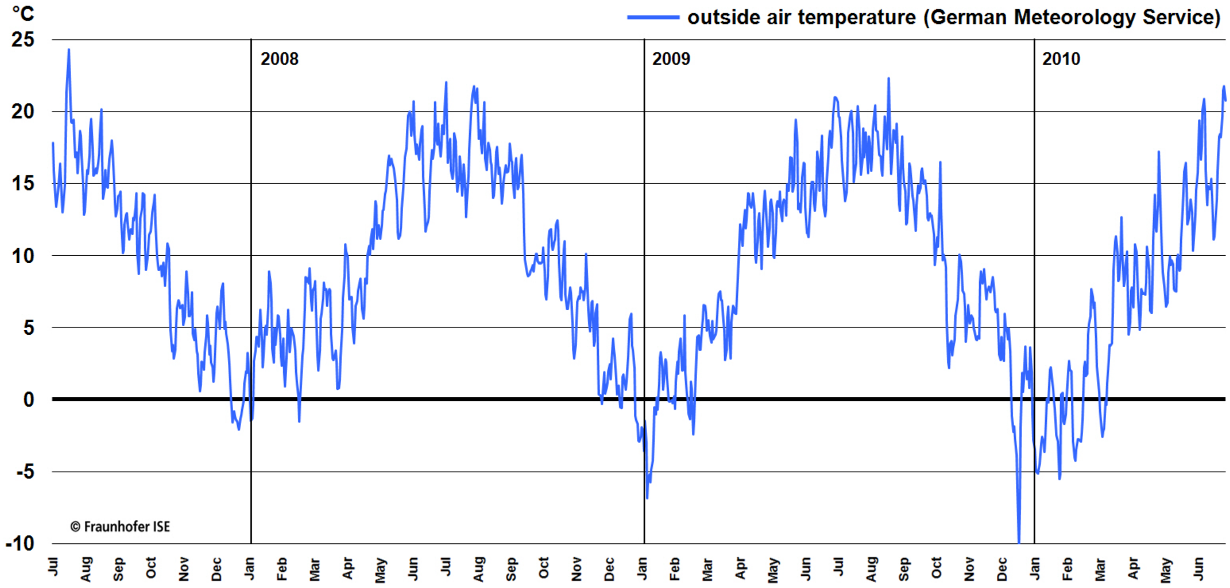


Figure 10: Average daily outside air temperature at the different measuring stations used by the German Meteorology Service (DWD)

5.2.1 Ground Source Heat Pumps

The Figure 11 illustrates the course of the monthly and annual SPFs of ground source heat pumps as well as the efficiency of the entire observation period from July 2007 to June 2010. The monthly values are represented by green bars, the annual values by grey bars. The annual SPFs refer to a period of time ranging from July to June. The numbers written on the bars stand for the amount of analysed heat pumps. The distinction of monthly available thermal energy in heating and DHW energy is represented by red and blue bars (absolute) and pie charts (relative).

During the entire observation period, ground source heat pumps reach an average SPF value of 3.88. With this efficiency thermal energy was produced, whereby avareagely 82 % was used for space heating and 18 % for DHW. The amount of evaluable heat pumps increased from 10 in the beginning to a maximum of 56 heat pumps.

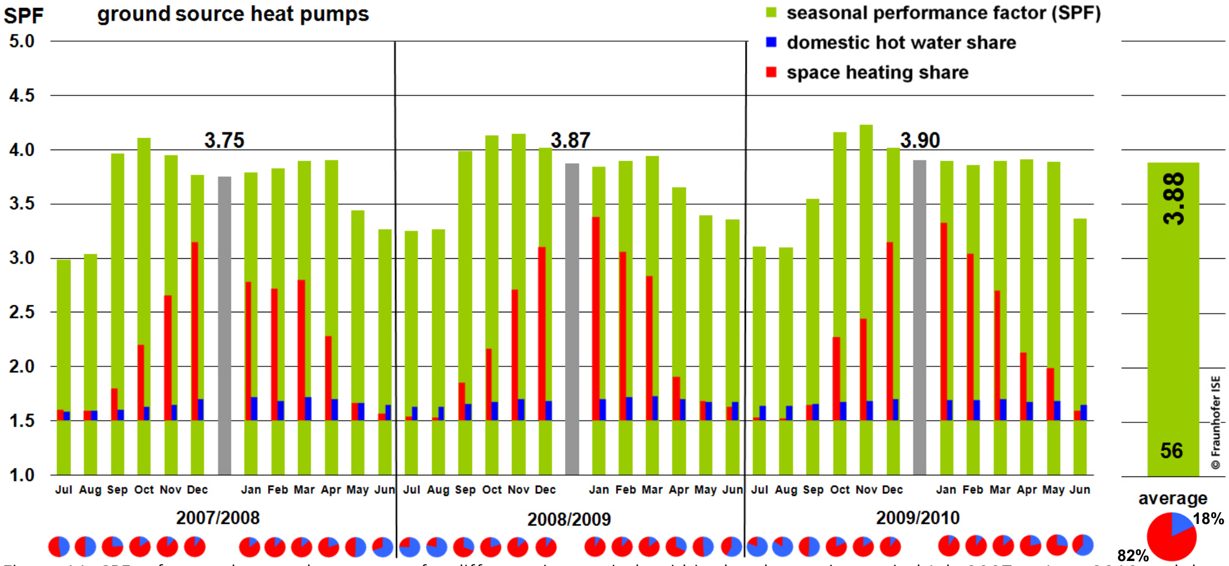


Figure 11: SPFs of ground source heat pumps for different time periods within the observation period July 2007 to June 2010 and the distinction of produced thermal energy as well as the amount of the evaluated heat pumps

The annual SPFs rise by 0.12 from the first to the second year and by 0.03 from second to the third year. The relatively small differences could stem from the increasing amount of evaluated heat pumps and differing efficiencies. This effect is even increased due to the fact that the project was realized in 2 phases. Moreover, it is worth mentioning that the average outside air temperature of the last three years as well as of the heating period has decreased.

The annual SPFs of the monitored three year period are quite similar whereas the various monthly SPFs demonstrate the altering operation points in which the heat pumps are working in the course of the year. There is a clear difference between SPF values of the summer and winter period, i.e. heating period. The average SPF amounts to 3.2[7] during the summer period and 3.9 during the heating period[8] whereas the higher values are reached at the beginning of the heating period. In this time, the heat pump benefits of high brine inlet temperatures and simulteanously low heat sink temperatures for space heating. The overall SPF emphasizes the influence of the SPFs reached within the heating period. This is shown by the red and blue bars which illustrate the division between space heating and domestic hot water (DHW) as well as the weighting of the monthly SPFs. In reverse, there is a low influence of the SPFs during the summer time. As far as ground source heat pumps are concerned, the variation

[7] months June, July and August of the entire evaluation period
[8] months October to April of the entire observation period

of heat source temperature is not as distinct as it is the case with the average heat sink temperature. The predominant use of underfloor heating enables average inlet temperatures of 36°C in the heating period whereas almost exclusively DHW with averagely 52°C was produced during the summer time. Consequently, the average heat sink temperature lies between these two values. The weighting for each month can be seen in the pie chart (heating or DHW mode). There is a significant dependence connected with the SPF value, e.g. in transition periods. The beginning of the heating period started abruptly in the first two years, though the value increased to almost 4.0, the share of energy for the heating amounted to three-fourths. Due to a warm September in 2009, only half of the energy was used for heating which resulted in a small SPF. The yearly transition period between heating, i.e. winter period and summer period differed too. While May could be seen as the month of transition (heating energy 50%) in the first year, it was April in 2009 (heating energy 70%). In 2010, however, hardly any transition period could be observed as the outside air temperature was very low and the share of heating energy until May amounted to almost 75%.

The project’s second phase brought about several modifications (cf. chapter 3.2). These had effects on the heat pump’s efficiency too. Therefore, SPF values in Figure 12 are divided into pumps of the first phase and those of the second phase. The number of evaluable pumps per month in the first phase ranged from 10 to 41, in the second phase from 1 to 15.

The overall SPF values show a significant development. Heat pumps of the second phase could increase by 0.28 and thus reach a high SPF of 4.09.

SPFs of the first and second phase could reach values of 4.08 and 4.07. Interestingly, both values are smaller than the overall SPF. This is due to evaluated heat pumps which have varying operation times and SPF values in different phases. Yearly SPFs of the first phase vary more significantly than those of the second phase. Beginning with an increase of 0.06 from the first to the second year, another increase by 0.03 could be measured from the second to the third year.

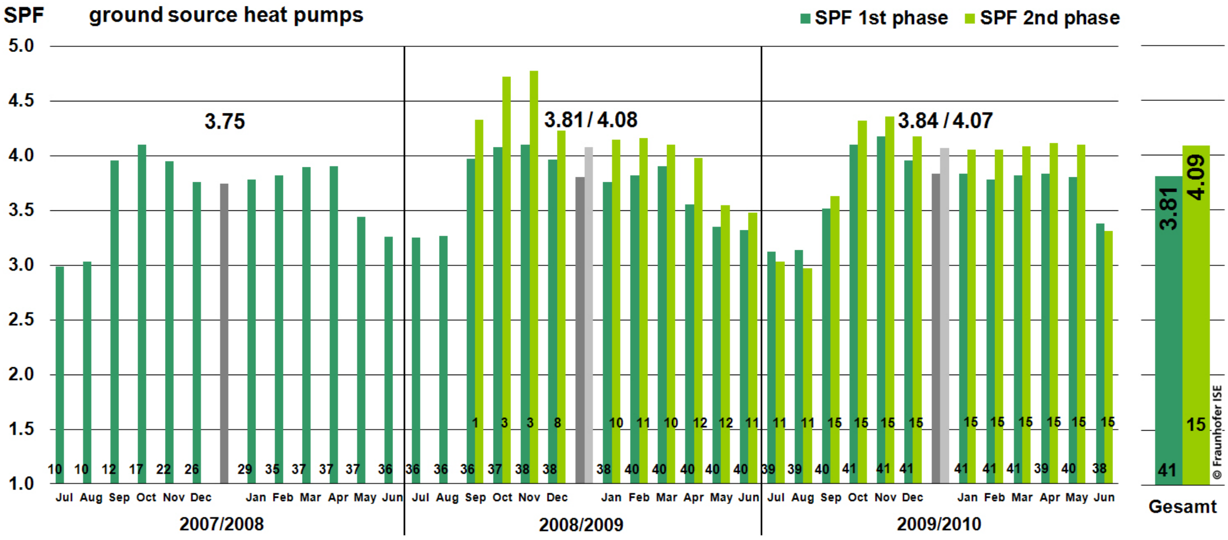
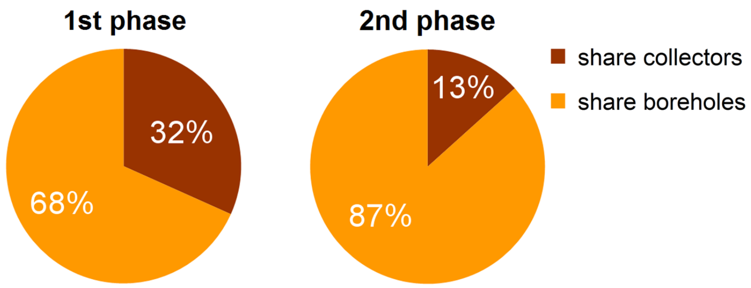


Figure 12: SPF values of ground source heat pumps measured in different time periods throughout July 2007 to June 2010, divided into first and second project phases

As the monthly SPFs show, the average values of pumps measured during the second phase is always higher than those of the first phase with the exception of the months of July and August 2009 as well as June 2010, here the values were lower. The range of the montly differing SPF values strongly suggests that there is a connection with the ground heat exchangers used in the different project phases. This connection is illustrated in Figure 13.

Figure 13: shares of the installed ground heat exchanger in each project phase



During the project's first phase, the number of ground source heat pumps with collectors amounted to 32%, in the second phase to 13% only. In this context it is worth mentioning that the slight differences of SPF values for the months of May to November result from the more efficiently working ground source collectors in this period. Extreme deviations of SPFs in the first months of the second phase are due to the small number of pumps and very high SPFs of one of them.

So far, the values mentioned represented SPF 2 with regard to the system boundaries. In chapter 5.1 three further boundaries were presented. Taking into consideration these system boundaries, Figure 14 illustrates the yearly as well as the overall SPFs for the entire period of time.

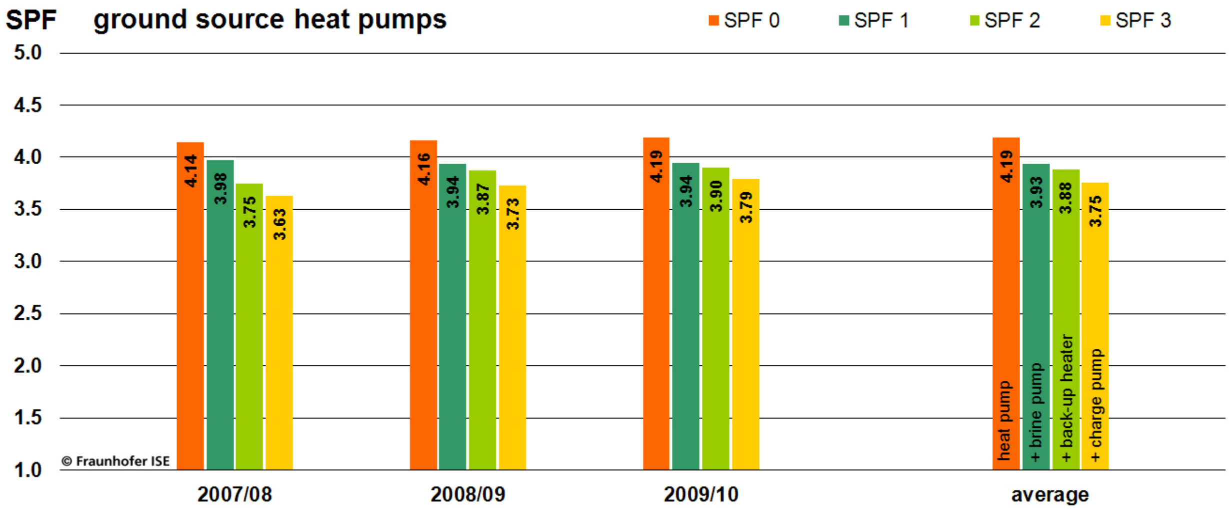


Figure 14: SPFs of ground source heat pumps from different time periods between July 2007 to June 2010 taking into consideration four system boundaries (for further explanation see chapter 5.1)

When enlarging the electrical consumers' system boundaries, SPFs for each period of time inevitably decrease. The value of the overall SPF shows which of the electrical consumers influence the SPF and how this is done. The biggest difference of 0.26 occurs between SPF 0 (4.19) and SPF 1 (3.93) and can be explained by the brine pump's power consumption. The small difference between SPF 1 and SPF 2 (0.05) results from the influence of the back-up heater. A slightly bigger influence of 0.13 between SPF 1 and SPF 2 can be observed with charging pumps.

Up to now, the focus was on average SPFs for a selection of heat pumps. Figure 4, however, presents the whole range considering the SPF of each heat pump individually. The bar chart below illustrates efficiency values of the 56 ground source heat pumps for the entire period of evaluation as well as the yearly SPF for the last observed year. The purpose of this selection is to present the overall efficiency of each heat pump without taking into account their individual operation time and furthermore show their yearly balance.

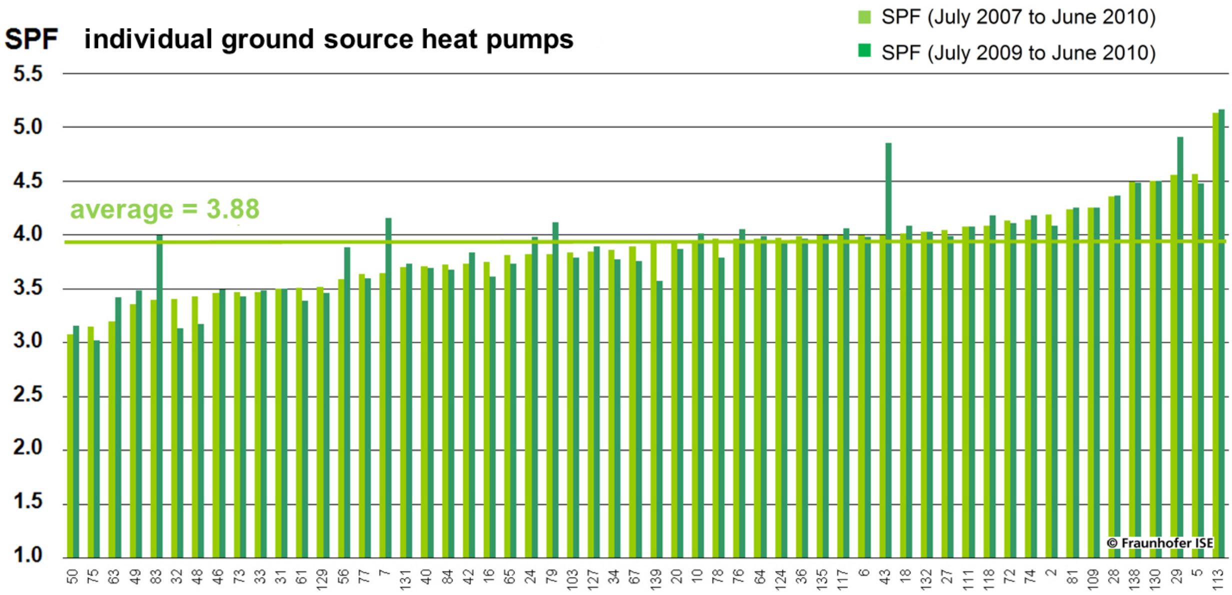


Figure 15: SPFs of ground source heat pumps for July 2007 to June 2010 and July 2009 to June 2010; the labelling corresponds to ID numbers known to manufacturers

The average SPF of 3.88 consists of individual values ranging from 3.1 to 5.1 illustrated as light green bars. The highest SPF has a value of 5.0. In this particular case, the pump belongs to the class of ground source heat pumps, however, it has a 300 m deep borehole which allows the use of water as heat transfer medium. This heat pump hardly influences the overall SPF. When ignoring its SPF, the new SPF would amount to 3.85 and thus is only reduced by 0.03. This number is consistent with the average SPF of the smallest and second-highest value (4.6) and thus proves the even distribution of the SPFs. The dark green bars show the yearly SPFs for the year 2009/10. For most of the heat pump systems, their values are similar to the overall SPFs, nevertheless there are a few exceptions showing significant differences. The yearly SPF of heat pump no. 139 is 3.6 and thus 0.4 smaller than the overall SPF. On the other hand, however, there are also very positive values such as those of heat pump no. 43 which increased by 0.9. Sorting yearly SPFs of 2009/10 would result in a range of SPFs from 3.0 to 5.2 with a second-highest value of 4.9. It is worth pointing out that the overall as well as the yearly SPFs did not show any values below 3.0. In fact, 20 out of 56 heat pump systems (36%) reached a value of 4.0 and higher.

5.2.2 Air Source Heat Pumps

Due to their heat source, air source heat pumps necessarily have a smaller SPF compared to ground source or water source heat pumps. Figure 16 shows the results of this type of heat pump. The chart's design is equivalent to Figure 11 of chapter 5.2.1. For further explanations see this chapter.

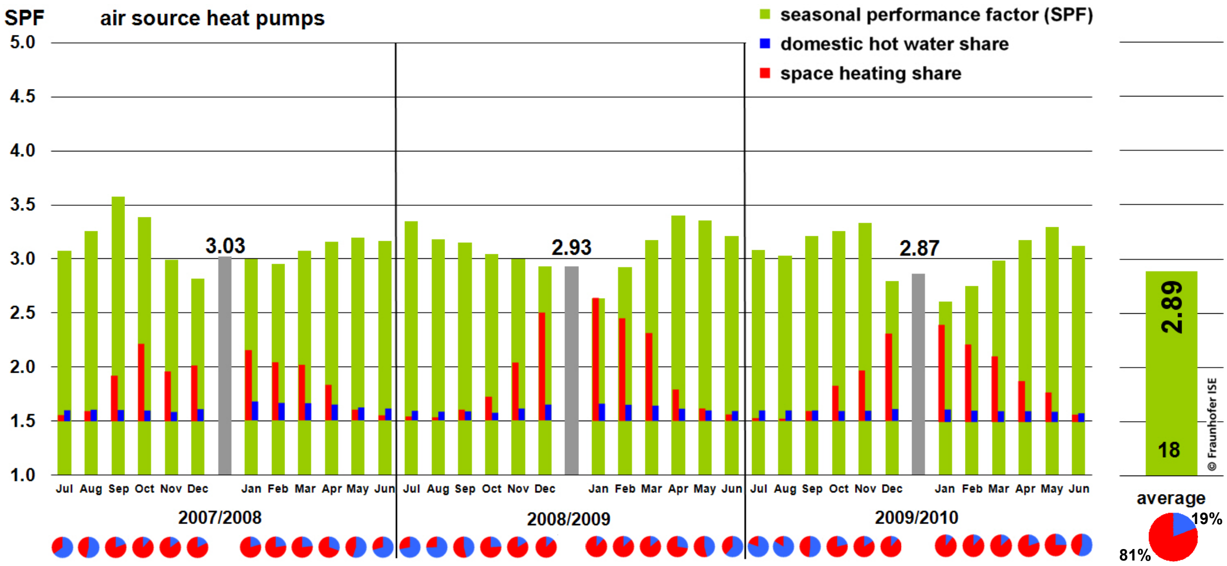


Figure 16: SPFs of air source heat pumps for different time periods within the observation period July 2007 to June 2010 and the distinction of produced thermal energy as well as the amount of the evaluated heat pumps

The data for air source heat pumps was smaller than for ground source heat pumps. In the beginning, one heat pump was evaluated, after enlarging systems step by step, in the end 18 systems could be analyzed. These heat pumps reached an overall efficiency of 2.89. As the building's heat demand is independent of the heat source, the produced energy for heating and DHW (relative and absolute) behaves like those of ground source heat pumps.

The yearly SPFs decreased continuously over the years. From 2007/08 to 2008/09 they decreased by 0.10, from 2008/09 to 2009/10 by 0.06. This correlates with slightly sinking outside air temperatures. The temperature decreased by 0.4 K from 2007 to 2008 and by 0.2 K from 2008 to 2009. In principal, one could explain these tendencies with the small amount of data and thus the influence of extreme values. The main influence, however, is due to heat pumps of the project's first phase which could not be evaluated until the last year. They reached a generally lower efficiency compared to the rest of the systems. This will be discussed in this chapter in more detail with the help of Figure 17.

The comparison of the two charts (air source and ground source heat pumps) shows big differences in monthly SPFs in the course of a year. While ground source heat pumps have significantly higher SPFs during the heating period, air source heat pumps work most inefficiently during this period of time. Extreme values of 2.6 were reached in January 2009 and 2010. Considering the greater number of heat pumps since October 2008 and thus taking into account these values, a second minimum in summer was reached. SPFs hardly reached 3.0 in August 2009.

The reasons for the low efficiency in summer and the extremely low one in winter can be traced back to the temperature difference between heat source and heat sink. Another factor which influences efficiency negatively can be seen in the control unit's energy consumption. As the consumption of electrical energy during this time is usually very low, it carries even more weight. While the energy consumption of ground source heat pumps is mainly influenced by the alternation of the heat sink temperature during the course of the year, air source heat pumps are also significantly influenced by the heat source temperature. During the heating period only low source temperatures are provided. Although during summer time source temperatures are significantly higher, because of the almost exclusive DHW production the heat sink temperatures increase at a similar rate. Consequently, the highest SPFs are detectable during the transitional period. In this period the outside air temperature, basically the heat source temperature, falls just short of the heating limit temperature, wheras the heating circuit gets charged with low temperatures. Thus the highest SPFs were reached in April 09 (3.40), November 09 (3.29) as well as in May 10 (3.23). During these three months the share of space heating energy amounts to between 75 % and 80 %.

Efficiency of air source heat pumps was also influenced by the systems of the project's second phase (see chapter 3.2 on the project's phases). SPFs of the first and second phase can be seen in Figure 17. In this context, it is important to mention that the already small number of systems is again divided into two parts as there is a first and second phase. Similar to ground source heat pumps of the second phase, air source heat pumps also have a higher SPF (difference of 0.17).

While heat pumps of the first phase remain relatively constant considering the yearly values, there is a decrease of 0.24 from 2008/9 to 2009/10. In the same period of time of the second phase, SPFs remain relatively constant. As already mentioned, weather conditions correlate slightly to SPFs of the first phase, however, do not correlate at all in the second phase.

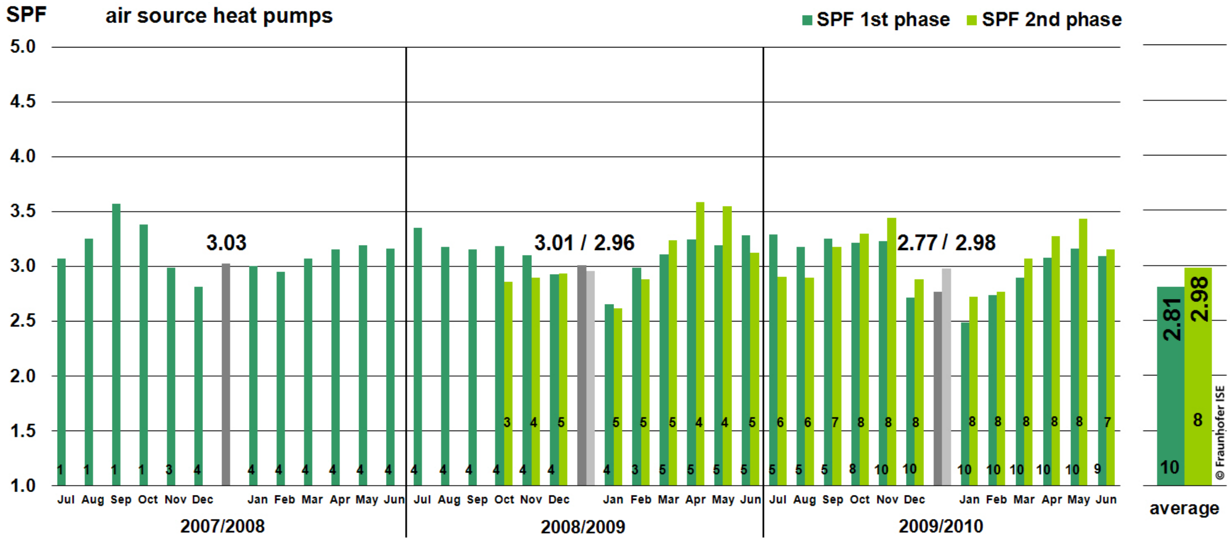


Figure 17: SPF values of air source heat pumps measured in different time periods throughout July 2007 to June 2010, divided into first and second project phases

In the first phase, several heat pump systems could not be evaluated until October 2009. These heat pumps, in particular, were the ones which did not work as efficiently as others. If they had not been taken into account, a SPF of 2.92 could have been achieved. This in turn puts into perspective higher SPFs of the second phase and also explains the decrease of the yearly SPF in 2009/10 which is illustrated in Figure 17.

Monthly SPFs show that air source heat pumps can reach values of more than 3.5 during the transition period between April and May 2009. Even in the following year and almost twice as much data, this value could nearly be achieved. The heat pump's lowest SPF was measured during the project's first phase and amounted to 2.5 due to the very cold January in 2009. These low values are also influenced by an increasing activity of the heating element.

Figure 18 shows SPFs of air source heat pumps for different system boundaries. SPFs were calculated for the entire period from July 2007 to June 2010 and for the three years individually. Similar to ground source heat pumps, clear differences occur especially between the smallest and biggest system boundaries. SPF 0 considers the compressor only and amounts to 3.17. SPF 1 also includes the ventilators and reaches a value of 2.95. Compared to the first value, this is a decrease of 0.22. The difference between SPF 1 and SPF 2 amounts to the relatively small value of 0.06. When taking into account charging pumps, there is a bigger difference of 0.15. Yearly SPFs of the different system boundaries have similar relations between each other compared to the overall SPFs.

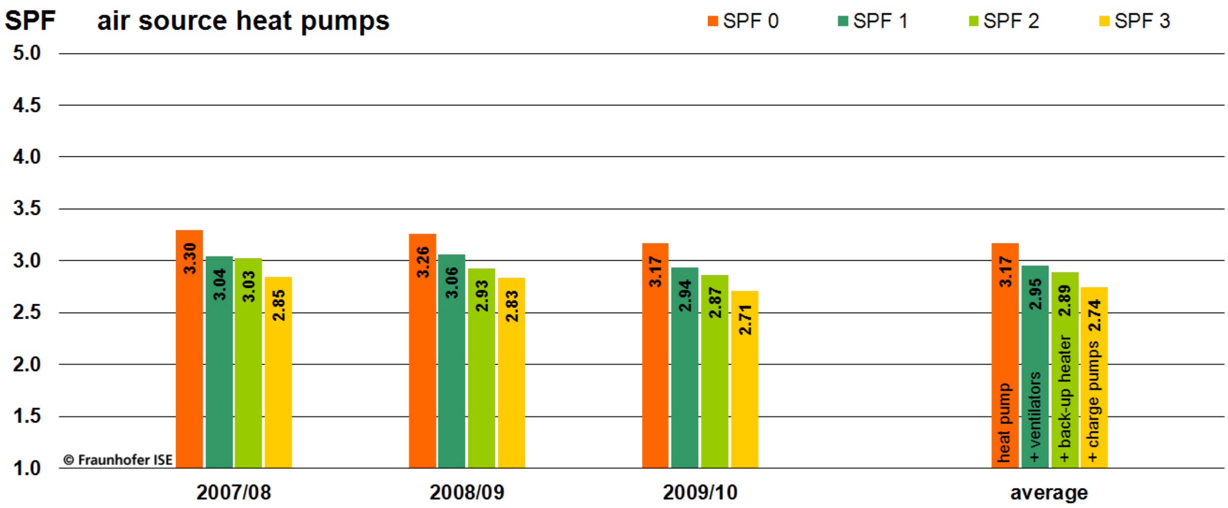


Figure 18: SPFs of air source heat pumps for different time periods ranging from July 2007 to June 2010 taking into consideration four system boundaries (for further explanation see chapter 5.1)

The bar chart of Figure 19 focuses on the efficiencies of each air source heat pump. The light green bars represent the overall SPFs of the evaluated period of time, the dark green ones stand for SPFs measured during the last evaluated year.

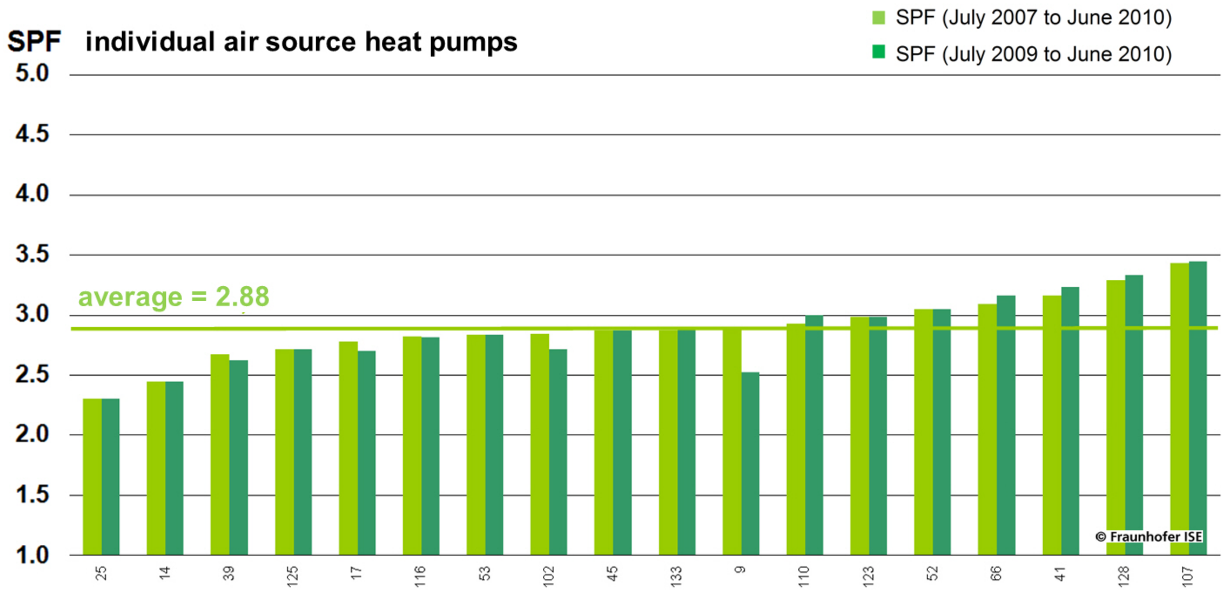


Figure 19: SPFs of air source heat pumps for July 2007 to June 2010 and July 2009 to June 2010 respectively; the labelling corresponds to ID numbers known to manufacturers

The average value of 2.88 consists of values with a minimum of 2.3 and a maximum of 3.4. Compared to ground source heat pumps, air source heat pumps do not show extreme values. When it comes to special limit values, 6 out of 18 heat pumps (33%) have a SPF which is higher than 3.0 and 16 out of 18 heat pumps (89%) show SPFs which are above 2.6 (primary energy factor according EnEV 2009 [3]). When comparing the overall and yearly SPF it becomes clear that heat pump system no. 9 is the only systems showing significant differences (-0.4). The spectrum of yearly SPFs, though, conforms to that of the overall SPFs.

5.3 Rating of the Seasonal Performance Factor – Efficency vs. Effectiveness

The main goal of the project "HP Efficiency" was to independently determine the efficiency of serially manufactured heat pumps of the low capacity class. Due to the amount of measured heat pumps, well-founded results for ground source and air source heat pumps could be achieved. The average SPF of ground source heat pumps amounts to 3.9 and to 2.9 for air source heat pumps. Leaving heat sources out of account, individual SPF values between 2.3 and 5.1 could be determined.

Thus, heat pumps produce energy for space heating and domestic hot water with very different efficiencies. The full-version of the present report describes a large amount of efficiency-influencing aspects. The variety of aspects makes clear that the efficiency value cannot be evaluated without mentioning the framework conditions too. The same applies to statements concerning ecological or economical characteristics of the energy supply system. Yet, in order to make an evaluation possible and at the same time be able to rate SPF values convincingly, the term efficiency for this section needs to be expanded by the term effectiveness. While efficiency refers to the input/output relation, effectiveness determines the dimension of objective achievements. This section's objectives are to save heating and primary energy. This, however, requires among other things the consideration of the energetic quality of the building's outer shell.

With the help of such a comprehensive approach, the Energieeinsparverordnung[9] (EnEV 2009 [3]) is met. These regulations set a maximum primary energy demand for a defined building type which has to be kept with the suitable heating system and/or the quality of the building's outer shell. Different constellations of efficiency and effectiveness are described below with practical examples gathered during the fieldtest. The efficiency of the heat pumps is determined by the SPF 2 (cf. system boundaries, chapter 5.1). Space heating and primary energy demand are calculated with the following two formulas 5 and 6.

[9] German Energy Saving Regulation of 2009

$$q_{heat} = \frac{Q_{heat}}{A_{buildung}} \qquad 5$$

$$q_{PE} = \frac{W_{EL} \cdot f_{PE}}{A_{buildung}} \qquad 6$$

q_{heat}	specific space heating energy consumption
Q_{heat}	space heating energy consumption
$A_{building}$	heated building area
q_{PE}	specific primary energy consumption
W_{EL}	electrical energy consumption of the heat pump
f_{PE}	primary energy factor electrical energy (2.6 according [3])

Figure 20 illustrates a good example for heat pump efficiency and energetic effectiveness. In this case, a ground source heat pump with boreholes supplies a building with energy for space heating and domestic hot water. The heated building area amounts to 252 m². In 2009, the heat pump reached a SPF value of 4.11 which is above average for ground source heat pumps. At the same time, the specific space heating energy consumption amounts to 52.7 kWh/(m²a) which is below average compared to the examined objects. With a value of 39.1 kWh/(m²a), the primary energy consumption is relatively low too. From all this it follows that example 1 shows an efficiently working heat pump in an effective overall system as far as energetical apects are concerned.

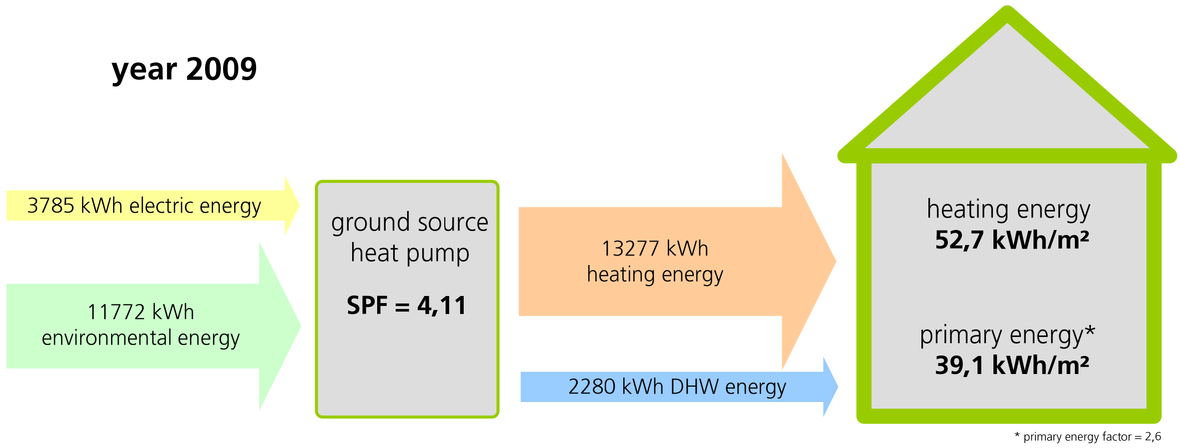


Figure 20: heat pump efficiency and energetic effectiveness of the whole system (example 1)

In comparison to the first example, the second one deals with an even more efficient ground source heat pump with boreholes installed in a building with a heated area of 130 m² (Figure 21). The heat pumps reached a SPF of 4.24 in 2009. Due to the lower quality of the building's outer frame, however, the specific energy comsumption for space heating amounts to the high value of 99.8 kWh/(m²a) and the primary energy consumption to 74.1 kWh/(m²a). Due to these values, the system's effectiveness has to be rated negatively although the heat pump's efficiency is very good.

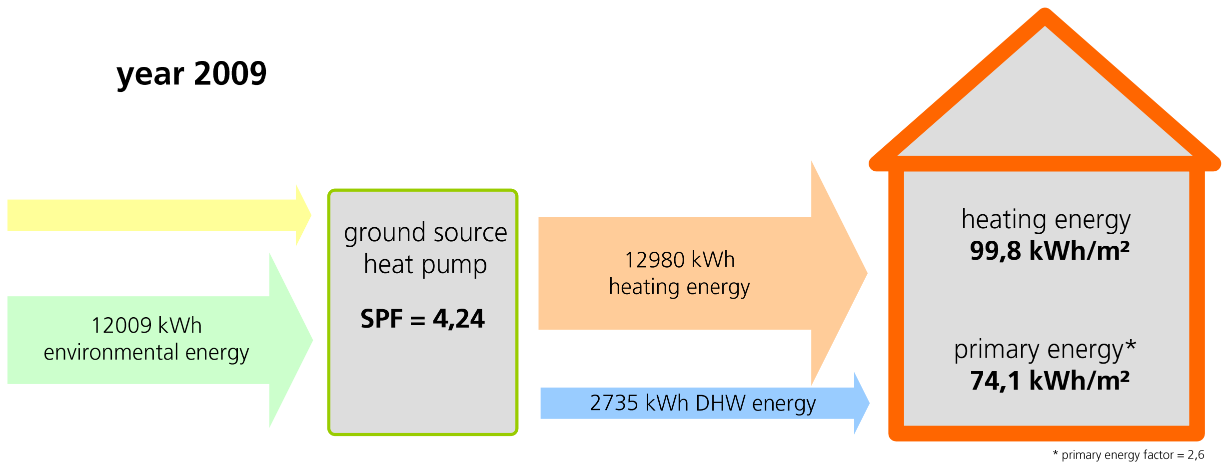


Figure 21: heat pump efficiency and energetic effectiveness of the whole system (example 2)

The third example is represented in Figure 22 and shows an air source heat pump in a well isolated building with a heated area of 161 m². With a space heating consumption of 46.7 kWh/m² in 2009, the overall system can be rated as effective in energetical terms. The efficiency of the heat pump, however, is very low because of its heat source (even if the SPF is relatively high in the context of air source heat pumps). The specific primary energy consumption amounts to 56.8 kWh/(m²a). In contrast to the first example, this value is higher than the specific energy consumption for space heating due to low heat pump efficiency

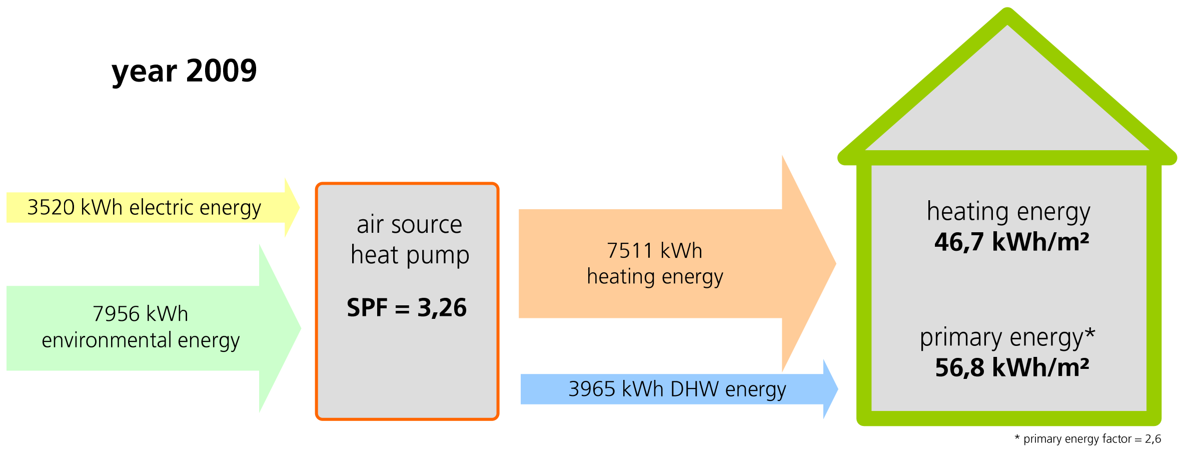


Figure 22: heat pump efficiency and energetic effectiveness of the whole system (example 3)

In a nutshell, heat pump efficiency can only be rated when framework conditions are also taken into consideration. The effectiveness of the whole system, however, is the actual and significant target figure. In terms of improvement measures, decreasing the energy demand should always be the first step as the effectiveness of the overall system definitely increases. The remaining demand should be covered with the highest possible efficiency. The higher the efficiency, the higher the contribution to an effective energy supply system.

6 Detected Errors and Improvement Suggestions for Design, Installation and Operation

This chapter deals with problems detected during the field test and provides improvement suggestions for design, installation and operation. The text is based on the long version of the report.

As already mentioned in this report, the fundamental requirement for an efficient heat pump operation is a low difference between the temperature of heat source and heat sink. Furthermore, the report emphasizes that achieving a good effectiveness, i.e. saving energy in general, is more important than achieving efficiency. Both aims could mainly be influenced in advance during the **design** phase.

When considering the installation of a heat pump, the first step is to analyse the **energy saving potentials**, especially in connection with the **building's outer frame**. The ways in which energy could be saved should be thought through in advance. The positive effects would be reflected in the installation of a heat pump with lower thermal power and simultaneously lower electrical energy usage. A prudent analysis of the profitability, taking into account the options mentioned above, could be done in advance.

Even in an energetically improved building, however, the heat pump's efficiency basically depends on the difference between the temperatures of heat sink and heat source. As far as the **heat sink** (heating circle, DHW) is concerned, it should be strived for the **lowest temperatures** possible. The greatest effect has the enlargement of heat-transmitting surfaces such as the utilization of underfloor or wall heating. In existing buildings with a low potential of restructuring, special low temperature radiators might be used. A good example in this context is an air source heat pump with a SPF of 3.3 examined in 2009. This heat pump is installed in a house in which every single square meter of living space (113 m²) is equipped with underfloor heating which enables annual average heating inlet temperatures of 31.5 °C and 27.0 °C of the return flow. During the entire field test the lowest annual heating inlet temperatures that could be measured amounted to 28.8 °C. The **heat source** should provide as **high temperatures** as possible, in particular during the heating period. These temperatures are primarily influenced by the type of the heat source or the design of the heat exchanger used. The highest temperatures during the heating period and the most constant temperatures in the course of a year can be reached by water source heat pumps. Slightly lower and more fluctuating temperatures are achieved by ground source heat pumps using boreholes. The applications with horizontal ground collectors supply even lower and more fluctuating temperatures in the course of a year than those with boreholes. The heat source temperatures of air source heat pumps provide the least suitable preconditions with regard to the heat pump's efficiency. In this context, the divergence between the outside air temperature and the space heating demand is essential. When selecting the appropriate heat source, one has to take more effects into account than efficiency and resulting ecological and economic effects only. These include local conditions such as the space available, approval procedures (especially in case of water source heat pumps) or the economic conditions with regard to investment costs.

During the design phase, setting up the heat distribution system is another issue to be considered. Besides directly supplying the heating circuit, there is the possibility to install buffer storage in a serial or parallel manner. These storages are mainly installed in order to bridge blocking times (energy supplier) as well as to enable longer compressor running times. The last-mentioned point, in particular, could be confirmed, especially during the transitional period in which low heating demand faces a heat pump which is designed for intensive heating phases. Air source heat pumps using reverse cycle defrosting are usually equipped with buffer storage. Furthermore, buffer storage ensures the minimum flow rate which the heat pump requires. Different types of storage also enable the integration of additional heat sources such as solar thermal systems. During the monitoring project, a connection between the setup of the heat distribution system and the heat pump's efficiency could be detected. **The most efficient ones were those which charged the heating circuit directly, i.e. systems without any buffer storage.** The efficiency of heat pump systems with buffer storage was slightly lower. The individual systems with serial and parallel buffer storage could not be compared because there were only few of these systems used in the field test. The difference between the average SPFs of systems without storage and those with combined storage is more significant. One reason lies in the partly inadequate loading strategy that was detected. Frequently, it could be observed that heating demand was answered with a storage load by the heat pump in DHW-mode. Higher inlet temperatures led to a lower efficiency. Therefore, advantages and disadvantages have to be considered carefully. All types of storage lose a certain amount of energy, so its benefits have to compensate at least for its losses. In this context, it is worth mentioning that storage will play an even more important role in the future with regard to the transfer of heat pump operation times in order to use renewable electrical energy more effectively (Smart Grid).

A further problem when it comes to the design of heat pump systems is the use of **primary pumps whose capacity is too high**. This especially applies to well pumps installed with water source heat pumps. Brine pumps in ground source heat pumps sometimes run with performance levels too high which leads to a higher consumption of electrical energy and consequently to a lower efficiency. Thus, the **use of high-efficiency pumps** is strongly recommended.

Heat pump systems require an **integral and object-specific planning** which should also include the building. A thorough design of the whole system which takes into account individual components too (heat source, heat pump, heat sink) has to be ensured. Furthermore, one has to consider the demanding installation process, the control and regulation of the heat pump and the higher complexity of the hydraulic setup.

Besides a well thought-out design, the careful **installation** of the heat pump system is important too. Special attention should be paid to the function of the hydraulic components as well as the correct installation of components ehich meet the control unit.

The division between heating and DHW circuit is either achieved with the help of a three-way valve and a pump or without the valve and one pump in each circuit. As far as the **three-way valves** are concerned, it could be observed that they did not close completely. This led to a slow but constant discharging of the DHW storage. This effect was even increased by the **unnecessarily operating charge pump**. Thus, during the installation it should be ensured that the valve closes completely. Alternatively using two pumps and leaving out the check valve partly resulted in a negative flow in the other circuit.

The use of storage requires the **correct installation of temperature sensors** as well as an appropriate parametrisation of the heat pump control unit. Some storage provides variable positioning of the temperature sensors. Immersion sensors require fixed positions, the measurement, however, is more precise. These measures aim at providing ideal conditions for the storage charge, especially for combined storage.

During the installation process, the electrical back-up heater can be deactivated. **Correctly designed ground source heat pumps do not require an electrical back-up heater**. It is only necessary in case of malfunction or if the building needs to be dried out. At worst, high thermal stress could lead to the damage of the borehole heat exchanger.

Furthermore, a **hydraulic balancing** as well as the **complete insulation** of pipes and other hydraulic components should be done as standard.

The heat pump should not be seen as a heating system which can be neglected once it is installed. Even in **operation** the efficiency can be influenced positively.

Efficiency can be influenced positively by adjusting heating and the DHW temperatures. Although both values are determined in the design phase, the real consumption as well as the actual demand may vary. Ideally, both values should be as low as possible. Normally the heating temperatures can easily be adapted by gradually **reducing the heating curve**.

Another option is to adjust the pump's capacity in the primary and secondary circuit. One should be aiming at ideal temperature differences in the heat exchanger by adjusting the flow rate appropriately.

7 Responsibility for Efficiency and Effectiveness

There are basically three groups that can help to make full use of the theoretically high potential of heat pumps and thus contributing to a real and high efficiency as well as to the effectiveness of the whole system: the heat pump manufacturers, the planners and installers as well as the users (residents) of the heat pump system.

The **manufacturers** have the responsibility to offer efficient and reliable heat pumps. As far as the last point is concerned, the field test could show that heat pump systems operate very reliably. Further potential for optimization, however, lies in the field of heat pump efficiency. This can be realized with a constant increase of the COP values, e.g. by improving individual components as well as the further development of appropriate control algorithm. Moreover, it is important to train and further educate staff and inform the users about how to use their heat pump efficiently. Finally, the manufacturers have to consider future challenges such as the integration of heat pumps in the Smart Grid, the increasing energy demand for cooling in summer and the combination with other heat sources.

The **planners** and **installers** have the best opportunity to influence a heat pump's efficiency. Correct planning as well as a careful and professional installation of the heat pump system is essential for their reliable and efficient operation. Under these conditions, only, heat pumps can meet the expectations in terms of economic and ecological advantages. Above all, the wide range of determined SPF values shows the significant potential for optimization in this field. Planners and installers have the obligation to inform the users about how to operate a heat pump efficiently.

Residents are able to influence the heat pump's efficiency and the energy consumption basically on two levels. First of all, it is the user who in the end decides about investing in such a system. This involves their willingness to construct a building with either a low demand of heating energy that is equipped with underfloor heating or to refurbish a building in order to increase its energy efficiency and thereby choosing the most suitable heat pump's heat source. As far as the heat system's configuration in existing buildings is concerned, residents can primarily influence the heat sink's temperature. Easy menu navigation on the heat pump's display allows a convenient adjustment of the heating curve. Furthermore, the residents could deactivate the electrical back-up heater and reactivate it if necessary. Hereby, unwanted back-up activity can be prevented in advance. As already mentioned, residents should be informed about the system before they actively use it. Necessary information should be provided by manufacturers, planners and installers. During the field test, one could divide the residents into two groups. One group did not show any interest in the heat pump and therefore had hardly any knowledge about it. The other group of residents was very interested in the system and thus tried to improve the heat pump's efficiency actively.

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