SYSTEM BOUNDARIES FOR SPF-CALCULATION

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Abstract: In the IEE project SEPEMO-Build a proposal for system boundaries and corresponding SPF calculation models for heating and cooling of heat pump systems for the use in field measurements has been developed. The system boundaries stretch from the heat pump refrigeration cycle to the whole heating system boundary in heat pump systems. The defined system borders will lead to a common system evaluation making a comparison of the different systems measured possible. The definition of the system boundaries directly impacts on the required measurement equipment to measure the parameters needed for the calculation of the different SPF. Therefore a measurement guideline has been developed, outlining the requirements for the measurement equipment in terms of accuracy, sampling interval etc. to be able to analyse the systems according to the defined system boundaries.
To illustrate the use of the methodology and to show the influence of the auxiliary devices on the system efficiency, the evaluation of 10 ground coupled heat pump systems according the developed methodology is carried out.

Key Words: heat pumps, seasonal performance factor, efficiency, system boundaries

INTRODUCTION

In the past years it became more and more common to use field measurements for the evaluation of the performance of heat pump systems. Unfortunately the results of the most field trials are not comparable due to the differences in the defined system boundaries used for the integration of the measurement equipment and the analysis of the measured data [FAWA 2003], [ISE 2008], [Delta 2011].
Therefore one part of the IEE-project SEPEMO-Build is focused on defining common system boundaries for calculating the SPF for heating and cooling of heat pump systems. These borders directly impact on the necessary equipment needed to measure the essential parameters for the calculation of the different SPF.

To allow system comparisons it is mandatory to develop a common monitoring methodology, which ensures a certain data quality. Consequently it is important to set the requirements on what to measure in order to make SPF calculations and to give information about the measurement quality that is needed.

The quality of the measurements is directly influenced by the accuracy of the sensors and the sampling intervals for storing data. Due to the fact that the various monitoring studies have not selected the same system boundaries, a transparent presentation of the boundaries will be necessary in the future. This will firstly simplify SPF calculations and should secondly allow the comparisons of the results of different field monitorings. However, in the course of the SEPEMO-Build project (www.sepemo.eu) standardized system boundaries for field monitoring will be defined.

2 SYSTEM BOUNDARY DESCRIPTION

For calculating the SPF for heating and cooling in heat pump systems, the system boundaries have been set to fulfill different needs. The definition of the system boundaries influences – in dependency on the impact of the auxiliary devices – also the results of the SPF. Therefore the SPF should be calculated according to different system boundaries (Figure 1).

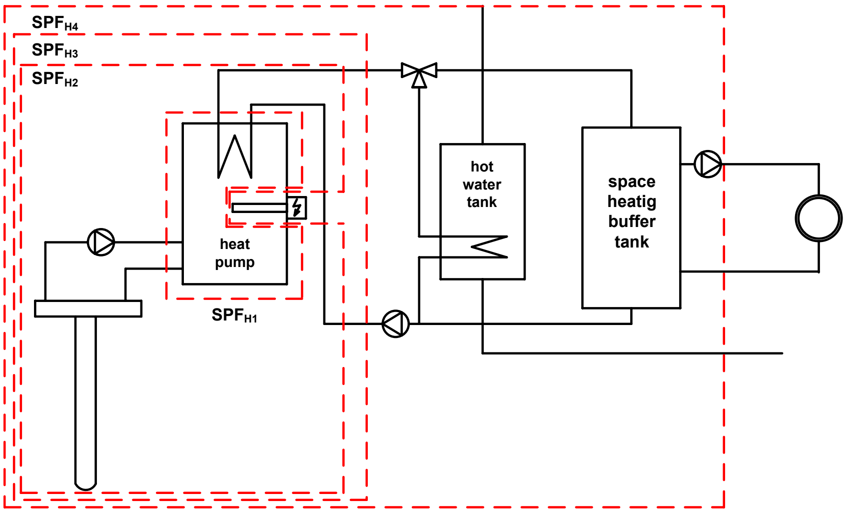

Figure 1: System boundaries for heating [SEPEMO D4.2, 2010]

This SPF-calculation method facilitates the quantification of the impact of the auxiliary devices like brine pumps and fans on the performance of the heat pump system. It also enables the comparison of heat pump system with other heating systems like oil or gas by allowing for the calculation of the CO_2- and primary energy reduction potential. Furthermore the quantity of renewable energy supplied by the heat pump system can be calculated and used for statistics. Therefore the system boundaries stretch from the heat pump refrigeration cycle to the whole heating system boundary in heat pump systems. The nomenclature defined in table 1 is used in the following figures and equations when describing the different system boundaries.

Table 1: Nomenclature

parameter	description	unit
SH	space heating	[-]
DHW	domestic hot water	[-]
HP	heat pump	[-]
Q_{H_hp}	quantity of heat of the HP in SH operation	[kWh]
Q_{W_hp}	quantity of heat of the HP in DHW operation	[kWh]
Q_{HW_bu}	quantity of heat of the back-up heater for SH and DHW	[kWh]
$E_{S\_fan/pump}$	electrical energy use of the HP source: fan or brine/well pump for SH and DHW	[kWh]
$E_{B\_fan/pump}$	electrical energy use of the heat sink: fans or pumps for SH and DHW	[kWh]
E_{bt_pump}	electrical energy use of the buffer tank pump	[kWh]
E_{HW_hp}	electrical energy use of the HP for SH and DHW	[kWh]
E_{HW_bu}	energy use* of the back-up heater for SH and DHW	[kWh]

*for additional heating other then electrical back up heater the energy content of the fuel demand has to be taken

For systems with an additional heating system other than an electrical back up heater (e.g. oil, gas or biomass) the quantity of heat and the energy content of the fuel demand have to be determined for the calculation of the SPF according to the system boundaries. For any additional (solar) thermal system, the electric auxiliary energy to run this system has to be measured. With the heat energy delivered to the heating system by the additional heating the energy supply ratio of the heat pump system is calculated.

2.1 System boundary heat pump unit

The system boundary shown in Figure 2 contains only the heat pump unit. SPF_{H1} evaluates the performance of the refrigeration cycle and allows a calculation of the SPF of the heat pump without the auxiliary drives to show the efficiency of the refrigerant cycle (Figure 2).

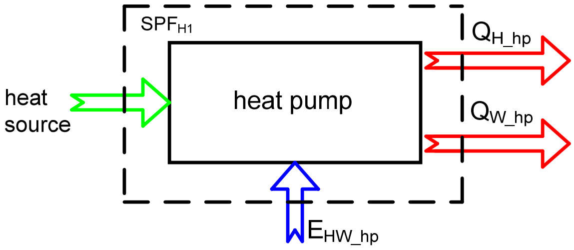

Figure 2: System boundary SPF_{H1} for heating [SEPEMO D4.2, 2010]

$$SPF_{H1} = (Q_{H\_hp} + Q_{W\_hp})/E_{HW\_hp} \quad (1)$$

2.2 System boundary use with RES-Calculations[1]

The system boundary SPF_{H2} contains the heat pump unit and the equipment needed to make use of the source energy available for the heat pump. This level of system boundary responds to the RES-Directive [RES Directive, 2009] requirements for calculating the used renewable energy by the heat pump. SPF_{H2} allows the calculation of the SPF including auxiliary drives for the heat source, but without back-up heater (Figure 3).

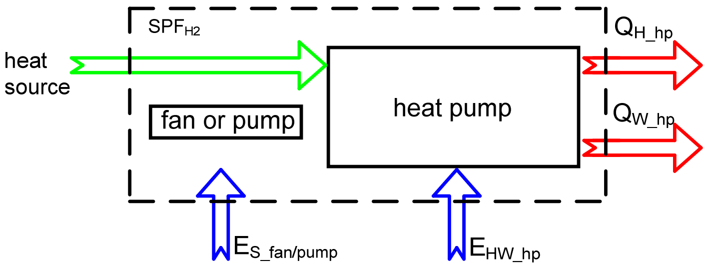

Figure 3: System boundary SPF_{H2} for heating [SEPEMO D4.2, 2010]

$$SPF_{H2} = (Q_{H\_hp} + Q_{W\_hp})/(E_{S\_fan/pump} + E_{HW\_hp}) \quad (2)$$

2.3 System boundary for comparing heating systems

The system boundary SPF_{H3} contains the heat pump unit, the equipment to make the source energy available and the back up heater (Figure 4). It represents the heat pump system and

[1] According to the European RES-directive, Directive 2009/28 EC

thereby can be used to compare heat pump systems with conventional heating systems e.g. oil or gas fired systems.

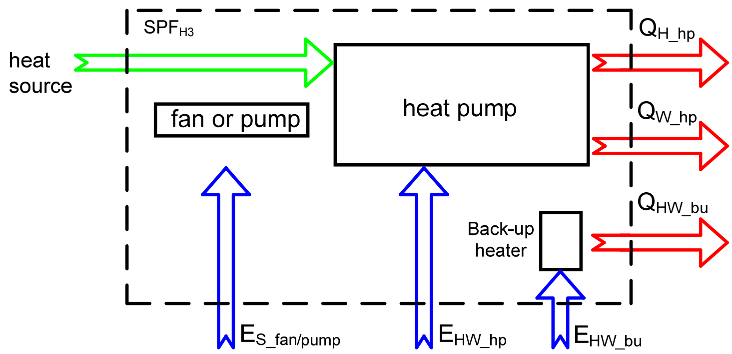

Figure 4: System boundary SPF_{H3} for heating [SEPEMO D4.2, 2010]

$$SPF_{H3} = (Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu})/(E_{S\_fan/pump} + E_{HW\_hp} + E_{HW\_bu}) \quad (3)$$

2.4 System boundary including all heating system equipment

SPF_{H4} allows a calculation of the SPF with the total produced thermal energy divided by the total energy consumption (Figure 5). This system boundary contains the heat pump unit, the equipment to make the source energy available, the back up heater and all auxiliary drives including the auxiliary of the heat sink system. SPF_{H4} represents the heat pump heating system including all auxiliary drives which are installed in the heating system.

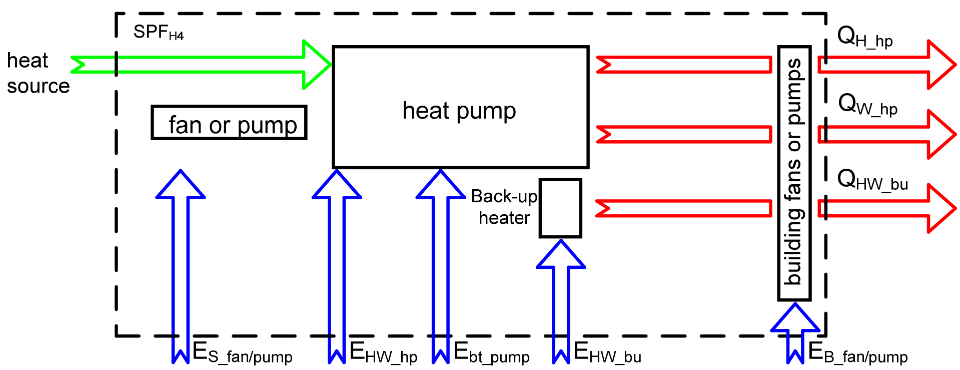

Figure 5: System boundary SPF_{H4} for heating [SEPEMO D4.2, 2010]

$$SPF_{H4} = (Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu})/(E_{S\_fan/pump} + E_{HW\_hp} + E_{bt\_pump} + E_{HW\_bu} + E_{B\_fan/pump}) \quad (4)$$

3 COMPARISON OF THE SYSTEM BOUNDARIES USED IN STANDARDS AND FIELD MEASUREMENTS

There are different existing standards and regulations for calculating the SPF. These calculation methodologies are mainly based on input from the testing standard EN 14511. The system boundaries of testing standards are however focused on the heating or cooling unit itself. In comparing test results, the system integration is not taken into account. Therefore these standards do not include the entire energy consumption of the auxiliary drives on the heat sink and heat source side.

For field measurements, some Nordic standards are available (NTVVS076, 1989, NTVVS115, 1997, NTVVS116, 1997). These standards have not been used on a broad European level, but they have been used for field measurements in Sweden. The standards have been used as reference in the SEPEMO project when the system boundaries have been established.

Due to the different framework conditions, there are differences between field testing and testing on a test rig, which can't be avoided because of reasons of practicability. The main difference in the evaluation methodologies originates from the evaluation purpose. While testing on a test rig is focused on the unit, the field measurements are determined by the system. Hence, the system boundaries for testing and field measurements will be slightly different and therefore have to be considered when comparing calculated and field measured SPFs. Within the project IEE SEPEMO-Build the following differences concerning the nomenclature of SPF, COP, EER, SCOP and SEER have been defined:

- SPF – evaluation of field measurement data according to the defined system boundaries
- COP/EER – measurements on test rigs according to certain standards or regulations e.g.: EN 15411, EHPA-Quality label
- SCOP/SEER - calculation out of testing results

4 MEASUREMENT EQUIPMENT

In order to implement a common system evaluation, it is not mandatory to use the same measurement equipment, but it is obligatory that during the measurements the same parameters have been recorded with comparable accuracies. The need for different measurement equipment derives from the different system boundaries [SEPEMO D4.1, 2011].
Therefore it is important to define what to measure in order to apply SPF calculations and to provide information about the measurement quality that is needed:

- Accuracy of the sensors
- sampling intervals of the data acquisition system
- measurement equipment quality (sensors)

Additionally, proper equipment integration into the system is highly important in order to gain accurate measurement.

4.1 Minimum results

For a common monitoring evaluation the following results (Table 2) should be mandatory, in order to compare the different systems in a reasonable way. To understand under which operating conditions the heat pump system was running, it is important to record additional information e.g. average supply temperature, indoor temperature,…

Table 2: required results [SEPEMO D4.1, 2011]

parameter	unit
Electric energy input – total	[kWh]
Electric energy input backup heater	[kWh]
Electric energy input pumps/fans heat source side	[kWh]
Electric energy input pumps/fans heat sink side	[kWh]
Energy output heating / cooling	[kWh]
Energy output DHW	[kWh]
SPF2	[-]

SPF3	[-]
Average supply temperature heat sink*	[°C]
Average return temperature heat sink*	[°C]
Average supply temperature DHW*	[°C]
Average return temperature DHW*	[°C]
Average supply temperature heat source*	[°C]
Average return temperature heat source*	[°C]
Average outdoor temperature*	[°C]
Average indoor temperature*	[°C]

*during operation of the unit

4.2 Measurement parameters

The measurement approach required consists of the determination of both, the heat delivered and the electrical energy consumed, by the heat pump. In the following figure 6 the mandatory measurement sensors needed to analyse the system according to the different system boundaries are described on the example of a ground coupled heat pump system for space heating and domestic hot water production.

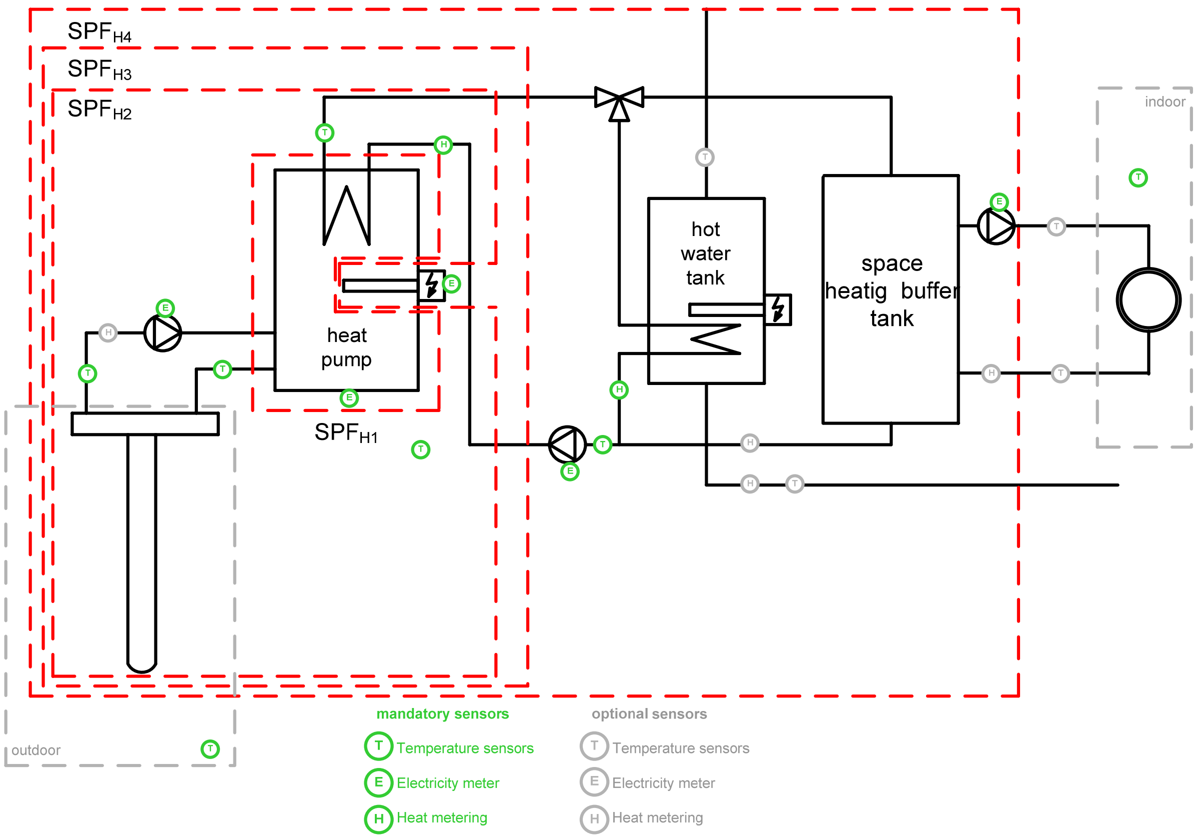

Figure 6: measurement sensors [SEPEMO D4.1, 2011]

According to the different system boundaries, different requirements on the mandatory equipment are given. The mandatory equipment in figure 6 is highlighted in green. The equipment marked light grey is optional to get additional information about the system operation.
The mandatory measurement equipment can be separated into two parts: firstly the energy meters for calculating the SPF according to the system boundaries and secondly the temperature/humidity/pressure-sensors to gather information about the boundary conditions under which the system was operating during the measurement season:

- Energy meter:
    - the electricity consumed by the heat pump compressor, controls and circulating pumps or fans
    - the heat delivered to the space heating and hot water systems

- physical performance measurements:
    - heat source temperature
    - heat sink temperatures
    - indoor-/outdoor temperature
    - outdoor air humidity

5 RESULTS ACCORDING DIFFERENT SYSTEM BOUNDARIES

Although the IEE project SEPEMO-Build was started in June 2009, the first field measurements according to the “Concept for Evaluation of SPF“ [SEPEMO D4.2, 2010] and the “Field Measurement Guideline” [SEPEMO D4.1, 2011] have been started by the end of 2010 only. Consequently there are no measured data of a whole season available at the moment. For showing the influence of the different system boundaries as described above, the data of 10 ground coupled heat pump systems fulfilling as much as possible the criteria of the project SEPEMO-Build have been selected. These sites have been measured by Fraunhofer ISE in the course of the project "Heat Pump Efficiency" [ISE 2010].

The selected systems are typical ground coupled heat pump systems for the use in single family houses with heat pumps covering a range of heating capacities between 8 and 12 kW. All heat pump systems operate in DHW and SH mode. Figure 4 shows the quantity of heat output from the heat pump for space heating and domestic hot water production and the total amount of heat delivered by the electric back up heater to the system during the measurement period of two years.
Three sites, number 8, 9 and 10, use a horizontal collector as heat source system, all the others are connected to borehole heat exchangers. Only the systems number 1, 6, 7 and 10 operate an electric back up heater. As the integrated back up heater in site 1 and 10 was operated only for a very short period of time, the amount of heat delivered by the back up heater of those systems was too small to be seen in Figure 7.

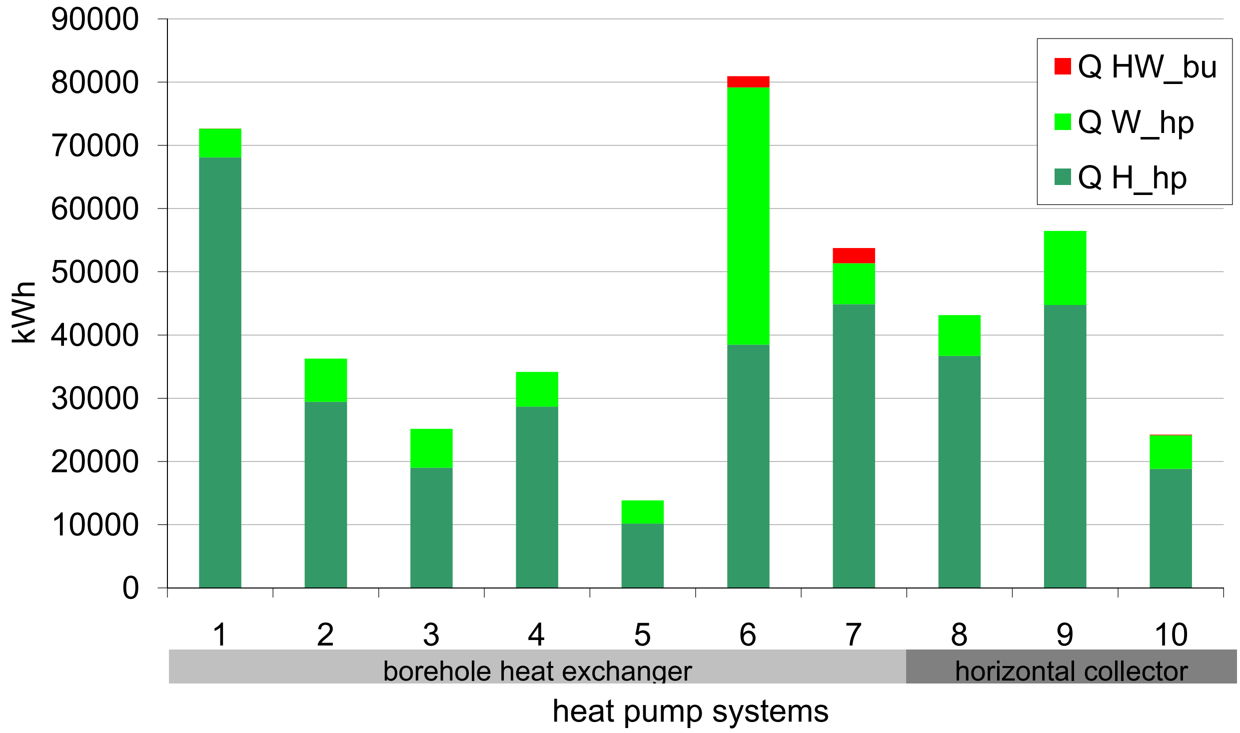

Figure 7: quantity of heat delivered by the heat pump and the back up heater

Due to the fact that only 4 systems were operating an electric back up heater, the energy coverage of the heat pump systems under surveillance is high and the results are between 95.5 % and 100 % (Figure 5). Additionally Figure 8 shows the ratio between heat used for space heating and domestic hot water production. Depending on the type of heat pump system the ratio is between 6 % and 51 %. The high demand on domestic hot water in site number 6 can be explained with different user behaviour. Excluding system number 6, the ratio between SH and DHW is between 6 % and 25 %, which is quite common for single family houses in Mid-Europe.

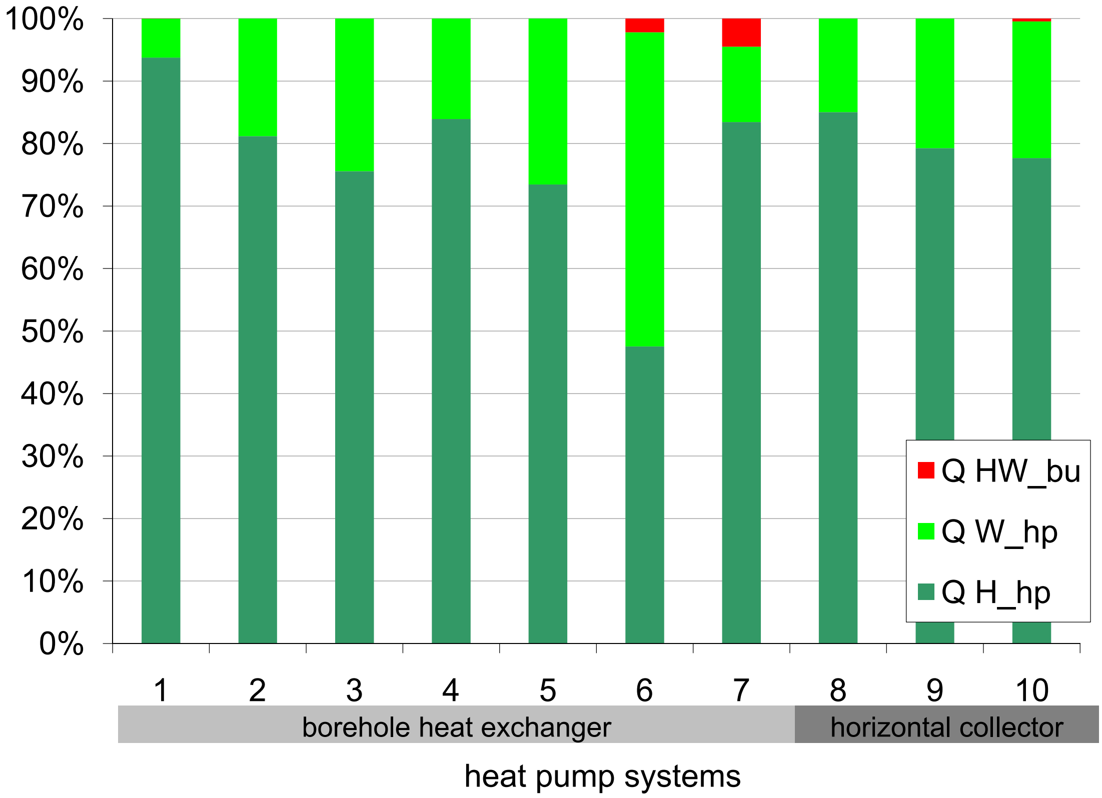

Figure 8: ratio between heat delivered by the heat pump and the back up heater

The total amount of electric energy needed to run the heat pump and its auxiliaries like circulating pumps and back up heaters are shown in Figure 9. Depending on the system design circulating pumps for a buffer tank are needed. Only the sites number 1, 4 and 9 have buffer tanks integrated in the space heating system, all the other heat pumps are directly connected to the heating distribution system. Due to the different system boundaries the auxiliaries will have influence on the SPF, which will be analysed later on in Figure 9.

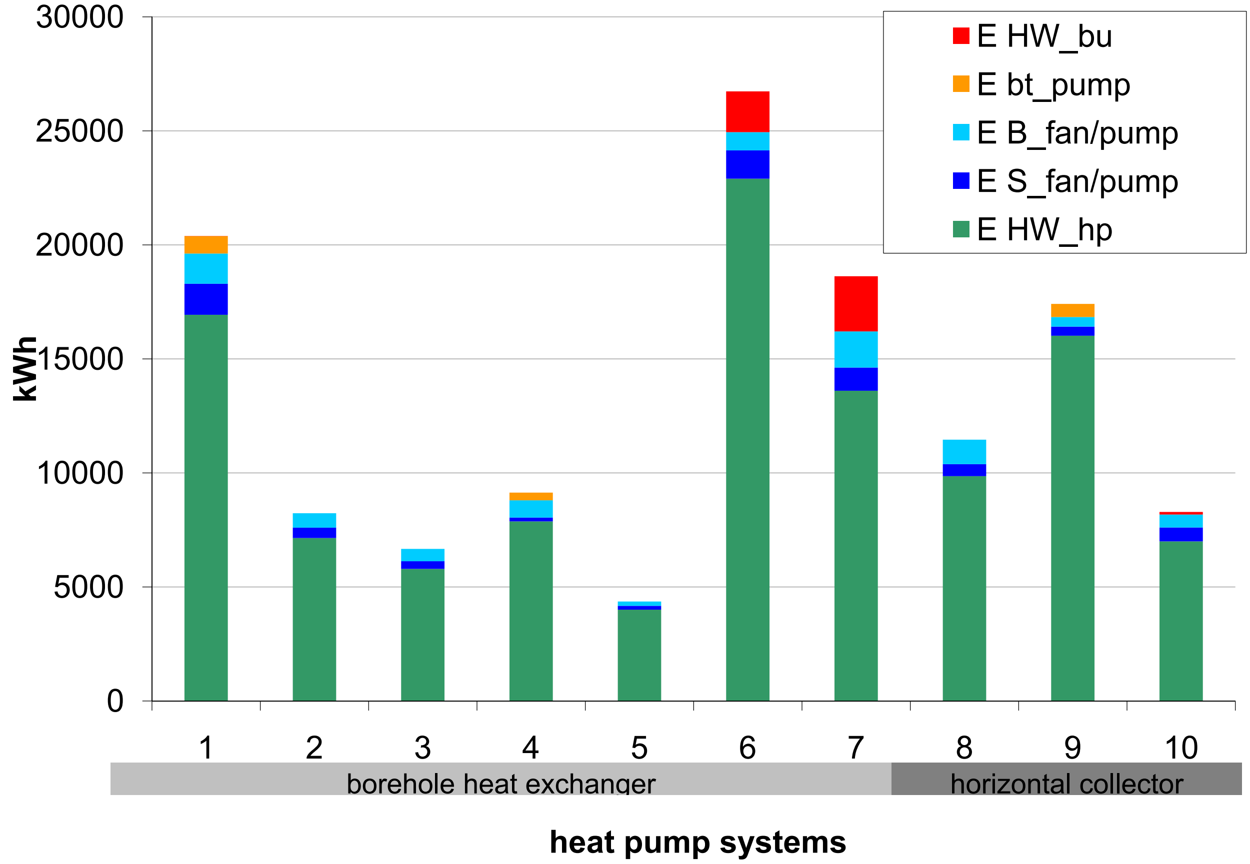

Figure 9: electrical energy demand of the heat pump and auxiliaries

Figure 10 shows the ratio between the total amount of electric energy needed to run the heat pump and the electric energy demand of the auxiliaries. The results for the electricity needed to operate the auxiliaries are between 8 % and 27 %. Additionally Figure 7 points out that the site numbers 1, 7 and 10 demand the highest amount of electric energy for their auxiliaries. System number 7 has the highest demand for the electric back up heater of all the systems, whereas site number 1 has the highest need for electric energy to run the buffer tank pump.

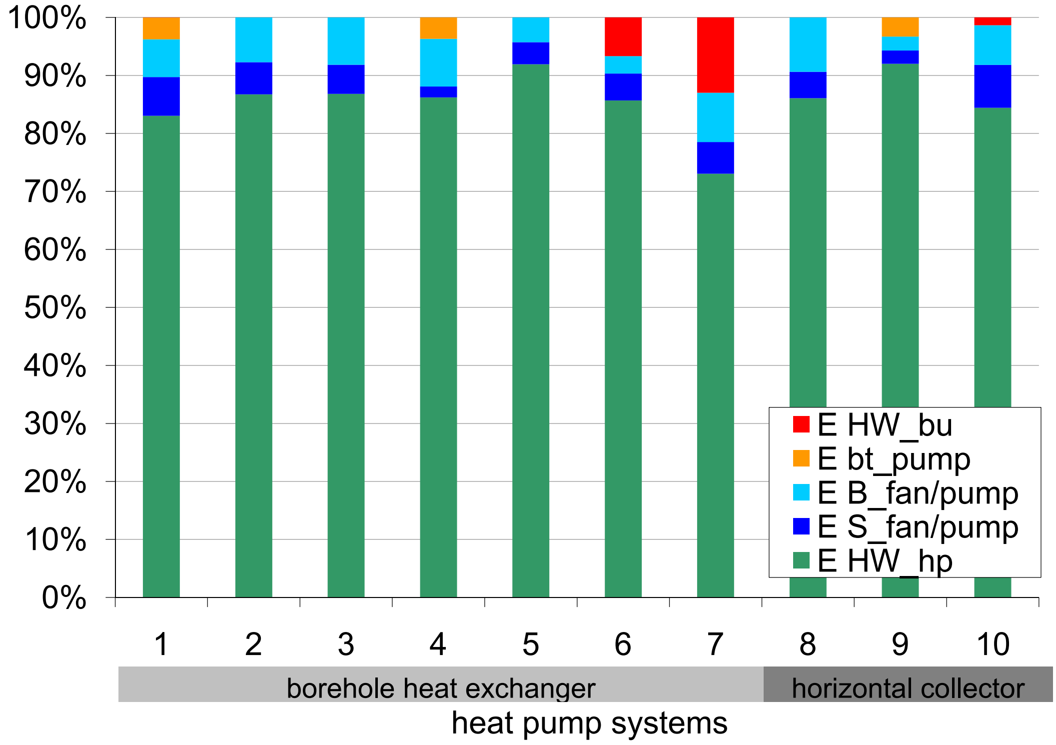

Figure 10: ratio between electrical energy demand by the heat pump and auxiliaries

On the one hand the system efficiency is influenced by the set system boundary, but on the other hand the operating conditions like the set temperatures on the heat sink side and the temperatures on the heat source side have an impact on the system efficiency. Figure 11 shows the average temperatures of the supply temperature for SH and DHW and the outlet temperature of the heat source during operation of the heat pump. Most of the systems showed supply temperatures for SH lower than 35 °C. Only the systems 3 and 5 displayed supply temperatures for SH higher than 40 °C. The average temperature for DHW is around 50 °C, except site 10 which had a rather high DHW-temperature of about 57 °C.

Furthermore Figure 11 shows the average heat source outlet temperature of the systems during operation, where system number 10 was operated with rather low heat source temperatures of about 0 °C. A too small designed horizontal collector could be the reason for that. On the other hand site number 3 and 7 show rather high temperature levels of their heat sources, which might be the result of well designed borehole heat exchangers. The temperature difference between heat sink and heat source influence the efficiency of the heat pump and therefore characterizes the operating conditions of the systems.

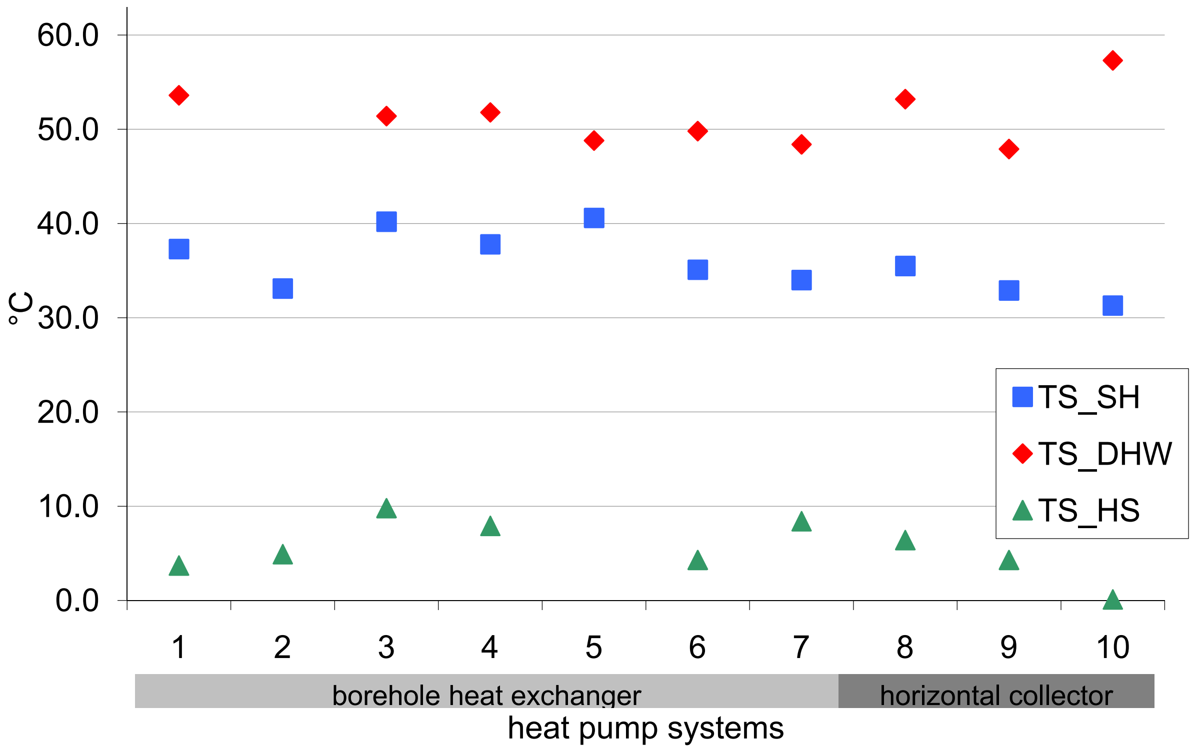

Figure 11: average heat sink and heat source temperatures during operation

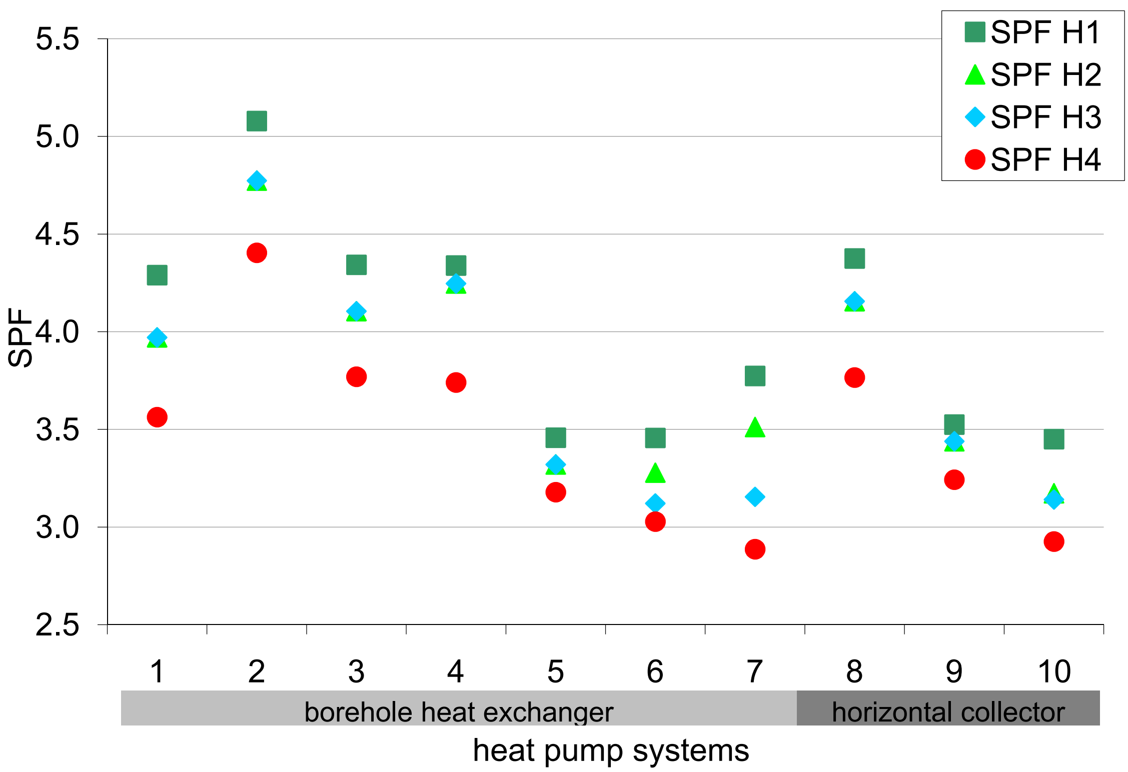

Figure 12: SPF according different system boundaries

The SPF calculated according to the four defined system boundaries SPF_{H1}, SPF_{H2}, SPF_{H3} and SPF_{H4} show how the efficiency of the different systems is influenced by the operating

conditions and by the system design, which directly impacts on the auxiliaries needed (Figure 12). According to the system boundaries SPF_{H2} and SPF_{H3} result in the same values when the systems do not have an electric back up, therefore only the sites number 6 and 7 show different results for SPF_{H2} and SPF_{H3}.
Sites number 1 and 7 have the largest differences between SPF_{H1} and SPF_{H4}. This can be due to the highest ratios between the total amount of electric energy needed to run the heat pump and the electric energy demand of the auxiliaries as explained above. In system number 7 the operation of the electric back up heater influences the result substantially. The big difference between SPF_{H1} and SPF_{H4} at site number 1 can be best explained with the high amount of electric energy demand for the buffer tank pump and the circulation pump in the heat source.
System number 4 shows the biggest drop between SPF_{H3} and SPF_{H4} of all the sites due to its highest amount of electric energy demand for the circulating pump in the heat sink and the buffer tank pump.
Due to its lowest heat source temperature and the highest temperature level for DHW the heat pump system number 10 has the lowest SPF_{H1}. Also site number 6 reaches a quite low SPF_{H1} compared to the other systems, which can be explained by the rather high ratio for DHW of 51 % as explained above.
Generally figure 12 points out that the different system boundaries show the impact of the integrated auxiliaries and that additionally for an interpretation of the SPF the operating conditions of the systems must be considered.

6 CONCLUSION

Measuring and reporting SPF of heat pump systems is an important means to determine the long term performance of the heat pump unit installed in the heating system. Depending on the specific topic to be reported, different system boundaries and hence different equations to determine the SPF should be used.
For comparing different field trials it is mandatory to use the same system boundaries for calculating the SPF as the definition of these boundaries directly influences the SPF of the system. In order to guarantee the quality of the recorded data to make a significant system evaluation it is highly important to set minimum requirements on the measurement equipment and in a second step, a proper equipment installation in the heat pump system is obligatory.
The efficiency of heat pumps systems represented as SPF is mainly influenced by the operating conditions and the set system boundaries for calculating the SPF. Therefore it is important to define minimum results for field trials in order to get a hint under which conditions the heat pump was operated. Furthermore it is necessary to calculate the SPF according to different system boundaries display the impact of the auxiliaries integrated in the system.
The IEE project SEPEMO-Build deals with these two main points in the “Concept for Evaluation of SPF“ [SEPEMO D4.2, 2010] and the “Field Measurement Guideline” [SEPEMO D4.1, 2011]. An analysis of the 10 selected ground coupled heat pump systems according to the defined system boundaries SPF_{H1}, SPF_{H2}, SPF_{H3} and SPF_{H4} together with the operating conditions shows, that the different system boundaries give a good overview on the impact of the different auxiliaries on the efficiency of the system, but to get the whole picture the operating conditions have to be taken into account.
By adopting this approach, different field measurements of heat pump systems will be much easier to compare in the future. It will also be easier to make comparisons to other heating systems efficiencies.

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