COMPARISON OF HEAT PUMP SPF FROM FIELD MEASUREMENTS WITH CALCULATION METHODS

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Abstract: In this study SPF is calculated for three of the four different system boundaries defined in the SEPEMO project. For seven facilities where the installed heat pump model also was tested in a laboratory, the laboratory test results were used to calculate SPF by using the calculation models used in standards. All analyzed heat pump systems are installed in Germany single family houses with floor heating. The heat pump is more or less comprehensive, only a very small amount of backup heat has been used during the year of measurement. The calculations of SPFs are based on the field measurements data from the Fraunhofer study. In the data we have received from the Fraunhofer study the total energy consumption for the heat pump system and its components is presented as well as the energy consumption divided into energy used for space heating and energy used for production of domestic hot water.

Key Words: Seasonal performance factor, Field measurements, calculation method

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 than electrical back up heater the energy content of the fuel has to be taken as input energy

1 INTRODUCTION

Heat pumps can supply a large part of renewable energy. This was established in the European RES directive (EU 2009). In this directive, it was laid down that aerothermal, geothermal and hydrothermal sources of energy are renewable. There is however a threshold on the efficiency of heat pumps in order to be classified as renewable. The efficiency criterion is put as an expression involving SPF, Seasonal Performance Factor for the heat pump.

Seasonal Performance Factor, SPF, is a term used mainly for real installations, compared to the Coefficient of performance, COP, which is evaluated in controlled lab environment. How SPF is estimated depends on the situation under which it is evaluated, see Figure 1 below.

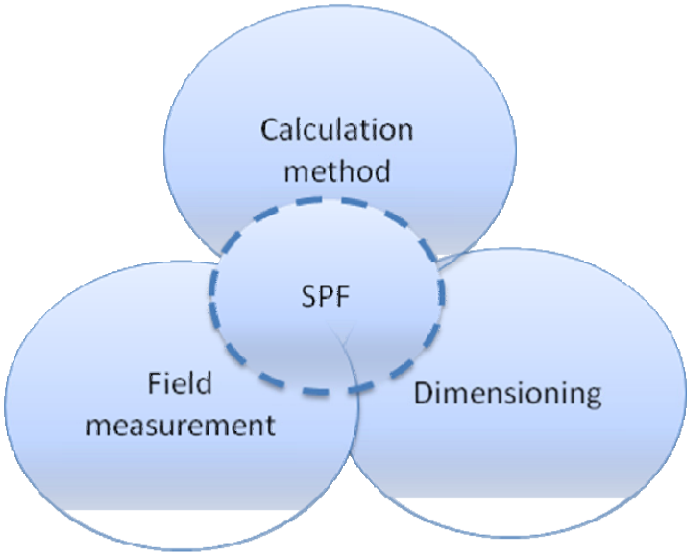

Figure 1. SPF can be determined in various ways, including field measurement, calculation methods and dimensioning software.

Based on lab measured performance data, SPF can be calculated according to calculation methods, that normally relates performance data in specific operating modes to annual climatic conditions, expressed as “bin models” where the number of hours in a year the temperature is between certain values are binned together. Model buildings are normally used to give annual heat demands and overall heat transfer resistances of the building.
For the installer of heat pumps, more specific details of the building must be prompted, as well as detailed data about the ground properties in the case of GSHP’s. Local climatic data is also used for estimating the heat demand. The climatic data contains a cold shock in order to dimension the heat pump capacity to extreme conditions that may occur during the lifetime of the installation. Other data such as the number of occupants, Domestic Hot Water (DHW) energy consumption is also normally entered in the software models for dimensioning.
To evaluate the real performance of the installed heat pump, field measurements are carried out to relate the useful heat produced to the energy input, often electrical power (but it could also be heat driven processes). The SPF of the heat pump is then often expressed as the ratio of the heat delivered to the heat distribution system (including DHW when relevant) to the electricity to operate the heat pump (including electricity to operate pumps and fans to bring the heat source to the heat pump).
The different level of detail given as input in the different stages of SPF calculation will lead to different SPF values.
This paper makes a comparison of field measured heat pumps performance with the calculated performance according to calculation methods included in European standards and in the Eco design (EU 2005) work undertaken by the European Comission. For the evaluation, measured data from the Fraunhofer field measurement study (Fraunhofer 2010) are used.

2 GENERAL INFORMATION ABOUT THE FIELD SITES

2.1 Heat (and Cooling-) Demand of the House

This study is focused on heat pumps for heating. The study is made for houses with different heat demand, and only ground source heat pumps are considered in this study. It is difficult to determine the actual energy demand of the house. When using the calculation models the required heat load of the house is decided by the capacity of the heat pump.

2.2 Indoor Climate

The indoor climate is expected to reach 20°C for all calculation models. In the calculation models the heat pump is used to reach a temperature of 16°C. Internal gains are expected to contribute to the final temperature increase. The actual indoor temperature has not been measured in the Fraunhofer field measurements. Thereby it is not possible to compare the real indoor temperatures with the temperatures estimated in the calculation models.

2.3 Outdoor Climate

The field measurements of the ground source heat pumps are carried out in Germany. The heat pumps installations used for the SPF calculations are spread over the country, from the Hamburg area in the north to Stuttgart in the south. The calculation models use the same temperature climate when calculating SPF for the ground source heat pumps. The climate corresponds to a European average climate defined in the Ecodesign Lot 1 (EU 2005) The "average climate" corresponding to Strasbourg, with the coldest temperature of -10°C has been used in the calculation models as this climate best corresponds to the German climate.

3 SYSTEM BOUNDARY DESCRIPTION

In the ongoing EU project SEPEMO-Build four SPF's with different system boundaries are defined. The definitions from the SEPEMO project (Zottl 2010) have been used for calculating the SPF for the field measurements. The four defined SPF's are (see Figure 2 for details):

SPF_{H1} includes only the heat pump unit itself. Thereby SPF_{H1} is identical to the average COP for the measured period.

$$SPF_{H1} = \frac{Q_{H\_hp} + Q_{W\_hp}}{E_{HW\_hp}}$$

SPF_{H2} consist of the heat pump unit and the equipment needed to make the heat source available the heat pump.

$$SPF_{H2} = \frac{Q_{H\_hp} + Q_{W\_hp}}{E_{S\_fan/pump} + E_{HW\_hp}}$$

SPF_{H3} represents the heat pump system SPF. SPF_{H3} includes the heat pump and the heat source pump as in SPF_{H2}, but also the back up heater.

$$SPF_{H3} = \frac{Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu}}{E_{S\_fan/pump} + E_{HW\_hp} + E_{HW\_bu}}$$

SPF $_{H4}$ includes all parts related to SPF $_{H3}$, additionally SPF $_{H4}$ also includes the equipment used for the distribution of the heat.

$$SPF_{H4} = \frac{Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu} + Q_{DHW\_bu}}{E_{S\_fan/pump} + E_{HW\_hp} + E_{bt\_pump} + E_{HW\_bu} + E_{B\_fan/pump}}$$

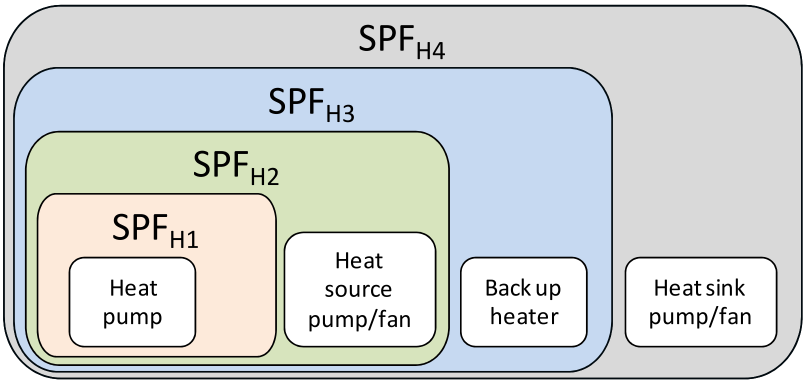

Figure 2 System boundaries for calculations of SPF

SPF$_{H1}$ is normally measured on the brine/water sides of the evaporator/condenser, but it could also be measured directly in the refrigeration loop with e.g. the Climacheck equipment (Climacheck 2010). This requires measurement of the pressure and temperature of the refrigerant. This methodology is very efficient if the status/condition or diagnosis of the heat pump is to be evaluated, but generally in domestic heat pumps, the measurement is not easy to carry out since measurement sockets are not generally installed.

4 CALCULATION OF SPF

In this study SPF is calculated for three of the four different system boundaries and categories by using data from the field measurements. The system boundaries used are SPF$_{H2}$, SPF$_{H3}$ and SPF$_{H4}$. The categories are “heating only”, “heating and domestic hot water production” and “domestic hot water production”. For facilities where the installed heat pump also has been tested in a laboratory, the laboratory test results were used to calculate the SPF by using the calculation models. This is the case for seven of the ground source heat pumps.

This chapter will explain how the calculations are performed and what assumptions are made for the different models.

4.1 Field Measurements

All analyzed heat pump systems were installed in German single family houses with floor heating. The heat pump is more or less monovalent, only a very small amount of backup heat has been used during the year of measurements. The heat pumps in the study were all installed in new built houses during the years 2004-2008. The data used for the SPF calculations are based on field measurements carried out during one year, with one exception the SPF for site no. 1 is based on data measured from January to August. The calculations of SPF’s are based on the field measurements data from the Fraunhofer study. In the data we have received from the Fraunhofer study the total energy consumption for the heat pump system and its components is presented as well as the energy consumption divided into energy used for space heating and energy used for production of domestic hot water. In this project we have not been able to evaluate exactly how these allocations have been made.

For some of the studied installation sites a part (up to 20%) of the total electricity consumption has been allocated neither to space heating nor to the domestic hot water production. This is mainly the case for the electricity consumption. For the heat produced no energy gap is seen between the total energy production and the energy divided into space heating and domestic hot water.

The calculated SPF's in the study are based on the energy allocated to the space heating only, this in order to make the results comparable to the results from the calculation models in prEN14825 (CEN 2009) and Lot 1 (EU 2005), which not include the production of domestic hot water.

4.2 Calculation Models

Today, challenges exist since there are several calculation methods used to calculate the SPF of heat pumps. In this paper, two of the methods have been investigated and compared with results from field measurements, CEN prEN14825 and the Lot 1 model of the Ecodesign.

Table 1. Brief description of the used calculation models.

Method	Type of model	Information
prEN 14825	CEN standard	3 climate zones In data based on lab measurements according to the standard EN 14511, but don't require interpolation of tested data or test at part load conditions.
Lot 1	Part of the ecodesign directive	3 climate zones In data based on lab measurements according to the standard EN 14511, but don't require interpolation of tested data or test at part load conditions. Alternatively a so called"Best testing practice" can be used (deviates from EN14511).

4.2.1 prEN14825

When using prEN14825, data according to Table 2 has to be filled in. The chosen climate, "average" gives that T_{design} is -10°C. $T_{bivalent}$ is the outdoor temperature where the capacity of heat pump covers the heat demand of the house. It is set to -10°C, to make the heat pump monovalent, like in the field study. TOL, the operation limit temperature, is set to -25°C. This temperature declares where the heat pump no longer can operate. The model calculates P_{design} as a result of $T_{bivalent}$ and is the heat demand of the house at T_{design}.

Table 2. Input data for the prEN14825 calculation model.

T_{design}	-10	°C
$T_{bivalent}$	-10	°C
TOL	-25,00	°C
P_{design}	8,81	kW

The test conditions for the heat pumps were taken from Table 20 in the standard, brine to water heat pump, average climate and low temperature application. The unit is assumed to be a fixed capacity unit with fixed outlet temperature. The heat pumps in the study where all tested in full load according to EN 14511. For the part load conditions the COP was calculated by using equation 12 in the standard. The test point used for the calculations was the 30°C/35°C point from EN 14511 laboratory data. The capacity and COP at $T_{bivalent}$ and TOL is set to the maximum, while the COP for the delivered capacity at the different outdoor temperatures is calculated by using equations from the standard prEN14825. The default degradation factor Cc=0.9 is used.

4.2.2 Ecodesign Lot 1 model

In Lot 1 there are some general inputs that have to be filled in into the excel sheet. The following inputs are used:
Reduced setback: Yes
Radiator (with setback): No
Floor heat (24h): Yes
Control: 4 – Weather ctrl BT
Pump: 3 fixed speed
Pump timer: 24h
Buffer: No
Tmino: -25°C

The only heat generator in use is the heat pump. No back up heater is included in the calculations. The default degradation factor, Cd= 0.15, is used. Default is also used for hpaux (=30W) and hpsb (=10W). The test conditions are taken from the reference test conditions in table V.3. in the standard. The test point used for the calculations was the 30°C/35°C point from EN 14511 laboratory data. The model recalculates the test data to fit with the test conditions of Lot 1 (table V.2.) Data for part load operation is calculated from equations of “option B” at page 27 in the standard, where COP_{min}= 0.89*COP at power output Phpmin=0.5*Php for a fixed capacity unit. From Lot 1 two different results are obtained, “etas” and “average COP”. Etas are calculated by involving the primary energy factor of 2.5 which makes it difficult to compare with other calculated SPF. However, “average COP” corresponds to SPF_{H1}.

5 RESULTS

The results from the SPF calculations of the different heat pump installations in field is compared with the results obtained from the calculation models using laboratory data as input. Most of the heat pumps installed in field operates both in floor heating mode and produces domestic hot water. The measurements include both kind of operations and the results are presented in Table 2 and Figure 3 below. SPF for domestic hot water production is always lower compared to operation in heating mode. The energy balances is not 100% complete for the field measurement, which is quite common in field measurements, since heat losses are present, but cannot be measured directly as they can be in the laboratory.

Table 3. The table shows two different SPF from the field measurements in two different levels. SPF for heating and DHW (domestic hot water) is lower than SPF for heating only. This is because COP for domestic hot water production is lower than COP for heating

Results field measurements				
	Heating and DHW	Heating and DHW	Heating only	Heating only
	SPF_{H1}	**SPF_{H3}**	**SPF_{H1}**	**SPF_{H3}**
site 3	3,70	3,46	4,66	
site 6			3,86	3,43
site 8	4,13	3,02	4,71	
site 9	3,97	3,64	4,53	
site 11	3,62	3,32	4,71	4,56
site 13	2,71	2,55	3,99	3,83
site 14	4,14	3,55	5,43	5,16

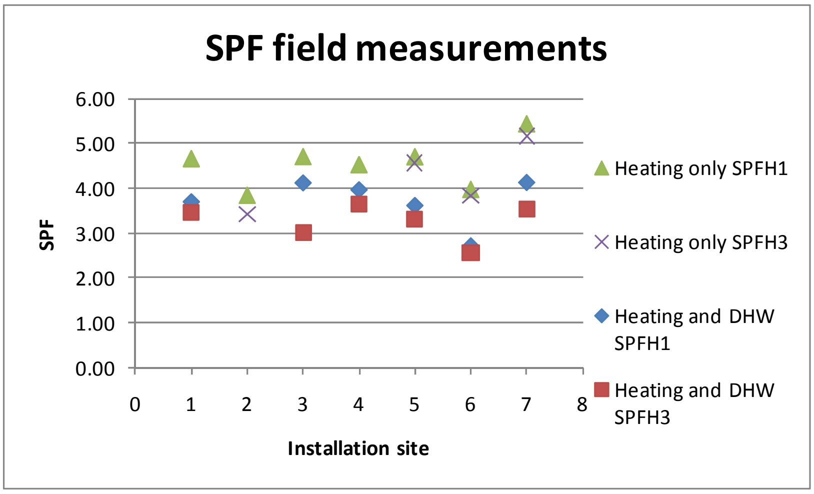

Figure 3 The figure show SPF results from two different SPF, “heat only” and “heat and DHW” (domestic hot water heating) at two different levels, “SPF_{H1}” and “SPF_{H3}”, from field testing.

The conditions for measurements in a laboratory and in field differ with respect to various factors e.g. the boundary conditions. SPF_{H1} in field measurements includes the electrical energy from the heat source brine pump, while “average COP” and “$SCOP_{net}$” only includes the head losses. This could make the electrical energy use a little larger for the field measurements, but on the other hand “average COP” and “$SCOP_{net}$” also contain head losses for the heat sink side which SPF_{H1} does not. The electrical energy from the heat sink pump for SPF_{H1} is included in SPF_{H3}.

Table 4. The table shows the results from using Lot 1. Average COP is comparable with SPF_{H1} from the field measurements. P_{design} shows the maximum capacity needed for the house

Results Lot 1			
	avg COP	etas	Pdesign
site 3	3,57	1,05	7,7
site 6	3,49	1,03	7,6
site 8	3,49	1,02	5,9
site 9	3,49	1,03	7,6
site 11	3,83	1,12	7,2
site 13	3,88	1,12	5,8
site 14	3,88	1,12	5,8

Table 5. The table shows results from using prEN14825. $SCOP_{net}$ is comparable with SPF_{H1} from the field measurements. P_{design} shows the maximum capacity needed for the house.

Results prEN14825			
	SCOPon	SCOPnet	Pdesign
site 3	3,66	3,66	8,81
site 6	3,58	3,58	8,7
site 8	3,6	3,6	7,17
site 9	3,58	3,58	8,7
site 11	3,96	3,96	9,64
site 13	4,02	4,02	8,01
site 14	4,02	4,02	8,01

Since the ground source heat pumps in this study are considered monovalent, the comparison of the results are mainly done for SPF_1 from the field measurements and SPF that corresponds to SPF_{H1} from the calculation models, “average COP” from Lot 1 and “$SCOP_{net}$” from prEN14825. The results are presented in Figure 4 below.

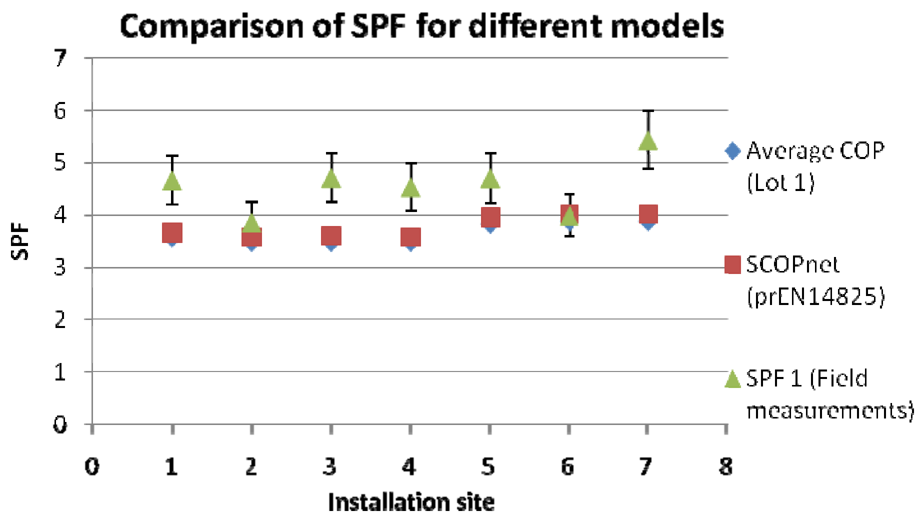

Figure 4. The figure shows a trend that SPF_{H1} is higher compared to "average COP" and "$SCOP_{net}$". Field measurements imply a higher uncertainty compared to measurements in a laboratory. The bars show an error of ±10% to cover the margins of error.

There are two main differences between "average COP" and "$SCOP_{net}$":

- There are differences in degradation for part load operation
- Lot 1 does not make a capacity balance of the heating demand of the house at each outdoor temperature.

The second factor results in that the design capacity, P_{design}, turns out to be larger for the house when using $SCOP_{net}$ compared to "average COP". The result show that P_{design} for "average COP" is approximately 13-28% lower compared to "average COP" and SPF is approximately 3-4% lower. The degradation of COP is a little bit tougher when using Lot 1 compared to using prEN14825. The comparison is illustrated in Figure 5 below.

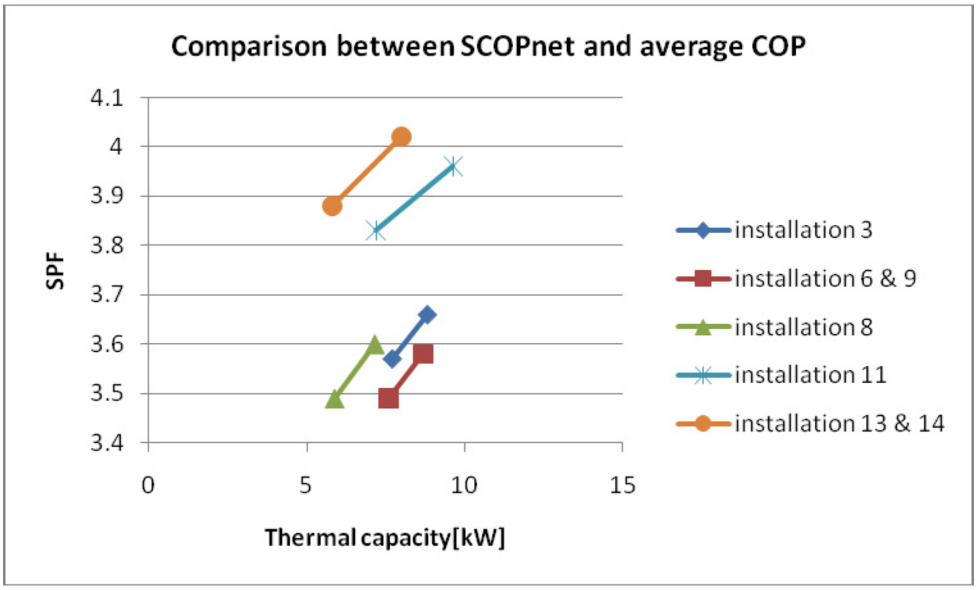

Figure 5. The figure illustrates the differences in design capacity when using EuP Lot 1 and prEN14825. The lower value corresponds to Lot 1 and the higher value corresponds to prEN14825.

6 CONCLUSIONS

SPF values calculated with the calculation models are frequently underestimating the SPF values compared to the SPF's measured in the field. It is important to further analyze this, since there is a risk that the energy saving potential as well as the RES contribution from heat pumps is underestimated.

The importance of SPF will increase with the Lot 1 coming into force. There is therefore important to have clear and transparent definitions on how the SPF should be calculated, and the definition should be accompanied by relevant system boundaries.

There is a need to further improve the accordance between field measurements and calculation models. In order to have better agreement between calculated and measured data, more factors than are used presently should be included in the calculation models. Among other things, a better representation of the heat source temperature should be taken into account.

Some of the field installations show different SPF_{H1} despite the same heat pump model is installed. This can be an indication of how important the sizing of the heat pump is. An oversized heat pump results in for example more part load operation and causes standby losses.

The calculation models show that there can be benefits when installing a heat pump where the bivalent temperature is higher than the lowest operation temperature of the year, even though backup heating is necessary.

We did not make an estimation of the measurement uncertainty in this work. Uncertainties in field measurements can easily be +/- 10 % or greater when assumptions regarding climate etc are considered.

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