MINIMUM ENERGY SPECIFICATIONS FOR COMPLEX HEAT PUMP SYSTEMS

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Abstract: From its special power saving fund the City of Zurich promotes, among other projects, the efficient use of electrical power consumed by heat pump systems. The existing test procedure for evaluating these systems has weaknesses in connection with large or complex installations: For this reason a test procedure has been prepared within the framework of a research project. With the aid of this standard procedure minimum energy specifications can be calculated as a basis for financial support for individual heat pump systems. In order to be able to take into account the complex specifications demanded for such systems and the wide spectrum available, the process has a modular design. The complete heat pump system was divided into three sectors: the heat source, the heat pump and the local heating network. With the help of a structogram, the most important energy impact factors can be taken into account according to the type of heat source, the type of system or application and the heating concept. Thus minimum energy specifications can be defined for a wide spectrum of systems with differing general conditions. In a subsequent project the test procedure can be checked for its use in practical applications on the basis of data samples compiled from a wider range of actual systems.

Key Words: ***Simple test procedure for large heat pumps, energy promotion criteria, minimum SPF for large heat pumps***

1 INTRODUCTION

The City of Zurich has been following an active energy policy for several years. The goals of this policy are in particular to reduce CO_2 emissions, to promote the rational use of energy and to advance the use of renewable energy sources. The city's own power facility ewz possesses power generation installations which emit practically no CO_2. Moreover, for efficient heat pump systems a promotion tariff is offered which, however, is dependent on using electricity products having the standard label „naturemade basic" as minimum. Energy-saving heat pump systems used for providing heating and hot water are also supported by granting investment contributions from Zurich's power saving fund. To receive a grant, certain criteria have to be met in connection with energy efficiency and non-profitability. For smaller systems the COP specifications demanded by the D-A-CH quality label[1] must be met and for complex systems a minimum Seasonal Performance Factor (SPF) is required, which is determined individually based on data obtained in practice. The test is carried out by specialists from the city's power facility ewz on the basis of system planning data quoted by the applicants. This test is not simple and up till now has not always provided satisfactory results.

[1] Promotion Association from Germany (D, IWP Initiativkreis Wärmepumpe e.V.), Austria (A, LGW Leistungsgemeinschaft Wärmepumpen), and Switzerland (CH, FWS), abbreviated D-A-CH, have created a common heat pump quality label, valid in all 3 countries. N extension to cover all of Europe is in preparation. For details see http://www.fws.ch/fws_061.html

For this reason at the beginning of 2006 a working group was formed from internal and external specialists in order, in an initial phase, to prepare a proposal for a systematic test procedure to enable an energy assessment of large and complex heat pump systems.

The members of the working group were:
- Bruno Bébié, energy deputy of the City of Zurich, initiator
- George Dubacher, ewz, manager of energy services
- Max Ehrbar, Enertec AG
- Peter Hubacher, Hubacher Engineering
- Jörg Ruosch, ewz, heat pump specialist, energy consultant to small and medium-size companies

The results of project phase 1 have been available since the middle of 2007. In a second phase these results will be consolidated and thoroughly verified on the basis of a larger number of data samples from actual systems. The Swiss Federal Office of Energy together with cantons Zurich and Basel City are now participating in this project.
This paper summarises the results of project phase 1.

2 PROJECT GOALS AND PROCEDURE

The main goal was to prepare a simple assessment tool to permit valid tests of large and complex heat pump systems submitted for support grants. An important aspect was to determine the minimum Seasonal Performance Factor (SPF), taking into account the most important influencing factors on both the source and sink side. Moreover as far as possible clear, effective, simple and easy to use assessment criteria should be made available. To achieve this the most important parameters from large heat pump systems, which have the greatest impact on the SPF, were analysed. The extremely complex matter was reduced down to a simple structure. This procedure demanded intensive work and creativity. The project team had no knowledge of any other investigations to which it could refer.

3 SYSTEM LIMITS

The system spectrum was divided into different types according the heat source, the type of system or application and heating concept. It was decided not to handle systems with double function for heating and cooling although such systems are becoming increasingly popular.

The following are the categories for the type of heat source:

a) Ground heat as source
   - ground-heat probe with brine, water/glycol mixture
   - ground-heat probe with water

b) Water as source:
   - ground water
   - surface water
   - waste water

c) Air as source
   - ambient air
   - exhaust air (heat use)

The following are the categories for the type of system and application:

d) hot water

e) room heating

f) energy for work processes

The following are the categories for the heating concept:

g) Monovalent operation: heat pump alone

h) Mono energy operation: heat pump and electro-heat storage device for peak loads

i) Bivalent operation:
- alternative operation
- parallel operation
- part parallel operation

4 ASSESSMENT LIMITS

To calculate the expected value of the Seasonal Performance Factor SPF, the heat pump system was divided into three sectors: the heat source HS, the heat pump HP and the local heating network LHN. We differentiated between single building applications and multi-building applications (networks). In single building applications, each building has its own heat generating system. In multi-building applications several separate buildings are supplied by a common heating system via a local heating network.

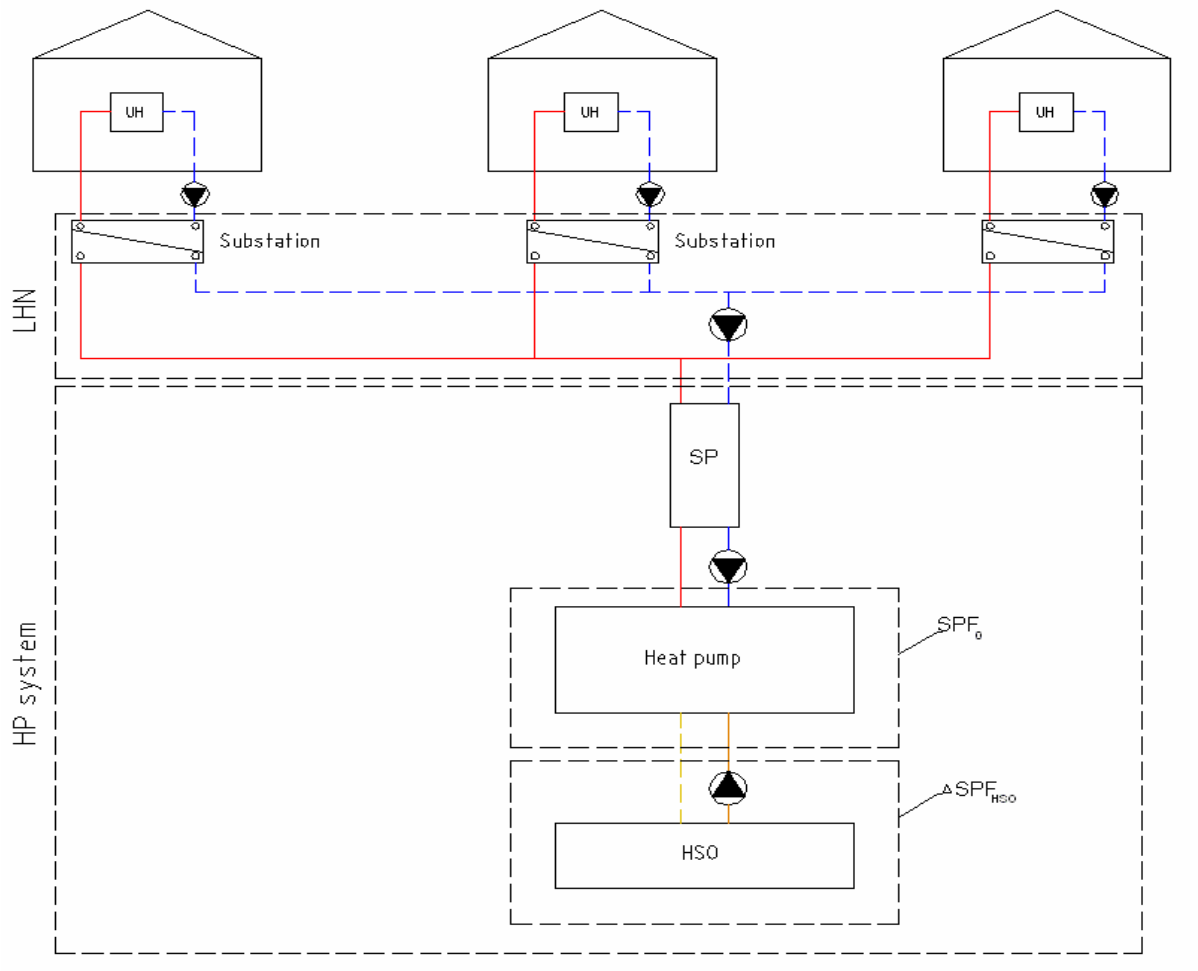


Figure 1: Assessment limits

4.1 Basic idea of procedure: modular system

In future to determine the amount of investment subvention for heat pump systems, among other things, an SPF should be calculated on the basis of empirical values. This is to be used on the one hand to check the plausibility of the SPF submitted by the applicant, and on the other hand to determine the amount of the subvention to be granted. The SPF will consist of several elements in modular form. The core element, the so-called SPFo, deals only with the energy consumed by the compressor. Auxiliary energy consumers are taken into account step by step and the necessary deductions made. If, at the same time, hot water is to be supplied, a further correction factor is necessary. In order to ensure that the assessment tool is easy to use, the various impacts and dependencies need to be so structured that each one can be dealt with individually and then combined in a completely integrated package.

The subdivision procedure is as follows:

- Pro heat source an SPF is specified which is dependent on the flow temperature set at the design stage. The SPFo is the performance factor which does not take into account losses occurring in the local heating network (heat losses, pump power, temperature differences). Pump power and temperature differences are also not taken into account on the source side.
- In the following, the standard values are quoted which are used for systems without special specifications available for the calculation:
  - The flow temperature from the condenser runs in step with heating requirements
  - For the heat source „air“, the long-standing climatic conditions according to SIA 2028[2] for the relevant location with the mean ambient temperature during the heating period are applied as standard for the temperature of the source. This has the advantage that data from all altitudes and waste heat systems are easy to acquire (parallel graphs with parameterised mean temperatures)
  - For ground water a temperature of 10°C is assumed
  - For treated waste water a temperature of 8°C is applied; for untreated waste water 10°C
- Finally successive deductions from the SPF are made for the heat source system HSO ($б_{HSO}$) and the local heating network LHN ($б_{sink}$) (see figures 2 and [1]).
- SPFo minus the deductions HSO and LHN gives the minimum specified SPF that permits the investment subvention from Zurich‘s power saving fund to be granted (see figure 2)
- When there is a local heating network, the distribution system produces further losses ($б_{sink}$) which also reduce the efficiency of the heat pump system.
- When the heat source for the heat pump is air/water the SPFo also includes the energy needed for the fan and defrosting.

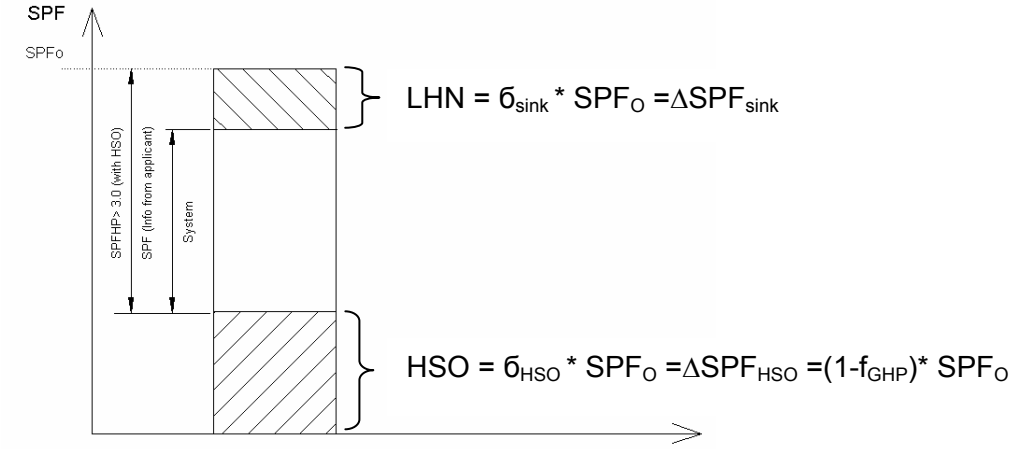


Figure 2: Graph of Seasonal Performance Factor SPF

[2] The new SIA standard 2028 contains climatic data from 40 weather stations in Switzerland

Losses produced in the local heating network are not taken into account in SPFwp (assessment limit see figure 1).
Figure 3 shows the modular system of the structogram for the procedure which is explained more fully in the following sections. Starting with the SPFo the procedure takes into account step by step the energy consumption on the heat source side and also for the heat energy distribution and hot water supply.

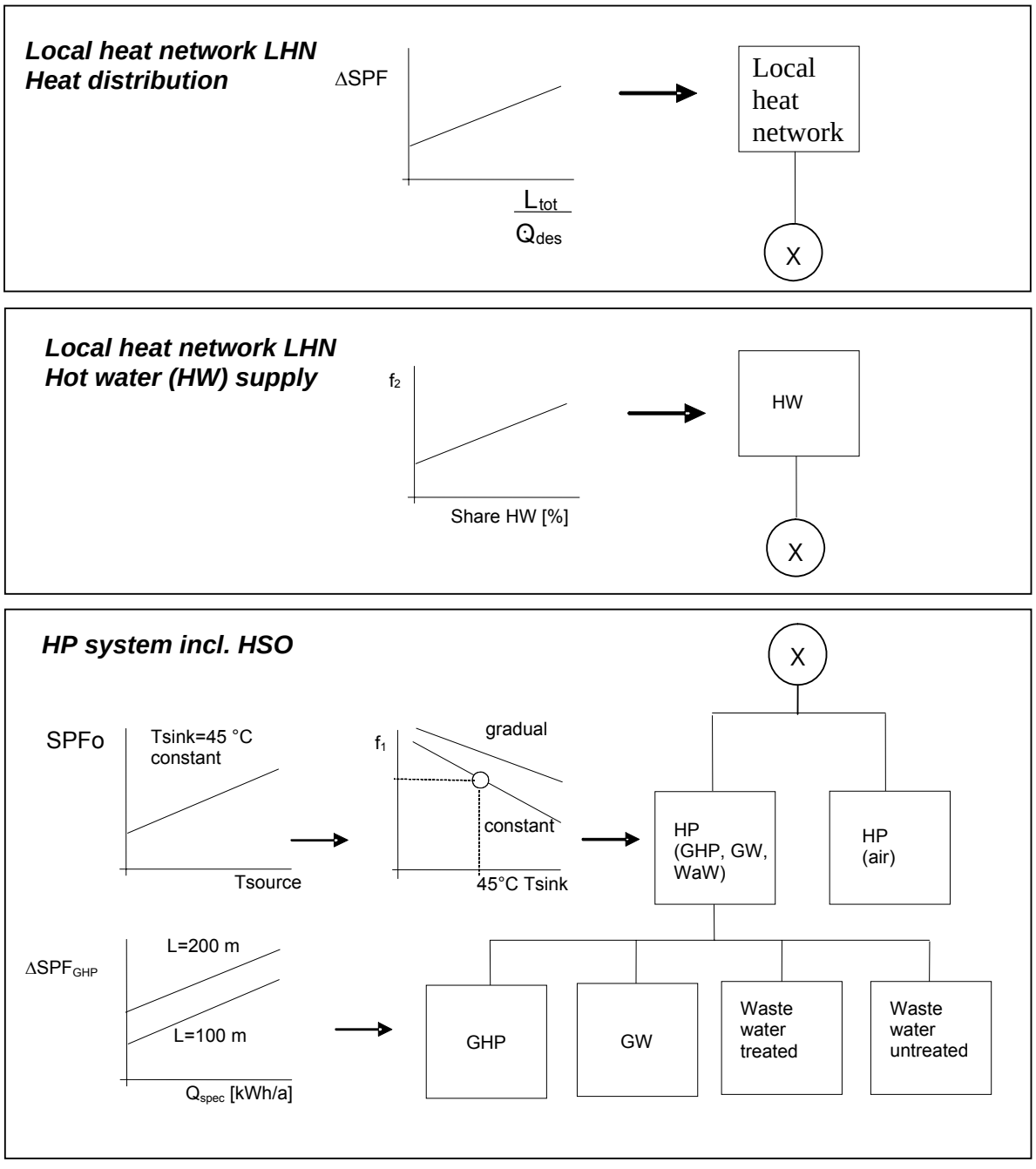


Figure 3: Structogram for calculating the SPF

5 SEASONAL PERFORMANCE FACTOR SPFo

A basic diagram is prepared for the SPFo for each heat source.
SMA Zurich is selected as climatic basis.

The basic diagram is prepared for the following sectors:

- Ground heat probes
- Ambient/exhaust air
- Ground water and surface water

5.1 Determining the SPFo

The starting point for determining the minimum acceptable SPF is the SPFo which is calculated from the model of the heat pump power, the course of the flow temperature and the course of the ambient temperature. It sets the highest possible seasonal performance factor for the given limiting conditions (course, environment, heat pump).
These limiting conditions are system-dependent. The selection of the flow temperature set at the design stage is the responsibility of the system planner. The annual course of the flow temperature is dependent on the operational concept. All of these can be taken into account, but much more work was involved and therefore it was decided not to take the individual flow temperatures into account. Limits for the assumptions are either a constant flow or a reducing flow according to the heating law. The „truth“ lies somewhere between. As basis we take the flow temperature into the heat distribution network and not the flow from the condenser. If the flow from the condenser is higher than the required flow for the heat distribution, this is not an optimum thermodynamic solution. The system planner’s goal must be to achieve the lowest possible increase in the flow from the condenser compared with the flow in the heat distribution network. A difference between the two flows is produced when either a local heating network is connected between them or when a heat storage unit is used.

The source temperature is naturally dependent on the type of source actually used. When the heat source is air, the ambient temperature is taken as the source temperature. For surface water it is the inflow temperature (any intermediate cycles are not taken into account). In this case a mean annual temperature is assumed. Annual temperature trends are not considered.

A central component is the heat pump itself. The heat produced and the electrical power consumed by the compressor are dependent on the design of the machine and its components. In this case either the results from a type approval test or the technical data quoted by the manufacturer can be used. The question here, however, is whether the data supplied by the manufacturer is to be simply accepted or whether empirical values from known good machines should be accepted for the SPF as basis for granting subvention on the investment. We advocate the second option for two reasons: The main purpose of such state subventions, among others, is to increase efficiency. The test procedure is considerably simpler if it is based on a standard model. If the machine is equipped with a power regulator, the full load is quoted for the heat pump model.

Under these conditions it is now possible to calculate an SPFo for every type of heat source and all types of application as a function of the flow temperature set at the design stage. The various types of application are reflected in the fixing of the flow temperature.

6 DESCRIPTION OF THE SPF ESTIMATE

The procedure is explained in the following steps for applications with a water/water heat pump and a brine/water heat pump.

6.1 SPFo for water/water and brine/water heat pump with local heating network

To carry out the test on the system, the seasonal performance factor is estimated on the basis of several key characteristics of the planned system. The estimates are based on mean values of actual systems and model calculations. The tester proceeds as follows:

6.1.1 Determining the SPFo (without heat source)

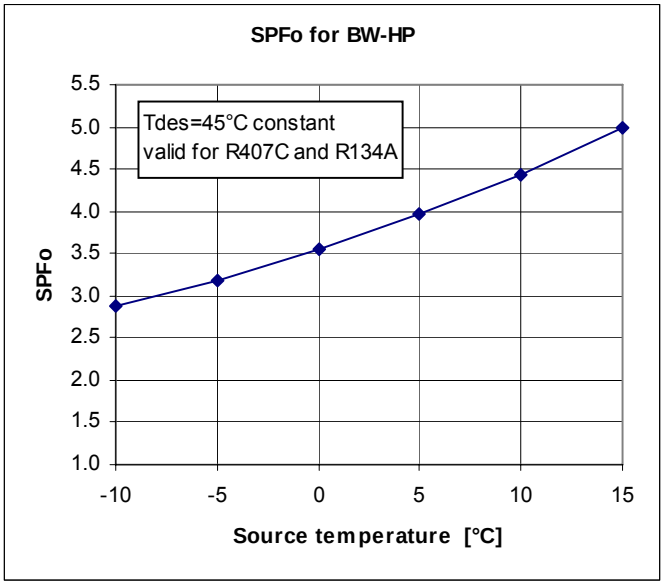


Figure 4: Basic diagram SPFo BW-HP

Figure 4 shows the SPFo determined for the example with a brine/water heat pump. The basis of the diagram is the mean value of the manufacturer's data which is based on 9 machines from two manufacturers in the power range 50 to 370 kW heat output. The source temperature to be entered is the ground water or brine temperature measured over the duration of the heating period. Note that a constant flow temperature of 45°C is valid for the diagram.

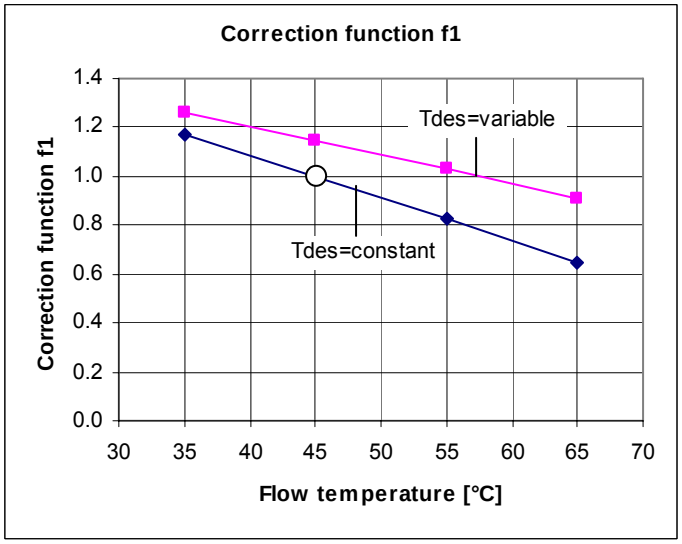


Figure 5: Correction function f1

$$SPF_{o,corr} = SPF_o * f_1$$

If the system data deviates from the basic value of a constant flow temperature of 45°C, the basic performance factor SPFo has to be corrected. This is carried out according to the above-mentioned information in figure 5.

For hot water supply it must be noted whether feeding is carried out with a constant temperature (layers) or gradual. For constant feeding, the hot water rated value can be used while for “gradual” a mean value between the initial feed condition and the hot water (HW) rated value is recommended (typical value approx. 40°C).

6.1.2 Taking into account the heat source water (ground water/surface water)

The performance factor SPFo does not include power required by auxiliary drives and any losses from the heat source system and local heating network (if available). These factors are taken into account account in a separate step to structogram figure 3. Figure 6 shows the impact of the power used for pumping the ground water.

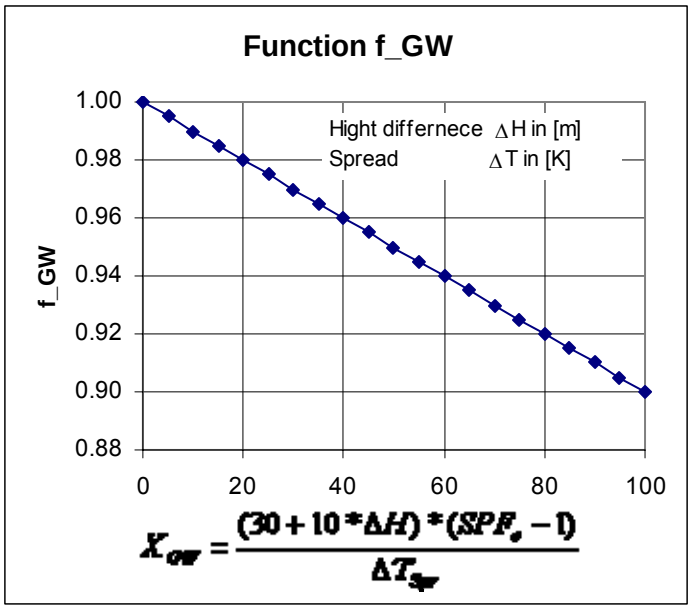


Figure 6: Correction function f_GW to take into account for pump power on the heat source side

If an intermediate cycle is used, the following expression has to be used instead of the x axis quantity:

$$\frac{(30+10*\Delta H)*(SPF_o-1)}{\Delta T_{spr}} * \frac{P_{el,GW}+P_{el,ZK}}{P_{el,GW}}$$

Pel,GW = electric power of ground water pump
Pel,ZK = electric power of intermediate cycle pump

Figure 7 shows the impact of the temperature differences when an intermediate cycle is used.

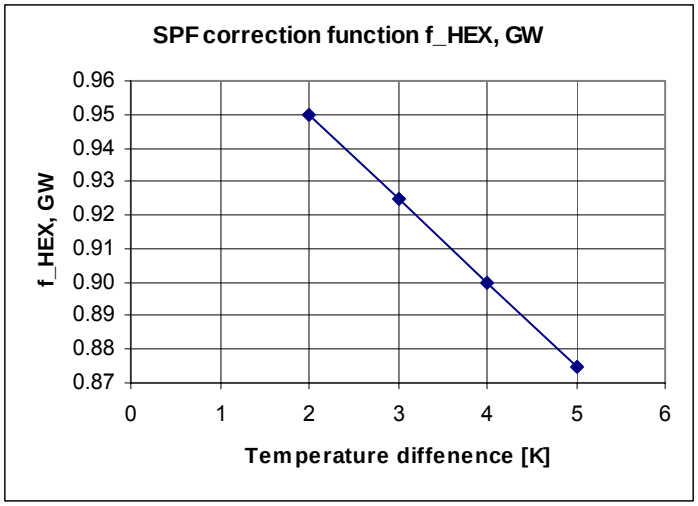


Figure 7: SPF function f_HEX, GW to take into account temperature decline in difference intermediate heat exchanger

6.1.3 Taking into account the impact of the heat source system (ground heat probe)

The performance factor SPFo does not include power required by auxiliary drives or any losses from the heat source system and local heating network (if available). These factors are taken into account in a second step according to structogram figure 3. The following diagram describes the procedure with a fluid having 25% glycol. The most important factor to be considered is the energy consumption of the brine pump. The pump energy consumption is described in figure 8 for the ground heat probe GHP 32 and 40 mm (external diameter).

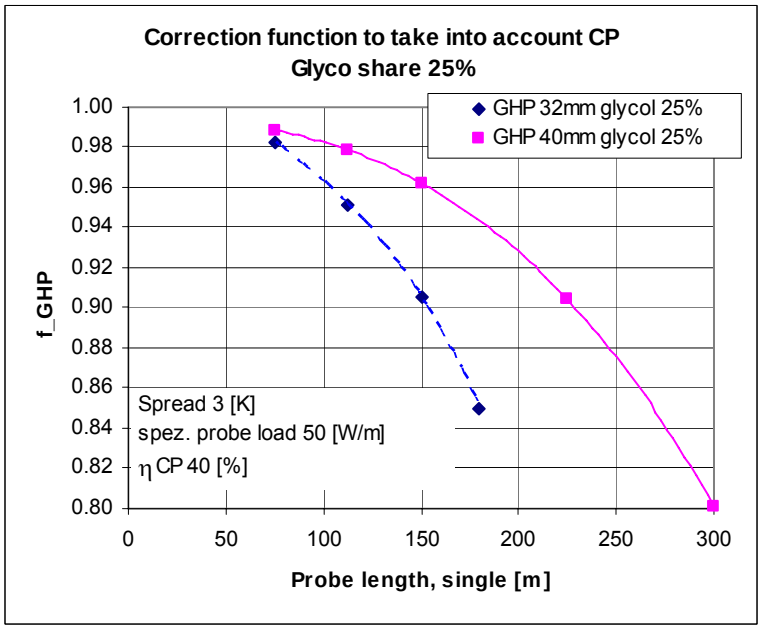


Figure 8: Correction factor to take into account the pump power GHP

If the spread is not 3 [K] and the pump efficiency η_{UP} is not 40% the value f_{GHP} is converted as follows:

$$f_{GHP} = f_{GHP,3[K]} * \left(\frac{3}{\Delta T_{spr}} \right)^{1.8} * \frac{40}{\eta_{UP}}$$

6.1.4 Taking into account a local heating network (LHN, if used)

When an application has a local heating network, additional energy is consumed by the pump required and also due to losses in the heat distribution network. In systems where heating is supplied to a single building, the considerations in 6.1.4 with regards to a local heating network are not included in the assessment, so that the procedure is simplified in this part. In figure 9a the power consumed by the pump in the local heating network is considered, taking into account the single length of all piping in the local heating network (P_{tot}) and the heat requirements set at the design stage ($Q_{h,des}$). In figure 9b the heat losses in the local heating network are taken into account and in figure 10, the temperature decline in an intermediate heat exchanger.

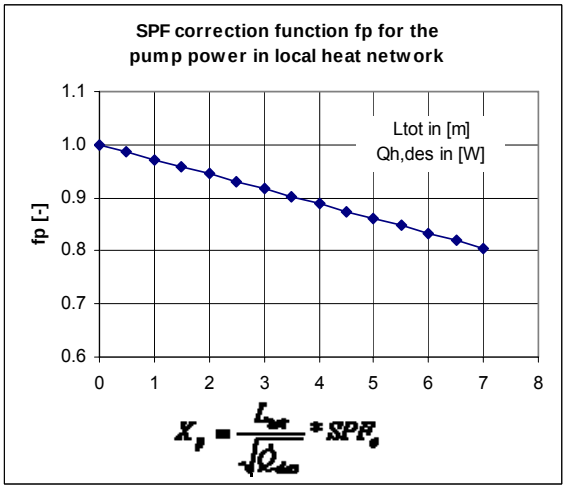


Figure 9a: Pump power in the local heating network

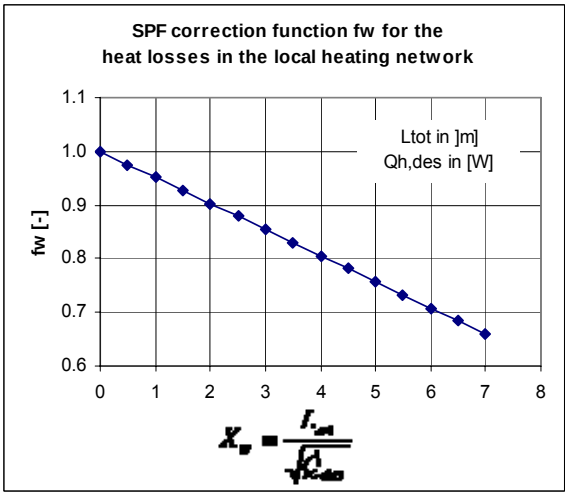


Figure 9b: Heat losses in the local heating network

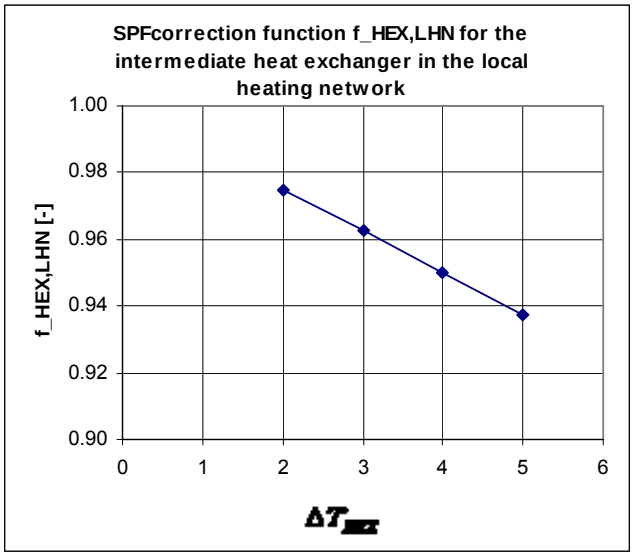


Figure 10 Intermediate heat exchanger in the local heating network

6.1.5 Calculation of the final SPF for heating only

All these corrections can be included in the following formulas:

Heat source groundwater:

$$SPF = SPF_0 * f_1 * \underbrace{f_{GW} * f_{HEX,GW}}_{\text{Groundwater}} * \underbrace{f_p * f_w * f_{HEX,LHN}}_{\text{Local heating network}}$$

Heat source earth:

$$SPF = SPF_0 * f_1 * \underbrace{f_{GHP}}_{\text{grond heat probe}} * \underbrace{f_p * f_w * f_{HEX,LHN}}_{\text{Local heating network}}$$

6.2 Calculating the total SPF for heating and hot water supply

The SPF for heating and hot water supply (HW) are each to be determined separately according to exactly the same procedure contained in sections 6.1 to 6.3.
The total SPF (SPF_{TOT}) is determined by a weighting factor with the energy share from the calculated „part“ SPF for heating (SPF_H) and hot water supply (SPF_{HW}) according to the following equation:

$$SPF_{TOT} = \frac{SPF_H \times Q_{Ha} + SPF_{HW} \times Q_{HWa}}{Q_{Ha} + Q_{HWa}}$$

6.3 Suitability of the test procedure in practice

In order to be able to carry out the procedure to determine the SPF for a system as explained above, the applicant for a subvention must provide the following information:

- Flow temperature set at the design stage
- Variable or constant flow temperature
- Source system: heat source (here ground water)
- Source system: ground water feed depth (height difference: ground water – heat pump)
- Source system: with or without intermediate cycle
- Source system: temperature difference with intermediate cycle

- Local heating network: designed power requirements
- Local heating network: single length of local heating network
- Local heating network: temperature difference, if separating heat exchanger available in sub-station

In a second phase of the project the draft for a test procedure for large or complex heat pump system described here will be consolidated in various sectors. On the basis of a larger number of data samples drawn from actual systems it will be checked for its suitability.

7 LIST OF ABBREVIATIONS

BW	brine/water
CP	circulation pump
f_{GW}	correction to determine the pump power at the source side
GHP	ground heat probe
GW	ground water
HP	heat pump
HSO	heat source
HW	hot water
LHN	local heating network (local heat distribution up to transfer to building)
Ltot	single length of all pipes in the local heating network
Qh,des	heating power requirements set at design stage
Q_{Ha}	
Q_{HWa}	
Pel,GW	electric power of ground water pump
Pel,ZK	electric power of intermediate cycle pump
SP	heat storage
SPF	Seasonal Performance Factor
SPF_{HP}	SPF heat pump incl. heat source considerations (HSO)
SPFo	SPF which only takes into account the heat pump's energy consumption
SPF_{TOT}	total SPF, weighted sum from part-SPF for heating and hot water supply
UH	heat used by building (see Fig.1)
WaW	waste water
WW	water/water
X_{GW}	coefficient to determine f_{GW}
Xp	coefficient to calculate pump losses in the local heating network
Xw	coefficient to calculate heat losses in the local heating network
$Б_{sink}$	$\equiv Q_{loss\ sink}/Q_{produced}$
$Б_{HSO}$	$\equiv Q_{loss\ sink}/Q_{produced}$
ΔH	geodetic pump height of the water pump
$\Delta Tspr$	temperature difference IN-OUT source
ΔT_{HEX}	temperature decline in an intermediate heat exchanger

8 REFERENCES

[1] Hubacher P.; Ehrbar M.; Bernal C. 2006. „Grosswärmepumpen – energetische und planerische Analyse von 10 Anlagen"; Vergleich verschiedener Anlagenkonzepte, Schlussbericht 2006, Bundesamt für Energie, Bern